Organisation Mondiale de la Santé Animale

World Organisation for Animal Health

Organización Mundial de Sanidad Animal

REVUE
SCIENTIFIQUE ET TECHNIQUE

SCIENTIFIC AND TECHNICAL
REVIEW

REVISTA
CIENTÍFICA Y TÉCNICA

Veterinary Services in a changing world: climate change and other external factors

Les Services vétérinaires dans un monde en mutation : le changement climatique et autres facteurs externes

Los Servicios Veterinarios en un mundo en transformación: el cambio climático y otros factores externos

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VOL. 40 (2)
AUGUST – AOÛT – AGOSTO
2021

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(Organisation mondiale de la santé animale – World Organisation for Animal Health – Organización Mundial de Sanidad Animal)
ISSN 0253-1933
ISBN 978-92-95115-82-8
https://doi.org/10.20506/rst.issue.40.2.3228

Conception maquette / *Graphic design* / Diseño de la maqueta: J. Prieur – Tous les chemins
Conception couverture / *Cover design* / Diseño de cubierta: P. Blandin – OIE
Images couverture / *Cover images* / Ilustraciones de cubierta:
Petite / *small* / pequeña: © Jaime Andres Bascuñan Valenzuela
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Preface

Veterinary Services in a changing world: climate change and other external factors

Animal agriculture is diverse and huge: the global industry employs over 1.5 billion people, occupies more than 40% of the Earth's ice-free surface, and provides 40% of the protein consumed globally. Demand for animal-source food continues to grow around the world, driven mainly by increased consumption in low- and middle-income countries, and this trend is likely to continue. At the same time, animal agriculture is a significant contributor to climate change and emerging zoonotic diseases, and there is concern over the well-being of workers, as well as the welfare of animals, among other challenges. In addition to being a creator of externalities (positive and negative spillover effects), animal agriculture is vulnerable to a wide range of external factors: climatic, economic, health, geopolitical, social and many others.

Recent events have vividly demonstrated how external factors – in this case, a disease, probably originating from animals – can cause enormous human health burdens and economic loss, and dramatically affect every facet of the ways in which the public and private sector operate. Coronavirus 2019 (COVID-19) was first identified in December 2019 in China. Since then, it has spread to nearly every part of the globe and, as of the date of writing, has not yet been controlled. COVID-19 has caused over four million deaths, making it one of the most lethal pandemics in history. The World Health Organization declared a Public Health Emergency of International Concern regarding COVID-19 on 30 January 2020, and later declared a pandemic on 11 March 2020. This has drawn unprecedented attention to the threat of emerging zoonotic infectious diseases, but has also renewed commitment to One Health as essential to the management and, more importantly, the prevention of such threats.

Veterinary Services are both affected by, and can have great effect on, emerging zoonotic diseases. What is more, zoonotic pandemics are only one of the external factors that Veterinary Services need to consider. Tragic as COVID-19 is, humanity, and the animals it keeps, has survived many epidemics and pandemics and there is cause for guarded optimism that this too will pass. Other external factors fall into the category of existential threats, that is, events that could cause human extinction or drastically curtail human potential. Climate change is widely considered to be, if not an existential threat, at least a catastrophe that could profoundly challenge the ability of humanity in multiple dimensions, potentially leading to mass food insecurity, abandonment of coastal settlements, migration, and increased drought, wildfire and flood catastrophes. Moreover, climate change is not the only external risk. The Stockholm Resilience Centre has identified nine limits (planetary boundaries) within which we must remain for the Earth to support life, and it is estimated that four have already been exceeded (see Alders *et al.*, this issue).

But while there are threats, there are also opportunities. External factors can be positive as well as negative. Indeed, even the COVID-19 pandemic has stimulated rapid technological advances, including mRNA vaccines with great potential for veterinary use. Other emerging and exciting innovations include big data and information technologies, both of which promise to revolutionise animal agriculture, as well as many other aspects of the economy and daily life.

Veterinary Services underpin animal agriculture, are a global public good, and make essential contributions to the four pillars of sustainable development: food and nutrition security, human health, societal well-being (including animal welfare), and economic development (including

https://doi.org/10.20506/rst.40.2.3229

trade). They must also ensure their performance and resilience in the face of external factors. For this reason, it is essential that Veterinary Services, encompassing both institutions and veterinary professionals, are able to understand, adapt to and influence external factors, such as climate change and disaster risk. But understanding such external factors, both present and emerging, is not enough; they must also strengthen their capacity to meet them. One approach that promises hope is to branch into new disciplines, such as Foresight. Indeed, given the complex and wicked problems that the world is facing, multidisciplinary approaches such as One Health have never been more important.

The OIE is the intergovernmental organisation responsible for improving animal health worldwide, with the mandate to strengthen Veterinary Services. The Organisation publishes international standards for Veterinary Services, and supports OIE Member Countries in carrying out assessments of their compliance with OIE standards, in making the case for investments in regulatory and operational systems, and in legislation development and review. In all these activities and more, it directly engages in capacity building of Veterinary Services around the globe.

As external factors rise to increasing prominence, we anticipate they will become progressively more important in the activities of the OIE and Member Countries. In 2017, the World Assembly of National Delegates to the OIE confirmed that a Technical Item should be developed on how external factors (e.g. climate change, conflict, socio-economics, trading patterns) will impact Veterinary Services, and the adaptations required over the next ten years.

The intention of this issue of the OIE *Scientific and Technical Review* is to present a series of articles that assist Members and the international community to become better prepared to survive and thrive in the uncertain years to come, by providing robust evidence on a range of issues relevant to preparedness, adaptation, mitigation and influencing factors. Accordingly, we have asked experts from a wide variety of disciplines and diverse backgrounds to provide an up-to-date analysis of such external factors. I am pleased to share their syntheses and trust they will be of interest and use to Veterinary Services and other stakeholders globally, as we reach for our preferred future.

I wish to extend my sincere gratitude to all of the authors who have contributed to this thoughtful and thought-provoking edition of the *Review*. I would also like to express my thanks to members of the OIE team who have supported and facilitated the authors and brought this edition to fruition during a particularly difficult year. And finally, I would like to thank the editors of this issue and the International Livestock Research Institute (ILRI) for our partnership.

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Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 363-365

Préface

Les Services vétérinaires dans un monde en mutation : le changement climatique et autres facteurs externes

L'agriculture animale est un secteur immense et très diversifié : il emploie, à l'échelle mondiale, plus d'un milliard et demi de personnes, exploite plus de 40 % de la surface terrestre hors cryosphère et fournit 40 % des protéines consommées dans le monde. La demande mondiale en denrées alimentaires d'origine animale continue de croître, à la faveur principalement de la consommation en hausse dans les pays à revenus faible et intermédiaire, tendance qui devrait se maintenir. Parallèlement, l'agriculture animale contribue de manière significative au changement climatique et à l'émergence de maladies zoonotiques et suscite également des inquiétudes concernant le bien-être des travailleurs du secteur, mais aussi des animaux eux-mêmes, entre autres problématiques. Si elle génère nombre d'externalités (retombées positives et négatives), l'agriculture animale est à son tour vulnérable aux facteurs externes, qui peuvent être de diverses natures : climatiques, économiques, sanitaires, géopolitiques, sociaux, parmi beaucoup d'autres.

La crise récente a montré avec acuité l'amplitude de l'impact de certains facteurs externes (dans ce cas, une maladie, ayant probablement une source animale) sur la santé humaine ainsi que les pertes économiques colossales qui en résultent, chaque aspect des activités déployées par le secteur public et privé s'en trouvant bouleversé. Le premier cas de Coronavirus 2019 (COVID-19) a été détecté en décembre 2019 en Chine. Depuis, l'épidémie s'est propagée pratiquement aux quatre coins du globe et, à l'heure où nous écrivons, elle n'est toujours pas maîtrisée. À ce jour, plus de quatre millions de personnes sont mortes des suites du COVID-19, ce qui en fait l'une des pandémies les plus meurtrières de l'histoire. Le 30 janvier 2020, l'Organisation mondiale de la santé a publié une déclaration qualifiant le COVID-19 d'urgence de santé publique de portée internationale (USPPI), suivie par une déclaration de pandémie le 11 mars de la même année. Depuis, la menace liée aux maladies infectieuses zoonotiques émergentes s'est portée au centre de toutes les attentions, en même temps que se renforçaient les engagements pris en faveur des démarches Une seule santé, en tant qu'élément essentiel de la gestion de ces menaces et, plus important encore, de leur prévention.

Les Services vétérinaires sont à la fois affectés par les maladies zoonotiques émergentes et capables de jouer un rôle déterminant pour influer sur leur émergence. Par ailleurs, les pandémies zoonotiques ne sont qu'un facteur externe parmi tous ceux que les Services vétérinaires doivent prendre en compte. Pour aussi tragique que soit le COVID-19, l'humanité et les animaux sous sa garde ont déjà survécu à maintes épidémies et pandémies dans l'histoire, de sorte que l'on peut raisonnablement s'attendre à ce que celle-ci aussi finisse par passer. Il existe d'autres facteurs externes qui relèvent de la catégorie des menaces existentielles, c'est-à-dire des événements pouvant provoquer l'extinction de l'humanité ou réduire radicalement son potentiel. Il y a aujourd'hui un vaste consensus sur le fait que le changement climatique est, sinon une menace existentielle, du moins une catastrophe qui pourrait profondément grever les capacités de l'humanité dans de très nombreux domaines et entraîner une insécurité alimentaire massive, le dépeuplement des zones littorales, un exode migratoire, une aggravation de la sécheresse et une multiplication des feux de forêt et des inondations. Le changement climatique n'est pas le seul risque externe. Le Stockholm Resilience Centre a identifié neuf

https://doi.org/10.20506/rst.40.2.3229

limites (frontières planétaires) qui ne doivent pas être transgressées si l'on veut que la Terre continue à soutenir le Vivant ; or, quatre de ces limites ont déjà été atteintes (voir Alders *et al.* dans ce numéro).

Parallèlement à ces menaces, des perspectives existent, qu'il faut savoir saisir. Les facteurs externes ne sont pas seulement négatifs ; certains sont également positifs. En effet, même la pandémie de COVID-19 a induit une dynamique propice à des avancées technologiques rapides, en particulier la mise au point de vaccins à ARN messager qui présentent un grand potentiel en médecine vétérinaire. Parmi les innovations émergentes et stimulantes que nous voyons se développer figurent aussi les mégadonnées et les technologies de l'information, qui vont probablement révolutionner l'agriculture animale ainsi que bien d'autres aspects de l'économie et de la vie quotidienne.

Les Services vétérinaires sont le soutien de l'agriculture animale ; ils constituent un bien public mondial et contribuent de manière essentielle aux quatre piliers du développement durable : la sécurité alimentaire et nutritionnelle, la santé publique, le bien-être sociétal (qui inclut le bien-être animal) et le développement économique (dont le commerce international). Les Services vétérinaires doivent également s'assurer de leurs performances et résilience face aux facteurs externes. C'est pourquoi il est essentiel que les Services vétérinaires, tant du côté institutionnel que de celui des praticiens de la médecine vétérinaire soient capables de comprendre les facteurs externes tels que le changement climatique et les risques de catastrophes, pour s'y adapter et tenter d'y influer. Mais comprendre ces facteurs externes existants et émergents ne suffira pas ; les Services vétérinaires doivent aussi renforcer leurs capacités à y faire face. L'aptitude à se diversifier en intégrant de nouvelles disciplines comme la prospective constitue une démarche prometteuse et porteuse d'espoir. En effet, étant donné les problèmes complexes et pernicieux auxquels le monde est confronté, les approches multidisciplinaires telles qu'Une seule santé sont plus importantes que jamais.

En tant qu'organisation intergouvernementale chargée d'améliorer la santé animale dans le monde, l'OIE a pour mandat de renforcer les Services vétérinaires. L'Organisation publie des normes internationales applicables aux Services vétérinaires et aide ses Membres à mener à bien des évaluations pour déterminer la conformité de leurs Services avec les normes de l'OIE, à présenter des plaidoyers pour des investissements dans les systèmes réglementaire et opérationnel, et à élaborer ou réviser leur législation. À travers ces activités et beaucoup d'autres, l'OIE est directement mobilisée pour renforcer les capacités des Services vétérinaires du monde entier.

Avec la montée en puissance des facteurs externes, nous pouvons anticiper la place croissante qu'ils vont prendre dans les activités de l'OIE et de ses Membres. En 2017, l'Assemblée mondiale des Délégués nationaux de l'OIE a décidé de consacrer un Thème technique à l'impact des facteurs externes (tels que le changement climatique, les conflits, la socio-économie et les structures des échanges commerciaux) sur les Services vétérinaires, et aux adaptations requises à cet égard pour la décennie à venir.

L'objectif du présent numéro de la *Revue scientifique et technique* de l'OIE est de réunir une série d'articles pour aider les Membres et la communauté internationale à mieux se préparer à survivre et à prospérer dans les années incertaines à venir, en leur apportant des éléments de réponse tangibles sur diverses questions concernant la préparation et l'adaptation aux facteurs externes, ainsi que sur les possibilités de les atténuer ou d'y influer. Pour ce faire, nous avons demandé à des experts issus de diverses disciplines scientifiques et secteurs de préparer une analyse actualisée de ces facteurs externes. Je

suis heureuse de porter ces synthèses à la connaissance du public et ne doute pas qu'elles seront utiles aux Services vétérinaires et à bien d'autres parties prenantes dans le monde, pour que nous donnions forme à l'avenir auquel nous aspirons.

Je souhaite exprimer mes plus vifs remerciements à tous les auteurs qui ont participé à ce numéro de la *Revue*, pour leurs contributions fécondes qui donnent beaucoup à réfléchir. J'aimerais également remercier les membres de l'équipe de l'OIE qui a soutenu et facilité les travaux des auteurs et mené à bout ce projet éditorial malgré l'année particulièrement difficile que nous venons de traverser. Enfin, j'exprime toute ma gratitude aux coordinateurs de ce numéro spécial et à l'International Livestock Research Institute (ILRI) pour notre fructueux partenariat.

Monique Éloit
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Prólogo
Los Servicios Veterinarios en un mundo en transformación: el cambio climático y otros factores externos

La producción animal constituye un sector enorme y diverso, que a escala mundial emplea a más de 1.500 millones de personas, ocupa más del 40% de la superficie terrestre libre de hielo y aporta el 40% de las proteínas consumidas en el mundo. La demanda de alimentos de origen animal sigue aumentando en todo el globo, impulsada básicamente por el mayor consumo en países de renta baja o mediana, tendencia que presumiblemente va a continuar. Al mismo tiempo, la producción animal contribuye en buena medida al cambio climático y a la aparición de enfermedades zoonóticas, sin olvidar la preocupación que suscita el bienestar de los trabajadores y el de los animales, entre otros problemas. Además de dar lugar a externalidades (efectos indirectos positivos y negativos), la producción animal está expuesta a todo un ramillete de factores externos, en particular climáticos, económicos, sanitarios, geopolíticos y sociales, entre otros muchos.

Los hechos recientes han dejado bien claro que los factores externos (en este caso una enfermedad, de origen probablemente animal) pueden engendrar una grave carga sanitaria e ingentes pérdidas económicas y afectar profundamente todas y cada una de las facetas de la labor y el funcionamiento de los sectores público y privado. La enfermedad por coronavirus de 2019 (COVID-19) fue descrita por primera vez en diciembre de 2019 en China. Desde entonces se ha extendido a casi todos los rincones del planeta y, en el momento de redactar estas líneas, aún sigue fuera de control. La COVID-19 ha causado más de cuatro millones de muertes, lo que hace de esta una de las pandemias más letales de la historia. El 30 de enero de 2020, la Organización Mundial de la Salud la declaró «emergencia de salud pública de importancia internacional» para poco después, el 11 de marzo de 2020, pasar a catalogarla de pandemia. Todo ello ha dado lugar a un interés sin precedentes por la amenaza de las enfermedades infecciosas zoonóticas emergentes, pero también ha generado una renovada adhesión a la lógica de «Una sola salud» como herramienta esencial para manejar y, aún más importante, prevenir este tipo de amenazas.

Los Servicios Veterinarios se ven afectados por las enfermedades zoonóticas emergentes y a la vez influyen sobremanera en ellas. Es más, las pandemias zoonóticas son solo uno de los factores externos que los Servicios Veterinarios deben tener en cuenta. Por trágica que resulte la COVID-19, la humanidad y los animales que la acompañan han sobrevivido a muchas epidemias y pandemias: hay motivos para profesar un cauto optimismo y pensar que también esta acabará pasando. Otros factores externos pueden ser catalogados de amenazas existenciales, es decir, sucesos que podrían llevar a la extinción del ser humano o reducir a la mínima expresión sus posibilidades. Muchos consideran que el cambio climático es, si no una amenaza existencial, cuando menos una catástrofe que podría erosionar profundamente la capacidad de la humanidad en múltiples ámbitos y eventualmente causar una inseguridad alimentaria masiva, el abandono de asentamientos costeros, migraciones y un aumento de los episodios de sequía, incendios descontrolados e inundaciones catastróficas. El cambio climático, además, no es el único factor de riesgo externo. El Centro por la Resiliencia de Estocolmo ha descrito nueve «límites planetarios»

https://doi.org/10.20506/rst.40.2.3229

que no debemos sobrepasar para que la Tierra pueda seguir sustentanto la vida y, según parece, cuatro de ellos ya han sido superados (véase, en este número, Alders *et al.*).

Ahora bien, a la vez que hay amenazas, también hay oportunidades. Los factores externos pueden ser también positivos, y no solo negativos. Incluso la pandemia de COVID-19, de hecho, ha estimulado rápidos avances tecnológicos, entre ellos las vacunas de ARNm, que tan promisorias resultan para un uso veterinario. Otras innovaciones incipientes y fascinantes, como los macrodatos o la tecnología de la información, prometen revolucionar la producción animal y otros muchos aspectos de la economía y la vida cotidiana.

Los Servicios Veterinarios apoyan la producción animal, son un bien de interés público mundial y resultan esenciales para los cuatro pilares del desarrollo sostenible: seguridad alimentaria y nutricional; salud humana; bienestar social (incluido el bienestar animal); y desarrollo económico (incluido el comercio). También deben garantizar su eficacia y resiliencia ante factores externos. Por tal razón es fundamental que los Servicios Veterinarios, que engloban tanto a las instituciones como a los profesionales de la veterinaria, estén en condiciones no solo de entender factores externos como el cambio climático o el riesgo de desastre, sino también de adaptarse a ellos y de influir en ellos. Pero el hecho de que los Servicios Veterinarios entiendan esos factores externos, ya actuantes o aún incipientes, no basta: también deben dotarse de mayor capacidad para afrontarlos. Un camino que parece esperanzador es el de abrirse a nuevas disciplinas, como la prospectiva. En realidad, los problemas que afronta el mundo son tan complejos y laberínticos que los planteamientos multidisciplinares, como el de «Una sola salud», son hoy más importantes que nunca.

El mandato de la OIE, que es la organización intergubernamental responsable de mejorar la sanidad animal en todo el mundo, incluye el fortalecimiento de los Servicios Veterinarios. La Organización publica normas internacionales destinadas a los Servicios Veterinarios y ayuda a sus Países Miembros a evaluar su grado de cumplimiento de las normas de la OIE, defendiendo la necesidad de invertir en los sistemas reglamentarios y operativos y en la elaboración y revisión de textos legislativos. Con todas estas actividades, y otras muchas, participa directamente en la capacitación de Servicios Veterinarios del mundo entero.

Dado que los factores externos tienen cada vez más peso y relevancia, cabe augurar que progresivamente irán cobrando también más protagonismo en las actividades de la OIE y sus Países Miembros. En 2017, la Asamblea Mundial de Delegados Nacionales ante la OIE confirmó que procedía elaborar un tema técnico sobre el modo en que los factores externos (cambio climático, conflictos, aspectos socioeconómicos, modalidades de comercio, etc.) van a repercutir en los Servicios Veterinarios y las adaptaciones que se requerirán en los diez próximos años.

Este número de la *Revista Científica y Técnica* de la OIE responde a la voluntad de presentar artículos que ayuden a los Países Miembros y a la comunidad internacional a prepararse mejor para sobrevivir y prosperar en los inciertos años que nos aguardan, aportando para ello sólidos datos científicos sobre una serie de problemas ligados a la preparación, la adaptación y la mitigación y también sobre los factores que influyen en este ámbito. Así pues, pedimos a una serie de expertos de muy diversas disciplinas y procedencias que preparasen un análisis actualizado de esos factores externos. Me complace compartir hoy su trabajo de síntesis con el lector y confío en que sea de interés y utilidad para los Servicios Veterinarios y otros interesados del mundo entero, para que entre todos logremos hacer advenir el futuro al que aspiramos.

Deseo expresar mi sincero agradecimiento a todos los autores que han contribuido a este profundo y sugerente número de la *Revista*. Debo también gratitud a los miembros del equipo de la OIE que han apoyado y facilitado el trabajo de los autores y llevado esta publicación a buen puerto durante un año especialmente difícil. Por último, quisiera agradecer su colaboración a los compiladores de este número y al Instituto Internacional de Investigación Zootécnica (ILRI).

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Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 371-373

Introduction

Veterinary Services in a changing world: climate change and other external factors

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This is the first issue of the *Scientific and Technical Review* that focuses on Foresight and the broad range of external factors that are likely to affect, and be affected by, Veterinary Services, both in the present and in the near future. The edition is particularly timely, coming at a moment of unprecedented interest in the role of animal agriculture and its relationship with people and the environment. Veterinary Services have shown remarkable openness to new concepts that have traditionally been outside their purview, as illustrated by issues of the *Scientific and Technical Review* over the last dozen years, which have covered One Health (1), economics (2), climate change (3, 4), and invasive species (5). However, as shown by a recent Technical Item, presented at the 87th General Session of the World Organisation for Animal Health in Paris in 2019, Veterinary Services have only taken on board comprehensive and rigorous Foresight analysis to a limited degree (5).

In this introduction, the authors define 'Foresight', as well as 'external factors'. They then provide an overview of the different papers within this issue and examine how they contribute to a better understanding of such factors.

There are many definitions of Foresight. Foresight is generally considered a broad term, covering all methods to explore issues and their influence on the futures that may arise. The typical Foresight methods include, but are by no means limited to, horizon scanning, trend analysis, casual layered analysis and scenario planning.

When entering into the realm of Foresight, other terms come into play: 'strategic foresight', 'futures studies', 'futurology' and 'forecasting'.

If Foresight is defined as the umbrella for methodologies designed to consider the futures that are arising, then 'strategic foresight' is an attempt to provide a framework in which numerous methodologies can be used to develop insight on possible futures to support present-day decision-making.

'Horizon scanning' was originally defined as a systematic outlook to detect early signs of potentially important developments, or a 'search for signals'. Scanning is an essential method in Foresight and is often the foundation (or bedrock) for frameworks such as strategic foresight.

On the other hand, 'forecasting' refers to making predictions about the future. This is antithetical to the principle of Foresight, which holds that the future is fundamentally unpredictable and definitive answers on what it holds are not possible. 'Futurology' and 'future studies' are broad terms, which include the use of Foresight methods.

In the face of increasingly complex issues and rapidly changing information, we can attempt to contextualise what is emerging by labelling realms in which Foresight methods and frameworks can be applied. For example, external factors are easier to define: they

https://doi.org/10.20506/rst.40.2.3230

are the factors outside an institution, organisation or business which affect, or have the potential to affect, these bodies and their activities, but which are outside their direct control (though not necessarily their influence). In contrast, internal factors include anything that takes place within the institution, organisation or business and is under its control, whether tangible or intangible.

This issue of the *Review* begins by setting out the context and background of the Foresight theme. Perry *et al.* address existing and future agricultural production systems, while Enahoro *et al.* focus on the current and future trade of livestock products. This is followed by a paper in which one of the present authors, Grace, undertakes a more in-depth exploration into Foresight methodologies and tools that may be relevant and useful to Veterinary Services, with concrete examples of their application.

The environment is the focus of the next three papers. In the first, Stephen and Soos focus on climate change, one of the greatest single concerns of our day. Next, Sivakumar looks at climate catastrophe and how strong links between Veterinary Services and the meteorological sector can help to mitigate risk. The third, by Alders *et al.*, extends this to consider other planetary boundaries (that is, nine global processes that, if not well managed, could destabilise the Earth). In addition to its contribution to climate change, livestock production has an important effect on three crucial planetary boundaries: the substantial loss of biodiversity and ecosystem services; changes in nitrogen, phosphorus and carbon cycles; and changes in land systems.

While these three papers highlight the negative externalities of animal production, the next paper takes a more optimistic view. El Idrissi *et al.* examine how big data, biotechnology and information communication technology could affect animal agriculture and Veterinary Services – hopefully, for the better. Doyle *et al.* look at another emerging issue, which Veterinary Services have embraced: values and ethics-related animal agriculture. In this paper, the authors explain how animal welfare science has moved from the 'five freedoms' to a broader concept of the 'five domains'.

The subsequent papers focus on four topics that comprise part of the core business of Veterinary Services, but where we have also seen and anticipate considerable change. The first, by Auty *et al.,* covers endemic disease risks to both animals and humans, noting that these are most problematic in developing countries. The authors pose the question, 'How can we realise the full potential of animal health systems for delivering development and health outcomes?'

In the next paper, Jost *et al.* focus on epidemic diseases, one of the most feared unwanted consequences of animal agriculture, especially when zoonotic. Magnusson *et al.* shine a light on antimicrobial resistance which, although long a topic of concern to veterinary professionals, has risen to extraordinary prominence in recent years.

We move to another complex topic in which animal agriculture is a major source of positive externalities (that is, benefits to those not involved in animal agriculture) and yet concern about negative externalities (harm to third parties) is growing; i.e. food and nutrition security and dietary change. The burden of human disease caused by obesity or being overweight is now greater than that caused by lack of food. Yet, millions of children are currently stunted from malnutrition, and this problem is associated with diets that are low in animal-source food. Carag *et al.* provide a thoughtful review of this intractable issue.

The next three papers shift the focus to factors that are arguably internal. Makita focuses on animal health and food safety risk assessment, a traditional but key task of most Veterinary Services, to update readers on the latest developments. Solomos and

Randolph consider institutional risk assessment and the ways in which organisations such as Veterinary Services can and should consider the financial, legal and personnel risks that might jeopardise their performance. Meanwhile, Weiland *et al.* turn their attention to continuing professional development and strengthening capacity.

The next paper looks at a new initiative to understand and measure animal disease and support its management more effectively. Called the 'Global Burden of Animal Disease' Programme, there are hopes for this project to be as game-changing as the first assessment of the Global Burden of Human Disease, launched in the 1990s. Huntington *et al.* provide a comprehensive summary of what this break through project might lead to.

The final paper reaches out even further to broader development issues. Schneider and Tarawali focus their lens on the Sustainable Development Goals of the United Nations, and the relationship between these objectives and animal production. They suggest ways in which Veterinary Services can contribute to their attainment, helping to create a better future for all.

References

1. Karesh W.B. (ed.) (2014). – One Health. *Rev. Sci. Tech. Off. Int. Epiz.*, **33** (2). doi:10.20506/rst.issue.33.2.56.

2. Rushton J. (ed.) (2017). – The economics of animal health. *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1). doi:10.20506/rst.issue.36.1.2604.

3. de la Rocque S., Morand S. & Hendricks G. (eds.) (2008). – Climate change: impact on the epidemiology and control of animal diseases. *Rev. Sci. Tech. Off. Int. Epiz.*, **27** (2). doi:10.20506/rst.issue.27.2.38.

4. Pastoret R.R. & Moutou F. (eds.) (2010). – Invasive species. Part 1: General aspects and biodiversity. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (1). doi:10.20506/rst.issue.29.1.43.

5. Pastoret P.-P. & Moutou F. (eds.) (2010). – Invasive species. Part 2: Concrete examples. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (2). doi:10.20506/rst.issue.29.2.44.

6. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K. & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item presented at the 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France. doi: 10.20506/TT.2984.

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Introduction

Les Services vétérinaires dans un monde en mutation : le changement climatique et autres facteurs externes

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Ce numéro de la *Revue scientifique et technique* est le premier consacré spécifiquement à la prospective et à l'ample éventail de facteurs externes susceptibles d'affecter et d'être affectés par les Services vétérinaires, aujourd'hui comme dans un avenir proche. Cette publication arrive à point nommé, alors que le rôle de l'agriculture animale et ses liens avec les populations humaines et l'environnement suscitent un intérêt sans précédent. Les Services vétérinaires ont fait preuve d'une ouverture d'esprit remarquable pour intégrer des concepts nouveaux qui, traditionnellement, n'étaient pas de leur ressort, comme en attestent plusieurs numéros de la *Revue scientifique et technique* parus au cours des douze dernières années et consacrés à Une seule santé (1), à l'économie (2), aux changements climatiques (3, 4) et aux espèces envahissantes (5). Cependant, comme le montre le récent Thème technique présenté lors de la 87e Session générale de l'Organisation mondiale de la santé animale tenue à Paris en 2019, les Services vétérinaires ne font appel à des analyses prospectives complètes et rigoureuses que dans des circonstances encore limitées (5).

Dans cette introduction, les auteurs proposent d'abords une définition des termes « prospective » et « facteurs externes ». Ils dressent ensuite un aperçu des différents articles de ce numéro en faisant ressortir l'éclairage qu'ils apportent pour mieux comprendre ces facteurs.

Il existe plusieurs définitions de la prospective. Le terme est généralement employé dans son acception la plus large pour désigner toute méthode d'exploration d'une problématique donnée qui étudie également son influence sur les différentes configurations de l'avenir tel qu'il pourrait se présenter. Les méthodes classiques dans ce domaine sont notamment (mais ne s'y limitent pas) : la veille prospective (ou balayage d'horizon), l'analyse des tendances, l'analyse causale multiniveau et la planification par scénarios.

En s'engageant plus avant dans le monde de la prospective, d'autres termes importants entrent en jeu : « prospective stratégique », « études sur les futurs », « futurologie » et « prévision ».

Si nous définissons la prospective comme la discipline recouvrant l'ensemble des méthodologies conçues pour examiner les configurations futures qui se profilent, alors la « prospective stratégique » est la tentative de fournir un cadre dans lequel plusieurs méthodes sont utilisées pour jeter une lumière nouvelle sur les futurs possibles, dans le but d'étayer les prises de décisions d'aujourd'hui.

Le « balayage d'horizon » a été défini à l'origine comme une veille systématique visant à détecter les signaux faibles d'une évolution potentiellement majeure ; c'est pourquoi on l'appelle aussi « veille de signaux ». La veille prospective est une méthode essentielle et constitue souvent la base (ou le substrat) de l'élaboration de cadres plus avancés, en particulier la prospective stratégique.

Le terme « prévision », quant à lui, se réfère aux prédictions que l'on peut faire concernant l'avenir. Cela constitue l'antithèse du principe sur lequel repose la prospective, qui tient l'avenir

https://doi.org/10.20506/rst.40.2.3230

pour imprévisible par essence et soutient qu'aucune réponse définitive ne peut être formulée quant à ce que l'avenir nous réserve. La « futurologie » et les « études sur les futurs » sont des termes généraux qui intègrent l'utilisation des méthodes de la prospective.

Confrontés à des problèmes de plus en plus complexes et à des informations qui ne cessent de changer, nous pouvons tenter d'appréhender ce qui est en train d'apparaître sous une forme contextualisée, en créant des domaines auxquels les méthodes et les cadres de la prospective peuvent s'appliquer. Par exemple, les « facteurs externes » constituent un domaine facile à définir : il s'agit de facteurs extérieurs à l'institution, à l'organisation ou à l'entreprise, qui affectent ou peuvent affecter ces entités ainsi que leurs activités, mais qui ne se trouvent pas sous leur contrôle direct (bien qu'ils puissent subir leur influence). À contrario, les facteurs internes désignent tout ce qui a lieu dans l'institution, l'organisation ou l'entreprise et qui se trouve sous son contrôle matériel ou immatériel.

Les articles de ce numéro de la *Revue* commencent par décrire le contexte et l'origine du thème de la prospective. Perry *et al.* traitent des systèmes de production agricole existants et futurs, et Enahoro *et al.* analysent la structure actuelle et future des échanges internationaux d'animaux d'élevage et de leurs produits dérivés. Dans l'article suivant, D. Grace, l'une des auteures de la présente introduction entreprend une analyse plus approfondie des méthodes et outils de prospective pouvant présenter une pertinence et une utilité pour les Services vétérinaires et fournit un exemple concret de leur application.

Les trois articles suivants sont axés sur l'environnement. Dans le premier, Stephen et Soos traitent du changement climatique, l'un des plus grands sujets de préoccupation de notre époque. Dans l'article suivant, Sivakumar s'intéresse aux catastrophes climatiques et montre qu'une collaboration renforcée entre les Services vétérinaires et le secteur météorologique peut contribuer à atténuer les risques. Enfin, Alders *et al.* élargissent l'examen pour inclure d'autres frontières planétaires (terme désignant les neuf processus du système terrestre qui pourraient déstabiliser la Terre s'ils sont mal gérés). Outre son rôle sur le changement climatique, la production animale a des effets importants sur trois frontières planétaires cruciales : une perte substantielle de biodiversité et des services écosystémiques ; des modifications des cycles de l'azote, du phosphore et du carbone ; et des changements dans l'affectation des sols.

Si ces trois articles soulignent les effets négatifs de la production animale, l'article suivant donne quelques perspectives plus optimistes. El Idrissi *et al.* examinent les effets sur la production animale et sur les Services vétérinaires du recours aux mégadonnées, aux biotechnologies et aux technologies de l'information et de la communication, effets dont il est espéré qu'ils seront bénéfiques. Doyle *et al.* s'intéressent à une autre problématique émergente, que les Services vétérinaires ont désormais intégrée : relier les valeurs et l'éthique à la production animale. Les auteurs de cet article expliquent l'évolution de la science du bien-être animal, où les « cinq besoins fondamentaux » ont cédé la place au concept plus large des « cinq domaines du bien-être animal ».

Les articles suivants sont consacrés à quatre sujets qui touchent au cœur du métier des Services vétérinaires, et qui ont également connu une transformation profonde et continueront d'en connaître à l'avenir. Dans le premier article, Auty *et al.* examinent les risques de maladies endémiques chez l'homme comme chez les animaux et font observer que la menace liée à ces maladies est plus préoccupante dans les pays en développement. Les auteurs posent la question de savoir comment réaliser tout le potentiel des systèmes de santé animale afin de contribuer avec des résultats tangibles au développement et à la santé.

Les épidémies sont examinées dans l'article suivant, par Jost *et al.*, étant l'une des conséquences indésirables les plus redoutées de l'élevage, en particulier lorsqu'il s'agit

de zoonoses. Magnusson *et al.* apportent ensuite un éclairage sur la résistance aux agents antimicrobiens : après avoir été pendant longtemps un sujet de préoccupation pour la profession vétérinaire, l'antibiorésistance est désormais au centre de toutes les attentions.

De là nous passons à un autre sujet complexe, où l'agriculture animale constitue une source importante d'externalités positives (c'est-à-dire d'avantages procurés à ceux qui n'y participent pas) tout en entraînant des effets de plus en plus préoccupants liés à ses externalités négatives (c'est-à-dire les effets nocifs pour des tiers) : la sécurité sanitaire des aliments, la sécurité de l'approvisionnement alimentaire et le changement de régimes alimentaires. L'impact des maladies causées par l'obésité ou par un surpoids dépasse désormais celui causé par la carence d'aliments. Pourtant, des millions d'enfants présentent actuellement un retard de croissance dû à la malnutrition, problème associé à des régimes alimentaires pauvres en nutriments d'origine animale. Carag *et al.* procèdent à une analyse réfléchie de ce problème inextricable.

Les trois articles suivants mettent l'accent sur les facteurs qualifiés sans conteste d'internes. Makita aborde la question de l'évaluation du risque pour la santé animale et la sécurité sanitaire des aliments, tâche à la fois classique et centrale pour la plupart des Services vétérinaires, en apportant un éclairage sur les récentes évolutions dans ce domaine. Solomos et Randolph examinent l'évaluation du risque institutionnel et ce que les organisations telles que les Services vétérinaires peuvent et devraient faire pour gérer les risques financiers, juridiques et liés aux ressources humaines susceptibles de compromettre leurs performances. Weiland *et al.* quant à eux s'intéressent au perfectionnement professionnel continu des vétérinaires et au renforcement de leurs capacités.

L'article suivant présente une nouvelle initiative mise en place pour mieux comprendre et mesurer les maladies animales afin de gagner en efficacité dans leur gestion. Il y a lieu d'espérer que ce projet, qui a pour nom « Impact mondial des maladies animales » changera considérablement la donne, comme l'avait fait avant lui la première évaluation de l'Impact mondial des maladies humaines dans les années 1990. La contribution d'Huntington *et al.* constitue une synthèse exhaustive des perspectives apportées par ce projet décisif.

Le dernier article va encore plus loin dans l'examen des questions de développement au sens large. Dans leur examen des objectifs de développement durable des Nations unies, Schneider et Tarawali s'intéressent aux liens entre ces objectifs et la production animale. Ils font quelques propositions sur la manière dont les Services vétérinaires pourraient contribuer à réaliser ces objectifs, en vue d'un meilleur futur pour tous.

Références

1. Karesh W.B. (coord.) (2014). – Une seule santé. *Rev. Sci. Tech. Off. Int. Epiz.*, **33** (2). doi:10.20506/rst.issue.33.2.56.

2. Rushton J. (coord.) (2017). – L'économie de la santé animale. *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1). doi:10.20506/rst.issue.36.1.2604.

3. De la Rocque S., Morand S. & Hendricks G. (coord.) (2008). – Changement climatique : impact sur l'épidémiologie et les stratégies de contrôle des maladies animales. *Rev. Sci. Tech. Off. Int. Epiz.*, **27** (2). doi:10.20506/rst.issue.27.2.38.

4. Pastoret P.P. & Moutou F. (coord.) (2010). – Espèces envahissantes. Partie 1 : aspects généraux et biodiversité. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (1). doi:10.20506/rst.issue.29.1.43.

5. Pastoret P.-P. & Moutou F. (coord.) (2010). – Espèces envahissantes. Partie 2 : exemples concrets. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (2). doi:10.20506/rst.issue.29.2.44.

6. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K. & Smith J. (2019). – Les effets des facteurs externes (tels que le changement climatique, conflits, facteurs socio-économiques et les échanges commerciaux) sur les Services vétérinaires et les adaptations qu'ils requièrent. Thème technique présenté à la 87e Session générale de l'Organisation mondiale de la santé animale (OIE), 26–31 mai, Paris (France). doi: 10.20506/TT.2984.

Introducción
Los Servicios Veterinarios en un mundo en plena transformación: el cambio climático y otros factores externos

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Este es el primer número de la *Revista Científica y Técnica* dedicado a la prospectiva y al amplio y diverso conjunto de factores externos que probablemente afectan a los Servicios Veterinarios y son afectados por ellos, tanto en el presente como en un futuro próximo. Esta publicación llega en un momento especialmente oportuno, cuando la función de la producción animal y su relación con las personas y el medio ambiente despiertan un interés sin precedentes. Los Servicios Veterinarios han hecho gala de una notable apertura a conceptos de nuevo cuño históricamente ajenos a ellos, como atestiguan varios números de la *Revista* de los últimos doce años referidos a temas que van de «Una sola salud» (1) a la economía (2), pasando por el cambio climático (3, 4) o las especies invasoras (5). No obstante, como se desprende del reciente tema técnico presentado en la 87ª Sesión General de la Organización Mundial de Sanidad Animal, celebrada en París en 2019, los Servicios Veterinarios solo han incorporado hasta cierto punto la práctica rigurosa de análisis prospectivos completos (5).

En esta introducción los autores, tras definir «prospectiva» y «factores externos», pasan revista al conjunto de artículos que forma este número y explican cómo estos artículos ayudan a conocer y comprender mejor los antedichos factores.

Hay muchas definiciones de «prospectiva». Por lo común se considera que este es un término genérico que engloba la totalidad de los métodos encaminados a estudiar ciertos problemas y su influencia en una u otra situación que presumiblemente pueda deparar el futuro. Aunque desde luego hay otros muchos, son típicos métodos de prospectiva el análisis (o barrido) de horizontes (*horizon-scanning*), el análisis de tendencias (*trends análisis*), el análisis causal estratificado (*causal layered analysis*) y la planificación de hipótesis (*scenario planning*).

Cuando uno se adentra en el reino de la prospectiva, otros términos o expresiones entran en escena: «prospectiva estratégica», «estudios del futuro», «futurología» y «pronóstico».

Si se entiende la «prospectiva» como un ámbito que acoge distintos métodos concebidos para examinar las situaciones futuras que empiezan a insinuarse en el horizonte, la «prospectiva estratégica» es un intento de establecer un marco desde el cual aplicar numerosos métodos que arrojen luz sobre esos posibles futuros para poder, a partir de ahí, adoptar decisiones en el presente.

El «análisis (o barrido) de horizontes» fue definido en un principio como una observación sistemática para detectar signos precoces de hechos que pudieran ser importantes, proceso llamado también «búsqueda de señales». El barrido es un método esencial en el ámbito de la prospectiva y suele ser el fundamento (la roca madre) en el que reposan sistemas de referencia como los de prospectiva estratégica.

https://doi.org/10.20506/rst.40.2.3230

El término «pronóstico», por su parte, supone la realización de predicciones sobre el futuro, en un sentido antitético al del principio de la prospectiva, según el cual el futuro es en esencia impredecible y no cabe dar con respuestas definitivas sobre lo que va a deparar. «Futurología» y «estudios del futuro» son expresiones generales que incluyen el uso de métodos de prospectiva.

Ante la creciente complejidad de los problemas y la rapidez con que cambia la información, podemos tratar de contextualizar lo que empieza a surgir etiquetando aquellos ámbitos en los que es posible aplicar los métodos y sistemas de referencia de la prospectiva. No resulta difícil, por ejemplo, definir «factores externos» como aquellos factores ajenos a una institución, organización o empresa que afectan o pueden afectar a esa entidad y su labor pero que escapan a su control directo (aunque no necesariamente a su influencia). Por oposición, los factores internos corresponden a todo aquello que ocurre dentro de la institución, organización o empresa y está bajo su control, ya sea tangible o intangible.

Este número de la *Revista* se abre situando el tema de la prospectiva en su contexto y presentando sus antecedentes. Perry *et al.* examinan los sistemas actuales y venideros de producción agrícola, mientras que Enahoro *et al.* se ocupan del comercio presente y futuro de ganado y productos derivados. En el artículo siguiente, una de las autoras de estas líneas, Grace, examina más a fondo los métodos y herramientas de prospectiva que pueden ser interesantes y útiles para los Servicios Veterinarios, ofreciendo un ejemplo concreto de su aplicación.

El medio ambiente es el eje central de los tres artículos siguientes. En el primero Stephen y Soos se centran en el cambio climático, problema este que, tomado aisladamente, es uno de los que más preocupan hoy en día. A continuación Sivakumar, examinando la cuestión de la catástrofe climática, explica cómo la existencia de estrechos vínculos entre los Servicios Veterinarios y el sector de la meteorología puede ayudar a mitigar el riesgo. En el tercero, Alders *et al.* amplían la perspectiva para tomar en consideración otros límites planetarios (esto es, nueve procesos planetarios que, de no estar bien gestionados, podrían desestabilizar la Tierra). Además de contribuir al cambio climático, la producción ganadera ejerce una marcada influencia en otros tres límites planetarios básicos: la sustancial pérdida de biodiversidad y servicios ecosistémicos; la modificación de los ciclos del nitrógeno, el fósforo y el carbono; y los cambios en los sistemas de tierras (usos del suelo).

Estos últimos tres artículos ponen el acento en las externalidades negativas de la producción animal, mientras que en el artículo siguiente, partiendo de una visión más optimista, El Idrissi *et al.* examinan la influencia (cabe esperar que positiva) que podrían tener los macrodatos, la biotecnología y la tecnología de la comunicación y la información en la producción animal y los Servicios Veterinarios. Doyle *et al.* se ocupan de otra reciente cuestión que los Servicios Veterinarios han hecho suya: la de los valores y los criterios éticos en el ámbito de la producción animal. En este artículo, los autores explican cómo la ciencia del bienestar animal ha pasado de las «cinco libertades» al concepto más general de los «cinco dominios» del bienestar animal.

Los artículos siguientes giran en torno a cuatro temas que corresponden a parte del principal cometido de los Servicios Veterinarios, pero en los que también se ha observado, y conjeturamos que seguirá habiendo, una notable evolución. En el primero, Auty *et al.* se ocupan de los riesgos que entrañan las enfermedades endémicas para animales y personas y recalcan que es en los países en desarrollo donde esta cuestión resulta más problemática. Los autores se plantean el interrogante de «cómo aprovechar al máximo el potencial de los sistemas de sanidad animal para obtener resultados sanitarios y de desarrollo».

En el siguiente artículo, Jost *et al.* se centran en las enfermedades epidémicas, que son una de las consecuencias involuntarias de la producción animal que más temor provocan, sobre todo si son zoonóticas. Magnusson *et al.* arrojan luz sobre la resistencia a los antimicrobianos, problema este que, si bien ya lleva tiempo preocupando a los profesionales de la veterinaria, ha cobrado un extraordinario protagonismo en los últimos años.

Pasamos después a otro tema de gran complejidad, respecto del cual la producción animal, aun trayendo consigo importantes externalidades positivas (esto es, beneficios para otras partes ajenas a ella), también es portadora de externalidades negativas (daños ocasionados a terceros) que generan creciente preocupación, relativas sobre todo a la seguridad alimentaria y nutricional y a la evolución de los regímenes alimentarios. El impacto de enfermedades humanas causadas por la obesidad o el sobrepeso es hoy mayor que el resultante de la falta de alimentos. Aun así, la malnutrición sigue provocando hoy en día retrasos del crecimiento en millones de niños, problema que está vinculado a regímenes alimentarios con escaso aporte de alimentos de origen animal. Carag *et al.* analizan con detenimiento esta espinosa cuestión.

Los tres artículos siguientes pasan a ocuparse de factores que parecen ser más bien internos. Makita expone al lector las más recientes novedades en materia de determinación del riesgo zoosanitario y de inocuidad de los alimentos, tradicional y a la vez fundamental cometido de la mayoría de los Servicios Veterinarios. Solomos y Randolph se ocupan de la determinación del riesgo institucional y del modo en que organizaciones como los Servicios Veterinarios pueden y deben tener en cuenta los riesgos económicos, jurídicos y ligados a su personal que podrían lastrar su eficaz desempeño. Weiland *et al.*, por su parte, se detienen en los procesos continuos de perfeccionamiento profesional y refuerzo de capacidades.

El siguiente artículo gira en torno a nueva iniciativa encaminada a conocer y cuantificar mejor las enfermedades animales y a respaldar una lucha más eficaz contra ellas. Existe la esperanza de que este programa, titulado «Impacto global de las enfermedades animales», traiga consigo un cambio del panorama tan profundo como el que en su día puso en marcha, allá por el decenio de 1990, la primera evaluación del impacto mundial de las enfermedades humanas. Huntington *et al.* ofrecen un exhaustivo resumen de los nuevos horizontes que se abren gracias a este innovador proyecto.

En el último artículo, yendo incluso más lejos, se abordan cuestiones de desarrollo aún más generales. Schneider y Tarawali centran su mirada en los Objetivos de Desarrollo Sostenible de las Naciones Unidas y en la relación entre esos objetivos y la producción animal, proponiendo fórmulas para que los Servicios Veterinarios ayuden a cumplirlos y a forjar de este modo un futuro mejor para todos.

Referencias

1. Stephen C. y Karesh W.B. (coords.) (2014). – Una sola salud. *Rev. Sci. Tech. Off. Int. Epiz.*, **33** (2). doi:10.20506/rst.issue.33.2.56.

2. Rushton J. (coord.) (2017). – Economía de la sanidad animal. *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1). doi:10.20506/rst.issue.36.1.2604.

3. de la Rocque S., Morand S. y Hendricks G. (coords.) (2008). – Cambio climático: influencia en la epidemiología y las estrategias de control de enfermedades animales. *Rev. Sci. Tech. Off. Int. Epiz.*, **27** (2). doi:10.20506/rst.issue.27.2.38.

4. Pastoret R.R. y Moutou F. (coords.) (2010). – Especies invasoras. Parte 1: generalidades y biodiversidad. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (1). doi:10.20506/rst.issue.29.1.43.

5. Pastoret P.-P. y Moutou F. (coords.) (2010). – Especies invasoras. Parte 2: ejemplos concretos. *Rev. Sci. Tech. Off. Int. Epiz.*, **29** (2). doi:10.20506/rst.issue.29.2.44.

6. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K. y Smith J. (2019). – Cómo los factores externos (por ejemplo cambio climático, conflictos, aspectos socioeconómicos y modelos comerciales) tendrán impacto en los Servicios Veterinarios, y las adaptaciones requeridas. Tema técnico presentado en la 87ª Sesión General de la Organización Mundial de Sanidad Animal (OIE), 26 a 31 de mayo, París, Francia. OIE, París (Francia). doi: 10.20506/TT.2984.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 383-394

Livestock production systems, their responses to the demand for animal-source food, and the implications for animal health services

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Summary
This paper reviews the rapidly changing global demands for animal-source foods, examines the agri-food systems behind these changes, and discusses the potential responses required by public-sector Veterinary Services to meet these new demands.

Keywords
Agri-foods – Animal-source foods – Production systems.

Introduction

Public-sector Veterinary Services fulfil statutory roles in most countries of the world, and their institutional strengths have largely focused on the control of major infectious diseases of animals. Whilst this remains a key responsibility, the environment in which public Veterinary Services and their clients operate is changing at a remarkable pace. This thematic issue pays specific attention to how climate change and other external factors impact Veterinary Services. In this paper, the authors explore the implications of changes in demand for animal-source foods (ASFs) for animal health services.

Defining fit-for-purpose animal health services

Animal health services have diverse roles. They must be able to respond to demands from a variety of different stakeholders, as well as to adapt and respond rapidly to crises and emergencies. The authors aim to explore what such responsibilities might entail in the context of rapidly changing and increasing demand for ASFs.

The central role of animal-source foods

The growth in the demand for and diversity of ASFs continues to shape the global livestock sector. These increases, however, have been uneven and there is substantial variation in the growth in demand, both by ASF and by region. For example, global increases in the demand for beef have been driven primarily by population growth, with most countries seeing declines in their per capita demand for beef, in comparison to 1990 levels. Brazil and China are the main exceptions. The demand for poultry, on the other hand, has increased in all regions (1). Moreover, different combinations of production systems and the juxtaposition of livestock agri-food systems at the national level, in addition to their diversity in different regions of the world, add an extra layer of complexity. Understanding these changes in demand and the accompanying evolution of livestock agri-food systems is key to providing functional and responsive Veterinary Services that ensure the production and safety of different ASFs.

Not by animal health alone

The spectrum of responsibilities of Veterinary Services has also evolved significantly in recent decades. It is no longer sufficient to understand and be responsive to the health and safety of ASFs and the production systems behind them. Veterinary Services should be equally cognisant of, and increasingly responsive to, the broader impact of the

https://doi.org/10.20506/rst.40.2.3231

sector on society, the effect of veterinary interventions on individual and societal goals and their social licence to act. Society's goals and ambitions have been captured in the Sustainable Development Goal (SDG) Agenda, set out by the United Nations. These 17 goals provide an internationally agreed-upon development framework in which it is possible to analyse the contribution of livestock agri-food systems to the 2030 Agenda – and the risks they could present to achieving specific SDGs (see, for example, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11). Livestock connect wildlife and environmental health to human health and are an important element in disease emergence and transmission. Inclusive approaches to managing disease threats at the animal–human–environmental interface, which involve producers at every level in the development and implementation of animal disease and food safety programmes, are becoming increasingly important. These trends involve greater understanding of the relationships among livestock, human health and livelihoods; new outputs from research; interactions among climate change, crops, land use and animals; and a new systemic approach to animal health management; and demand greater attention from Veterinary Services in all countries.

Further development and implementation of a One Health perspective (see Box 1) of Veterinary Services need to take consideration of, and be responsive to, broader issues, such as:

– antimicrobial resistance (18)

– endemic disease affecting productivity and performance

– emerging zoonotic diseases (19)

– multi-sectoral dialogue and preparedness for emerging diseases (20)

– key links between stakeholders and institutions and knowledge of the wide variety of different participants in the value chain

– the economic impacts of diseases, measures for their control, and corresponding trade-offs (see, for example, 21).

While it is undoubtedly necessary to service these evolving demands, there are questions as to whether the current concept of One Health is sufficient to cover the breadth of veterinary responsibilities in a changing world.

The perishability of most ASFs puts special demands on their marketing and preparation to prevent contamination and other food safety risks. For numerous poor people in low- and middle-income countries (LMICs), food-borne disease is frequent and generally under-reported. Food-borne pathogens are an important contributor to diarrhoeal diseases, which the World Health Organization (WHO) estimates to cause economic losses of between US$ 33 billion and US$ 77 billion, and 1.8 million human deaths, each year (22).

The widespread use of antimicrobial drugs as preventative measures or growth promoters in livestock production is of growing concern (23). Inappropriate use may contribute to increasing resistance, which makes these drugs ineffective in treating infectious or parasitic infections in humans and animals. The use of such drugs has grown as livestock systems intensify around the world. In addition, residues harmful to consumers can be an issue in certain types of livestock agri-food systems.

Intensive livestock production often involves the geographical clustering of large numbers of genetically similar animals. Strong biosecurity and health protection regimes may prevent infectious disease problems, but outbreaks can occur when a pathogen mutates to a more virulent form, eludes the treatment or vaccine used, acquires resistance to antibiotics, or enters undetected into the food chain. Traditional extensive livestock production systems – which often involve animals from different owners roaming freely over large areas but still in relatively high densities – can also facilitate disease spread, both among local animal populations and over large distances (24).

Well-recognised diseases continue to cause significant losses to production and livelihoods. Outbreaks of notifiable diseases cause disruption to international trade and prevent access to more lucrative markets. In addition, such events often have concomitant disastrous effects on closely linked industries and activities. Livelihood strategies driven by poverty and desperation that contribute to pollution hot spots, and the spread of insect vectors due to climatic change, also predispose communities to both human and animal disease outbreaks. The poorer sectors of societies often bear a disproportionate share of the burden of (zoonotic) disease because of their close contact with livestock in unsanitary conditions. The tasks of improving management practices and controlling zoonoses and food-borne diseases should therefore be more closely integrated (25).

Technological advances have revolutionised our ability to detect, diagnose, cure and prevent animal diseases. Some of these technologies are specific to health, such as lateral flow diagnostics, while others are novel applications to health problems, e.g. disease reporting via advanced mobile-phone applications (26). Since the appearance of severe acute respiratory syndrome (SARS) and H5N1 highly pathogenic avian influenza (HPAI), there has been a growing realisation that new and emerging zoonotic diseases do not only threaten the health of susceptible humans. They also have increasingly severe economic impacts on a wide range of enterprises and industries, with direct and indirect economic losses over the last decade estimated at around US$ 80 billion (27). The recent SARS Coronavirus 2 (CoV-2) pandemic provides additional evidence that much greater global investment will be required in the surveillance and monitoring of emerging zoonotic threats; global data-

Box 1
The promise of One Health

The concept of One Health (described by the Centers for Disease Control and Prevention as a collaborative, multi-sectoral, and transdisciplinary approach, working at the local, regional, national, and global levels, with the goal of achieving optimal health outcomes recognising the interconnection between people, animals, plants, and their shared environment [12]), has taken on a new globalised lease of life with the emergence of COVID-19. The World Organisation for Animal Health (OIE) has provided an extensive description of the origins and history of One Health (13), which has been further supplemented from different sources (see, for example, 14, 15, 16). Recent pandemics, such as avian influenza ('bird flu'), swine flu, severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS) have highlighted the need for the One Health approach to be taken more seriously, but the lack of preparedness and response to the COVID-19 pandemic illustrates that the implementation of One Health has not matched its potential.

Authors present different interpretations of the overall concept of health management at the interface between ecosystem health, animal health and human health, and highlight the synergistic benefits of closer cooperation between the human, animal and environmental health sciences, as well as the importance of dismantling disciplinary and professional silos (17). One Health has been used as an advocacy tool for an holistic, 'big-picture' approach to pursuing sustainable health sciences, and as a funding mechanism to bring health-focused scientists into interdisciplinary research. The concept has been more popular with veterinary scientists and their human medicine counterparts. There have also been different interpretations of the potential scope for engaging various scientific disciplines, such as modelling. Arguably, the One Health approach has yet to be recognised as being functional and operational at international, national, local and disciplinary levels.

Several new One Health initiatives and networks are now active and play a range of different roles to support animal health services. These include:
- the One Health Centre in Africa
- the Centers for Disease Control and Prevention
- the Global Health Security Agenda
- the One Health Platform.

The One Health Centre in Africa

The goal of the One Health Research, Education and Outreach Centre in Africa is to improve the health of humans, animals and ecosystems through building capacity, strengthening local, regional and global networks, and providing evidence-based policy advice on One Health in sub-Saharan Africa. The centre has four thematic areas: neglected tropical zoonotic diseases, emerging infectious diseases, food safety and informal markets, and prevention and control of antimicrobial resistance (www.ilri.org/news/one-health-centre-africa).

The Centers for Disease Control and Prevention

The One Health experts of the Centers for Disease Control and Prevention (CDC) are working globally to implement a One Health zoonotic disease prioritisation process. This project is intended to build collaboration across disciplines and sectors to focus limited resources on preventing, detecting and responding to those zoonotic diseases of greatest national concern (www.cdc.gov/onehealth/index.html).

The Global Health Security Agenda

The Global Health Security Agenda (GHSA) is a group of 69 countries, international organisations, non-governmental organisations and private-sector companies that have come together to achieve the vision of a world safe and secure from global health threats posed by infectious diseases (ghsagenda.org/).

One Health Platform

The One Health Platform is a scientific reference centre and a network of One Health stakeholders. It is an independent, international, not-for-profit organisation that fosters science for the greater good (onehealthplatform.com/home).

sharing; the development of bespoke vaccination strategies (should we vaccinate people or livestock?); and different platform technologies for vaccines.

The livestock sector is responsible for an estimated 14.5% of global greenhouse gas (GHG) emissions (28), but there is substantial potential to reduce this figure through efficiency gains in resource use, better recycling, moving towards lower carbon protein sources and putting strong policies in place to incentivise change. The sector also has the potential to provide significant carbon sequestration, as part of its many ecosystem services. This issue is well recognised, and much has been done to measure and understand livestock system contributions in different countries and to explore mitigation options. Wider adoption of existing best practices and technologies in feeding, health and husbandry, and manure management – as well as greater use of currently under-used technologies such as biogas generators and energy-saving devices – could help the global livestock sector cut its outputs of global warming gases by as much as 30%, by becoming more efficient and reducing energy waste (28). However, GHG mitigation technologies may

come at a cost to animal welfare and other environmental variables. Clearly, practices and technologies that have beneficial rather than detrimental co-effects should be favoured (29, 30). There is also increasing debate about the mitigation impacts that may be derived from changes in demand (e.g. 8).

The interface between wildlife, domestic animals and livestock, and humans is changing continuously due to our encroachment into natural areas. In addition, stressors on natural ecosystems are thought to affect pathogen-shedding patterns by wildlife species, possibly lowering the threshold for spillover (31). While food and food production in the last decades of the 20th century were characterised by significant productivity increases, this increase in yield per hectare is starting to show signs of plateauing in most regions of the world (2). To continue to meet the growing demand for food, feed and biofuel, further acreage expansion by converting natural habitats into agricultural land is expected in a number of regions of the world, thus continuing to increase the likelihood of spillover events. Additional factors, including climate change, and the changing distributions and densities of arthropod vectors (32), lend further urgency to the need to develop and implement sustainable interventions to mitigate pathogen spillover and spread.

Building fit-for-purpose Veterinary Services – case studies

Case study 1: North Africa and the Middle East

This region is one of the most complex in the world from many perspectives, and this is manifest in its relationship with livestock and agri-food systems (33). Climatically, virtually the entire region experiences extremely low rainfall, severely limiting its capacity to produce food and raise livestock. From an epidemiological viewpoint, there are some positive aspects to the arid environment: gastrointestinal parasites and ectoparasites are much more limited here than in the environments south of the Sahara and in southern Europe. Nevertheless, there remain many environments and conditions under which such parasites thrive. Since this region is a net importer of livestock and livestock products to service demand, it is at high risk of importing diseases and other human and animal health threats from multiple sources in its neighbours and trading partners. The region also presents a wide range of economic well-being, poverty levels and security, as well as diverse interfaces between people, the environment, and livestock and livestock enterprises.

The various diseases present in the region behave in different ways, have different host associations, have different transmission risk pathways, and, most importantly, have a variety of impacts on different stakeholders. In addition, certain countries have particular risks associated with their trading patterns. Egypt, for example, has specific risks associated with the movement of animals northwards from Sudan, while the Gulf States face distinct risks with the importation of live animals from the Horn of Africa (HoA).

What are the demands on animal health services to meet the increasing demand for ASFs in this region? They comprise:

– fundamental clinical animal health services (including herd health, performance monitoring, vaccination, etc.)

– national emergency preparedness and response, official disease control campaigns (vaccination, etc.), early warning, disease prediction, contingency planning

– national zoonotic disease preparedness, management and response

– food and feed safety and hygiene

– the reduction of vulnerability and promotion of resilience during conflicts

– leadership and capacity in animal health and disease control.

Fundamental clinical animal health services (including herd health, performance monitoring, vaccination, etc.)

The need for basic clinical animal health services is particularly strong within small- and medium-scale systems engaged in the intensification process in the areas of dairying, small ruminants and poultry. Many of these services could be privately financed, supported by enabling legislation. Medium-scale enterprises could source animal health services through agri-business involvement, or through the development of cooperatives/franchises. Smallholders, however, particularly those in rural areas, will likely continue to require public-sector support, possibly with the addition of smart subsidies to service providers, to incentivise the provision of services in rural and remote settings.

National emergency preparedness and response, official disease control campaigns (vaccination, etc.), early warning, disease prediction, contingency planning

Those involved in this component of animal health services would take the lead responsibility for controlling transboundary animal diseases (TADs). They would play the major role in disease preparedness, planning

and response activities, such as vaccination, movement controls, quarantine and slaughter, as well as in forecasting disease dynamics, carrying out disease risk assessments and contingency planning. This might include the instigation of a contingency operation fund, supported by the private sector.

National zoonotic disease preparedness, management and response

This component of animal health services incorporates antimicrobial resistance monitoring and communication. This fosters and sustains functional links with human health services and communities at both the local and national level in a One Health environment.

Food and feed safety and hygiene

There is also a need to monitor and set standards for food safety for the different commodities emerging from value chains, in both the formal and informal sector. In regard to feed resources, both domestic and imported feed resources being used by these multiple value chains also require standards and monitoring. This is essential with the growing demand for commercial poultry and dairy feeds.

Reducing vulnerability and promoting resilience in conflict situations

The provision of services must pay particular attention to those livestock health issues that affect the production systems of the extremely poor and vulnerable communities in all countries of the region, and the special needs of livestock systems caught in war and zones of extreme insecurity. Perhaps there is an opportunity for greater and more innovative provision of incentives to community-based animal health providers to continue to provide services to these at-risk livestock holders.

Leadership and capacity in animal health and disease control

There is arguably a crucial need for greater capacity building in veterinary/animal health services, both in educational institutes such as universities and training colleges, and in continuing professional development for government and private health services. This capacity needs to be consistent with the key demands and drivers of the five classes of animal health services listed above. It is important to note that, given the growth in livestock enterprises in this region, the multitude of disease threats, and the impacts of climate change, much of the present capacity is insufficiently driven by demand.

Beyond education and continuing professional development, there is also a need for strong government leadership in creating and maintaining partnerships between the public and private sectors in the field of pharmaceutical and biological products used in livestock enterprises; ensuring the constructive engagement of the private sector; and sound technical oversight.

Case study 2: the Thai poultry industry

In the space of two decades, the 1970s and 1980s, Thailand went from backyard poultry production to become the world's number one exporter of value-added poultry, and the fourth overall producer of broiler meat, with Japan and the European Union (EU) as its major markets.

More than three decades of impressive yearly growth came to an abrupt end in early 2004, however, when an outbreak of HPAI was officially confirmed in the country. In response to the outbreak, all importing countries banned imports of raw poultry meat from Thailand. At that time, 65% of poultry exports by weight were in the form of raw, frozen meat and 35% took the form of cooked products. Japan, Thailand's largest market, also temporarily banned cooked products, although later it accepted these from facilities that had been inspected and approved by its officials. How did the veterinary sector respond to this situation?

Most HPAI outbreaks occurred in native chickens, ducks, laying quail and commercial chickens. The Thai government's response to outbreaks consisted of a stamping-out policy: affected and potentially exposed birds were culled and their owners compensated. Compulsory registration was introduced for free-ranging poultry, including ducks. Owners of fighting cocks (and the stadia where the fights were staged) had to register.

In early 2004, there were an estimated 10 to 11 million free-ranging ducks in Thailand. Free-ranging ducks were herded in rice paddies and moved by truck between sites when the food supply was depleted. Health investigators in Thailand realised that there was a high correlation between the presence of free-ranging ducks and the spread of HPAI to chickens. In closed systems, with high biosecurity standards, no infections were detected in ducks, but HPAI virus was prevalent in the free-ranging birds. Often these infected ducks showed no signs of disease: the transporting of these 'silent carriers' around the country was therefore a high-risk means of spreading the disease.

In response, the government made housing ducks compulsory. To facilitate this, the government ordered the Thai Bank of Agriculture and agricultural cooperatives to make cheap loans available to finance barn construction.

The HPAI outbreaks between 2004 and 2008 acted as a catalyst to cause wide-ranging structural changes across

Thailand's poultry industry, driven by the large-scale export industry, importers, and the Thai government. More stringent biosecurity, food hygiene and animal welfare regulations and standards were imposed and enforced by the Thai government and importing countries. The industry underwent significant consolidation, with fewer, larger, more integrated poultry companies emerging to dominate the export trade. These included indigenous and multi-national companies. The predominant business model shifted from contract rearing to fully vertically integrated businesses that encompassed breeding farms, feed mills, rearing units, slaughterhouses and processing facilities, as well as domestic retail outlets and fast-food restaurants.

One result of the strict biosecurity arrangements now in place in the Thai poultry industry is that the country is well positioned to avoid HPAI outbreaks – there has been no outbreak since 2008, despite outbreaks in nearby countries. The shift to predominantly cooked products also means that, in the event of an outbreak, Thailand will be able to continue exporting, avoiding a severe dip in exports as experienced in 2004.

Recognising that it would be difficult, in some cases, to maintain disease-free status for a whole country, in 2005 the World Organisation for Animal Health (OIE) introduced the idea that a sub-population of birds within a country could have a different health status. The OIE defines a compartment as:

> 'One or more establishments (premises in which animals are kept) under a clearly defined common biosecurity management system containing an animal sub-population with a distinct health status with respect to a specific disease or diseases for which required surveillance, control and biosecurity measures have been applied for the purposes of disease control and/or international trade' (34).

In 2008, the Department of Livestock Development in Thailand introduced a compartmentalisation system whereby large-scale poultry farms or clusters of such farms could be treated as a compartment. Specific disease surveillance and prevention measures are carried out within a buffer zone of one kilometre around each farm in these compartments. These measures include routine clinical surveillance and sampling of birds through cloacal swabs.

The Thai government lobbied the EU and Japan to allow the resumption of exports of frozen, raw, poultry meat from compartments that could demonstrate freedom from disease and the requisite biosecurity and other measures. This approach was, however, not successful. The EU only lifted its nationwide ban on frozen, raw poultry in July 2012, with Japan following suit in December 2014, nearly ten years after the ban first came into effect. The situation was not helped by the widely held view that the Thai government initially suppressed information about the outbreak of HPAI; although officially reported in January 2004, it is believed to have begun in November 2003. It has been speculated that the government was influenced by poultry exporters to suppress the announcement that HPAI had been detected. The eventual announcement of the HPAI outbreak in Thailand coincided with the announcement of the first human cases.

To date, Thailand's compartmentalisation approach has not been recognised by the EU or Japan, although some Middle Eastern countries have allowed imports of frozen, raw chicken from Thailand under its compartmentalisation arrangements (35). More broadly, there are very few examples in the world where an exporting country's compartmentalisation system has been recognised by importing countries.

Case study 3: livestock sector growth in Bangladesh and veterinary capacity to respond

Bangladesh has seen substantial growth in the demand for ASFs in response to its rapidly growing population and income (36). This has fuelled an increase in livestock populations and the intensification of livestock systems, in particular, poultry and dairy. Animal health constraints, along with those of feeding and breeding, are paramount in this development and intensification process. How is the veterinary profession responding to this growing demand for its services?

The poultry industry is the largest and most important livestock sector in the country, and has long been considered by many to be crucial to agricultural growth, poverty reduction and the provision of dietary protein for the Bangladeshi people. The poultry sub-sector is particularly important in that it provides an important source of nutrition, is a worthwhile economic enterprise for women and the poorer sectors of society, and presents a range of employment opportunities (37). The diverse poultry industry comprises broiler chickens, layer chickens, native chickens and ducks.

The production of broiler and layer chickens is characterised by large-scale, intensive, commercial production systems with modern technology and imported hybrids, and by small- and medium-scale enterprises of 2,000 to 25,000 birds. Native chicken production, on the other hand, is usually a backyard activity undertaken by rural households using minimal inputs, but there is also small-scale commercial production of local chickens. The Bangladesh smallholder poultry model has been analysed and described in several publications (38, 39, 40, 41, 42, 43, 44).

In Bangladesh's dairy sector, the demand for milk has grown dramatically, and the country is not able to meet this demand (35), producing only about 43% of the required quantity. Of total domestic milk production, about 90% comes from cattle, 8% from goats and the remaining 2% from buffalo. The country has about 23.1 million cattle, 1.39 million buffalo and 24.2 million goats.

The smallholder dairy sector is growing, and there is an increasing number of processing organisations. Perhaps the most notable is Milkvita (the Bangladesh Milk Producers' Cooperative Union Limited or BMPCUL) (www.amul.com/m/about-us).

Milkvita operates as a vertically integrated enterprise, drawing its supply from 1,800 primary milk-producing societies, and is involved in both the collection and processing of milk. It employs 27 veterinarians, who provide the cooperative's producers with clinical support, run through mobile clinics, with a supporting team of 235 veterinary assistants. As with many graduate employers, Milkvita cites the practical weaknesses of graduates when they finish university (in recent years most have come from Bangladesh Agricultural University), and they are given an internal training programme for one year.

Bangladesh has an impressive record of establishing veterinary schools within its territory. However, the country now finds itself at a juncture where it must carefully define its changing veterinary landscape to determine who its future employers will be, and what skills and qualities these employers will require of veterinarians over the next decade.

Almost inevitably, as a basis for better animal disease control knowledge, skills and preparedness, Bangladesh's veterinary institutions will have to give increasing importance to understanding livestock production systems, their dynamics, and their impacts on disease dynamics. In addition, it will be essential to use ASF value chains as a framework for understanding disease dynamics, disease risk and disease impact, as well as the implementation of disease control. These are all central to an understanding of the roles and services offered by the veterinary profession.

Case study 4: livestock and livestock commodity trade between countries of the Horn of Africa and those of the Arabian Peninsula

Annual livestock-related exports from the HoA and neighbouring countries to high-value markets in the countries of the Arabian Peninsula (AP) are estimated to be close to US$ 1 billion. Although this trade has been a success story, it has also been severely affected by disease-associated trade bans, as well as the concerns of buyers and consumers in AP countries about the ability of HoA countries to export safe products.

When exploring the potential for greater trade between the HoA and the AP, the OIE recently commissioned a feasibility study to examine how trade between these two regions could be enhanced (45). This study shows that several issues hamper trade between the two regions, including a lack of trust and communication, low stakeholder capacity and weak animal health system performance. Importantly, the OIE recommended enhancing the capacities of the exporting countries by improving traceability, infrastructure, animal health and certification, the performance of their Veterinary Services, vaccine production and diagnostic facilities.

Case study 5: the importance of public–private partnerships in the effective and economically feasible delivery of Veterinary Services

Traditionally, Veterinary Services applied to priority TADs have been seen as a public good, with the public sector picking up the costs of disease control. This has particularly been the case with foot and mouth disease (FMD).

Uruguay has successfully controlled FMD and has been recognised by the OIE as FMD-free with vaccination since 2003. A particularly important feature of this disease-free status is that a small country with a human population of around three million has developed and maintained an international market in different livestock commodities to all regions of the globe, capturing approximately 4% of the world meat market. The interest in and aspiration to FMD freedom are shared equally between the public and private sector. From the public-sector viewpoint, Uruguay is playing a leading role in meeting the broader aspirations of the Hemispheric Program for the Eradication of Foot-and-Mouth Disease 2011–2020, together with Panama and the other countries of South America, to eradicate FMD under the coordination of the Pan American Foot-and-Mouth Disease Center. From the private-sector viewpoint, the international meat trade contributes substantially to Uruguay's gross domestic product, and the stakeholders who benefit include farmers of different scales, marketing organisations and others in the country's extensive network of value chains.

The cost of FMD control in Uruguay is estimated to be US$ 37 million. The private-sector contribution to this sum is just under half (48%). The country recently evaluated the costs and benefits of adjusting its national FMD policy to one of FMD freedom without vaccination (given that this status would provide additional potential market opportunities), and examined the risks associated with such a change in policy (46). The evaluation was commissioned by a partnership between the Ministry of Livestock, Agriculture

and Fisheries, the Instituto Nacional de Investigación Agropecuaria, and the private Instituto Nacional de Carnes, in a unique and arguably model public–private partnership.

Conclusions

The above examples indicate that changing demand for ASFs in various regions of the world, with a diverse range of livestock agri-food systems, has put additional demands on Veterinary Services. Defining such fit-for-purpose animal health services in the absence of their specific context is difficult. The case studies do allow us, however, to postulate the broad requirements and objectives for such added services at the international level, and for high-income countries (HICs) and LMICs.

International veterinary responsibilities

At the global and regional level, the growth in demand for ASFs requires that additional attention be paid to coordinated surveillance and monitoring of existing TADs and potential interactions between wildlife and livestock agri-food systems. Data collected through such monitoring, shared through global networks, will enable real-time analysis to assist in identifying outbreaks of TADs and emerging zoonotic threats. These processes need to be combined with an increased understanding of the role that different livestock agri-food systems (and combinations of these) play in TADs and pathogen amplification and emerging zoonotic threats. Such an understanding is necessary if we are to reduce the number of potential 'melting-pot' situations, where livestock agri-food systems come into contact with wildlife and nature. The combination of data and insights obtained through such mechanisms will enable us to design an appropriate response capacity, including the further development of relevant vaccine platform technologies and the configuration and design of preventative livestock agri-food systems. While such tasks are often thought to be solely within the realm of public Veterinary Services, the accrual of benefits derived from such programmes generally justifies the exploration of bespoke producer–public-sector cost-sharing approaches.

Additional requirements in high-income countries

High-income countries pose additional demands on ASFs, particularly in regard to animal welfare and well-being. In future, we will have to expand our focus to deal with such issues as: improving animal welfare in production systems, transitioning to low-carbon-footprint livestock agri-food systems, and increasing circularity through, for example, the reintroduction and safe use of swill and other feed-base changes. Other aspects that will require additional attention are the reduced use of animals in experimentation (through, for example, the further development of organoids and other replacement methods) and the role of companion animals in pathogen amplification/epidemiology. A change in focus on zoonoses – paying less attention to solely human impacts and more to the role of livestock agri-food systems in non-communicable diseases – is another important aspect to this broadened perspective of a One Health approach to Veterinary Services.

Additional requirements in low- and middle-income countries

Low- and middle-income countries often host a kaleidoscope of production systems, which play diverse roles in the provision of ASFs and livelihoods, in a ratio that differs widely from country to country, and which receive different levels of political attention. In intensifying the transition towards high-production/low-impact agri-food systems, production diseases must become a key focus of Veterinary Services. The use of antimicrobials, health performance monitoring and preventative medicine all fall within this brief. Ideally, much of this is the responsibility of private veterinary providers, but long-standing traditional practices mean that these areas are also dealt with by public-sector services.

Changes in demand for ASFs are often the root cause of changing interactions between pathogens, nature and society. Whilst much of the attention around these issues should justifiably be directed towards infectious pathogens, understanding the different social, economic and environmental trade-offs in the redesign and reorganisation of existing agri-food systems is also an essential part of dealing with the threat of emerging diseases.

Importantly, LMICs are characterised by a wide diversity of agri-food systems requiring different sets of veterinary expertise. This is a challenge in many countries, where decreases in public-sector funding have led to large gaps in professional staffing, with inadequate numbers of graduate veterinarians to respond to the demand for expertise. Linked to this is the slow speed with which veterinary schools are able to 'catch up' with the educational demands of emerging agri-food systems.

Les systèmes de production animale, leur adaptation à la demande en denrées alimentaires d'origine animale et les conséquences pour les services de santé animale

B.D. Perry & J.T. Dijkman

Résumé
Les auteurs examinent la demande mondiale en denrées alimentaires d'origine animale et ses évolutions extrêmement rapides, ainsi que les systèmes agroalimentaires qui sous-tendent ces changements ; ils abordent ensuite les différentes mesures que les Services vétérinaires du secteur public devraient envisager afin de répondre à ces nouvelles exigences.

Mots-clés
Denrées alimentaires d'origine animale – Secteur agroalimentaire – Systèmes de production.

Los sistemas de producción animal, sus respuestas a la demanda de alimentos de origen animal y consecuencias para los servicios zoosanitarios

B.D. Perry & J.T. Dijkman

Resumen
Los autores examinan la demanda mundial de alimentos de origen animal, que cambia con gran rapidez, describen los sistemas agroalimentarios que se encuentran detrás de esta evolución y consideran las posibles respuestas de los Servicios Veterinarios del sector público que se requieren para atender esta nueva demanda.

Palabras clave
Agroalimentos – Alimentos de origen animal – Sistemas productivos.

References

1. Herrero M., Mason-D'Croz D., Godde C.M., Palmer J., Thornton P.K. & Gill M. (2018). – Livestock and land and the environmental limits of animal source food consumption. *In* Proc. Science Forum 2018, 10–12 October, Stellenbosch, South Africa. Consultative Group on International Agricultural Research (CGIAR) International Science and Partnership Council, Rome, Italy, 39 pp. Available at: cgspace.cgiar.org/bitstream/handle/10568/98842/SF18_background_paper_herrero.pdf (accessed on 21 March 2021).

2. Food and Agriculture Organization of the United Nations (FAO) (2017). – The future of food and agriculture – trends and challenges. FAO, Rome, Italy, 180 pp. Available at: www.fao.org/3/i6583e/i6583e.pdf (accessed on 21 March 2021).

3. Food and Agriculture Organization of the United Nations (FAO) (2018). – Transforming food and agriculture to achieve the SDGs: 20 interconnected actions to guide decision-makers. FAO, Rome, Italy, 76 pp. Available at: www.fao.org/3/I9900EN/i9900en.pdf (accessed on 21 March 2021).

4. Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development, United Nations International Children's Emergency Fund, World Food Programme & World Health Organization (2018). – The state of food security and nutrition in the world 2018: building climate resilience for food security and nutrition. FAO, Rome, Italy, 202 pp. Available at: www.fao.org/3/I9553EN/i9553en.pdf (accessed on 21 March 2021).

5. Caron P., Ferrero y de Loma-Osorio G. […] & Verburg G. (2018). – Food systems for sustainable development: proposals for a profound four-part transformation. *Agron. Sustain. Dev.,* **38** (4), 41. doi:10.1007/s13593-018-0519-1.

6. Development Initiatives (2018). – 2018 Global Nutrition Report: shining a light to spur action on nutrition. Development Initiatives, Bristol, United Kingdom, 161 pp. Available at: reliefweb.int/sites/reliefweb.int/files/resources/2018_Global_Nutrition_Report.pdf (accessed on 21 March 2021).

7. World Resources Institute (WRI) (2018). – Creating a sustainable food future: a menu of solutions to feed nearly 10 billion people by 2050. WRI, Washington, DC, United States of America. Available at: research.wri.org/wrr-food (accessed on 21 March 2021).

8. Willett W., Rockström J. […] & Murray C.J.L. (2019). – Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet*, **393** (10170), 447–492. doi:10.1016/S0140-6736(18)31788-4.

9. Swinburn B.A., Kraak V.I. […] & Dietz W.H. (2019). – The global syndemic of obesity, undernutrition, and climate change: the Lancet Commission report. *Lancet*, **393** (10173), 791–846. doi:10.1016/S0140-6736(18)32822-8.

10. Intergovernmental Panel on Climate Change (IPCC) (2018). – Global warming of 1.5°C: an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (V. Masson-Delmotte *et al.*, eds). IPCC, Geneva, Switzerland. Available at: www.ipcc.ch/sr15/ (accessed on 21 March 2021).

11. Intergovernmental Panel on Climate Change (IPCC) (2019). – Summary for policymakers. *In* Climate change and land: an IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (P.R. Shukla *et al.*, eds). IPCC, Geneva, Switzerland. Available at: www.ipcc.ch/srccl/ (accessed on 21 March 2021).

12. Centers for Disease Control and Prevention (CDC) (2021). – One Health basics. CDC, Atlanta, United States of America. Available at: www.cdc.gov/onehealth/basics/index.html (accessed on 21 March 2021).

13. Evans B.R. & Leighton F.A. (2014). – A history of One Health. *In* One Health (W. Karesh, ed.). *Rev. Sci. Tech. Off. Int. Epiz.,* **33** (2), 413–420. doi:10.20506/rst.33.2.2298.

14. Boqvist S., Söderqvist K. & Vågsholm I. (2018). – Food safety challenges and One Health within Europe. *Acta Vet. Scand.,* **60** (1), 1. doi:10.1186/s13028-017-0355-3.

15. Mackenzie J.S. & Jeggo M. (2019). – The One Health approach – why is it so important? *Trop. Med. Infect. Dis.,* **4** (2), 88. doi:10.3390/tropicalmed4020088.

16. Osterhaus A.D.M.E., Vanlangendonck C. […] & Wagenaar J.A. (2020). – Make science evolve into a One Health approach to improve health and security: a white paper. *One Hlth Outlook*, **2** (1), 6. doi:10.1186/s42522-019-0009-7.

17. Amuasi J.H., Walzer C., Heymann D., Carabin H., Huong L.T., Haines A. & Winkler A.S. (2020). – Calling for a COVID-19 One Health research coalition. *Lancet*, **395** (10236), 1543–1544. doi:10.1016/S0140-6736(20)31028-X.

18. World Health Organization (WHO) (2020). – Antimicrobial resistance. WHO, Geneva, Switzerland. Available at: www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance#:~:text=What%20is%20antimicrobial%20resistance%3F,spread%2C%20severe%20illness%20and%20death (accessed on 21 March 2021).

19. Karesh W.B., Dobson A. […] & Heymann D.L. (2012). – Ecology of zoonoses: natural and unnatural histories. *Lancet*, **380** (9857), 1936–1945. doi:10.1016/S0140-6736(12)61678-X.

20. Machalaba C.C., Salerno R.H. […] & Wannous C. (2018). – Institutionalizing One Health: from assessment to action. *Hlth Secur.*, **16** (Suppl. 1), S37–S43. doi:10.1089/hs.2018.0064.

21. Bloom D.E., Cadarette D. & Sevilla J.P. (2018). – Epidemics and economics: new and resurgent infectious diseases can have far-reaching economic repercussions. *Finance Dev.*, **55** (2), 46–49. Available at: www.imf.org/external/pubs/ft/fandd/2018/06/economic-risks-and-impacts-of-epidemics/bloom.pdf (accessed on 21 March 2021).

22. GBD 2016 Diarrhoeal Disease Collaborators (2018). – Estimates of the global, regional, and national morbidity, mortality, and aetiologies of diarrhoea in 195 countries: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet Infect. Dis.,* **18** (11), 1211–1228. doi:10.1016/S1473-3099(18)30362-1.

23. Ma F., Xu S., Tang Z., Li Z. & Zhang L. (2021). – Use of antimicrobials in food animals and impact of transmission of antimicrobial resistance on humans. *Biosaf. Hlth*, **3** (1), 32–38. doi:10.1016/j.bsheal.2020.09.004.

24. Food and Agriculture Organization of the United Nations (FAO) (2013). – World livestock 2013: changing disease landscapes. FAO, Rome, Italy, 130 pp. Available at: www.fao.org/3/i3440e/i3440e.pdf (accessed on 21 March 2021).

25. Grace D., Lindahl J., Wanyoike F., Bett B., Randolph T. & Rich K.M. (2017). – Poor livestock keepers: ecosystem–poverty–health interactions. *Philos. Trans. Roy. Soc. Lond., B, Biol. Sci.*, **372** (1725), 20160166. doi:10.1098/rstb.2016.0166.

26. Thumbi S.M., Njenga M.K., Otiang E., Otieno L., Munyua P., Eichler S., Widdowson M.-A., McElwain T.F. & Palmer G.H. (2019). – Mobile phone-based surveillance for animal disease in rural communities: implications for detection of zoonoses spillover. *Philos. Trans. Roy. Soc. Lond., B, Biol. Sci.*, **374** (1782), 20190020. doi:10.1098/rstb.2019.0020.

27. Belay E.D., Kile J.C., Hall A.J., Barton-Behravesh C., Parsons M.B., Salyer S. & Walke H. (2017). – Zoonotic disease programs for enhancing global health security. *Emerg. Infect. Dis.,* **23** (13), S65–S70. doi:10.3201/eid2313.170544.

28. Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A. & Tempio G. (2013). – Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy, 139 pp. Available at: www.fao.org/3/i3437e/i3437e.pdf (accessed on 21 March 2021).

29. Ahmed M., Ahmad S., Waldrip H.M., Ramin M. & Ali Raza M. (2020). – Whole farm modelling: a systems approach to understanding and managing livestock for greenhouse gas mitigation, economic viability and environmental quality. *In* Animal manure: production, characteristics, environmental concerns and management (H.M. Waldrip, P.H. Pagliari & Z. He, eds). American Society of Agronomy (ASA) Special Publication **67**. ASA, Madison, United States of America, 345–371. doi:10.2134/asaspecpub67.c25.

30. MacLeod M. & Moran D. (2017). – Integrating livestock health measures into marginal abatement cost curves. *In* The economics of animal health (J. Rushton, ed.). *Rev. Sci. Tech. Off. Int. Epiz.,* **36** (1), 97–104. doi:10.20506/rst.36.1.2613.

31. Van Langevelde F., Rivera Mendoza H.R., Matson K.D., Esser H.J., De Boer W.F. & Schindler S. (2020). – The link between biodiversity loss and the increasing spread of zoonotic diseases. Document for the Committee on Environment, Public Health and Food Safety, Policy Department for Economic, Scientific and Quality of Life Policies. European Parliament, Luxembourg City, Luxembourg, 32 pp. Available at: www.europarl.europa.eu/RegData/etudes/IDAN/2020/658217/IPOL_IDA(2020)658217_EN.pdf (accessed on 21 March 2021).

32. Caminade C., McIntyre K.M. & Jones A.E. (2019). – Impact of recent and future climate change on vector-borne diseases. *Ann. N.Y. Acad. Sci.*, **1436** (1), 157–173. doi:10.1111/nyas.13950.

33. Food and Agriculture Organization of the United Nations (FAO) (2016). – Livestock contribution to food security in the Near East and North Africa. *In* Proc. FAO Regional Conference for the Near East, 9–13 May, Rome, Italy. FAO, Rome, Italy, 13 pp. Available at: www.fao.org/3/a-mp852e.pdf (accessed on 21 March 2021).

34. Kahn S. & Muzio Llado F. (2014). – Implementation of the compartmentalisation concept: practical experience and perspectives. *In* Proc. 22nd Conference of the OIE Regional Commission for the Americas, 10–14 November, Guadalajara, Mexico. OIE, Paris, France, 18 pp. Available at: www.oie.int/fileadmin/Home/eng/Publications_&_Documentation/docs/pdf/TT/2014_AME2_Kahn_A.pdf (accessed on 21 March 2021).

35. Rakpong J. (2011). – Regulatory aspects of EU–Thai trade relations in the area of food safety. PhD thesis. University College London, London, United Kingdom, 425 pp. Available at: discovery.ucl.ac.uk/id/eprint/1348547/1/1348547.pdf (accessed on 21 March 2021).

36. Bangladesh Institute for Development Studies (BIDS) (2014). – Barriers to the development of livestock sector in Bangladesh. Policy Brief No. **1408**. BIDS, Dhaka, Bangladesh, 8 pp. Available at: office.mcc.com.bd/bids/uploads/policydoc/Policy_Brief-2014-8.pdf (accessed on 21 March 2021).

37. Raihan S. & Mahmud N. (2008). – Trade and poverty linkages: a case study of the poultry industry in Bangladesh. CUTS CITEE Working Paper No. **6/2008**. CUTS Centre for International Trade, Economics & Environment (CITEE), Jaipur, India, 15 pp. Available at: www.researchgate.net/publication/237817180_Trade_and_Poverty_Linkages_A_Case_Study_of_the_Poultry_Industry_in_Bangladesh (accessed on 21 March 2021).

38. Jensen H.A. (1996). – Semi-scavenging model for rural poultry holding. *In* Proc. XX World's Poultry Congress, Vol. I, 2–5 September, New Delhi, India. World's Poultry Science Association, Pune, India, 61–70. Available at: handle.nal.usda.gov/10113/CAT10862694 (accessed on 21 March 2021).

39. Jensen H.A. (2000). – Paradigm and visions: network for poultry production in developing countries. *In* Proc. Poultry as a Tool in Poverty Eradication and Promotion of Gender Equality (F. Dolberg & P.H. Petersen, eds.), March 22–26 1999, Tune Landboskole, Denmark. DSR Forlag, Frederiksberg C, Denmark. Available at: www.fao.org/3/AC154E/AC154E00.htm (accessed on 21 March 2021).

40. Saleque A. & Mustafa S. (1997). – Landless women and poultry: the BRAC model in Bangladesh. *In* Proc. Integrated Farming in Human Development (F. Dolberg and P.H. Petersen, eds), 25–29 March 1996, Tune Landboskole, Denmark. DSR Forlag, Frederiksberg C, Denmark. Available at: www.cabdirect.org/cabdirect/abstract/19981805735 (accessed on 21 March 2021).

41. Saleque A. (2000). – Scaling-up: critical factors in leadership, management, human resource development and institution building in going from pilot project to large-scale implementation – the BRAC poultry model in Bangladesh. *In* Proc. Poultry as a Tool in Poverty Eradication and Promotion of Gender Equality (F. Dolberg & P.H. Petersen, eds), March 22–26 1999, Tune Landboskole, Denmark. DSR Forlag, Frederiksberg C, Denmark. Available at: wwww.fao.org/3/AC154E/AC154E00.htm (accessed on 21 March 2021).

42. Fattah K.A. (2000). – Poultry as a tool in poverty eradication and promotion of gender equality. *In* Proc. Poultry as a Tool in Poverty Eradication and Promotion of Gender Equality (F. Dolberg & P.H. Petersen, eds), March 22–26 1999, Tune Landboskole, Denmark. DSR Forlag, Frederiksberg C, Denmark. Available at: wwww.fao.org/3/AC154E/AC154E00.htm (accessed on 21 March 2021).

43. Ahmed N. (2000). – The smallholder poultry model in Bangladesh. *In* Possibilities for Smallholder Poultry Projects in Eastern and Southern Africa (G. Pedersen, A. Permin, & U.M. Minga, eds). Proc. Workshop, 20–25 May, Morogoro, Tanzania. Network for Smallholder Poultry Development, Copenhagen, Denmark.

44. Dolberg F. (2001). – A livestock development approach that contributes to poverty alleviation and widespread improvement of nutrition among the poor. *Livest. Res. Rural Dev.*, **13** (5). Available at: www.lrrd.org/lrrd13/5/dolb135.htm (accessed on 21 March 2021).

45. Mtimet N., Grace D., Wieland B., Knight-Jones T., Wanyoike F., Rich K., Perry B., Kiara H., Mutai F. & Ballantyne P. (2020). – Better enforcement of standards for safer trade in livestock and livestock products across the Red Sea: feasibility study for a joint Horn of Africa–Arabian Peninsula initiative. World Organisation for Animal Health, Paris, France. Available at: hdl.handle.net/10568/107951 (accessed on 21 March 2021).

46. Perry B., Rich K.M. […] & Rushton J. (2020). – Integrating the technical, risk management and economic implications of animal disease control to advise policy change: the example of foot-and-mouth disease control in Uruguay. *EcoHealth,* **17** (3), 381–387. doi:10.1007/s10393-020-01489-6.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 395-411

Current and future trade in livestock products

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Summary

Rising per capita consumption, economic growth, and urbanisation, particularly in developing countries, have been driving an increased global demand for food. These changing socio-economic trends, which have greatly influenced changes in dietary patterns globally and, more specifically, have increased consumption of livestock products in developing countries, are expected to endure and to place new pressures on livestock-sector infrastructure and the delivery of veterinary services. This paper summarises current trade in meat and presents plausible projections for the future. It highlights the impact of animal disease on trade and considers the effect of ongoing disease outbreaks, particularly the outbreaks of African swine fever and COVID-19, on current and future trade dynamics. The authors analysed published statistics on the demand for, and international trade in, livestock products at national and regional levels and made projections of the same up to 2050, generated from an integrated model of the global agricultural and food system. The resulting analyses identified patterns of trade consistent with growing populations, increasing incomes and changing diets in developing countries. The analyses also pointed to slow expansion of livestock production, and the impacts of countries' disease status on livestock trade. For most of the livestock products analysed, economic model projections indicate increased consolidation of production and exports among a few countries. Marked increases in the trade in livestock products suggest a changing role for Veterinary Services in facilitating trade and extension in the years to come.

Keywords

African swine fever – Consumption – COVID-19 – Demand – Foot and mouth disease – Livestock – Production – Scenario – Trade – Veterinary Services.

Introduction

The composition of world agricultural trade substantially changed in the decades leading up to the 2010s, with changes in food consumption that occurred in one region having important consequences for production and trade elsewhere (1). From the early 1960s, most developing countries witnessed a substantial increase in demand for high-value livestock products, with meat, milk and eggs being the most tradable goods, whilst, in high-income countries, demand for foreign brands expanded intra-industry trade in processed consumer-ready products (1, 2). Since then, meat and meat products have progressively become a significant and essential part of global food diets among all categories of consumers, although indications are emerging of a further nutritional shift in richer countries towards reduced meat consumption (3, 4).

The main drivers of higher global food demand are increasing populations, economic growth, urbanisation (which can lead to higher per capita consumption) and increased dietary diversity, particularly in developing countries (5, 6, 7). These changing socio-economic trends have significantly contributed to the shift towards the increased consumption of livestock products (8, 9). The current nutrition transitions in developing countries are expected to endure and are likely to have implications for the supply and trade of livestock products and for the infrastructure of the livestock sector (10, 11, 12, 13).

Currently, around 14% of livestock production is internationally traded (14). However, global trade, which tends to be dominated by the same few countries, has been increasing in volume and changing in terms of products traded. Animal disease status remains an important

https://doi.org/10.20506/rst.40.20.3232

consideration for trade in livestock and livestock products, with notifiable diseases such as foot and mouth disease (FMD) influencing market access, and, consequently, public and private investment in the livestock sector.

This paper summarises current trade in livestock products, particularly meat, and presents plausible projections for the future. The authors will further highlight the role of animal disease on trade patterns and examine the effect of ongoing disease outbreaks, particularly the outbreaks of African swine fever (ASF) and COVID-19, on current and future trade dynamics. As patterns of production, consumption, and trade change, there will be differential implications for the role of Veterinary Services in facilitating trade and extension, upon which this discussion will touch.

Production and consumption of meat

Rapid growth and technological innovation in the last two decades have led to profound structural changes in the livestock sector, including a shift in the geographic locus of demand and supply to the developing world (15). The move towards increased consumption of livestock products has affected the global food economy. In developing countries, where the bulk of the world's population resides, meat consumption has been growing (Fig. 1). Increased meat consumption requires increased production of animal feedstuffs from the crop and fishery sectors, so the trend toward greater meat consumption is increasing aggregate agricultural output.

The rapid growth in the meat sector has been largely due to rising demand for poultry meat, which has consistently increased at around three times the population growth rate over each of the past five decades. Figure 1 shows that between 2010 and 2019 poultry consumption in developing countries consistently outpaced production. In contrast, the consumption of pork in developing countries, including the People's Republic of China, one of the world's largest pork producers and consumers, has been decreasing. Global consumption of red meat (cattle, sheep and goats) has not fallen, but it has grown only slightly over the last ten years. It is important to note, however, that the expansion in aggregate meat consumption in many developing countries (mostly outside of Asia) has been due to population growth, and not to increased consumption per capita. Growth in consumption per person has instead been stagnant or non-existent, especially in ruminant meat (cattle, sheep, and goats) and pork (when China is excluded) (15).

Current trends in meat trade

An increase in the consumption of livestock products and changes to trade policies (economic liberalisation) has increasingly facilitated a rise in the trade of livestock products (8). Trade has been further facilitated by developments in transport, such as long-distance cold-chain shipments, which have made it possible to trade and transport perishable crops, livestock products, and feedstuffs over long distances (17).

Trade in livestock products has continuously increased over the last 20 years (Fig. 2). Between 1990 and 2018, the volume of meat exports increased more than threefold (327%). However, trade in crop products still dominates agricultural trade. The proportion of meat in agricultural exports has fluctuated substantially, between 5.6% and 7.5%, for the last 20 years.

Although the majority of livestock products are consumed within the country of production, the continuous rise in consumption of livestock products and the increasing degree of openness to trade has made it possible for some countries to specialise in exporting certain livestock products. Figure 3 illustrates patterns of meat exports, revealing that exports of beef from Oceania and Latin America, pork from Europe and North America, poultry from Latin and North America, and mutton from Oceania have steadily been increasing in the last ten years.

On a volume basis, Brazil has been the largest beef exporter in the world since 2017, followed by Australia, India, and the United States of America (USA) (Fig. 4). Not previously a net exporter, India has risen to become one of the top beef exporters in the world over the past decade, fuelled by rising demand in developing countries. Foot and mouth disease status is a significant driver of global trade patterns in beef (and lamb), as countries that are free from FMD typically source meat from countries with a similar FMD status. There is a further distinction between those countries that are FMD-free with vaccination and those that are FMD-free without vaccination, and the highest export prices tend to be received by countries that do not vaccinate (19). Only a handful of countries (USA, Canada, Australia, New Zealand, and countries within the European Union) have FMD-free without vaccination status. There is some discussion in South America, particularly in Brazil and Uruguay, about ending the policy of blanket vaccination in order to obtain FMD-free without vaccination status (20). The commercial benefits of being FMD-free are sizable. It allows countries to maximise carcass value by sending specific cuts to those markets that are willing to pay the most for them, giving countries greater flexibility in marketing and pricing.

As with all meat products, but especially with beef, trade is predominantly in boneless cuts, with frozen cuts predominating on a volume basis. High-value fresh cuts are typically traded to European and East Asian countries from Latin America and Australia/USA. Exports to China are rising substantially; for example, they now comprise

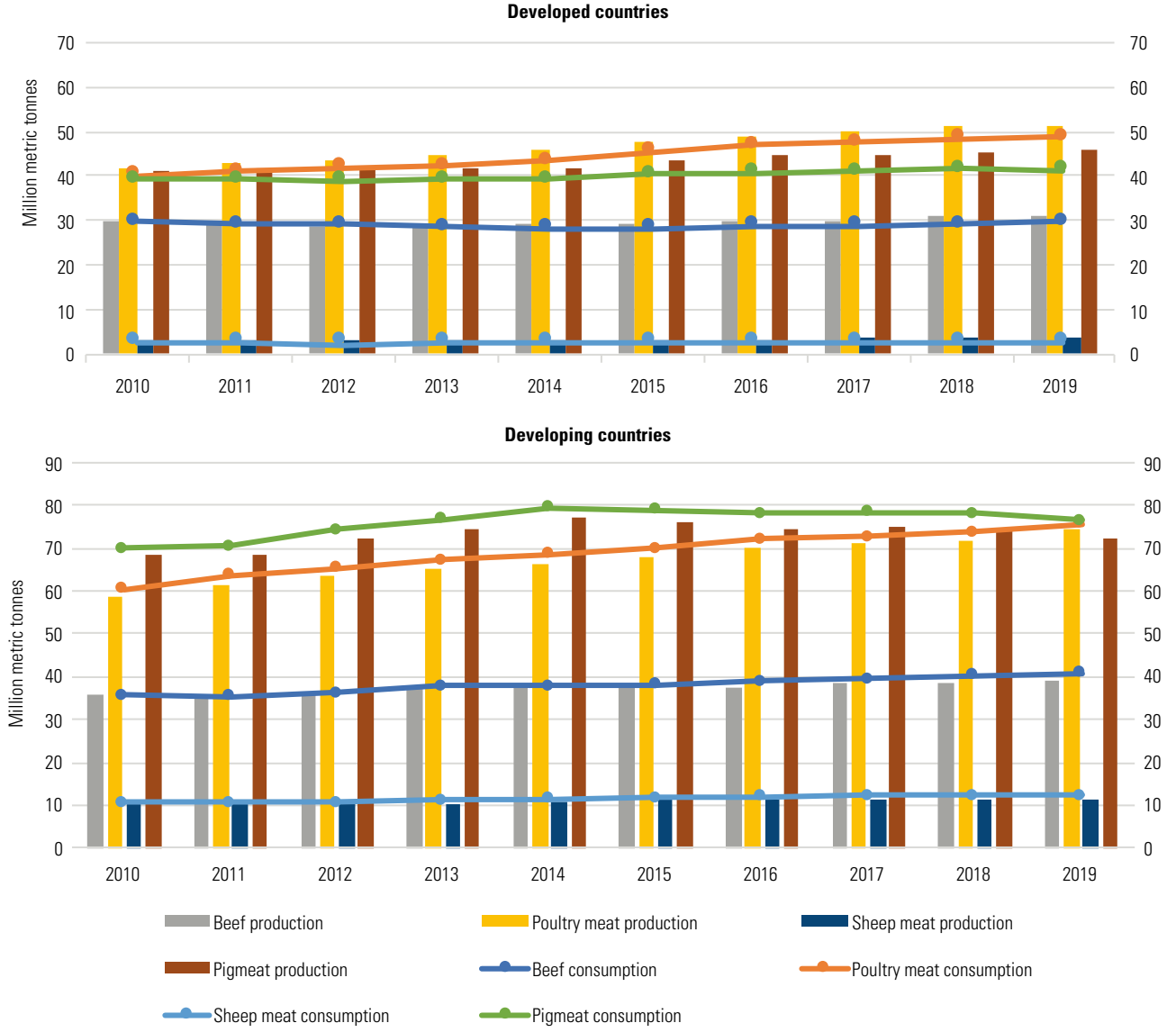


Fig. 1
Meat production and consumption by developed and developing countries (2010–2019)
Source: Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations (16)

70% of Uruguay's beef exports (20). Trade in offal is also substantial, with significant and rising exports to West Africa from European markets and Brazil.

Globally, sheep and goat meat exports have been dominated by Oceania, mainly Australia and New Zealand. In the last five years, the average annual export volume of sheep and goat meat has increased by 3% for Australia, while remaining constant for New Zealand. Smaller percentages of goat and sheep meat originated from some countries in Europe (United Kingdom, Ireland, Spain, and Belgium), Asia (India and China) and Africa (Namibia) (Fig. 4). Unlike other meat categories, demand for sheep and goat meat has been more modest, although it has been rising steadily in some markets, particularly the Middle East (21).

Figure 3 shows that global exports of pork from Europe and North America have steadily risen in the last ten years, almost entirely as a result of strong demand from some Asian countries (Fig. 5), particularly China, Japan, and the Republic of Korea (Fig. 6). This trend might continue in the coming few years because of the recent ASF-induced decrease in pork production in Asia, particularly in China, where over 20% of the pig herd was culled or died due to disease (25, 26).

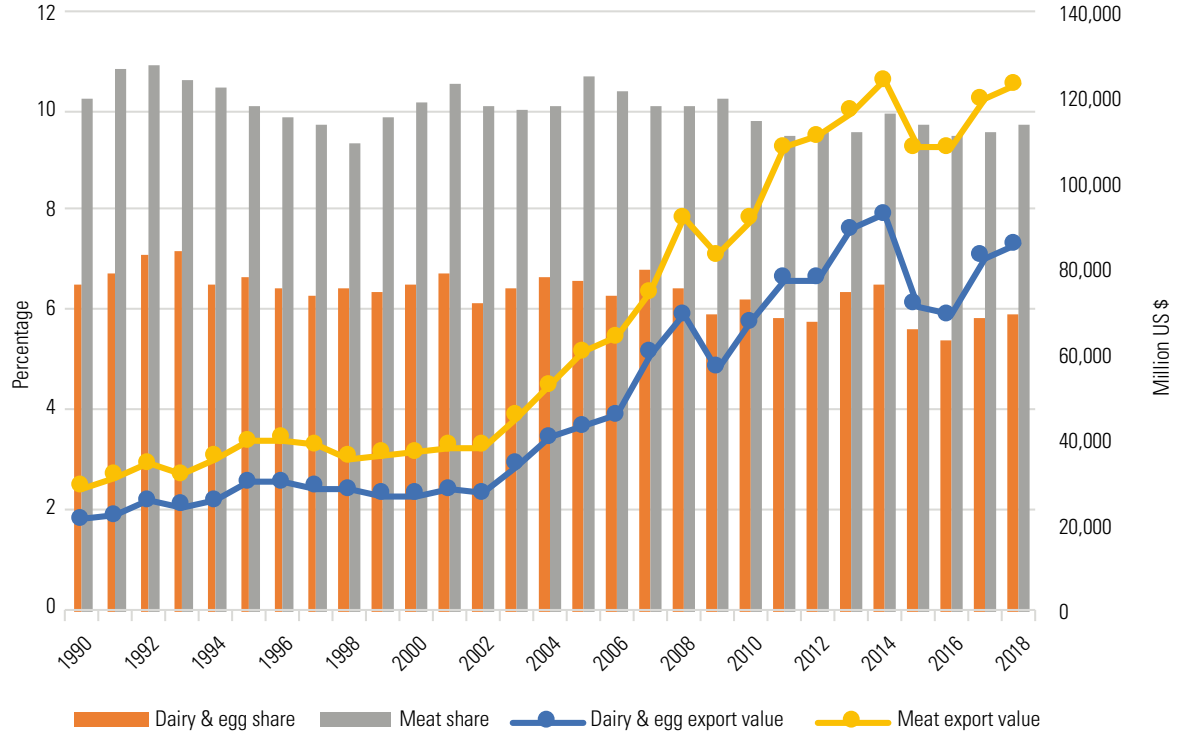


Fig. 2
Value of livestock products (million US$) and their share (percentage) of global agricultural export value (1990–2018)
Source: Food and Agriculture Organization of the United Nations (14)

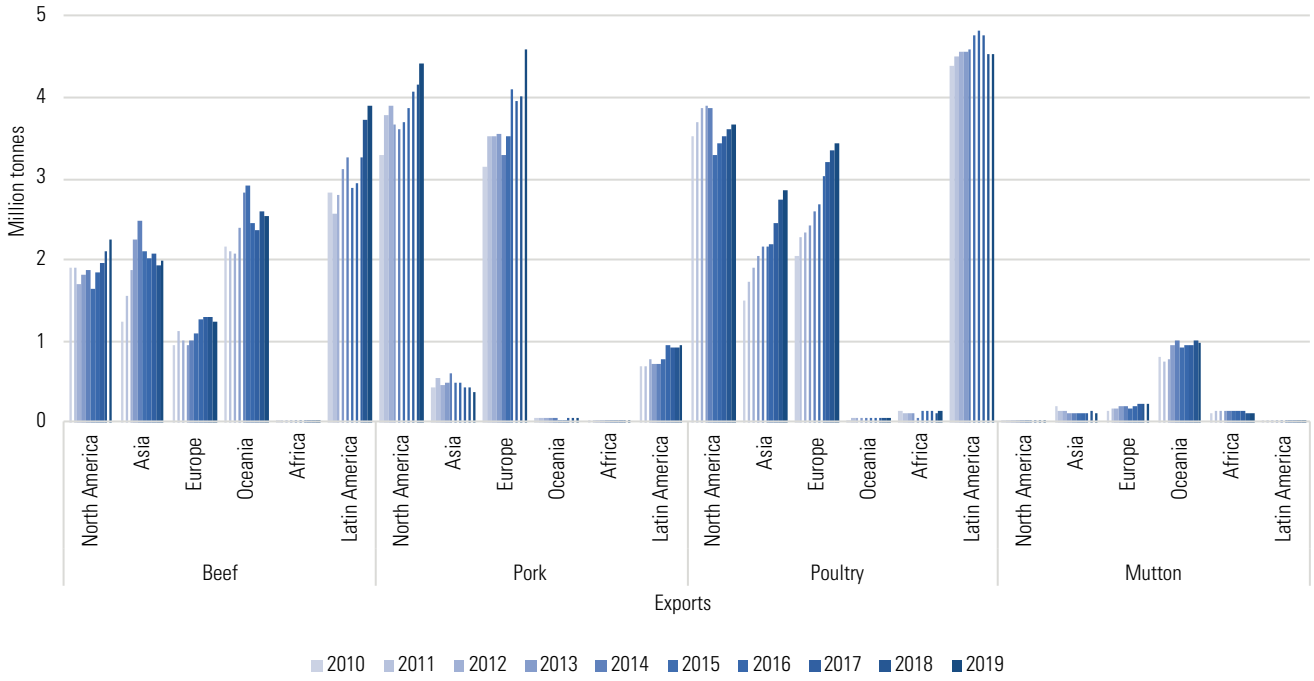


Fig. 3
Exports of major livestock products by region (2009–2019)
Source: Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations (16)

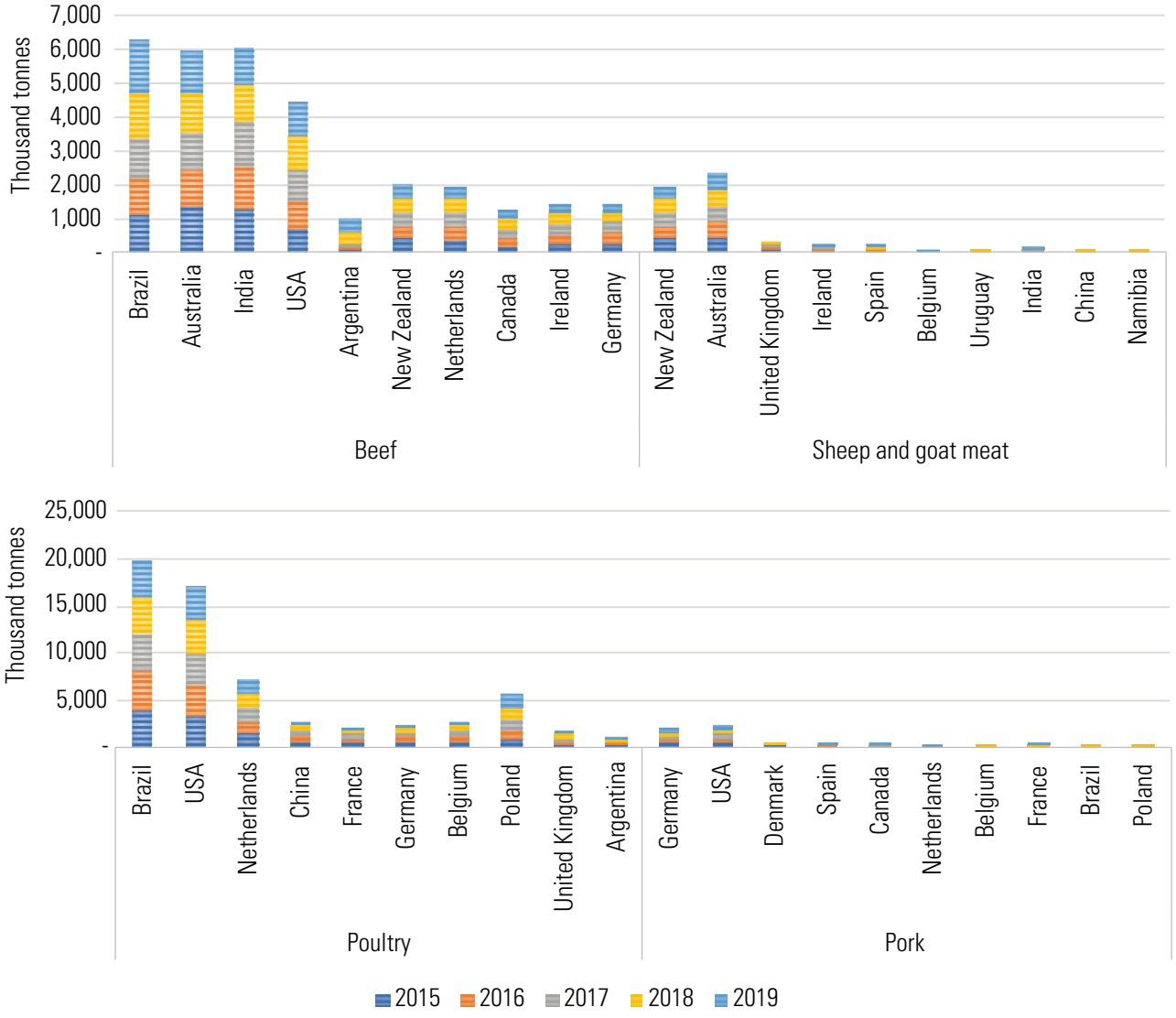


Fig. 4
Top ten exporters of red and white meat (2015–2019)
Source: United Nations International Trade Statistics (UN Comtrade) Database (18)

Poultry meat exports have been increasing as robust demand from countries like China, including Hong Kong, Special Administrative Region of the People's Republic of China, propels shipments from Brazil and the USA (Fig. 6). However, because of restrictions related to control of highly pathogenic avian influenza, some potential poultry meat exporters may have been unable to capture the benefit of rising imports in China and some other Asian countries (Fig. 4).

Figure 5 shows global imports of meat. Asia, followed by North America and Europe, is the major importer of beef. Beef imports by Asian countries (fuelled by China) have consistently increased in the last ten years, having almost doubled in 2019, with a 98% increase since 2010. Similarly, the USA's beef imports increased by approximately 11% between 2010 and 2019. In contrast, Europe's beef imports decreased by 18% over the same period as demand and population growth slowed.

The major beef-importing countries in Asia are China, Japan, Hong Kong, Special Administrative Region of the People's Republic of China, and the Republic of Korea (Fig. 6). In North America, the USA has the highest levels of beef imports (much of it being trimmings and manufactured meat for domestic production of products such as hamburgers). In Europe, Italy and Germany are the region's lead importers of beef. Mutton is a relatively

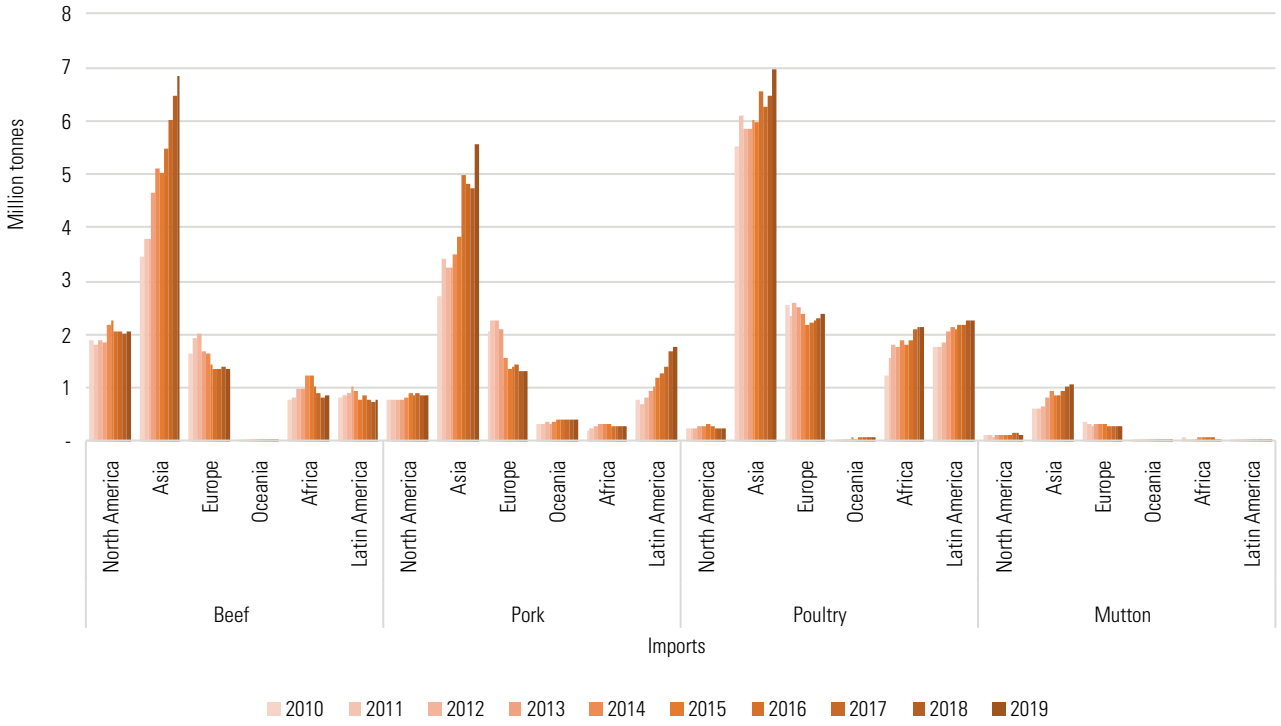


Fig. 5
Imports of major livestock products by region (2009–2019)
Source: Organisation for Economic Co-operation and Development and Food and Agriculture Organization of the United Nations (16)

less traded meat; however, the volume of mutton imports by Asian countries, particularly China, has shown a steady increase in the last ten years (Fig. 5).

The trend for pork and poultry imports is similar (Fig. 5). Asia is the global leader in pork and poultry imports. Between 2009 and 2019, pork imports in Asian countries increased by about 106%. It is remarkable that, since 2013, pork imports in Europe have decreased by 37%, while in Latin American countries they have steadily increased by 86%. As shown in Figure 6, China, Italy, Japan, Germany, Poland, and the Republic of Korea have been the major pork importers over the last ten years.

Poultry imports in developing countries have been increasing steadily over the last ten years due to the growing consumption of poultry meat in these countries (Fig. 1). At the regional level (Fig. 5), imports in Asia, Africa, and Latin America have increased. Globally, the list of the top poultry-importing countries includes Hong Kong, Special Administrative Region of the People's Republic of China, Saudi Arabia, Japan, China, Germany, the United Kingdom, the Netherlands, and France (Fig. 6).

While we do not present comprehensive data on it here, there is considerable formal and informal trade in live animals globally. According to data from the United Nations International Trade Statistics Database (UN Comtrade), Australia exported nearly 500,000 cattle to Indonesia and just under 280,000 cattle to Turkey in 2017 (18). There is significant formal and informal trade of sheep and goats from the Horn of Africa to the Middle East as well, and one study, citing UN Comtrade data, revealed that live sheep and goats worth US$1 billion were imported into Gulf countries from the Horn of Africa in 2015 (22). There are also sizable volumes of pastoral trade across the Sahel in West Africa, although exact figures are unknown (23). A recent study estimated that over 60% of marketed animals in Mali are exported to regional markets (24).

Projections of global meat trade to 2050

Issues of model specification and accuracy, as well as inherent uncertainties, make it difficult to predict future supply and demand, or associated global trade; however, analytical models exist that help quantify plausible future scenarios in ways that can be reliably applied to policy making for agriculture, food and related sectors (27, 28, 29). The authors used one such model, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), to derive indications of how global exports and

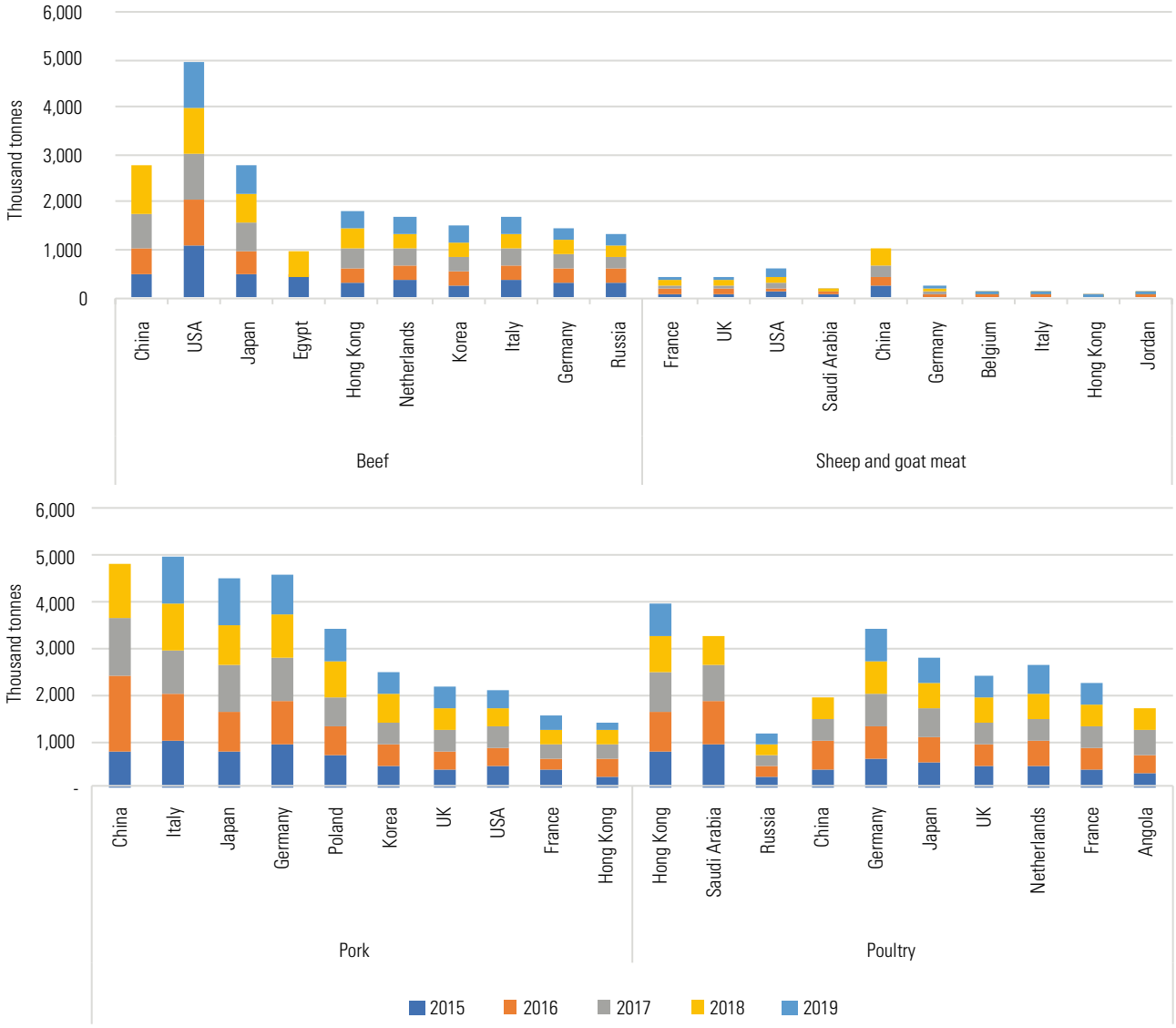


Fig. 6
Top ten importers of red and white meat (2015–2019)
Source: Authors' own elaboration, using IMPACT model calculations (30)

imports of livestock-derived food products will likely evolve in the future (30). IMPACT is a suite of integrated models with economic, crop, livestock, hydrology and climate components that has been widely used for scenario analysis of the global food system (29). To project future trade patterns, the model uses different scenarios in which the main drivers of change in global agricultural and livestock systems are assumed to either follow historical trends or deviate from them, and the effects of any deviations can be assessed by analysing the outcomes of the different scenarios. The authors analysed the model's results to assess country- and regional-level variations in international trade in meat to 2050, adopting the model's 'business-as-usual' scenario, that is, a scenario in which there is moderate socio-economic change and in which trends closely follow what has been observed in the last few decades. This scenario was compared (in the case of effects on prices only) with two other scenarios of socio-economic change: low global economic (and high population) growth and high economic (and low population) growth. The trends characterising the socio-economic scenarios influence countries' outcomes in terms of the demand for, and trade of, food and agricultural products over the long-term.

A 'no climate change' condition was imposed on the three socio-economic change scenarios, such that climate-induced effects on the agricultural sector were assumed to have remained unchanged since 2005. This is an analytical convenience that allows for the potential effects of socio-economic variables to be clearly distinguished from the

effects of climate-related variables. A fourth scenario, the climate change scenario, was then included in the analysis (again, in the context of scenario effects on food prices only). This scenario assumes that there will be an increase in average global temperatures and that the livestock sector will face a harsher climate in 2050. The IMPACT model and its alternative scenarios of the future are well documented (30) and details are not repeated here. The paper instead draws on the model's established results to highlight some implications for international trade in meat.

Of the four different meat types included in the analysis, the model projections suggest that international trade in poultry will increase by the most, both in quantity terms and relative to a selected baseline year of 2010. Net exports of pork, beef and lamb also increase relative to this base.

In 2050, net trade in the poultry sector is positive for developed countries and Latin America, while developing regions of Asia and Africa and Eastern Europe are net importers in aggregate (Fig. 7). The USA and Brazil top the list of net-exporting countries in 2050. Net export quantities from the top ten exporter countries for poultry products (over the decade prior to 2010) reach 26 million metric tonnes (MT) in 2050, i.e. 87% of poultry net exports for all countries in that year. The volume in 2050 is a 223% increase from the level in 2010 for this category of exporters.

On the import side, poultry trade remains highest in Asia, but Africa and parts of Europe also make important contributions (Fig. 7). India alone accounts for more than a third of the global net imports, while Indonesia and Malaysia contribute nearly 10%. Countries with high net import quantities in 2050 include Russia, the United Kingdom and Ghana.

In the pork sector, according to the model projections, global exports grow by about 240% over 2010 estimates. The top ten net exporters in 2050 account for 66% of the projected 30.5 million MT of net exports, with Asia as the main continental destination (Fig. 8). From the standpoint of trading countries, the USA remains a dominant pork-exporting country in 2050, contributing 32% of global net pork exports. Brazil (9%), Denmark, Poland and the Netherlands (~6% each), and Canada (4%) also make sizeable contributions to the global totals.

China has by far the highest net import volumes (62%) of pork in 2050, driving the net import position of Asia. Other countries with reasonably high net imports include Japan, the Republic of Korea and the Philippines (~10% of global net imports). In Europe and Africa, high net importers include the United Kingdom (4%) and Nigeria (3%), respectively.

In the beef sector, the global volume of trade increases from 8.5 million MT in 2010 to 20.1 million MTs in 2050 (an increase of 135%). International trade in beef is characterised mainly by net exports from Latin America to the rest of the world (Fig. 9). Brazil, Argentina and Uruguay contribute 11.1 million MT or 55% of all net beef exports. Australia is also a major net exporter (8% of the global total in 2050), as are New Zealand and Canada (around 3% share each).

The USA is projected to be the largest net importer of beef, at 3.7 million MT or roughly 18% of the global total. Other countries post modest shares of the global total (4% to 8%). These include countries in continental Asia (Pakistan, Philippines, Afghanistan), Europe (United Kingdom, Russia) and Africa (Niger, Burkina Faso).

Net exports of meat from sheep and goats are projected to increase by 268%, from 1.5 million MT in 2010 to 5.6 million MT in 2050 (Fig. 10). The direction of trade is mainly from developed and developing countries in the Americas to Asia. Africa goes from a net-exporting region in 2010 to a net importer in 2050. Australia and New Zealand together account for 24% of global net exports, and Iran for 8%. India, Turkey, Ireland and Spain each have 2% to 4% shares of the total net exports of sheep and goat meat.

The top five importing countries for small ruminant meat are China, Nigeria, Pakistan, Uganda and Tanzania, which together account for 75% of net imports. In 2050, more countries export sheep and goat meat than import it (which is not the case for other meat), indicating a more disparate distribution of production centres globally.

Finally, assessing four alternative model scenarios, that is, moderate (business-as-usual) economic growth, low economic growth, high economic growth, and a climate change future, showed potential economic and climate-driven changes in consumer demand. A scenario of worsening economic conditions globally lowers the aggregate demand for many foods, including meat (lowering market prices), while harsher climate conditions, which trigger shrinking of agricultural production, suppress meat supply (raising prices) (Fig. 11).

Discussion

The trends in trade of livestock and livestock products that have been presented here have several important market and policy implications. From the standpoint of Veterinary Services, a growing consolidation of the meat export trade among a few countries and rising imports across the developing world have different policy effects in each setting. In the importing countries where there is growing affluence and rising demand (particularly in developing

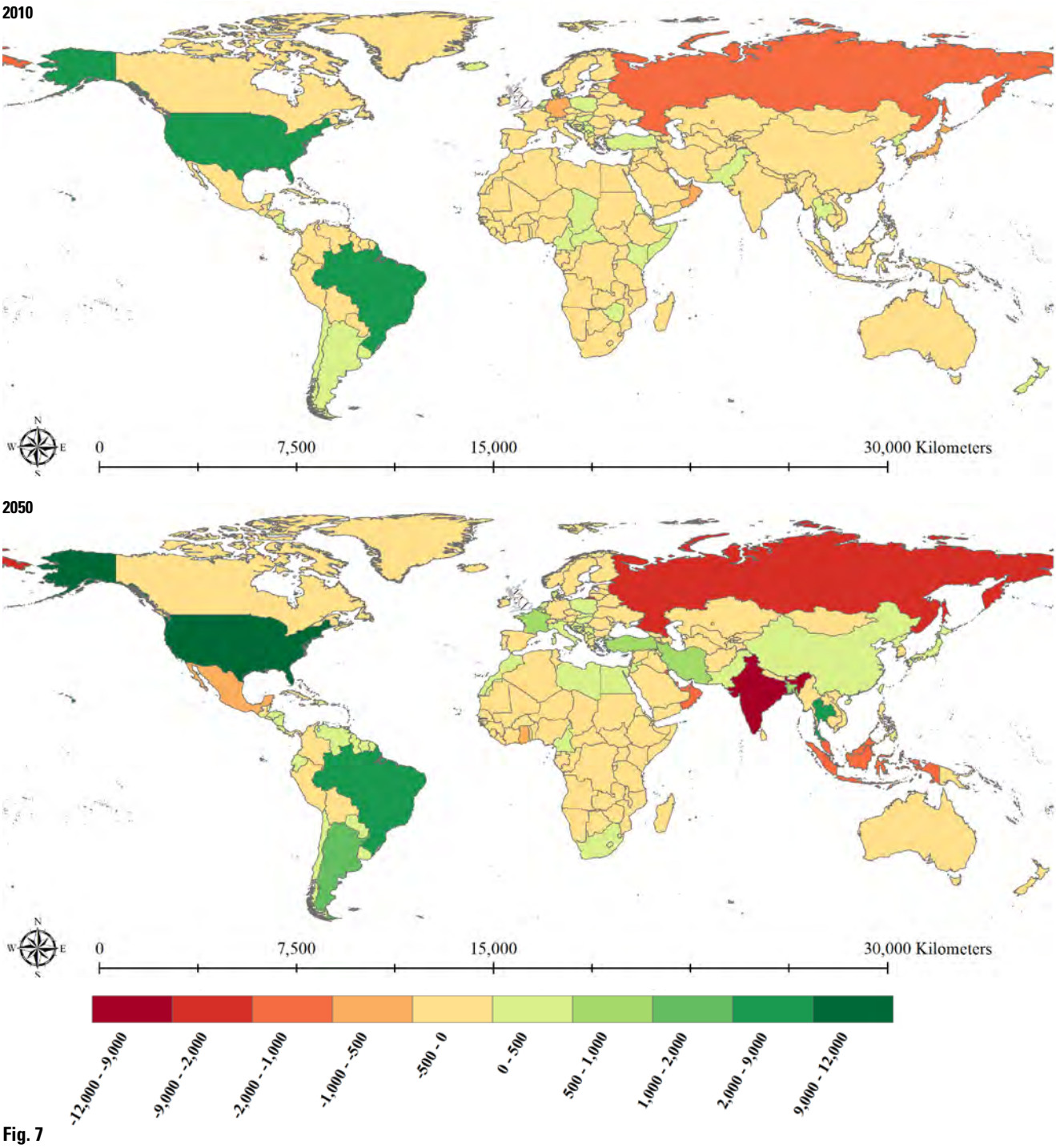


Fig. 7

Net trade of poultry meat in 1,000 metric tonnes, under a scenario of medium economic growth to 2050

Positive values indicate net exports and negative values indicate net imports

Source: Authors' own elaboration, using IMPACT model calculations (30)

countries), there will be a greater need to ensure food quality and meat safety for consumers. Increased competition with imported products will put pressure on domestic producers, so Veterinary Services will have an important role to play in providing extension services to help producers ensure that local products are not crowded out. As noted by past studies (31), Veterinary Services will also need to take on a more multi-faceted role in promulgating and implementing risk-based approaches along the food chain. This will require:

– improved legislation and regulatory guidelines for domestic and international standards

– harmonisation of standards and compliance with relevant norms of the Agreement on the Application of Sanitary and

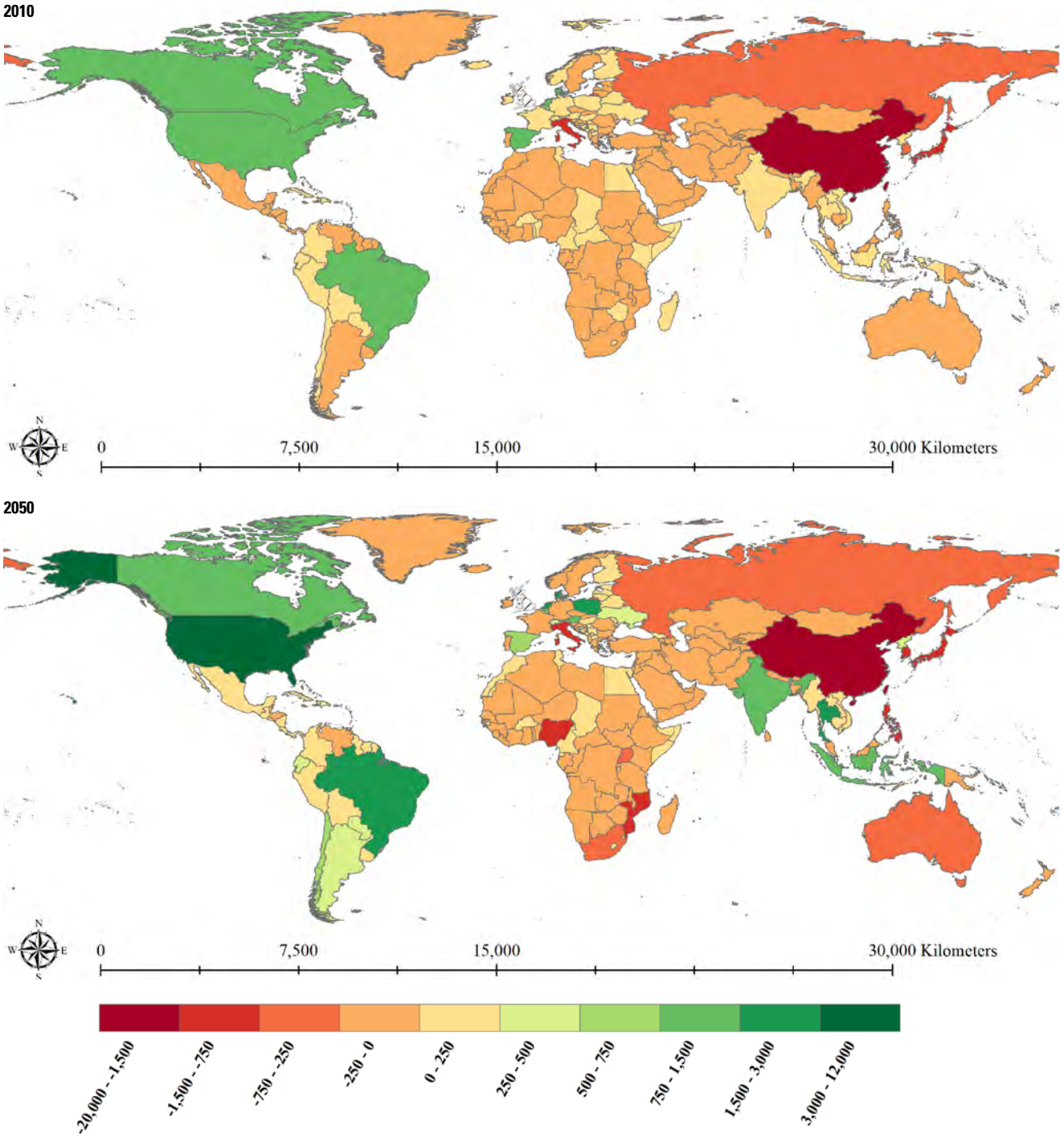


Fig. 8

Net trade of pig meat in 1,000 metric tonnes, under a scenario of medium economic growth to 2050

Positive values indicate net exports and negative values indicate net imports

Source: Authors' own elaboration, using IMPACT model calculations (30)

Phytosanitary Measures and Codex Alimentarius, as well as mutual recognition of other country standards

– strengthened monitoring and surveillance capacity across the food chain to identify prospective hazards and diseases

– enhanced communication among food chain actors.

For exporting countries, most of which are developed countries, the implications of the projected trends are less pronounced, but the continued facilitation of exports and compliance with standards will be paramount, necessitating greater intra-regional and international harmonisation of standards to ensure the smooth flow of trade. The COVID-19

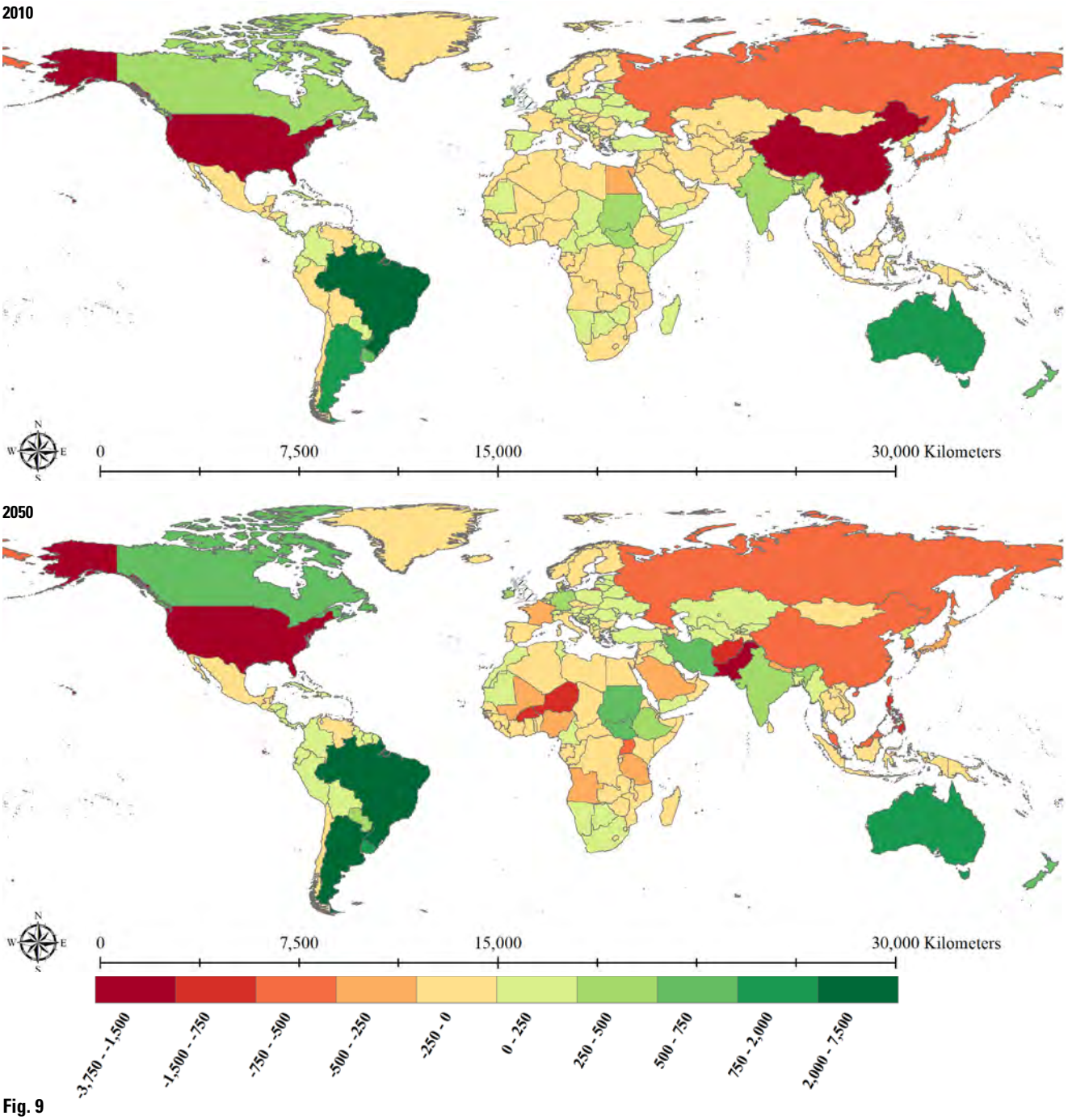


Fig. 9

Net trade of bovine meat in 1,000 metric tonnes, under a scenario of medium economic growth to 2050

Positive values indicate net exports and negative values indicate net imports

Source: Authors' own elaboration, using IMPACT model calculations (30)

pandemic has further highlighted the importance of regulation and biosecurity in food marketing, and their importance will only increase over time as international trade in meat products continues to grow.

Projections for poultry and pork trade are particularly significant for future policy. It is projected that the majority of poultry exports will come from the same few countries, while imports will be more dispersed globally. In many importing countries, however, the projected changes from 2010 to 2050 are quite substantial, with potential for major disruptions to local production and/or systems that support poultry production and consumption. The model's projections about pork imports into Asia (particularly China) are important for similar reasons.

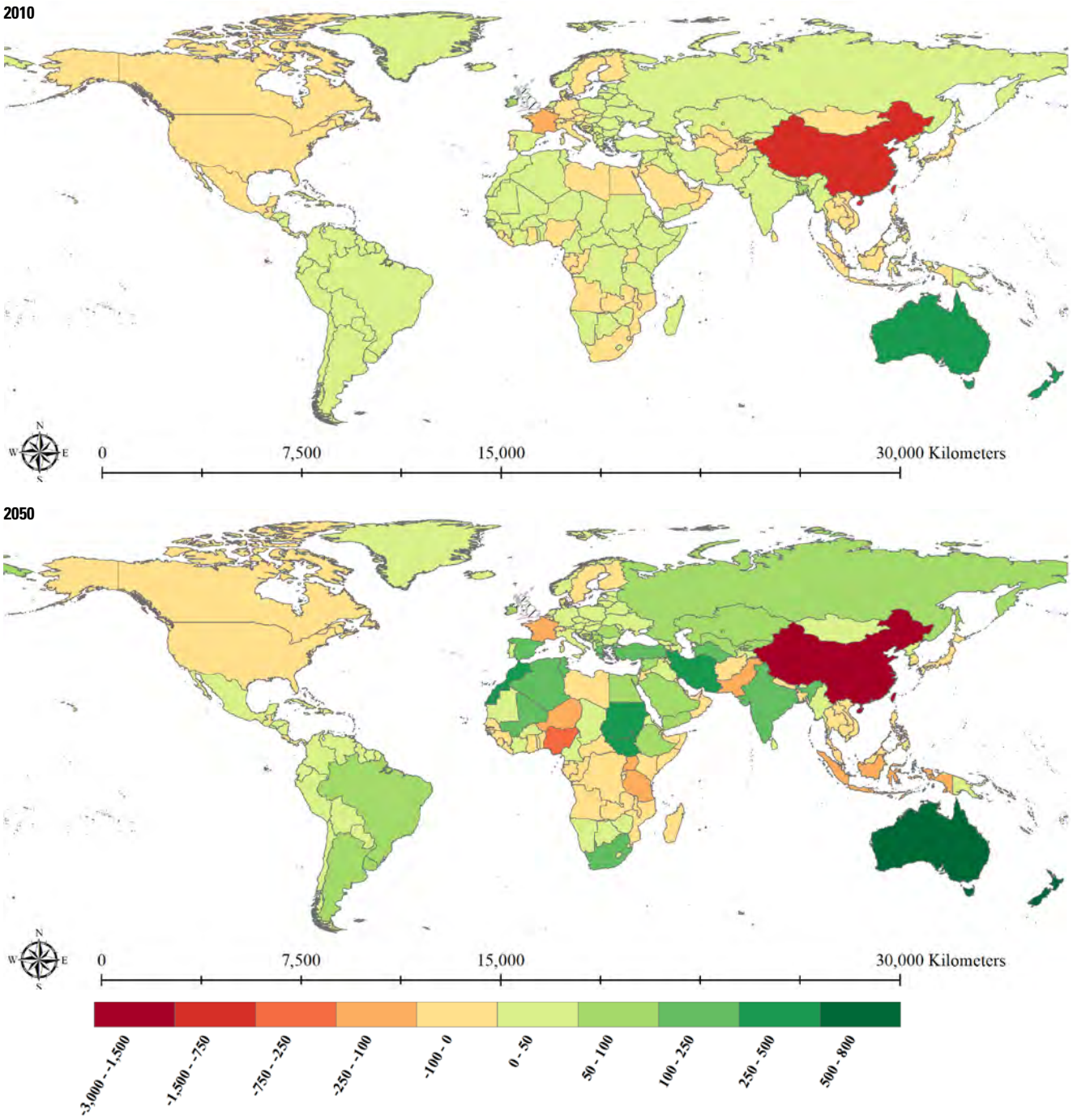


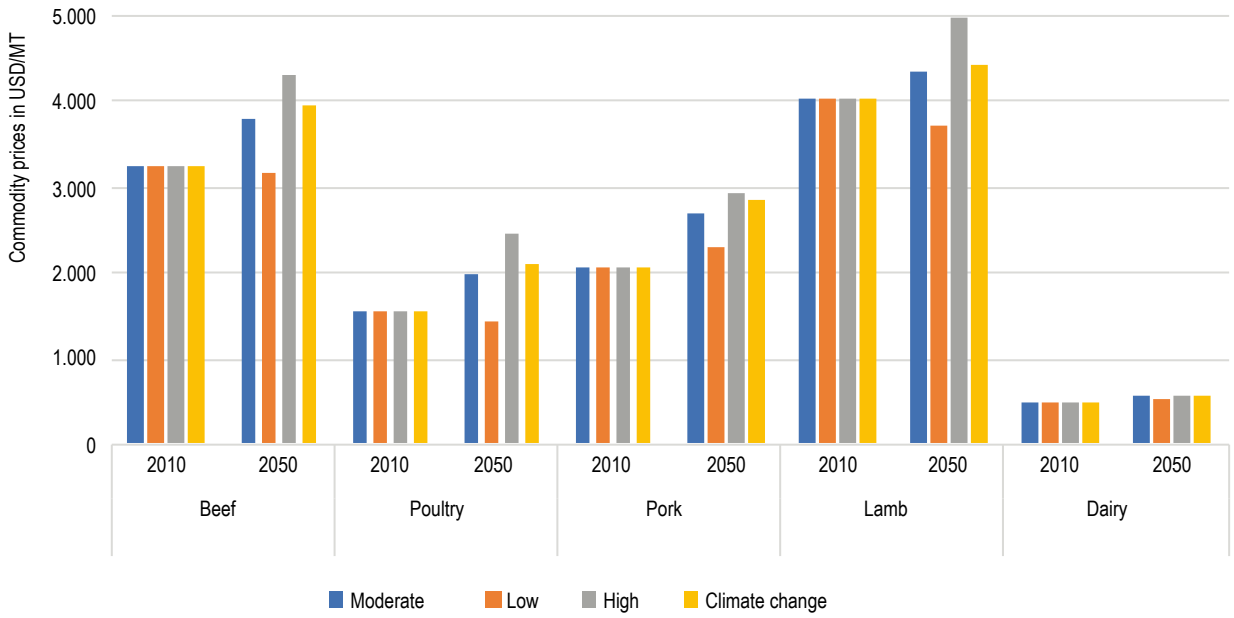
Fig. 10

Net trade of sheep and goat meat in 1,000 metric tonnes, under a scenario of medium economic growth to 2050

Positive values indicate net exports and negative values indicate net imports

Source: Authors' own elaboration, using IMPACT model calculations (30)

The business-as-usual projections for the beef trade indicate that some small exporting countries will see their beef imports rise substantially by 2050. These results are particularly significant in the case of countries that surrounding countries rely on for livestock and animal products. Niger and Burkina Faso, for example, are currently major livestock exporters within their immediate sub-regions (mostly of live cattle), but they are expected to be major beef importers in 2050. In theory, this could lead to reduced pressure from the threat of cross-border animal diseases, but it raises concerns about food security and the supply of animal protein, not only within Niger and Burkina Faso, but also in the countries of the sub-region that rely on them for livestock animals (32). Overall, it is anticipated



MT: metric tonne
USD: United States dollar

Fig. 11

Projected world prices of livestock commodities under alternative scenarios of global economic and climate change

Source: Authors' own elaboration, using IMPACT model calculations (30)

that trade will be a major channel through which changes in the global economy will impact on the livestock sector and economy of many countries.

The links between international trade, animal health and veterinary epidemiology are well established, with historical examples of major outbreaks of cross-border animal diseases arising from both formal and informal trade (33). Formal trade of livestock animals and products, however, tends to be more highly regulated by legislation, with measures in place to limit the introduction of diseases from abroad. Informal and/or illegal cross-border animal trade, on the other hand, poses heightened challenges to animal disease management (34). Weak regulation associated with informal cross-border movement of animals, including in the area of disease surveillance, has been linked with increased infectious disease transmission in swine (34, 35), cattle (36), non-livestock animals (37) and even human populations (38).

The economic slump caused by the COVID-19 pandemic, coupled with other economic downturns, will also likely cause many uncertainties in global food markets (39). Compared to other markets, the agri-food market has shown more resilience to the crisis, but it has, nevertheless, been negatively impacted. For example, whilst global production of poultry meat expanded in 2020, it did so at half the 2019 rate. The pandemic has also aggravated the effects of animal disease on production, with the 2020 outbreaks of ASF viral disease across Asia leading to a significant drop in the production of pig meat.

Meat prices have also been greatly impacted by the pandemic and have since witnessed a global slump, largely due to decreasing import demand, with the hardest hit products being ovine meat, followed by poultry, pig and bovine meats (39). In general, lower prices – whether they are the result of a drop in demand or an increase in supply – may be favourable to consumers but can have negative impacts on producers. In many countries in Africa, the impacts may be more marked in rural areas with a high dependence on livestock and other agricultural production. On a more aggregate level, lower prices affect countries that are net exporters of livestock products, potentially impacting the capacity of affected countries to support the producing sectors. Climate impacts are also important and could exacerbate the direct economic outcomes of trade dynamics.

Les échanges internationaux de produits de l'élevage aujourd'hui et demain

D. Enahoro, S. Bahta, C. Mensah, S. Oloo & K.M. Rich

Résumé

La demande mondiale en denrées alimentaires connaît une hausse continue sous l'effet conjugué de la progression de la consommation par habitant, de la croissance économique et de l'urbanisation, en particulier dans les pays en développement. Ces tendances socio-économiques ont modifié les structures des régimes alimentaires dans le monde, plus spécifiquement dans les pays en développement où la consommation de denrées alimentaires d'origine animale s'est accrue, et elles vont très certainement perdurer et exercer de nouvelles pressions sur les infrastructures du secteur de l'élevage comme sur les prestations de services vétérinaires. Les auteurs font une synthèse de l'état actuel des échanges internationaux de viande et présentent quelques projections plausibles concernant l'avenir. Ils soulignent l'impact des maladies animales sur les échanges et examinent les répercussions que les foyers actuels de maladies peuvent avoir sur les dynamiques actuelles et futures des échanges, en citant la peste porcine africaine et l'épidémie de COVID-19 à titre d'illustrations. Les auteurs analysent ensuite les statistiques publiées relatives à la demande en produits issus de l'élevage et aux échanges internationaux de ces produits à l'échelle nationale et régionale, et présentent leurs propres projections de ces tendances jusqu'en 2050, élaborées à partir d'un modèle intégré du système agricole et alimentaire mondial. Les analyses qui en résultent font apparaître que les structures des échanges évolueront parallèlement à la croissance démographique, à l'augmentation des revenus et aux modifications des régimes alimentaires dans les pays en développement. Les analyses relèvent également une croissance lente de l'élevage, ainsi que les conséquences du statut sanitaire des pays sur les échanges commerciaux. Pour la plupart des produits issus de l'élevage pris en compte dans cette analyse, les projections du modèle économique prévoient une concentration accrue de la production et des exportations, dans un nombre limité de pays. Une augmentation marquée des échanges de produits issus de l'élevage devra s'accompagner d'une évolution du rôle des Services vétérinaires afin de faciliter les échanges et de soutenir leur extension dans les années à venir.

Mots-clés

Consommation – COVID-19 – Demande – Échanges internationaux – Élevage – Fièvre aphteuse – Peste porcine africaine – Production – Scénario – Services vétérinaires.

Comercio actual y futuro de productos ganaderos

D. Enahoro, S. Bahta, C. Mensah, S. Oloo & K.M. Rich

Resumen

El aumento del consumo per cápita, el crecimiento económico y los procesos de urbanización, especialmente en los países en desarrollo, han venido induciendo una mayor demanda mundial de alimentos. Estas tendencias socioeconómicas han influido sobremanera en la evolución de los regímenes alimentarios en todo el mundo y, más concretamente, han llevado a un mayor consumo de

productos ganaderos en los países en desarrollo. Según apuntan las previsiones, esta evolución se prolongará en el tiempo y ejercerá nuevas presiones sobre la infraestructura del sector pecuario y la prestación de servicios veterinarios. Los autores resumen la situación actual del comercio de productos cárnicos y presentan proyecciones plausibles de lo que puede deparar el futuro. Tras destacar el peso que tienen las enfermedades animales en el comercio, examinan los efectos de brotes infecciosos hoy en curso, en particular de peste porcina africana y COVID-19, sobre la dinámica actual y futura del comercio. Los autores analizaron las estadísticas publicadas sobre la demanda y el comercio internacional de productos procedentes de la ganadería, por países y regiones, tras lo cual hicieron proyecciones del curso de estas tendencias hasta 2050, generadas a partir de un modelo integrado del sistema agrícola y alimentario mundial. Los análisis resultantes depararon una configuración del comercio coherente con poblaciones cada vez más numerosas, un creciente nivel de ingresos y cambios en el régimen alimentario en los países en desarrollo. Los análisis también apuntaban a una lenta expansión de la producción pecuaria y ponían de relieve la influencia de la situación sanitaria de los países en el comercio de ganado. Para la mayoría de los productos ganaderos analizados, las proyecciones de los modelos económicos apuntaban a una mayor concentración en unos pocos países de la actividad de producción y exportación. La marcada intensificación del comercio de productos ganaderos lleva a pensar en una evolución del papel de los Servicios Veterinarios para facilitar el comercio y su extensión en los próximos años.

Palabras clave
Comercio – Consumo – COVID-19 – Demanda – Fiebre aftosa – Ganado – Hipótesis – Peste porcina africana – Producción – Servicios Veterinarios.

References

1. Gehlhar M. & Coyle W. (2001). – Chapter 1. Global food consumption and impacts on trade patterns. *In* Changing structure of global food consumption and trade (A. Regmi, ed.). Agriculture and Trade Report WRS-01-1. United States Department of Agriculture, Washington, DC, United States of America, 4–13. Available at: naldc.nal.usda.gov/download/34108/PDF (accessed on 31 May 2021).

2. Food and Agriculture Organization of the United Nations (FAO) (2012). – Global trends and future challenges for the work of the organization. Web annex. FAO, Rome, Italy, 89 pp. Available at: www.fao.org/3/md883E/md883E.pdf (accessed on 31 August 2020).

3. Halweil B. & Nierenberg D. (2008). – Chapter 5. Meat and seafood: the global diet's most costly ingredients. *In* State of the World 2008: ideas and opportunities for sustainable economies, 25th Ed. (Worldwatch Institute, ed.). Routledge, London, United Kingdom. doi:10.4324/9781849772600.

4. Mathijs E. (2015). – Exploring future patterns of meat consumption. *Meat Sci.*, **109**, 112–116. doi:10.1016/j.meatsci.2015.05.007.

5. Food and Agriculture Organization of the United Nations (FAO) (2017). – The future of food and agriculture: trends and challenges. FAO, Rome, Italy. Available at: www.fao.org/3/i6583e/i6583e.pdf (accessed on 31 May 2021).

6. Umali-Deininger D. & Sur M. (2007). – Food safety in a globalizing world: opportunities and challenges for India. *Agric. Econ.*, **37** (s1), 135–147. doi:10.1111/j.1574-0862.2007.00240.x.

7. Fukase E. & Martin W. (2020). – Economic growth, convergence, and world food demand and supply. *World Dev.*, **132**, Article No. 104954. doi:10.1016/j.worlddev.2020.104954.

8. Kearney J. (2010). – Food consumption trends and drivers. *Philos. Trans. R. Soc. Lond., B. Biol. Sci.*, **365** (1554), 2793–2807. doi:10.1098/rstb.2010.0149.

9. Gandhi V.P. & Zhou Z. (2014). – Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China. *Food Res. Int.*, **63** (Part A), 108–124. doi:10.1016/j.foodres.2014.03.015.

10. Desiere S., Hung Y., Verbeke W. & D'Haese M. (2018). – Assessing current and future meat and fish consumption in sub-Sahara Africa: learnings from FAO Food Balance Sheets and LSMS household survey data. *Glob. Food Sec.*, **16**, 116–126. doi:10.1016/j.gfs.2017.12.004.

11. Enahoro D., Lannerstad M., Pfeifer C. & Dominguez-Salas P. (2018). – Contributions of livestock-derived foods to nutrient supply under changing demand in low- and middle-income countries. *Glob. Food Sec.*, **19**, 1–10. doi:10.1016/j.gfs.2018.08.002.

12. Zhou Y. & Staatz J. (2016). – Projected demand and supply for various foods in West Africa: implications for investments and food policy. *Food Policy*, **61**, 198–212. doi:10.1016/j.foodpol.2016.04.002.

13. Enahoro D., Mason-D'Croz D., Mul M., Rich K.M., Robinson T.P., Thornton P.K. & Staal S.S. (2019). – Supporting sustainable expansion of livestock production in South Asia and sub-Saharan Africa: scenario analysis of investment options. *Glob. Food Sec.*, **20**, 114–121. doi:10.1016/j.gfs.2019.01.001.

14. Food and Agriculture Organization of the United Nations (FAO) (2020). – FAOSTAT Database. FAO, Rome, Italy. Available at: www.fao.org/faostat/en/#data (accessed on 31 August 2020).

15. Food and Agriculture Organization of the United Nations (FAO) (2012). – FAO statistical yearbook: world food and agriculture. FAO, Rome, Italy. Available at: www.fao.org/3/i2490e/i2490e00.htm (accessed on 31 May 2021).

16. Organisation for Economic Cooperation and Development (OECD) & Food and Agriculture Organization of the United Nations (FAO) (2020). – OECD-FAO Agricultural Outlook 2020–2029. OECD Publishing, Paris, France & FAO, Rome, Italy, 330 pp. doi:10.1787/1112c23b-en.

17. Food and Agriculture Organization of the United Nations (FAO) (2009). – The state of food and agriculture 2009: livestock in the balance. FAO, Rome, Italy. Available at: www.fao.org/3/i0680e/i0680e00.htm (accessed on 31 May 2021).

18. United Nations (UN) (2020). – UN Comtrade Database. UN, New York, United States of America. Available at: comtrade.un.org/ (accessed on 13 August 2020).

19. Rich K.M. & Winter-Nelson A. (2007). – An integrated epidemiological-economic analysis of foot and mouth disease: applications to the Southern Cone of South America. *Am. J. Agric. Econ.*, **89** (3), 682–697. doi:10.1111/j.1467-8276.2007.01006.x.

20. Perry B., Rich K.M. […] & Rushton J. (2020). – Integrating the technical, risk management and economic implications of animal disease control to advise policy change: the example of foot-and-mouth disease control in Uruguay. *EcoHealth*, **17**, 381–387. doi:10.1007/s10393-020-01489-6.

21. Locke R. & O'Connor J. (2017). – Market Information Report: Sheepmeat's unique global position. Meat & Livestock Australia, Sydney, Australia, 20 pp. Available at: www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/other-reportanalysis/sheepmeats-unique-global-position.pdf (accessed on 31 May 2021).

22. Mtimet N., Grace D., Wieland B., Knight-Jones T., Wanyoike F., Rich K., Perry B., Kiara H., Mutai F. & Ballantyne P. (2020). – Better enforcement of standards for safer trade in livestock and livestock products across the Red Sea: feasibility study for a joint Horn of Africa-Arabian Peninsula initiative. OIE, Paris, France, 176 pp. Available at: hdl.handle.net/10568/107951 (accessed on 31 May 2021).

23. Williams T.O., Spycher B. & Okike I. (2006). – Improving livestock marketing and intra-regional trade in West Africa: determining appropriate economic incentives and policy framework. International Livestock Research Institute, Nairobi, Kenya, 122 pp. Available at: hdl.handle.net/10568/1572 (accessed on 31 May 2021).

24. Rich K.M., Wane A. & Fall A. (2019). – Perspectives on the competitiveness of live animal versus meat exports in Mali. International Livestock Research Institute, Nairobi, Kenya. Available at: hdl.handle.net/10568/106332 (accessed on 31 May 2021).

25. Reuters (2019). – Up to 200 million pigs to be culled or die from swine fever in China: Rabobank. *Reuters*, 12 April. Available at: www.reuters.com/article/us-china-swinefever-pork/up-to-200-million-pigs-to-be-culled-or-die-from-swine-fever-in-china-rabobank-idUSKCN1RO0MP (accessed on 31 August 2020).

26. Patton D. (2020). – Special report: before coronavirus, China bungled swine epidemic with secrecy. *Reuters*, 5 March. Available at: www.reuters.com/article/us-swinefever-china-epidemic-specialrepo-idUSKBN20S189 (accessed on 31 May 2021).

27. Flies E.J., Brook B.W., Blomqvist L. & Buettel J.C. (2018). – Forecasting future global food demand: a systematic review and meta-analysis of model complexity. *Environ. Int.*, **120**, 93–103. doi:10.1016/j.envint.2018.07.019.

28. Robinson S., van Meijl H. […] & von Lampe M. (2014). – Comparing supply-side specifications in models of global agriculture and the food system. *Agric. Econ.*, **45** (1), 21–35. doi:10.1111/agec.12087.

29. Rosegrant M.W., Sulser T.B. […] & Willaarts B. (2017). – Quantitative foresight modeling to inform the CGIAR research portfolio. Project Report for USAID. International Food Policy Research Institute, Washington, DC, United States of America, 225 pp. Available at: ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131144 (accessed on 31 May 2021).

30. Robinson S., Mason d'Croz D., Islam S., Sulser T.B., Robertson R.D., Zhu T., Gueneau A., Pitois G. & Rosegrant M.W. (2015). – The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): model description for version 3. IFPRI Discussion Paper **01483**. International Food Policy Research Institute, Washington, DC, United States of America, 128 pp. Available at: ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825 (accessed on 31 May 2021).

31. McKenzie A.I. & Hathaway S.C. (2006). – The role and functionality of Veterinary Services in food safety throughout the food chain. *In* Animal production food safety challenges in global markets (S.A. Slorach, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **25** (2), 837–848. doi:10.20506/rst.25.2.1697.

32. McDermott J.J., Enahoro D.K. & Herrero M.T. (2013). – Chapter 8. Livestock futures to 2020: how will they shape food, environmental, health, and global security? *In* Food security and sociopolitical stability (C.B. Barrett, ed.). Oxford University Press, Oxford, United Kingdom. doi:10.1093/acprof:oso/9780199679362.003.0008.

33. Zepeda C., Salman M. & Ruppanner R. (2001). – International trade, animal health and veterinary epidemiology: challenges and opportunities. *Prev. Vet. Med.*, **48** (4), 261–271. doi:10.1016/S0167-5877(00)00200-2.

34. Beltran-Alcrudo D., Falco J.R., Raizman E. & Dietze K. (2019). – Transboundary spread of pig diseases: the role of international trade and travel. *BMC Vet. Res.*, **15**, Article No. 64. doi:10.1186/s12917-019-1800-5

35. Lichoti J.K., Davies J., Maru Y., Kitala P.M., Githigia S.M., Okoth E., Bukachi S.A., Okuthe S. & Bishop R.P. (2017). – Pig traders' networks on the Kenya-Uganda border highlight potential for mitigation of African swine fever virus transmission and improved ASF disease risk management. *Prev. Vet. Med.*, **140**, 87–96. doi:10.1016/j.prevetmed.2017.03.005.

36. Dean A.S., Fournié G., Kulo A.E., Boukaya G.A., Schelling E. & Bonfoh B. (2013). – Potential risk of regional disease spread in West Africa through cross-border cattle trade. *PLoS One*, **8** (10), 1–9. doi:10.1371/journal.pone.0075570.

37. Ward M.P. & Hernández-Jover M. (2015). – A generic rabies risk assessment tool to support surveillance. *Prev. Vet. Med.*, **120** (1), 4–11. doi:10.1016/j.prevetmed.2014.11.005.

38. Fèvre E.M., Bronsvoort B.M. de C., Hamilton K.A. & Cleaveland S. (2006). – Animal movements and the spread of infectious diseases. *Trends Microbiol.*, **14** (3), 125–131. doi:10.1016/j.tim.2006.01.004.

39. Food and Agriculture Organization of the United Nations (FAO) (2020). – Food outlook: Biannual report on global food markets: June 2020. Food Outlook, **1**. FAO, Rome, Italy, 169 pp. doi:10.4060/ca9509en.

Foresight methodologies useful to Veterinary Services

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Summary
The world is facing a broad range of challenges related to agriculture, and particularly the livestock sector, including threats to productivity, the natural environment and human health. While much research has been conducted into potential risks and their drivers, the 2020 COVID-19 pandemic demonstrated how governments can be affected by shocks that are to some extent predictable but for which they are often ill prepared. Policy seeks to anticipate and also influence the future and, as policy-makers, national Veterinary Services have an important role in both anticipating and influencing the future of their countries and the world. In the first part of this paper, the author summarises a wide range of Foresight methodologies and tools relevant to, or used by, Veterinary Services or veterinary researchers. This discussion is followed by an example of the adaptation and application of a Foresight framework tailored specifically to Veterinary Services. Finally, the author draws conclusions on Foresight methodologies useful to Veterinary Services.

Keywords
Foresight – Policy – Scenario analysis – Veterinary Services.

Introduction

Foresight has been defined as 'a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint action' (1). In these challenging and rapidly changing times, it is more important than ever to be prepared for an uncertain and fundamentally unpredictable future. Veterinary Services have a key role in influencing or mitigating many of the emerging or intensifying factors that threaten livestock and animal systems or could transform them in ways that affect human lives and livelihoods. Some of the major current issues in which the livestock, wild-meat and fish sectors play an important or central role include:

– emerging zoonotic diseases, some with pandemic potential
– global greenhouse gas emissions and climate change
– environmental pollution and degradation
– increasing ethical concerns about animal welfare.

In addition, these sectors play a role in:

– changing landscapes and providing ecological services
– supporting livelihoods for poor producers
– providing nutritious food for consumers, especially those who lack high-quality protein and nutrients
– providing livestock products that may lead to overconsumption linked to the obesity epidemic and non-communicable disease
– acting as a major source of food-borne disease.

As can be seen, these issues cover both positive and negative impacts, making planning and policy development complex.

Foresight methodologies

Foresight as a broad approach was first used by militaries during the Second World War and became popular in the private sector (especially the energy sector) from the 1970s onwards. Since the 1990s, there has been a surge of interest in the approach, which is now increasingly used in the public and private sectors (often referred to as 'corporate foresight' in the latter) to support planning and preparedness as well as proactively moving to a desired goal. Over the last two decades, there has been limited but increasing application of Foresight to animal health and diseases. In the United Kingdom, the Office of Foresight was developed in 2001

https://doi.org/10.20506/rst.40.2.3233

as the result of a major foot and mouth disease outbreak (2). Recent costly animal health events caused by infectious diseases, such as African swine fever, and by zoonotic diseases, such as bovine spongiform encephalopathy, highly pathogenic avian influenza, Ebola and COVID-19, have underlined the importance of ensuring Veterinary Services have the capacity to manage animal health in the present and are prepared for future risks.

Typical objectives of a Foresight exercise include shaping strategy and informing policy-making; building strategic visions; developing capabilities; building a Foresight culture; and mobilising joint action. Several methodological guides for Foresight exercises are relevant to Veterinary Services, although none is specifically developed for or adapted to Veterinary Services. Some of the more widely used include the following, listed in chronological order:

– *Inventory of Foresight Methodologies and Studies* provides a history of Foresight and describes tools commonly used (3);

– The report *Preparing for High-impact, Low-probability Events*, written after Eyjafjallajökull, focuses on how shocks cascade through economies and on building resilience, particularly with regards to high-impact, low-probability (HILP) events; it contains lessons that are highly relevant to the COVID-19 pandemic (4);

– The manual *Horizon Scanning and Foresight* addresses Foresight in food safety and related fields (5);

– *Foresight: the Manual* provides an overview of the use of Foresight principles and methods (6);

– *The Futures Toolkit* was designed for policy professionals, especially those new to futures thinking; the toolkit provides background information and describes tools (7);

– Foresight Training Modules is a set of materials and products to better understand Foresight and how to incorporate it into the policy-making process (8);

– *The Future is Ours*: this toolkit offers a set of 12 techniques to help non-governmental organisations and their partners to navigate the present and shape the future (9);

– The SADC [Southern African Development Community] Futures Foresight Training Tool Kit aims to develop Foresight skills to promote climate-resilient agriculture (including livestock) in the South African Development Community region (10).

These resources have been developed by a range of governmental, non-governmental and intergovernmental organisations and their focus varies from specific issues (HILP, food safety) to generic support for policy-making.

Many of these guides and toolkits draw on work from academic groups that have engaged in developing frameworks and providing a conceptual basis for Foresight exercises (11, 12, 13, 14).

Foresight methodologies use one or more (typically more) tools to generate evidence and insights. Foresight tools are categorised in different ways; a common classification focuses on the techniques used to gather information: qualitative, quantitative and semi-quantitative (12). This classification is also used for risk assessment, which many Veterinary Services use regularly. Table I summarises some of the Foresight tools used by or relevant to animal health and disease. Where possible, it provides recent, high-quality references to the use of the tools in animal health or veterinary medicine, which may serve as a guide for those interested in applying them.

A Foresight framework suitable for Veterinary Services

A Foresight exercise tailored specifically to Veterinary Services was used to develop a Technical Item for the OIE (15). (The tools from Table I that were used appear in boldface.) The framework used was developed and implemented for over 30 years at the University of Houston (14). The exercise began with 'scene setting', which involves setting out the objectives and scope of the Foresight exercise ('How external factors [e.g. climate change, conflicts, socio-economics, trading patterns] will impact Veterinary Services, and the adaptations required') and providing a glossary, as much Foresight terminology is somewhat abstruse. Scene setting sets out the Foresight issue and its scope in terms of geography and time. The more precise the definition, the more focused the information search. It is also important to specify the objectives of the Foresight exercise, who is expected to use it and how.

The next section was the 'current assessment' – that is, a snapshot of the current situation highlighting essential facts, quantities and structures about the domain (in this example, adaptation of Veterinary Services to external factors); identifying key players who will be affected or have an interest in the possible outcomes (**stakeholder analysis**), their current interests and announced goals and plans for the future; and the historical events that brought about the domain's current state.

The next section focused on forecasting. Identifying what is driving future change (including events, trends, cycles and shocks) is central to understanding the potential future of the domain. A common method for driver mapping starts with a **brainstorming** exercise to generate a long list of major drivers affecting the delivery of Veterinary Services (Table II). Individual brainstorming is sometimes more effective than group brainstorming. Driver mapping

Table I
Summary of selected Foresight tools

Category	Tool
Qualitative tools	**Backcasting** defines an imagined future and then works backwards to identify how to attain that future. It has been used to a limited extent in veterinary medicine, for example in considering the future of veterinary research (16).
	Stress testing is the process of determining whether a policy or programme can maintain effectiveness under worst-case scenarios. It has not been widely used in animal health but could have value in exploring the widely acknowledged gap between policy and implementation in many low- and middle-income countries.
	Brainstorming is a creative and interactive method used in face-to-face and online group working sessions to generate new ideas around a specific area of interest. It aims at removing inhibitions and breaking out of narrow and routine discussions. Brainstorming is often part of stakeholder meetings on animal health.
	Scenario planning involves the production of accounts of 'plausible' future events based on a creative combination of data, facts and hypotheses. This activity requires insightful and intuitive thinking about possible futures, normally based on a systematic analysis of the present. It has been used to a limited extent in animal health, for example in considering the effect of Brexit on animal health surveillance (17).
	Horizon scanning involves observation, examination, monitoring and systematic description of the external environment; this often considers different domains or drivers, such as social, technological, economic, environmental, political, legal, regulatory, ethical and demographic factors. It has been used in animal health by government agencies, especially the United Kingdom and Australia (18).
	Expert panel consists of a group of around 10 to 20 people considered especially knowledgeable who deliberate on futures of specific aspects in which they have expertise. This is widely used in animal health, especially by international agencies (19) but also by the private sector (20).
	SWOT analysis is a method that first identifies factors internal to the organisation or geopolitical unit in question (resources, capabilities, etc.) and classifies them in terms of 'strengths' and 'weaknesses', while external factors are classified as 'opportunities' and 'threats'. A relatively simple method, it has been widely used in animal health, for example in analysing China's prevention and control strategy for COVID-19 (21).
	Wild cards and weak signals (Wi-We). Wild cards are situations/events with a perceived low probability of occurrence but potentially high impact if they were to occur. Weak signals are unclear observables bringing messages from the future (including about wild cards). They have been little used in animal health, although there is speculation in non-academic literature that COVID-19 may be considered a wild card and was preceded by weak signals, such as concern over wildlife trade and the emergence of novel human disease from animals.
	Gap analysis is the identification and investigation of specific differences between the current position and the ideal future situation. It is used by the OIE in its hallmark Performance of Veterinary Services tool.
Semi-quantitative tools	**Delphi** involves repeated polling of the same individuals, feeding back (sometimes) anonymised responses from earlier rounds of polling, with the idea that this process will allow for better judgements to be made without undue influence from forceful or high-status advocates. It has been widely used in veterinary studies, e.g. for a survey on One Health in Australia (22), and software is available to facilitate use.
	Multi-criteria analysis is a prioritisation and decision-support technique specially developed for complex situations and problems in which there are multiple criteria by which to weigh up the effect of a particular intervention. It has been widely used in animal health, including for prioritisation of disease (e.g. transboundary animal disease in Belgium [23]) and evaluation of control options (e.g. bovine tuberculosis in Ethiopia [24]).
	Roadmapping identifies the actions, steps, technologies, milestones and resources to reach a desired goal. Roadmaps have been widely used by Veterinary Services for disease control (for example of tuberculosis [24]) as well as other aspects of animal health, such as in global research into infectious animal disease (26).
	Stakeholder analysis or mapping is a strategic planning technique that takes into account the interests and strengths of different stakeholders in order to identify key objectives in a system and recognise potential alliances, conflicts and strategies. These methods are quite common in business and political affairs. They are also widely used in animal health, for example in a study on animal health surveillance in Australia (27).
Quantitative tools	**Benchmarking** is a method commonly used for marketing and business strategy planning and has recently become more popular in governmental and intergovernmental strategic decision-making processes. The main focus here is on what others are doing in comparison to what the entity in question is doing. Benchmarking has been widely used in private veterinary practices, especially in high-income countries. It has also been used to identify the most critical measures and important sources of differences among farms in terms of performance (28).
	Modelling, simulation and gaming generally refer to the use of computer-based technologies to explore the relations between different factors and outcomes. They are used very widely in veterinary epidemiology; for example, dozens of models have been developed for Rift Valley fever transmission (29, 30).
	Trend extrapolation is among the longest-established tools of forecasting. It provides a rough idea of how past and present developments may look in the future – assuming, to some extent, that the future is a kind of continuation of the past. It has had limited use in animal health but is widely used in rural development and sustainability analysis.

Table II
Hypothetical example of driver mapping

Domain	Trend	Shock	Importance for domain
Environment	Failure of climate change mitigation and adaption Major biodiversity loss Clean energy dominates	Runaway warming Extreme weather events Ecosystem collapse Water crisis	Climate-sensitive diseases increase or decrease More animal emergencies
Economic	Increasing trade Concentrated trade Illicit trade increases Increasing wealth Africanisation of deep poverty	Return to protectionism Fiscal crisis in key economy Food price shock Energy price shock	Divergence importers and exporters More companion animals More resources for Veterinary Services Pro-poor health services
Societal	Urbanisation Changing diets Increasing world population Broadening values Increasing nationalism	Major shift to vegetarianism Mass involuntary migration	More livestock More diseases from intensification Livestock in emergencies More work on welfare
Geopolitical	Multipolar world More open government Decentralisation Changing role of inter-governmental agencies Challenge to governance	Inter-state conflict Failure of governance Large-scale terrorist attacks	More animal emergencies Operational challenges
Health	Rising chronic disease Emerging antimicrobial resistance Rising foodborne disease in LMICs	Pandemic Major food-borne disease outbreak	Animal role in disease emergence Animal role in surveillance and control
Technology	Biotechnology Laboratory meat Big data Blockchain Robotics Artificial intelligence	Cybercrime Critical information infrastructure breakdown Adverse unintended consequences of technology	Increased productivity Reduction in livestock Breach in data New ways of working

Certainty high	Certainty moderate	Certainty low
Importance high	Importance moderate	Importance low
Black: some combination of the above (e.g. certainty high but importance low)		

LMICs: low- and middle-income countries

requires identifying which drivers are most important for the future of the policy area or strategic endeavour. One must also distinguish between certain and uncertain outcomes resulting from the action of drivers.

Once a long list has been gathered, drivers are typically grouped into categories. These categories derive from **horizon scanning** and are often summarised by acronyms:

– PEST: political, economic, social and technological factors

– PESTLE: political, economic, social, technological, legal and ethical factors

– PESTLED: political, economic, social, technological, legal, ethical and demographic factors

– STEEP: social, technological, economic, environmental and political factors

– STEER: social, technological, economic, environmental and regulatory factors.

In the example described, a combination of PESTLE and STEER was used.

This step was followed by a **scenario analysis**, for which four scenarios were offered; the first was the 'baseline future', which uses **trend analysis** to extrapolate from current trends, cycles and potential shocks to develop a baseline future. As actual futures rarely follow extrapolation, plausible alternate futures were derived, bringing in faint

signals, wild cards and other disruptors. Based on inputs from an **expert panel**, a 'preferred future' scenario was identified. Preferred futures are value driven and used in organisational planning to bring about a desired future.

The baseline and alternate futures provide opportunities and challenges that require adaptation of Veterinary Services. The preferred future, in addition, would require influence from Veterinary Services for its attainment. The final section asked for inputs on how the OIE could support Veterinary Services in these efforts. Table III summarises the process.

Table III
Summary of Foresight exercise for Veterinary Services based on the Houston Framework

– Scene setting (domain definition, objectives)
– Current assessment (current conditions, stakeholders, history, constants)
– Forecast (cycles, trends, plans, investments)
– Alternate and preferred futures (adaptation, challenges, opportunities)
– Support needed to attain preferred future

This example demonstrates one way in which a Foresight approach can be applied to Veterinary Services. There are opportunities to use other Foresight approaches and frameworks with different methodologies for a range of purposes across Veterinary Services, and some have already been used in various Foresight exercises.

Conclusions

Foresight is not a prediction tool, and forecasts have been increasingly discredited as a result of their unreliability. Rather, Foresight aims to broaden thinking about the future, increase preparedness and influence the present to help bring about a preferred future. It differs from traditional planning by considering plausible, possible, probable and preferred futures equally. As such, it is intrinsically more robust than conventional planning, which all too often does not attain its objectives because of assumptions that are not met (or questioned), failure to consider external factors, and a deterministic rather than stochastic approach to future events. For example, the COVID-19 pandemic has derailed many well-laid plans.

Foresight has not been widely used by Veterinary Services but has great potential to improve strategy and policy development and to improve the performance, reputation and funding of Veterinary Services. There is clearly an opportunity to emphasise the increasing recognition by governments (including Veterinary Services) of the need to develop Foresight capacity more generally. However, doing so requires building capacity in Foresight and identifying methodologies and tools that are most relevant to Veterinary Services. This paper provides an overview and links to sources that can guide Veterinary Services in the implementation of Foresight and lead to a better future for animals and humans. ■

Les méthodes de prospective utiles pour les Services vétérinaires

D. Grace

Résumé
Le monde est confronté à un large éventail de défis en lien avec l'agriculture et plus particulièrement avec le secteur de l'élevage, parmi lesquels figurent les menaces pesant sur la productivité, l'environnement naturel et la santé humaine. Alors même que maints travaux de recherches ont été menés sur les risques potentiels et leurs facteurs déterminants, la pandémie de COVID-19 de 2020 a montré que les gouvernements peuvent être atteints par des chocs qui sont, jusqu'à un certain point, prévisibles, mais auxquels ils sont souvent mal préparés. La politique cherche à anticiper et à influencer l'avenir ; en tant que responsables des politiques à mener, les Services vétérinaires nationaux jouent un rôle majeur

aussi bien pour anticiper l'avenir de leur pays et du monde que pour y influer. Dans une première partie, l'auteure décrit brièvement les diverses méthodes et outils de prospective utilisés par les Services vétérinaires ou les chercheurs du secteur vétérinaire, ou qui présentent un intérêt pour eux. Elle examine ensuite l'exemple d'un cadre de prospective qui a été adapté et appliqué dans le but de répondre spécifiquement aux besoins des Services vétérinaires. Enfin, elle tire des conclusions sur les méthodes de prospective les plus utiles pour les Services vétérinaires.

Mots-clés
Analyse par scénarios – Politiques – Prospective – Services vétérinaires.

Métodos de prospectiva útiles para los Servicios Veterinarios

D. Grace

Resumen
El mundo hace frente a un rosario de problemas ligados a la agricultura, y en especial al sector ganadero, entre ellos las amenazas que pesan sobre la productividad, el medio natural y la salud humana. Aunque se ha investigado mucho sobre los posibles riesgos y sus condicionantes, la pandemia de COVID-19 de 2020 puso de relieve cuán afectados pueden verse los gobiernos por choques hasta cierto punto predecibles, pero para los cuales suelen estar mal preparados. Las políticas tienen por objetivo anticipar el futuro y también influir en él. Los Servicios Veterinarios nacionales, como artífices que son de ciertas políticas, cumplen una importante función a la hora de prever y orientar el futuro de su país y del mundo. En la primera parte del artículo, la autora resume toda una serie de métodos y herramientas de prospectiva que emplean los Servicios Veterinarios o los investigadores en veterinaria o que revisten interés para ellos. A continuación presenta un ejemplo de adaptación y aplicación de un marco de prospectiva concebido específicamente para los Servicios Veterinarios. Por último, extrae conclusiones sobre los métodos de prospectiva que son de utilidad para los Servicios Veterinarios.

Palabras clave
Análisis de situaciones hipotéticas – Política – Prospectiva – Servicios Veterinarios.

References

1. Miles I., Saritas O. & Sokolov A. (2016). – Foresight for science, technology and innovation. Springer Nature, Cham, Switzerland.

2. King D.A. & Thomas S.M. (2007). – Taking science out of the box – Foresight recast. *Science*, **316** (5832), 1701–1702. doi:10.1126/science.1146051.

3. Nicolini F. & Bagni M. (2012). – Inventory of foresight methodologies and studies: work package 5. Global Strategic Alliances for the Coordination of Research on the Major Infectious Diseases of Animals and Zoonoses (STAR–IDAZ), London, United Kingdom. Available at: www.star-idaz.net/app/uploads/2018/07/WP5-Inventory-of-Foresight-Methodologies.pdf (accessed on 4 July 2021).

4. Lee B., Preston F. & Green G. (2012). – Preparing for high-impact, low-probability events: lessons from Eyjafjallajökull. Chatham House, London, United Kingdom, 61 pp. Available at: www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/r0112_highimpact.pdf (accessed on 4 July 2021).

5. Food and Agriculture Organization of the United Nations (FAO) (2014). – Horizon scanning and foresight: an overview of approaches and possible applications in food safety. Background paper for the FAO Early Warning Alert Horizon Scanning Food Safety Technical Workshop, Rome, Italy, 22–25 October 2013. FAO, Rome, Italy, 36 pp. Available at: www.fao.org/3/a-i4061e.pdf (accessed on 4 July 2021).

6. United Nations Development Programme (UNDP) Global Centre for Public Service Excellence (GCPSE) (2014). – Foresight: the manual. GCPSE, Singapore, Singapore. Available at: www.undp.org/content/dam/rbap/docs/meetTheSDGs/GCPSE_ForesightManual_online.pdf (accessed on 4 July 2021).

7. United Kingdom Government Office for Science (2017). – The futures toolkit: tools for futures thinking and foresight across UK government. Government Office for Science, London, United Kingdom, 113 pp. Available at: assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/674209/futures-toolkit-edition-1.pdf (accessed on 26 July 2021).

8. Policy Horizons Canada (2018). – Foresight training modules. Government of Canada, Ottawa, Canada. Available at: horizons.gc.ca/en/resources/ (accessed on 26 July 2021).

9. Save the Children (2019). – The future is ours: strategic foresight toolkit – making better decisions. Save the Children UK, London, United Kingdom, 144 pp. Available at: resourcecentre.savethechildren.net/node/16327/pdf/strategic_foresight_toolkit_online.pdf (accessed on 4 July 2021).

10. Chesterman S., Neely C., Gosling A., Quinn C., Chevallier R., Lipper L. & Thornton P. (2020). – Toolkit for developing skills and capacity in applying foresight to climate resilient agricultural development in the SADC Region. Module 3: Visioning and causal analysis. SADC futures: developing foresight capacity for climate resilient agricultural development knowledge series. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Wageningen, the Netherlands, 72 pp. Available at: hdl.handle.net/10568/109510 (accessed on 4 July 2021).

11. Brown M.J.F., Dicks L.V. […] & Stout J.C. (2016). – A horizon scan of future threats and opportunities for pollinators and pollination. *PeerJ*, **4**, e2249. doi:10.7717/peerj.2249.

12. Popper R. (2008). – How are foresight methods selected? *Foresight*, **10** (6), 62–89. doi:10.1108/14636680810918586.

13. Habegger B. (2009). – Horizon scanning in government: concept, country experiences, and models for Switzerland. Center for Security Studies, Zurich, Switzerland, 36 pp. Available at: www.babs.admin.ch/content/babs-internet/en/publikservice/downloads/gefrisiken/_jcr_content/contentPar/accordion/accordionItems/divers_documents/accordionPar/downloadlist/downloadItems/663_1480002162771.download/horizonscanningingovernment.pdf (accessed on 4 July 2021).

14. Bishop P.C. & Hines A. (2012). – Teaching about the future. Palgrave Macmillan, Basingstoke, United Kingdom. doi:10.1057/9781137020703.

15. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K., & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item. In *Proc.* 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France, 28 pp. doi:10.20506/TT.2984.

16. Heffernan C. (2014). – Backcasting the future of animal health research [PowerPoint presentation]. STAR–IDAZ Workshop: meeting the future research needs on infectious animal diseases and zoonoses – A global Foresight exercise, 17–20 June, Moscow, Russia, 21 pp. Available at: www.slideshare.net/clheffernan/backcasting-the-future-of-animal-health-research (accessed on 4 July 2021).

17. Boden L.A., Auty H., Reeves A., Rydevik G., Bessell P. & McKendrick I.J. (2017). – Animal health surveillance in Scotland in 2030: using scenario planning to develop strategies in the context of 'Brexit'. *Front. Vet. Sci.*, **4**, 201. doi:10.3389/fvets.2017.00201.

18. Vanderstichel R., Van Der Linden I., Renwick S. & Dubuc M. (2010). – Foresight: an innovative approach for animal health emergency preparedness. *Can. Vet. J.*, **51** (4), 372–374. Available at: europepmc.org/article/med/20592824 (accessed on 4 July 2021).

19. High Level Panel of Experts on Food Security and Nutrition (HLPE) (2016). – Extract from the report – sustainable agricultural development for food security and nutrition: what roles for livestock? Summary and recommendations. HLPE, Rome, Italy, 12 pp. Available at: www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_S_and_R/HLPE_2016_Sust-Agr-Dev-FSN-Livestock_S-R_EN.pdf (accessed on 4 July 2021).

20. Hegelund L. & Sørensen J.T. (2007). – Developing a HACCP-like system for improving animal health and welfare in organic egg production – based on an expert panel analysis. *Animal*, **1** (7), 1018–1025. doi:10.1017/S1751731107000213.

21. Wang J. & Wang Z. (2020). – Strengths, weaknesses, opportunities and threats (SWOT) analysis of China's prevention and control strategy for the COVID-19 epidemic. *Int. J. Environ. Res. Public Hlth*, **17** (7), 2235. doi:10.3390/ijerph17072235.

22. Degeling C., Johnson J., Ward M., Wilson A. & Gilbert G. (2017). – A Delphi survey and analysis of expert perspectives on One Health in Australia. *EcoHealth*, **14**, 783–792. doi:10.1007/s10393-017-1264-7.

23. Bianchini J., Humblet M.-F., Cargnel M., Van der Stede Y., Koenen F., De Clercq K. & Saegerman C. (2020). – Prioritization of livestock transboundary diseases in Belgium using a multicriteria decision analysis tool based on drivers of emergence. *Transbound. Emerg. Dis.*, **67** (1), 344–376. doi:10.1111/tbed.13356.

24. Gutema F.D., Agga G.E., Makita K., Smith R.L., Mourits M., Tufa T.B., Leta S., Beyene T.J., Asefa Z., Urge B. & Ameni G. (2020). – Evaluation of the control options of bovine tuberculosis in Ethiopia using a multi-criteria decision analysis. *Front. Vet. Sci.*, **7**, 586056. doi:10.3389/fvets.2020.586056.

25. Dean A.S., Forcella S., Olea-Popelka F., Idrissi A.E., Glaziou P., Benyahia A., Mumford E., Erlacher-Vindel E., Gifford G., Lubroth J., Raviglione M. & Fujiwara P. (2018). – A roadmap for zoonotic tuberculosis: a One Health approach to ending tuberculosis. *Lancet Infect. Dis.*, **18** (2), 137–138. doi:10.1016/S1473-3099(18)30013-6.

26. Entrican G., Charlier J., Dalton L., Messori S., Sharma S., Taylor R. & Morrow A. (2020). – Construction of generic roadmaps for the strategic coordination of global research into infectious diseases of animals and zoonoses. *Transbound. Emerg. Dis.*, **68** (3), 1513–1520. doi:10.1111/tbed.13821.

27. Hayes L., Manyweathers J., Maru Y., Loechel B., Kelly J., Kruger H., Woodgate R. & Hernandez-Jover M. (2021). – Stakeholder mapping in animal health surveillance: a comparative assessment of networks in intensive dairy cattle and extensive sheep production in Australia. *Prev. Vet. Med.*, **190**, 105326. doi:10.1016/j.prevetmed.2021.105326.

28. Waldner C.L., Parker S. & Campbell J.R. (2019). – Identifying performance benchmarks and determinants for reproductive performance and calf survival using a longitudinal field study of cow-calf herds in western Canada . *PLoS One*, **14** (7), Article No. e0219901. doi:10.1371/ journal.pone.0219901.

29. Niu T., Gaff H.D., Papelis Y.E. & Hartley D.M. (2012). – An epidemiological model of Rift Valley fever with spatial dynamics. *Comput. Math. Methods Med.*, **2012**, 138757. doi:10.1155/2012/138757.

30. Gachohi J.M., Njenga M.K., Kitala P. & Bett B. (2017). – Modelling vaccination strategies against Rift Valley fever in livestock in Kenya. *PLoS Negl. Trop. Dis.,* **10** (12), e0005049. doi:10.1371/journal.pntd.0005049.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 421-430

The implications of climate change for Veterinary Services

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Summary
Climate change affects the entire veterinary domain. Veterinary Services must, therefore, add climate change to their list of responsibilities. Although the goals of preventing disease, maintaining productivity, and sustaining healthy systems will remain, the form and scope of Veterinary Services will need to change. Climate change will have direct and indirect impacts on determinants of animal health in multiple, interacting ways, across a range of scales. Veterinary Services will need to work across the spectrum of health determinants if they intend to both address pre-existing problems expected to worsen with climate change and prepare for unanticipated threats. Animals will feel the impact of climate change through multiple, often interacting, means including changing patterns of infectious diseases, increased exposure to heat, contaminants and extreme weather, changes in access to the natural resources they need for daily living and shifts in animal ecology, sociobiology and population dynamics. To meet expectations for action across the veterinary domain, Veterinary Services need to: a) provide services to mitigate impacts; b) reduce population vulnerability to lessen those impacts; c) enhance population resilience to avoid impacts; and d) address climate change risks at their sources. Health intelligence that combines hazard surveillance with population reconnaissance (to determine vulnerability) will be needed to adaptively allocate resources. Rather than focus on risk management only, programmes will need to include capacity building for healthy, resilient animal populations and animal health systems. Transformative changes are needed to allow Veterinary Services to address the inter-related challenges of sustainable development, climate change, and biodiversity loss. This will require partnerships and governance models that share and integrate knowledge and understanding of changes in global and local socio-ecological systems.

Keywords
Adaptation – Animal health – Climate change – Determinants – Resilience – Veterinary – Vulnerability.

Introduction

National Veterinary Services are expected to implement activities across the veterinary domain (1). The World Organisation for Animal Health (OIE) defines the veterinary domain as, 'all the activities that are directly or indirectly related to animals, their products and by-products, which help to protect, maintain and improve the health and welfare of humans, including by means of the protection of animal health and animal welfare, and food safety' (2). Climate change impacts all aspects of the veterinary domain. The World Health Organization declared climate change to be the world's biggest public health threat, and there is no reason to doubt that the same holds true for animal health.

The Director General of the OIE explained that, 'National Veterinary Services preserve and develop animal resources,

https://doi.org/10.20506/rst.40.2.3234

reducing poverty and hunger worldwide through improving rural livelihoods and feeding the world. Their additional impact on global health security by addressing "risk at source" for emerging pandemic threats, antimicrobial resistance and food safety crises further safeguards the planet' (3). Veterinary Services must now add climate change to their remit due to its overwhelming impact on animal resources (through its effects on domestic animal and wildlife health, animal production and agricultural practices), poverty, hunger, emerging infectious diseases, and global health security. How we respond to climate change will have profound implications for people, biodiversity, economies, and ecosystems.

What is climate change?

Climate change is a long-term shift in global or regional climate patterns. Currently, the phrase 'climate change' is commonly used to refer specifically to the rise in global temperatures from the mid-20th century to the present. Recent changes in climate can be linked, for the most part, to the greenhouse effect, the process whereby radiant heat is absorbed and then re-emitted by gases in the atmosphere, trapping heat in the lower atmosphere. The heat-trapping capacity of the atmosphere depends on its chemical composition and, more specifically, on the amount of atmospheric greenhouse gases (GHGs) it contains. The recent anthropogenically driven accumulation of GHGs has reduced the rate of heat loss to space, with a subsequent warming effect on the global climate system (4).

The evidence of anthropogenically driven warming of the global climate system is unequivocal, as is the evidence that recent changes in climate are resulting in widespread impacts on natural and social systems. The rate of climate change is not consistent across the globe. For instance, warming in Canada is, on average, about double the magnitude of global warming, and northern Canada has warmed and will continue to warm at more than double the global rate (4). The observed direct and indirect effects of climate change will be modified, amplified, or dampened by the nature, availability and sustainability of ecosystem services, which are supported by biodiversity, demographic change, and socio-economic development (5). The main impacts of climate change on natural systems are related to atmospheric and oceanic warming, the diminution of snow and ice, and the rising of sea levels. The Intergovernmental Panel on Climate Change (IPCC) noted that, 'all aspects of food security are potentially affected by climate change, including food production, access, use and price stability' (6). Climate change is projected to reduce global biodiversity and undermine food security, leading the IPCC to conclude that 'limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication' (6).

Defining animal health in a climate change context

The IPCC 5th Assessment Report concluded that health impacts from climate change are inevitable (6). As the anticipated consequences of climate change are occurring faster than expected (7), a growing number of countries and cities have declared climate emergencies. The impacts on animal health are increasing and transcending species and borders. Worldwide, people, animals and ecosystems are experiencing increased heat, extreme weather events, declining air quality, expanded ranges of parasites and pathogens, habitat loss, wildfires and diminished food and water safety and security. People and animals must now face and adapt to the inevitable changing patterns and rates of morbidity, mortality, and productivity.

Targets and priorities for Veterinary Services in anticipation of a changing climate will depend, in part, on how animal health is defined. Too often, animal health remains defined as the absence of specific infectious diseases. This definition is insufficient to encourage robust action on climate change mitigation or adaptation. The concept of health as the capacity provided to animals by interacting individual, environmental, ecological, and social attributes and circumstances, rather than a biological state of absence of disease, is better suited for climate change planning. Moreover, this definition is consistent with prevailing definitions of human health and evolving definitions of wildlife health (8).

The underlying attributes and circumstances that ultimately shape the health of individuals and populations are called the determinants of health. Determinants of health influence the physiological and behavioural capacity essential for normal growth, development, survival and reproduction, all of which are need to allow animals to meet the requirements of daily living. Determinants also provide capacities to adapt to or recover from stressors or hazards operating at the individual and population level. Determinants of health, whether in domestic or wild animal populations, include individual-level factors (e.g. genotype, immune function, condition, behaviour, social status), population-level factors (e.g. density, social structure, husbandry, demographics), and environmental factors (e.g. climate, season, habitat quality, food and water security), as well as socio-economic and cultural factors (e.g. policies, cultural practices, values and beliefs) (8). Climate change will have direct and indirect impacts on determinants of animal health in multiple, interacting ways across a range of scales, from the sub-cellular to global levels (9). Vulnerability to the direct and indirect health impacts of climate change varies widely by species, location, and management system, but is ultimately determined by exposure to the effects of

climate change and capacity to adapt to or cope with those effects (10). The determinants of health provide the raw material necessary for coping with, or adapting to, climate change. Thus, climate change strategies will need to work across the spectrum of determinants of health.

Healthy animals must be able to respond to, cope with, or adapt to multiple challenges, changes, or hazards (e.g. stressors) brought about by climate change in their dynamic social or physical environment, whether those challenges are predictable or not. Most attention in the animal health literature has focused on how climate change will impact infectious diseases, especially vector-borne disease (11). Maintaining a focus on infectious diseases at the exclusion of other determinants of health will severely limit the role of Veterinary Services in fulfilling their obligation to address global security needs, which they must do if they are to protect animal health and safeguard the planet in the face of a rapidly changing climate. Emerging evidence and experience in public health suggests that, to be fully effective, climate change and health management efforts must not only tend to the preventive and curative functions of the health sector, but also must protect and manage the determinants of health that fall outside the usual scope of practice of Veterinary Services (12).

Overview of climate change and animal health impacts

Veterinary Services are constrained by a lack of systematic study of the current and anticipated effects of climate change on animals. Fewer formal or comprehensive climate change studies have been done on animal health compared to human health (13). Little scholarly work has been dedicated to identifying evidence-based, sustainable adaptation actions for animal health (11). This section of the paper provides a high-level introduction to the main topics being discussed in the literature on animal health climate change adaptation, as reviewed in 2019 (11).

Infectious diseases

Climate has influenced, and will continue to influence, the occurrence and severity of infectious diseases in natural and agricultural systems. Studies on the role of climate impacts on host–pathogen relationships and the emergence and dynamics of infectious pathogens are accumulating (11). Changes in food webs, timing of lifecycles, and weather patterns will influence infectious and parasitic disease transmission pathways and frequency. While most attention has focused on vector-borne diseases, waterborne, windborne, and enteric infections can also be expected to increase (14).

The relationship between climate change and infectious diseases is not straightforward, as can be illustrated by the dynamics of avian influenza viruses (AIVs) in wild and domestic animal populations. Highly pathogenic or zoonotic AIVs continue to be a global concern, as they have the potential to threaten avian populations, human health and food security. Wild migratory waterfowl are natural reservoirs for most subtypes of AIVs (15), can transport AIVs across and between continents along migratory pathways (16 and references therein), and drive seasonal dynamics of AIV via the influx of immunologically naïve juveniles each breeding season (17). Outbreaks in poultry have been associated with migrating waterfowl in Asia (18) and North America (19). Climate change has the potential to affect the dynamics and emergence of novel AIVs through multiple routes (20). Although increasing temperatures may reduce virus survivability in water (21), impacts on movement and behaviour of migratory birds may increase opportunities for transmission, viral reassortment, emergence of novel strains and spread (22). Impacts on migratory behaviour could result in changes to timing of migration, northward expansion or shifts in distribution, an increase in the length of the breeding season, and altering population density and species compositions along flyways and stopover sites (20, 22, 23). Agricultural systems such as rice crops provide a major interface between domestic ducks and wild birds, and thus play a large role in the spread and evolution of AIVs (24). Lengthened growing seasons and northward expansion of paddy rice resulting from rising human populations as well as warming temperatures (25) may further increase opportunities for spread, reassortment, and emergence of novel strains (20). Veterinary Service strategies to better anticipate and manage pathogens such as AIV will require multi-sector coordination and planning to identify modifiable factors within complex, dynamic socio-ecological systems that are changing with the climate.

Heat

Heat stress due to rising temperatures will not only cause suffering and premature death, but will also result in reduced productivity and fertility (14). Heat stress can negatively affect livestock health by causing metabolic alterations and oxidative stress (26) and by suppressing the immune and endocrine system, thereby enhancing disease susceptibility (27). Increased temperatures in marine and aquatic systems similarly threaten fisheries and aquaculture. As water temperatures increase water quality declines, harmful algae blooms become more frequent, water oxygen levels decrease and reduced feeding and growth occur, all of which can increase the incidence of diseases (28). The experience in the human health sector has clearly demonstrated the importance of heat-related problems (29) and highlighted the need to include strategies for adaptation to, and mitigation of, increasing temperatures as part of the Veterinary Services climate change agenda.

Contaminants

A literature review conducted by Noyes *et al.* (30) concluded that climate change will affect the environmental distribution and toxicity of chemical pollutants. Climate change alterations to food webs, lipid dynamics, ice and snow melt, and organic carbon cycling will affect pollutant levels in water, soil, air, plants, and animals. Flooding and melting events will remobilise contaminants and redistribute them onto grazing lands, thus contaminating animals and animal products (31). Changes in the distribution and abundance of insect pests are expected to change both *how much* pesticide enters the environment and *when* it enters the environment. (31). Increased production, frequency, and distribution of mycotoxins (32) and toxic algae (33) have implications for both animal health and food safety in terrestrial and aquatic systems. There is compelling evidence that increasing temperatures may alter the biotransformation of contaminants to more bioactive metabolites (30). Moreover, there is evidence of the synergistic effects of the combination of contaminants and parasitic or infectious diseases (34). Concomitant changes in patterns of contaminants and infectious diseases will undoubtedly result in syndemics of unexpected effect and severity and will have implications for animal health and food safety.

Extreme weather

The impacts of extreme weather events, such as typhoons, hurricanes, floods, wildfires and drought have animal health and welfare implications that in turn will have public health, economic and mental health implications. Despite this, many countries omit animals from their national and regional contingency planning (35). Efforts to incorporate One Health approaches into emergency preparedness for extreme weather disasters are, however, beginning to appear (36). The estimated losses of over a billion animals during the 2019 Australian wildfires, which led to reduced meat, wool, and honey production, along with untold social and ecological effects, exemplify the devastating impact that extreme weather (in this case, drought preceding the fires) can have on animal health.

Effects on other determinants of health

An animal's welfare is compromised when the circumstances in which it lives do not fit its evolved adaptations (37). The environments in which animals have evolved are changing with climate change. Oceans are acidifying. Desertification is occurring in some regions, while ice and snow loss are affecting others. Droughts are leading to crop failures and fires. There will be a reduction in water resources in most dry subtropical regions, and the frequency of droughts will likely increase, intensifying competition for water. The annual cycles of plants and animals are changing, affecting food webs, crop production, and disease cycles. All these changes will influence how wild and domestic animals access their needs for daily living and will impact how management decisions change to adapt to these changing determinants of animal health.

The role of Veterinary Services

Veterinary Services have four general climate change management options:

a) intervene before an adverse impact occurs by protecting determinants of health that affect population vulnerability or resilience

b) undertake warning surveillance and health intelligence to find adverse effects or high-risk situations quickly, and respond with early interventions to prevent significant impacts and reduce vulnerabilities

c) provide services to help populations recover from or cope with negative impacts that are occurring

d) collaborate in cross-sectoral policies and programmes that aim to eliminate or reduce climate change risks at the source, by targeting the causes of anthropogenic climate change.

Climate change impacts on animal health will be exacerbated by unanticipated threats created by climate change as well as by pre-existing problems that climate change will amplify (38). The priority for addressing amplified pre-existing problems is to ensure sufficient accessible and mobilisable animal health services that can be adaptively deployed and/or enhanced in response to locally changing situations. Veterinary Services will require timely situational awareness to deploy animal health services in advance of disaster or severe impacts. Key actions in this scenario include:

a) implementing adaptable surveillance and monitoring systems to ensure early detection and warning of expected health outcomes or hazards

b) implementing health intelligence activities to detect circumstances that are altering population exposure to, sensitivity to, and/or capacity to adapt to known climate change hazards and risk (i.e. tracking population vulnerability)

c) strengthening core veterinary capacities, and building sustainable policies and infrastructures to manage increased effects and changing distributions of existing or reasonably expected threats

d) reducing socio-economic inequities that affect access to veterinary care.

A hazard-by-hazard approach to risk management is insufficient for climate change preparedness, because the

interaction of climate change with other global and local forces is producing an increasing number of unanticipated and unimaginable hazards of increasing severity. Extreme or unanticipated events associated with climate change, such as hurricanes or pandemics, have so far caused more damage to human health than have amplified known problems (39). Thus, Veterinary Services must prepare for the unexpected. Better surprise anticipation comes with improved awareness of changes in the distribution of and exposure to emerging hazards, or changes in willingness to act on early signals of possible harms (40). Surveillance programmes need to be expanded to connect specialised pools of knowledge within and outside of the Veterinary Services. This will allow hazards to be detected and acted upon in advance of harms and make it possible to track changing exposures and vulnerabilities before a harm can occur. Surprise preparation also comes from tracking and bolstering the determinants of health that enhance the capacity of a farm, a population, or a community to cope with unexpected harms (40). Shifting from pathogen surveillance to health intelligence that combines hazard surveillance with population reconnaissance (to determine vulnerability) will help Veterinary Services better target scarce resources. It will also enable them to launch programmes to improve the health of vulnerable populations before a climate impact occurs or becomes unacceptable or unmanageable.

A climate change strategy concerned with unanticipated health impacts requires investment in:

a) identifying and addressing pre-existing socio-economic, ecological, and health inequities that exacerbate climate change vulnerability

b) proactively building capacity for individuals and populations to cope with multiple interacting threats and stressors before an impact occurs

c) developing capacity in the Veterinary Services to enable them to adaptively respond to surges in unexpected disasters, emergencies, or disease outbreaks

d) integrating animal health climate change adaptation into agriculture planning and ecosystem management

e) incorporating climate change health literacy as a core component of Veterinary Services, to encourage and enable proactive adaptive and mitigative behaviours within and outside the Veterinary Services

f) investigating and communicating how the effects of climate change on animal health subsequently have an impact on conservation, sustainable food production systems, food security, public health, and community resilience, to encourage political and multi-sectoral collaboration

g) fostering innovative leadership, partnerships, and governance that support cross-sectoral, collaborative actions.

Because of compelling evidence that animal health harms are now or are soon to be realised, this paper has largely focused on climate change adaptation, which involves adjustments in responses to the current and expected effects of climatic change. It is also critical that efforts be made to reduce or prevent emission of greenhouse gases at their source to slow or halt the acceleration and duration of climate change. Animal health climate change mitigation actions generally focus on reducing the carbon footprint of Veterinary Services and limiting the greenhouse gas emissions caused by feeding, housing, and caring for livestock, fish, and companion animals. Innovations in animal husbandry and feeding predominate the literature on these subjects.

Discussion

Veterinary Services face the challenge of preventing adverse health consequences and finding health benefits likely to result from climate change. The components of effective adaptation to the future impact of climate change will be unpredictable and emergent rather than predictable and planned (41). This is due to the unprecedented rate of social and environmental change and the complexity of interactions between co-occurring global threats and anthropogenic climate change. Climate change is part of a larger syndrome of systemic environmental and social changes. It must be put into the broader context of other largescale changes, such as land-use changes, habitat loss, and loss of biodiversity. Although the ultimate goals of Veterinary Services – preventing disease, maintaining productivity, and sustaining systems that promote health – will remain unchanged, the form and scope of Veterinary Services will need to evolve.

Veterinary Services cannot isolate their climate change response from their responses to other threats. Our world is experiencing multiple anthropogenically-driven global crises simultaneously. Many of the concurrent global threats are intrinsically linked, not only in their ultimate causes, but also in their solutions. There is increasing global awareness of the need to take action on the 'causes of the causes' that are shared between climate change, food insecurity, biodiversity loss and other mega-threats. A joint statement of the Global Health Security Agenda Steering group (42) stressed that, in a time of multiple concurrent global threats, humanity will only be able to deal with the risk of climate change through global solidarity, international partnerships, and cooperation across multiple sectors. It emphasised the importance of cooperating on issues of shared concern and taking a whole-of-government and whole-of-society approach. Veterinary Services will need to shift from a veterinary focus to an animal health services focus if it is to mitigate, as well as adapt to, climate change

across the veterinary domain. This will require strategic partnerships with a breadth of disciplines that can influence determinants of animal health as well as the social systems that influence them. Veterinary Services can fill a leadership gap by promoting animal health, linked with ecological and human health, as part of society-wide climate change plans and actions (38).

If Veterinary Services are to meet their obligations as set out by the OIE to 'protect, maintain and improve the health and welfare of humans, including by means of the protection of animal health and animal welfare, and food safety' (2), they are obliged to provide a continuum of climate change actions. This continuum includes:

a) providing services to mitigate climate change impacts

b) reducing population vulnerability to lessen those impacts

c) enhancing population resilience to avoid or cope with the impacts

d) attacking climate change risks at their sources.

Veterinary Services will not be able to provide this continuum of care without strengthening links between animal health practice, policy, and research, cooperating with the social, ecological, economic, and human health sectors, and working in concert with communities to build locally relevant actions. It will require Veterinary Services to expand their thinking on animal health and climate change to include not only risk management but also capacity building for healthy, resilient animal populations and animal health systems.

Climate change, biodiversity loss, and emergence of novel pathogens are occurring at unprecedented rates, with increasingly devastating consequences. These mega-threats are intrinsically linked, with each resulting from the massive and widespread destruction, exploitation, and pollution of our environment (43). The other major problem they share is that the poorest communities and most vulnerable populations (including women, children, and indigenous peoples) tend to be, and will continue to be, disproportionately affected by their consequences. Business-as-usual will exacerbate these global threats, while also exacerbating pre-existing global inequalities. Transformative solutions are needed for 'society to come to grasp with confronting the inter-related challenges of sustainable development, climate change, and biodiversity' (44).

Climate change action falls within the remit of Veterinary Services and they are well placed to provide leadership to build resilience to climate change. By taking action across every area of the veterinary domain, from disease prevention to sustainable food systems and ecosystem health, Veterinary Services can promote reciprocal maintenance; in other words, humans care for animals and ecosystems, and, in turn, healthy animals and a healthy environment help maintain human health.

Acknowledgements

The authors appreciate the input and constructive comments provided by Dr Martine Dubuc, Associate Deputy Minister of Environment and Climate Change Canada, and Bruce Pauli, Chief, Ecosystem Health Research, Environment and Climate Change Canada.

Les conséquences du changement climatique pour les Services vétérinaires

C. Stephen & C. Soos

Résumé

Le changement climatique affecte l'intégralité du champ vétérinaire. Par conséquent, les Services vétérinaires doivent inscrire le changement climatique sur la liste des priorités relevant de leur responsabilité. Certes, les objectifs liés à la prévention des maladies, au maintien de la productivité et à la protection durable de systèmes sains restent inchangés, mais la structure et la portée des Services vétérinaires doivent être repensées. Le changement climatique va avoir des impacts directs et indirects sur les déterminants sanitaires qui relèvent du monde

animal, sous des formes multiples et interdépendantes et à diverses échelles. Les Services vétérinaires doivent envisager le spectre entier de ces déterminants sanitaires s'ils veulent à la fois traiter les problématiques préexistantes dont l'aggravation sous l'effet du changement climatique est attendue et se préparer à faire face à d'autres menaces encore inconnues. Les animaux vont subir l'impact du changement climatique sous des aspects multiples qui parfois interagissent entre eux : modification de la structure des maladies infectieuses, exposition accrue à la chaleur, aux polluants et aux conditions climatiques extrêmes, accès perturbé aux ressources naturelles vitales au quotidien, modifications de l'écologie animale, de la sociobiologie et de la dynamique des populations. Afin de répondre aux attentes d'une action intégrée couvrant la totalité du champ vétérinaire, les Services vétérinaires doivent : a) assurer des services visant à atténuer les impacts ; b) réduire la vulnérabilité des populations afin de limiter ces impacts ; c) accroître la résilience des populations en vue d'éviter les impacts ; et d) traiter les risques liés au changement climatique à leur source. Il sera indispensable de mettre en place un système de renseignement sanitaire associant la surveillance des dangers et la connaissance des populations (pour prendre en compte leurs vulnérabilités) afin de procéder à une allocation des ressources adaptée. Plutôt que de se centrer sur la seule gestion du risque, les programmes devront également miser sur le renforcement des capacités pour des populations animales et des systèmes de santé animale sains et résilients. Une approche axée sur les changements transformatifs est nécessaire pour que les Services vétérinaires puissent relever les défis interconnectés que représentent le développement durable, le changement climatique et la perte de biodiversité. Cela nécessitera des partenariats et des modèles de gouvernance capables de partager et d'intégrer les connaissances et la compréhension du changement au sein des systèmes socio-écologiques, à l'échelle tant mondiale que locale.

Mots-clés
Adaptation – Changement climatique – Déterminants – Résilience – Santé animale – Vétérinaire – Vulnérabilité.

Consecuencias del cambio climático para los Servicios Veterinarios

C. Stephen & C. Soos

Resumen
El cambio climático afecta a la totalidad del ámbito veterinario. De ahí la necesidad de que los Servicios Veterinarios lo incluyan dentro de sus áreas de responsabilidad. Aunque los objetivos de prevenir enfermedades, mantener la productividad y preservar sistemas sanos seguirán vigentes, la forma y el alcance de los Servicios Veterinarios deberán cambiar. El cambio climático repercutirá directa e indirectamente en los determinantes de la salud animal a diversas escalas y por múltiples vías interconectadas. Para poder responder a problemas preexistentes que previsiblemente se agravarán con el cambio climático y a la vez prepararse para amenazas imprevistas, los Servicios Veterinarios deberán poder trabajar en todo el espectro de los determinantes de la salud. Hay varios mecanismos, a menudo interdependientes, a través de los cuales los efectos del cambio climático se dejarán sentir en los animales, en particular la evolución de las características de enfermedades infecciosas, la mayor exposición a

altas temperaturas, los contaminantes y fenómenos meteorológicos extremos, la modificación del acceso a recursos naturales necesarios para vivir y la transformación de la ecología y sociobiología animales y las dinámicas de población. Para responder a lo que se espera de ellos y de su trabajo en todos los ámbitos de la veterinaria, los Servicios Veterinarios deben: a) proporcionar servicios destinados a atenuar las consecuencias; b) reducir la vulnerabilidad de las poblaciones para aminorar el peso de esas consecuencias; c) mejorar la resiliencia de las poblaciones para evitar las consecuencias; y d) conjurar en su origen los riesgos derivados del cambio climático. Para asignar los recursos de forma adaptada y reactiva se precisarán servicios de información zoosanitaria que combinen la vigilancia de los factores de peligro y la observación de las poblaciones (a fin de determinar su vulnerabilidad). Será necesario que los programas, en lugar de girar únicamente en torno a la gestión de riesgos, incluyan también la adquisición de capacidad en pro de sistemas de sanidad animal y poblaciones animales saludables y resilientes. Harán falta cambios transformadores para que los Servicios Veterinarios estén en condiciones de responder a los problemas interconectados del desarrollo sostenible, el cambio climático y la pérdida de diversidad biológica, lo que su vez requerirá alianzas y modelos de gobernanza que sirvan para compartir e integrar el conocimiento y la comprensión de los cambios que experimentan los sistemas socioecológicos a escala tanto mundial como local.

Palabras clave
Adaptación – Cambio climático – Determinantes – Resiliencia – Sanidad animal – Veterinario – Vulnerabilidad.

References

1. World Organisation for Animal Health (OIE) (2019). – OIE Tool for the Evaluation of the Performance of Veterinary Services. OIE, Paris, France, 68 pp. Available at: www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/docs/pdf/2019_PVS_Tool_FINAL.pdf (accessed on 3 August 2020).

2. World Organisation for Animal Health (OIE) (2019). – Chapter 3.4. Veterinary Legislation. *In* Terrestrial Animal Health Code. OIE, Paris, France. Available at: www.oie.int/fileadmin/Home/eng/Health_standards/tahc/current/chapitre_vet_legislation.pdf (accessed on 3 August 2020).

3. World Organisation for Animal Health (OIE) (2020). – Improving Veterinary Services. OIE, Paris, France. Available at: www.oie.int/en/what-we-offer/improving-veterinary-services/ (accessed on 12 July 2021).

4. Bush E. & Lemmen D.S. (eds) (2019). – Canada's changing climate report. Government of Canada, Ottawa, Canada, 444 pp. Available at: www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR_FULLREPORT-EN-FINAL.pdf (accessed on 3 August 2020).

5. Hoegh-Guldberg O., Jacob D. […] & Zhou G. (2018). – Chapter 3. Impacts of 1.5ºC global warming on natural and human systems. *In* Global Warming of 1.5°C: an IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (V. Masson-Delmotte *et al.*, eds). Intergovernmental Panel on Climate Change, Geneva, Switzerland, 138 pp. Available at: www.ipcc.ch/sr15/ (accessed on 3 August 2020).

6. Intergovernmental Panel on Climate Change (IPCC) (2014). – Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, R.K. Pachauri & L.A. Meyer, eds). IPCC, Geneva, Switzerland, 151 pp. Available at: archive.ipcc.ch/report/ar5/syr/ (accessed on 26 February 2021).

7. Mascarelli A.L. (2009). – What we've learned in 2008. *Nature Clim. Change*, **1**, 4–6. doi:10.1038/climate.2008.142.

8. Wittrock J., Duncan C. & Stephen C. (2019). – A determinants of health conceptual model for fish and wildlife health. *J. Wildl. Dis.*, **55** (2), 285–297. doi:10.7589/2018-05-118.

9. Black P.F. & Butler C.D. (2014). – One Health in a world with climate change. *In* One Health (W.B. Karesh, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **33** (2), 465–473. doi:10.20506/rst.33.2.2293.

10. Yohe G.W. (2001). – Mitigative capacity: the mirror image of adaptive capacity on the emissions side. *Clim. Change*, **49** (3), 247–262. doi:10.1023/A:1010677916703.

11. Stephen C. & Wade J. (2020). – Missing in action: sustainable climate change adaptation evidence for animal health. *Can. Vet. J.*, **61** (9), 966–970. Available at: europepmc.org/article/med/32879522 (accessed on 20 January 2021).

12. World Health Organization (WHO) (2015). – Strengthening health resilience to climate change: technical briefing. WHO, Geneva, Switzerland, 24 pp. Available at: www.who.int/phe/climate/conference_briefing_1_healthresilience_27aug.pdf (accessed on 12 July 2021).

13. Lubroth J. (2012). – Climate change and animal health. *In* Building resilience for adaptation to climate change in the agriculture sector (A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz, eds). Proc. Joint FAO/OECD Workshop, 23–24 April. Food and Agriculture Organization of the United Nations, Rome, Italy, 63–70. Available at: www.fao.org/3/i3084e/i3084e.pdf (accessed on 3 August 2020).

14. Forman S., Hungerford N., Yamakawa M., Yanase T., Tsai H.J., Joo Y.S., Yang D.K. & Nha J.-J. (2008). – Climate change impacts and risks for animal health in Asia. *In* Climate change: impact on the epidemiology and control of animal diseases (S. de La Roque, S. Morand & G. Hendrickx, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **27** (2), 581–597. doi:10.20506/rst.27.2.1814.

15. Webster R.G., Bean W.J., Gorman O.T., Chambers T.M. & Kawaoka Y. (1992). – Evolution and ecology of influenza A viruses. *Microbiol. Rev.*, **56** (1), 152–179. Available at: pubmed.ncbi.nlm.nih.gov/1579108/ (accessed on 20 January 2021).

16. Ramey A.M., DeLiberto T.J., Berhane Y., Swayne D.E. & Stallknecht D.E. (2018). – Lessons learned from research and surveillance directed at highly pathogenic influenza A viruses in wild birds inhabiting North America. *Virol.*, **518**, 55–63. doi:10.1016/j.virol.2018.02.002.

17. Nallar R., Papp Z., Epp T., Leighton F.A., Swafford S.R., DeLiberto T.J., Dusek R.J., Ip H.S., Hall J., Berhane Y., Gibbs S.E.J. & Soos C. (2015). – Demographic and spatiotemporal patterns of avian influenza infection at the continental scale, and in relation to annual life cycle of a migratory host. *PLoS One*, **10** (6), Article No. e0130662. doi:10.1371/journal.pone.0130662.

18. Tian H., Zhou S. […] & Xu B. (2015). – Avian influenza H5N1 viral and bird migration networks in Asia. *Proc. Natl. Acad. Sci. U.S.A.*, **112** (1), 172–177. doi:10.1073/pnas.1405216112.

19. Humphreys J.M., Ramey A.M., Douglas D.C., Mullinax J.M., Soos C., Link P., Walther P. & Prosser D.J. (2020). – Waterfowl occurrence and residence time as indicators of H5 and H7 avian influenza in North American poultry. *Sci. Rep.*, **10**, Article No. 2592. doi:10.1038/s41598-020-59077-1.

20. Morin C.W., Stoner-Duncan B., Winker K., Scotch M., Hess J.J., Meschke, J.S., Ebi K.L. & Rabinowitz P.M. (2018). – Avian influenza virus ecology and evolution through a climatic lens. *Environ. Int.*, **119**, 241–249. doi:10.1016/j.envint.2018.06.018.

21. Brown J.D., Goekjian G., Poulson R., Valeika S. & Stallknecht D.E. (2009). – Avian influenza virus in water: infectivity is dependent on pH, salinity and temperature. *Vet. Microbiol.*, **136** (1–2), 20–26. doi:10.1016/j.vetmic.2008.10.027.

22. Tian H., Zhou S. […] & Xu B. (2015). – Climate change suggests a shift of H5N1 risk in migratory birds. *Ecol. Model.*, **306**, 6–15. doi:10.1016/j.ecolmodel.2014.08.005.

23. Altizer S., Bartel R. & Han B.A. (2011). – Animal migration and infectious disease risk. *Science*, **331** (6015), 296–302. doi:10.1126/science.1194694.

24. Gilbert M., Xiao X. & Robinson T.P. (2017). – Intensifying poultry production systems and the emergence of avian influenza in China: a 'One Health/Ecosystem' epitome. *Arch. Public Health*, **75**, Article No. 48. doi:10.1186/s13690-017-0218-4.

25. Zhang Y., Wang Y. & Niu H. (2017). – Spatio-temporal variations in the areas suitable for the cultivation of rice and maize in China under future climate scenarios. *Sci. Total Environ.*, **601–602**, 518–531. doi:10.1016/j.scitotenv.2017.05.232.

26. Lacetera N. (2019). – Impact of climate change on animal health and welfare. *Anim. Front.*, **9** (1), 26–31. doi:10.1093/af/vfy030.

27. Das R., Sailo L., Verma N., Bharti P., Saikia J., Imtiwati P. & Kumar R. (2016). – Impact of heat stress on health and performance of dairy animals: a review. *Vet. World*, **9** (3), 260–268. doi:10.14202/vetworld.2016.260-268.

28. Handisyde N.T., Ross L.G., Badjeck M.-C. & Allison E.H. (2006). – The effects of climate change on world aquaculture: a global perspective. Final Technical Report to DFID. Stirling Institute of Aquaculture, Stirling, United Kingdom, 151 pp. Available at: www.researchgate.net/publication/265497647_The_Effects_of_Climate_Change_on_World_Aquaculture_A_Global_Perspective (accessed on 3 August 2020).

29. Gamble J.L., Balbus J. […] & Wolkin J.F. (2016). – Chapter 9. Populations of concern. *In* The impacts of climate change on human health in the United States: a scientific assessment. U.S. Global Change Research Program, Washington, DC, United States of America, 247–286. Available at: health2016.globalchange.gov/low/ClimateHealth2016_09_Populations_small.pdf (accessed on 3 August 2020).

30. Noyes P.D., McElwee M.K., Miller H.D., Clark B.W., Van Tiem L.A., Walcott K.C., Erwin K.N. & Levin E.D. (2009). – The toxicology of climate change: environmental contaminants in a warming world. *Environ. Int.*, **35** (6), 971–986. doi:10.1016/j.envint.2009.02.006.

31. Tirado M.C., Clarke R., Jaykus L.A., McQuatters-Gollop A. & Frank J.M. (2010). – Climate change and food safety: a review. *Food Res. Int.*, **43** (7), 1745–1765. doi:10.1016/j.foodres.2010.07.003.

32. Van der Fels-Klerx H.J., Liu C. & Battilani P. (2016). – Modelling climate change impacts on mycotoxin contamination. *World Mycotoxin J.*, **9** (5), 717–726. doi:10.3920/WMJ2016.2066.

33. Griffith A.W. & Gobler C.J. (2020). – Harmful algal blooms: a climate change co-stressor in marine and freshwater ecosystems. *Harmful Algae*, **91**, Article No. 101590. doi:10.1016/j.hal.2019.03.008.

34. Marcogliese D.J. & Pietrock M. (2011). – Combined effects of parasites and contaminants on animal health: parasites do matter. *Trends Parasitol.*, **27** (3), 123–130. doi:10.1016/j.pt.2010.11.002.

35. Garde E., Pérez G.E., Acosta-Jamett G. & Bronsvoort B.M. (2013). – Challenges encountered during the veterinary disaster response: an example from Chile. *Animals*, **3** (4), 1073–1085. doi:10.3390/ani3041073.

36. Stauffer K.E. & Conti L. (2014). – One Health and emergency preparedness. *Vet. Rec.*, **175** (17), 422–425. doi:10.1136/vr.g5246.

37. Stephen C. & Wade J. (2018). – Wildlife population welfare as coherence between adapted capacities and environmental realities: a case study of threatened lamprey on Vancouver Island. *Front. Vet. Sci.*, **5**, Article No. 227. doi:10.3389/fvets.2018.00227.

38. Stephen C., Carron M. & Stemshorn B. (2019). – Climate change and veterinary medicine: action is needed to retain social relevance. *Can. Vet. J.*, **60** (12), 1356–1358. Available at: europepmc.org/article/med/31814645 (accessed on 20 January 2021).

39. Streets D.G. & Glantz M.H. (2000). – Exploring the concept of climate surprise. *Glob. Environ. Change*, **10** (2), 97–107. doi:10.1016/S0959-3780(00)00015-7.

40. Stephen C., Berezowski J. & Misra V. (2015). – Surprise is a neglected aspect of emerging infectious disease. *Ecohealth*, **12** (2), 208–211. doi:10.1007/s10393-014-1001-4.

41. Hanlon P. & Carlisle S. (2008). – Thesis: Do we face a third revolution in human history? If so, how will public health respond? *J. Public Health*, **30** (4), 355–361. doi:10.1093/pubmed/fdn058.

42. Global Health Security Agenda (GHSA) (2020). – Joint Statement of the Global Health Security Agenda Steering Group, GHSA. Available at: ghsagenda.org/joint-statement-of-the-ghsa/ (accessed on 3 August 2020).

43. Convention on Biological Diversity (CBD) (2010). – Introduction: climate change and biodiversity. CBD, Montreal, Canada. Available at: www.cbd.int/climate/intro.shtml (accessed on 3 August 2020).

44. Barilla Center for Food and Nutrition (BCFN) (2020). – People and nature: lessons learned from the Covid-19 pandemic. BCFN, Parma, Italy. Available at: www.barillacfn.com/en/magazine/food-and-society/people-and-nature-lessons-learned-from-the-covid19-pandemic/ (accessed on 3 August 2020).

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 431-438

Climate services' role in safeguarding pastoral disaster communities

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Summary
Climate change due to increasing greenhouse gas (GHG) emissions is one of the most pressing issues facing society on a global scale. The growth of GHG emissions between 2000 and 2010 was higher than in each of the previous three decades, and each of the past four decades has been successively warmer than any preceding decades since 1850. Continued GHG emissions will cause further warming and changes in the climate system. Climate change affects livestock production in multiple ways, both directly and indirectly. Many of the impacts on the livestock sector result from increasing frequency and magnitude of weather and climate extremes such as droughts, flash floods, untimely rains, frost, hail and severe storms. This article describes some of the most vulnerable disaster communities in Asia, Africa, Australia, Europe and South America. It then describes the importance of meteorological information provided by national Meteorological and Hydrological Services to help Veterinary Services support sustainable management of livestock in vulnerable pastoral communities.

Keywords
Climate change – Climate services – Disaster communities – Meteorological information.

Introduction

Article 1 of the United Nations Framework Convention on Climate Change defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (1). Over the last three decades, climate change has emerged as one of the most crucial issues for humankind, with serious implications for sustainable development.

Around 30% of the Earth's land surface is currently dedicated to livestock production through pastures (approximately 25%) and feed crops (approximately 5%) (2). The livestock sector accounts for 40% of the global agricultural gross domestic product and 1.3 billion people depend upon livestock husbandry for their livelihood (3). In particular, livestock is a key asset for resource-poor farmers in pastoral and agro-pastoral systems. As the human population expands, global demand for food of animal origin is steadily growing and the livestock sector will continue to expand accordingly.

Climate can affect ruminant husbandry both directly and indirectly (4). Direct effects of, for example, air temperature, humidity and wind speed influence animal performance indicators such as growth, meat production, wool production and reproduction. Indirectly, weather conditions or climate change may significantly affect feed resources, which in turn influence livestock productivity; the carrying capacity of rangelands; the buffering ability of ecosystems and their sustainability; and the distribution of diseases and parasites.

Observed and future climate change

Observations of the climate system indicate that human activities are contributing to a warming of the Earth's atmosphere. Between 1850 and 2000, the human world's energy use increased by a factor of approximately 15 (5). Over this period, the mixture of fossil fuels used changed dramatically. Atmospheric concentrations of carbon dioxide, methane, nitrous oxide and other greenhouse gases have been increasing steadily since 1750 due to human activity (6).

https://doi.org/10.20506/rst.40.2.3235

Warming from past anthropogenic emissions will persist for centuries and will continue to cause long-term changes in the climate system and have many associated impacts.

The global average surface temperature warmed by 0.85°C between 1880 and 2012 (6). Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C (6). The change in global average temperature from 1850 to 2018 is depicted in Figure 1 (7). Global warming is likely to reach 1.5°C between 2030 and 2052 if the temperature continues to increase at the current rate.

Most of the problems caused by weather and climate for people and livestock are the result of extremes, or catastrophes. A rise in the frequency and intensity of extreme weather and climate events has been observed since about 1950 (6). Annual losses from weather disasters such as hurricanes, hailstorms and wildfires frequently run into the hundreds of billions of dollars. Since 1980, weather-related natural disasters have caused losses of some US$ 4,200 billion and killed nearly a million people (9).

Disaster communities

According to the United Nations High Commission for Refugees, climate change is the defining crisis of modern times and disaster displacement is one of its most devastating consequences. Many people are living in climate 'hot spots', where they typically lack the resources to adapt to an increasingly hostile environment. The domino effect of disaster upon disaster triggered by climate change leaves already impoverished communities no time to recover. These communities can be described as disaster communities.

Climate change affects livestock production in multiple ways, both directly and indirectly. The most important impacts are experienced in animal productivity, yields of forage and feed crops, animal health and biodiversity. In tropical climates, heat stress negatively impacts animal growth, milk production and reproduction (10). Under weather conditions of arid and semi-arid regions, heat stress is most common in the summer season. This paper focuses on pastoral communities as these are some of the most vulnerable to climate change and especially to catastrophes, given their reliance on extensive grazing, location in remote areas with consequent lack of access to resources and, in many cases, relative poverty.

Pastoralists comprise several hundred million livestock keepers distributed all over the world whose unique livelihoods face challenges linked to their environment and to the mobility that characterises them. Some examples of disaster communities in Asia, Africa, Australia, Europe and South America are discussed below.

Asia

Mongolia, which is situated in the very centre of the Asian mainland, and covers 1.53 million square kilometres (km^2), has an extreme continental climate (11), with arid and semi-arid regions occupying about 40% of the total surface. The Mongolian economy relies heavily on livestock production.

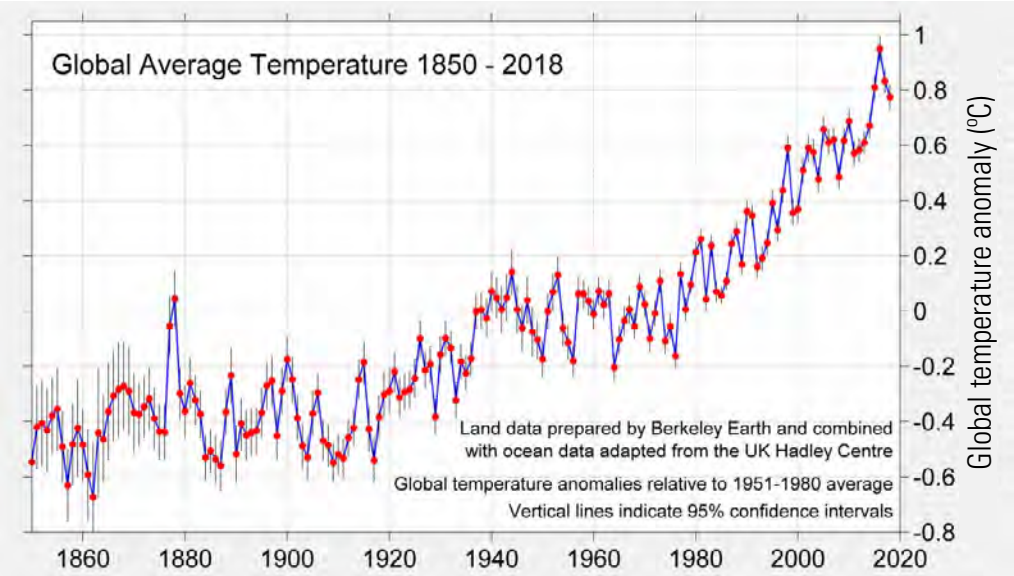

Fig. 1
Change in global average temperature 1850–2018 (7)

Cattle breeding pasture covers 90% of the territory. Pasture production is variable from year to year, and in some years it is quite low because of prolonged drought and warm weather conditions during the growing season.

More than half of Kazakhstan (approximately 100 million hectares) is desert and traditionally used for cattle grazing. The rate of pasture desertification in Kazakhstan could increase this century, according to climate change research (12). Owing to the doubling of CO_2 concentrations in the atmosphere, air temperatures could increase more significantly over the next 60 to 70 years, by as much as 3°C to 4°C in the desert regions of Kazakhstan and up to 5°C to 7°C in some cases. Consequently, crucial changes may take place in the agro-climatic growing conditions of pasture vegetation and in the condition of pastureland in Kazakhstan (13).

In Uzbekistan, each season is associated with a distinct phase of life for Karakul sheep, and weather conditions may have varying effects on their physiology (14). At the beginning of pregnancy, from late October through to December, sheep experience weather conditions that are favourable enough for grazing. During late pregnancy, the weather conditions become much less favourable, leading in some cases to hypothermia in cold weather. Interruptions in grazing are the result of both individual and compound meteorological conditions (15).

India is the largest milk producer in the world, having produced 163.7 million tonnes in 2016–17, and eighth in terms of meat production (4). The average milk productivity per animal is comparatively very low due to a variety of biophysical and socio-economic factors. Climate change studies predict that rising mean surface temperature is likely to hasten livestock vulnerability to heat stress and diseases directly and affect the availability of feed and fodder indirectly.

Most grazing areas in Thailand are tropical natural pastures. Pasture production is relatively low in terms of quality and quantity and it fluctuates as a function of seasonal and meteorological conditions (16). The rangelands in Thailand are used for local beef cattle, improved breeds of beef cattle, dairy cattle and buffaloes. The carrying capacity is approximately three animals per hectare in the rainy season and one animal per hectare in the four-month dry season.

Africa

Africa is one of the most vulnerable continents to climate variability and change due to its high exposure to climate shocks and stresses (e.g. droughts) and relatively low adaptive capacities (17). The difficulties faced by ten different pastoral communities in Chad (Mbororo), Uganda (Bahima, Nyakwe and Tepeth), Ethiopia (Afar), Kenya (Laikipia Maasai and Samburu), Tanzania (Maasai) and Burkina Faso (Peulh and Bella) are described in a consultancy report titled *Weather and climate services for effective climate adaptation of indigenous pastoralists in Africa*, submitted for the United Nations Educational Scientific and Cultural Organization (UNESCO) Climate Frontlines project (M.V.K. Sivakumar, unpublished report, 2017).

Pastoral groups in North Africa herd their animals in arid and semi-arid lands and face numerous urgent problems, including climate change, population growth, insecurity and migration. In West and Central Africa, pastoralists are a large and economically important population group with a strong pastoral identity. The Touareg, the Fulani and other pastoralists in West and Central Africa face many challenges. Western Sahara has a surface of 266,000 km^2 and in the 1960s, 70% of its inhabitants were nomads. Nomadic grazers move along the territory and adapt and change in accordance with weather conditions and the consequent presence or lack of pastures.

In most of the agro-pastoral areas of Ethiopia, the prevailing livestock include cattle, sheep, goats, camels, horses, mules and donkeys (16). The inhabitants practise a grazing system that involves exploiting any region with sufficient water and pasture until they must move to find new access to water and pasture following the dry season. Most of the rangelands are overstocked, though exact figures are difficult to ascertain.

In Kenya, there are nomadic pastoralists in the northern rangelands and agro-pastoralists and ranchers in the southern rangelands (16). The general condition of these rangelands is fair to poor. The harsh climate, and especially unreliable rainfall, renders these areas suitable only for pasture production, hence the keeping of livestock.

Australia

In Australia, most regions are characterised by low rainfall and a spatially variable climate that is mostly arid and semi-arid, although there are some areas of seasonally high rainfall in the tropics. The main ecosystem types are native grasslands, shrub lands, woodlands and tropical savanna woodlands (16). Sheep and cattle overwhelmingly dominate Australian grazing. A total of 408 million hectares are involved in carrying 23 million cattle and 115 million sheep, close to carrying capacity.

Europe

There is a wide variation in herbage production potential within the temperate zone due to climatic variation. It has been estimated that the potential dry matter production of temperate-type grassland, with moderate levels of nitrogen use (about 250 kilograms per hectare per year) and with monthly harvests, varies from less than 10 tonnes per hectare

per year to approximately 15 tonnes per hectare per year between the northern and southern regions of Europe (18).

South America

In the Amazon, pasture is the predominant new land use in the deforested regions, representing 85% of all agricultural lands (10). Deforested land area in the Brazilian Amazon totalled 58.7 million hectares in 2000 (19).

Importance of meteorological information for sustainable management of livestock

Understanding the scope and use of meteorological information can help Veterinary Services in translating knowledge to mitigate climate change and climate catastrophes. The main climatic elements affecting the exploitation of pastures and the livestock industry are temperature, rainfall and humidity, and their main effects are on the composition and quantity of the pasture vegetation (16). Meteorological forecasts (daily, decadal and seasonal) can allow indigenous pastoral communities to better protect their cattle and to increase livestock productivity.

Weather forecasting explores the applications of weather and climate information to sustain or improve on-farm animal performance in terms of factors such as growth, reproduction, and milk and wool production (15). Management intervention is needed not only to improve the genetic potential of the animals, but also to ameliorate the constraints on production set by the climate, the physical environment and various health hazards.

Agrometeorological information is assembled and processed at regional hydrometeorological centres (HMCs) and transferred to regional agricultural divisions, and hence to further users. The basic data collected by field surveys and meteorological stations include air temperature, precipitation, the condition of pasture vegetation (phase of development, height, productivity) and warnings for dangerous hydrometeorological conditions.

Indigenous pastoralists hold a wealth of traditional knowledge on weather and climate, and improved interactions between them and the meteorological community could help integrate this traditional knowledge with modern weather and climate forecasts, as described in the author's 2017 consultancy report for UNESCO. Such integrated forecasts and their applications in the field could help the indigenous pastoralists to better manage their herds and increase pastoral production.

The relationship between national Meteorological and Hydrological Services (NMHSs), which are the providers of climate services, and pastoralists, who are users of climate information, must be well organised and sustainable. Veterinary Services can play a key role both in identifying necessary information and in making it available to farmers. Climate prediction services are developed through ongoing engagement between providers and users, as shown in Figure 2 (20). The user engagement stage refers to the understanding of user needs, decision-making cycles, dependencies and other related factors. This stage in the process is essential to establish user trust in climate information and thus to enhance uptake and usefulness of the climate information.

Fig. 2
Process of developing climate services (adapted with permission from 20)

For a successful climate service, the component of delivery of products must involve both a mechanism for delivery of information (for example via web portal, e-mail, phone call, mobile app or television) and opportunities for interaction, assistance with interpretation, troubleshooting or a collaborative decision-making process.

Feedback, monitoring and evaluation are essential for capturing the user experience and hence improving the service and its utility. This should be a continuous process that allows both providers and users to evaluate the benefits of the service.

For estimates of the conditions of growth and development and the productivity of grass and natural pasture vegetation, physical–statistical models are used, including methods to forecast their productivity with a one- to two-month outlook (16). The success of these quantitative estimations and forecasts has been considerable. The resulting information is published in ten-day agrometeorological bulletins and appropriate reviews by the Hydrometeorological Centre of Russia and regional HMCs and delivered to regional consumers.

In Thailand, the Department of Livestock Development receives weekly agrometeorological information from the Meteorological Department and circulates this to 33 animal nutrition research centres (16). The information is

used as guidance to implement activities related to pasture production and to measure and prevent damage resulting from unfavourable conditions.

Measures taken as a result include actions to:

– preserve sufficient roughage for the dry period

– distribute the preserved feed as a function of agrometeorological conditions and the expected feed status

– produce pasture seed in the areas that have favourable agrometeorological conditions.

The most important drought mitigation activities (21) that should be accomplished for livestock are the following:

– move to places not affected by drought

– use modern technology to regulate herd size

– provide feed

– create a local fodder supply

– supply additional water to animals eating dry food

– do not overgraze

– distribute livestock at an adequate rate to poor grassland

– provide population drought warnings and assessments.

Conclusions

The livestock sector, especially the subsector that depends on extensive grazing in marginal land, is a highly weather-dependent and climate-sensitive sector. Many regions in the world are vulnerable to climate change in view of their large populations, the large number of people facing food insecurity and projected impacts of climate change on the agriculture and livestock sector. There is a need for better assessment of risks associated with variable and uncertain environmental conditions. National Meteorological and Hydrological Services have much to contribute in addressing this priority, and timely availability of weather and climate information and early warnings could facilitate both strategic and tactical decisions in increasing and sustaining livestock production. Veterinary Services can be key partners in translating and disseminating this information.

Le rôle des services climatiques dans la sauvegarde des communautés pastorales sinistrées

M. Sivakumar

Résumé

Le changement climatique dû à l'augmentation des émissions de gaz à effet de serre constitue l'un des problèmes les plus pressants auxquels la société est confrontée à l'échelle mondiale. L'augmentation des émissions de gaz à effet de serre a été plus élevée entre 2000 et 2010 qu'au cours des trois décennies précédentes, et chacune des quatre décennies écoulées a été successivement plus chaude que toutes les décennies antérieures depuis 1850. La persistance des émissions de gaz à effet de serre se traduira par une intensification du réchauffement climatique et par d'autres modifications du système climatique. Les changements climatiques ont des effets multiples sur la production animale et interviennent de plusieurs manières, à la fois directement et indirectement. Une grande partie de l'impact subi par le secteur de l'élevage est dû à la fréquence et à la magnitude croissantes des phénomènes climatiques et météorologiques extrêmes tels que sécheresses, crues soudaines, précipitations intempestives, gel, grêle et tempêtes violentes. L'auteur décrit certaines communautés sinistrées parmi les plus vulnérables en Asie, en Afrique, en Australie, en Europe et en Amérique du Sud. Il souligne ensuite l'importance des informations météorologiques fournies par les Services météorologiques et hydrologiques

nationaux, grâce auxquelles les Services vétérinaires peuvent mieux soutenir les communautés pastorales vulnérables dans leurs efforts pour une gestion durable des cheptels.

Mots-clés
Changement climatique – Communauté sinistrée – Information météorologique – Services climatiques.

Función de los servicios climáticos en la protección de comunidades pastorales afectadas por desastres

M. Sivakumar

Resumen
El cambio climático causado por la creciente emisión de gases de efecto invernadero es uno de los problemas más acuciantes que afronta la sociedad a escala mundial. El aumento de las emisiones de gases de efecto invernadero entre 2000 y 2010 fue mayor que en los tres decenios anteriores. Asimismo, cada uno de los cuatro pasados decenios fue sucesivamente más cálido que cualquiera de los anteriores desde 1850. Las incesantes emisiones de gases de efecto invernadero traerán consigo un mayor calentamiento y más transformaciones del sistema climático. El cambio climático afecta a la producción ganadera por numerosas vías, tanto directas como indirectas. Muchos de sus efectos sobre el sector ganadero son fruto de la frecuencia y magnitud crecientes de fenómenos climáticos y meteorológicos extremos, como sequías, inundaciones súbitas, lluvias intempestivas, heladas, granizadas y fuertes tormentas. Tras referirse a algunas de las más vulnerables comunidades afectadas por desastres de Asia, África, Australia, Europa y Sudamérica, el autor explica la importancia de la información meteorológica que facilitan los Servicios Meteorológicos e Hidrológicos nacionales para ayudar a los Servicios Veterinarios a respaldar una gestión sostenible del ganado en comunidades vulnerables que viven del pastoreo.

Palabras clave
Cambio climático – Comunidades afectadas por desastres – Información meteorológica – Servicios climáticos.

References

1. United Nations General Assembly (1994). – United Nations Framework Convention on Climate Change: resolution/adopted by the General Assembly, 20 January 1994, A/RES/48/189. Available at: www.refworld.org/docid/3b00f2770.html (accessed on 6 July 2021).

2. Monfreda C., Ramankutty N. & Foley J.A. (2008). – Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochem. Cycles*, **22** (1), GB1022. doi:10.1029/2007GB002947.

3. Food and Agriculture Organization of the United Nations (FAO) (2009). – State of food and agriculture – livestock in the balance. FAO, Rome, Italy, 180 pp. Available at: www.fao.org/3/i0680e/i0680e.pdf (accessed on 1 July 2021).

4. Singh S.V. (2018). – National use of weather forecast for livestock management in agrometeorological services. Animal Physiology Division. Indian Council of Agricultural Research. National Dairy Research Institute, Karnal, India, 77 pp. Available at: www.researchgate.net/profile/Sohan-Vir-Singh/publication/328139048_National_Use_of_Weather_Forecast_for_Livestock_Management_in_Agrometeorological_Services/links/5bbb3347a6fdcc9552d945c1/National-Use-of-Weather-Forecast-for-Livestock-Management-in-Agrometeorological-Services.pdf (accessed on 1 July 2021).

5. Smil V. (2017). – Energy and civilization: a history. MIT Press, Cambridge, United States of America, 568 pp.

6. Intergovernmental Panel on Climate Change (IPCC) (2013). – Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the IPCC (T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley, eds). Cambridge University Press, Cambridge, United Kingdom, 1535 pp. Available at: www.ipcc.ch/report/ar5/wg1/ (accessed on 1 July 2021).

7. Intergovernmental Panel on Climate Change (IPCC) (2018). – Summary for policymakers. *In* Special report: global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty (V. Masson-Delmotte, P. Zhai […] & T. Waterfield, eds). World Meteorological Organization, Geneva, Switzerland, 32 pp. Available at: www.ipcc.ch/sr15/chapter/spm/ (accessed on 1 July 2021).

8. Berkeley Earth (2019). – Global temperature report for 2018. Berkeley Earth, Berkeley, United States of America. Available at: berkeleyearth.org/2018-temperatures-new/ (accessed on 1 July 2021).

9. Munich Re (2019). – Extreme weather risks. Munich Re, Munich, Germany. Available at: www.munichre.com/en/risks/extreme-weather.html (accessed on 1 July 2021).

10. Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M. & De Haan C. (2006). – Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome, Italy, 26 pp. Available at: www.fao.org/3/a0701e/a0701e00.pdf (accessed on 1 July 2021).

11. Dagvadorj D. (1997). – Weather and climate related to pasture and livestock production in arid and semi-arid regions. CAgM Report **79**, WMO/Technical Document No. **989**. World Meteorological Organization, Geneva, Switzerland, 32 pp. Available at: library.wmo.int/index.php?lvl=notice_display&id=10914#.Xx_rKZ4zY2y (accessed on 1 July 2021).

12. Pilifosova O.V., Eserkepova I.B. & Dolgih S.A. (1997). – Regional climate change scenarios under global warming in Kazakhstan. *Clim. Change*, **36**, 23–40. doi:10.1023/A:1005368404482.

13. Lebed L., Belenkova Z. & Turbacheva T. (1997). – O vliyanii izmenenij klimata na pastbishcha Kazakhstana [About climate changes impact on the Kazakhstan pastures]. *Gidrometeorologiya i ehkologiya* [Hydrometeorol. Ecology], **3** (4), 79–90.

14. Babushkin O.L. & Lebed L.V. (2002). – Validation of information requirements on livestock and pasture production in arid and semi-arid regions. CAgM Report No. **86**, WMO/Technical Document No. **1134**. World Meteorological Organization, Geneva, Switzerland, 84 pp. Available at: library.wmo.int/index.php?lvl=notice_display&id=10921#.Xx_xGp4zY2w (accessed on 1 July 2021).

15. Babushkin O.L. (1981). – Vliianie pogodnykh uslovii na provedenie zimnego vypasa karakul'skikh ovets v Uzbekistane [The influence of weather conditions on winter pasturing of Karakul sheep in Uzbekistan]. *Trudy SANIl Goskomgidrometa* [Transactions of the Central Asian Research Institute of the State Committee on Hydrology and Meteorology], **83**, 73–77.

16. Lebed L.V., Gandega Y. & Rijks D. (2004). – Impact of agrometeorological information on rangeland and pasture ecology and management. CAgM Report **96**, WMO/Technical Document No. **1229**. World Meteorological Organization, Geneva, Switzerland, 28 pp. Available at: library.wmo.int/index.php?lvl=notice_display&id=10931#.Xx_wj54zY2w (accessed on 1 July 2021).

17. Intergovernmental Panel on Climate Change (IPCC) (2014). – Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the IPCC (Core Writing Team, R.K. Pachauri & L.A. Meyers, eds). IPCC, Geneva, Switzerland, 169 pp. Available at: www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf (accessed on 1 July 2021).

18. Bouman B.A.M., Schapendonk A.H.C.M., Stol W. & Van Kraalingen D.W.G. (1996). – Description of growth model LINGRA as implemented in CGMS. Quantitative Approaches in Systems Analysis No. **7**. Wageningen University DLO Research Institute for Agrobiology and Soil Fertility & C.T. de Wit Graduate School in Production Ecology, Wageningen, the Netherlands, 93 pp. Available at: edepot.wur.nl/336784 (accessed on 1 July 2021).

19. Kaimowitz D., Mertens B., Wunder S. & Pacheco P. (2004). – Hamburger connection fuels Amazon destruction: cattle ranching and deforestation in Brazil's Amazon. Center for International Forestry Research, Bogor, Indonesia, 10 pp. Available at: www.cifor.org/publications/pdf_files/media/amazon.pdf (accessed on 1 July 2021).

20. World Meteorological Organization (WMO) (2016). – Use of climate predictions to manage risks. WMO-No. **1174**. WMO & World Health Organization, Geneva, Switzerland, 46 pp. Available at: library.wmo.int/doc_num.php?explnum_id=3310 (accessed on 1 July 2021).

21. Sivakumar M.V.K., Gommes R. & Baier W. (2000). – Agrometeorology and sustainable agriculture. *Agr. Forest Meteorol.*, **103** (1), 11–26. doi:10.1016/S0168-1923(00)00115-5.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 439-453

Planetary boundaries and Veterinary Services

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Summary

National Veterinary Services (NVS) play a crucial role in animal health, production and welfare. They are also intimately involved with safeguarding global health security and the health of the planet. Climate change is just one of the nine planetary boundaries (PBs), i.e. Earth system processes, that can be used to monitor the vital signs of our living planet.

In this paper, the authors identify the positive and negative impacts of human-induced management of aquatic and terrestrial animals in relation to these PBs. In the context of NVS, the authors provide an overview of the real and potential impacts of NVS policies on Earth systems and offer suggestions as to how new sustainability paradigms may assist with reviewing and revising NVS mandates and facilitating stakeholder engagement. Opportunities are proposed for the World Organisation for Animal Health to contribute to the global debate on the role of aquatic and terrestrial animal agriculture and wildlife in sustainable development. In addition, the paper suggests that a wider debate is required in relation to recent significant increases in domestic animal populations and PBs.

Intersectoral and interdisciplinary collaboration are required to achieve the transformation of the framework in which NVS operate. While such transformations cannot be driven by the veterinary profession alone, veterinarians have proven very effective operators in the One Health arena. By building on these intersectoral linkages, it will be possible for our profession and NVS to actively contribute to the crucial discussions and transformations required to pull Earth system metrics back within safe boundaries.

Keywords

Agro-ecology – Animal-source food – Circular food systems – Climate change – Earth system processes – National Veterinary Services – One Health – Planetary boundaries – Sustainable diets – Sustainable production.

Introduction

National Veterinary Services (NVS) play a crucial role in animal health, production and welfare; they are also intimately involved with safeguarding global health security and the health of the planet (1). For example, delivering sensitive and responsive animal disease surveillance systems and addressing the impact of climate change on aquatic and terrestrial animals, both domestic and non-domestic, are receiving increasing attention (1, 2, 3). However, disease and climate change are linked to only two of the nine

https://doi.org/10.20506/rst.40.2.3236

planetary boundaries (PBs), i.e. Earth system processes, that can be used to monitor the vital signs of our living planet.

Veterinarians deal with boundaries routinely. In clinical practice, boundaries or limits of what constitute normal ranges of various physiological functions are used to determine the health or otherwise of animals. In terms of environmental health, the PBs concept provides a mechanism for review and discussion of the nine broad metrics that reflect the stability, status and trajectory of the Earth system (Table I) (4, 5, 6). The PBs concept is a communication device for conceptualising a specific set of limits and can help to focus attention and define overarching goals for the veterinary profession. The nine Earth system metrics are:

- biosphere integrity
- biogeochemical flows
- ocean acidification
- land-use change
- global freshwater use
- stratospheric ozone depletion
- atmospheric aerosol loading
- chemical pollution
- climate change.

Table I
An overview of the nine processes known as 'planetary boundaries' and the indicators used to monitor their status (5, 6)

Boundary (i.e. Earth system metrics)	**Indicators**
Biosphere integrity	Extinctions per million species-years Biodiversity Intactness Index
Biogeochemical flows	Amount of nitrogen removed from the atmosphere for human use Quantity of phosphorus flowing into the oceans
Ocean acidification	Global mean saturation state of aragonite in surface sea water
Land-use change	Area of forested land as percentage of original forest cover
Global freshwater use	Maximum amount of consumptive blue water use (km^3 per year)
Stratospheric ozone depletion	Concentration of ozone
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis
Chemical pollution	Amount emitted, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in the global environment
Climate change	Atmospheric carbon dioxide and methane concentrations Change in radiative forcing

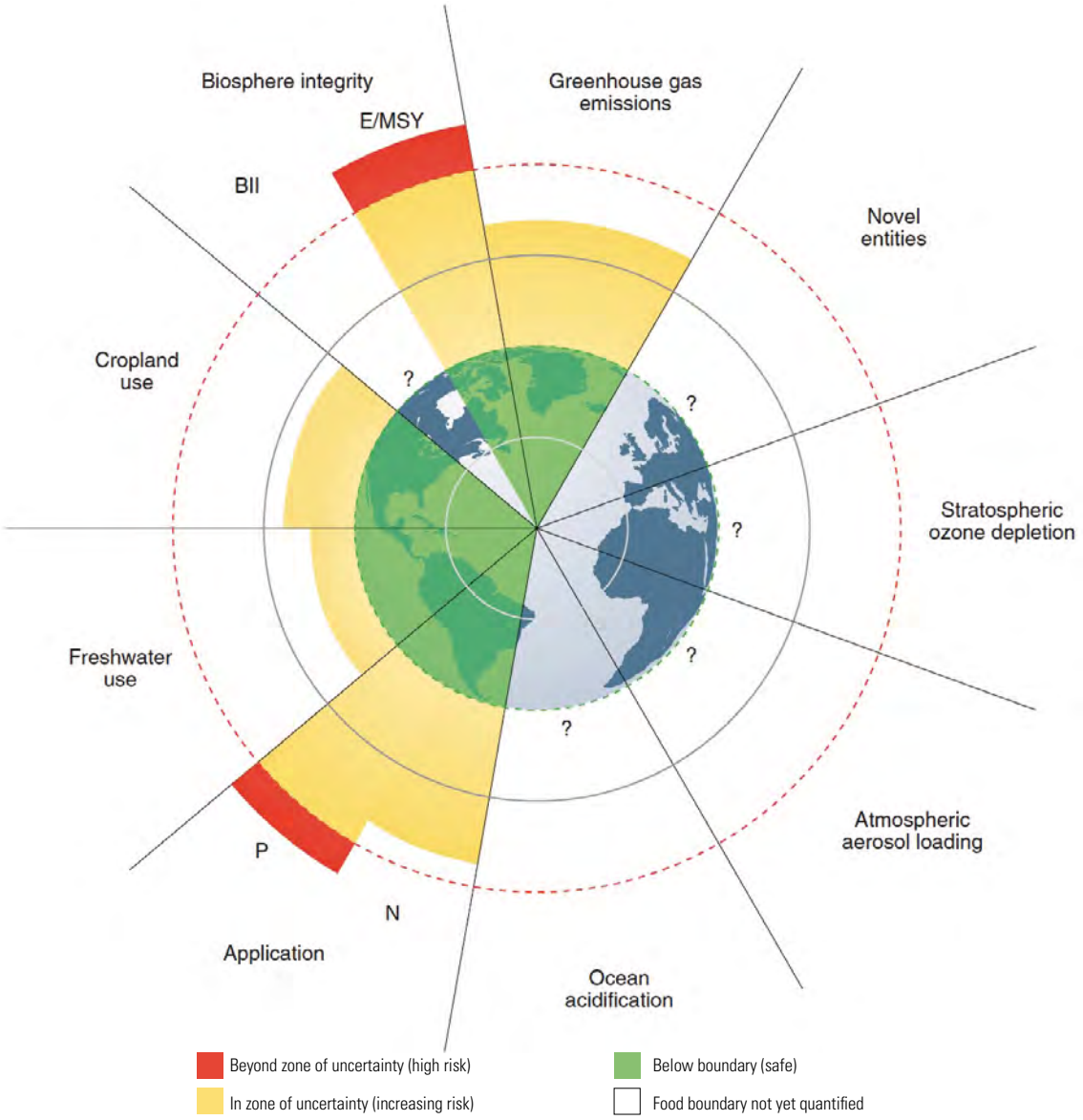
The framework defines a 'safe operating space' for humanity and animals based on the intrinsic biophysical processes that regulate the stability of the Earth system (6). Crossing these boundaries increases the risk of generating large-scale, unwanted, abrupt or irreversible environmental changes.

In 2020, Rockström *et al*. (5) illustrated how the PBs concept could be employed to communicate options for 'planet-proofing' the global food system, which was reported to transgress five of the nine PBs (Fig. 1). The article first defined the PBs for food system thresholds to identify the critical overuse of global commons. Second, it stressed the need to look beyond carbon and climate. The authors argued that 'building resilient food systems requires a systems-approach integrating carbon, nitrogen, phosphorus, water, soils, biodiversity and biome stability; and taking a truly inter-disciplinary planetary health approach by addressing food cultures, nutritional security and geopolitical stability, as well as the role of governance, trade and equity' (5).

This paper identifies the positive and negative impacts of human-induced management of aquatic and terrestrial animals in relation to the PBs. In the context of NVS, the paper provides an overview of the real and potential impacts of NVS policies on the Earth system and highlights how new sustainability paradigms (including circular economics [7] and the 'doughnut' model of social and planetary boundaries [8]) may assist with reviewing and revising NVS mandates and facilitating stakeholder engagement. The authors indicate opportunities for the World Organisation for Animal Health (OIE) to contribute to the global debate on the role of animal agriculture in sustainable development. In addition, the paper suggests that a wider debate is required within the profession concerning the impact on PBs of the huge growth in numbers and biomass of domestic aquatic and terrestrial animals. To facilitate this discussion, domestic animals have been divided into four categories: animals that directly contribute to human health, food security, nutrition and livelihoods (e.g. aquatic and terrestrial food animals, traction animals, bees, etc.) via (a) extensive, (b) semi-intensive, or (c) intensive production systems, and (d) animals that rely on humans for their food security and other needs and do not directly contribute to human physical health, food security and/or nutrition (e.g. most companion animals) (Table II).

How national Veterinary Services policies relate to planetary boundaries

Veterinarians and NVS are uniquely placed to contribute to considerations of both the impact that animals have on



E/MSY: extinctions per million species-years
BII: Biodiversity Intactness Index
P: phosphorus
N: nitrogen

Fig. 1

An estimate of the global food system's transgression of planetary boundaries

Here, the safe operating space (green) provides an estimate of the food-related share of the planetary boundaries. The zone of uncertainty (yellow) defines dangerous risk, whereas the high-risk zone (red) indicates where production has exceeded the assessed uncertainty range in science. The range of uncertainty originates both from quantitative assessments and expert judgement. Control variables have been normalised for the zone of uncertainty; the centre of the figure therefore does not represent zero values for control variables. Processes for which the food system contribution or the planetary boundary itself have not yet been quantified are highlighted with a question mark (5). Values are based on Fig. 6 from Jurgilevich *et al.* (7); image credit: PIK, 2019; taken from Rockström *et al.* (5)

landscapes and also that the environment has upon animal health and production. Aquatic and terrestrial animals have a range of positive and negative effects on processes that can result in either exceeding PBs or staying within them. These effects are moderated by the actions taken by veterinarians and NVS. The animals are in turn affected by changes to these Earth system processes (Table III), requiring action by veterinarians and NVS. There are notable examples where NVS policies contribute to improving these Earth processes via animal health legislation on infectious disease prevention and control, responsible antimicrobial stewardship and animal welfare. A positive example of this

Table II
Classification of aquatic and terrestrial domestic animals compiled to facilitate discussions concerning contributions to sustaining the Earth system

Category	Description	Legal status
Extensive production	Directly contributing to human food security, nutrition, socio-cultural obligations and livelihoods – raised under extensive conditions involving browsing, filtering, foraging, grazing and scavenging for feed (that is usually not suitable for human consumption) in low-density units. Animals able to exhibit most natural behaviours. Usually high diversity of species, breeds and age groups which buffers against various disruptions. May displace indigenous peoples	Property, protected by animal welfare and disease control legislation (9)
Semi-intensive production	Directly contributing to human food security, nutrition and livelihoods – raised under semi-intensive conditions involving the provision of supplementary feed in addition to browsing, filtering, foraging, grazing and scavenging for feed in medium-density units. Animals able to exhibit most natural behaviours. Some degree of diversity of species, breeds and age groups	Property, protected by animal welfare and disease control legislation (9)
Intensive production	Directly contributing to human food security, nutrition and livelihoods – raised under intensive conditions with all feed (frequently including food suitable for human consumption) requirements transported from off-site locations and provided directly to animals in high-density units. Temperature may be artificially controlled. Natural behaviours frequently constrained. Usually limited diversity of aquatic and terrestrial species and breeds with animals kept in same-age groups	Property, protected by animal welfare legislation when enacted (9)
Companion animals	Raised and cared for by people to meet a range of human requirements not including food, where feed and other requirements of the companion animals are provided. Natural behaviours frequently constrained. Some diversity of species, breeds and ages at community level with ongoing breeding of animals with reduced welfare (e.g. brachycephalic dog breeds)	Family members requiring evacuation during emergencies in some countries, protected by animal welfare legislation (10, 11)

is the way in which governments of many shrimp-farming countries have banned the sourcing of shrimp broodstock and/or seed from the wild. This has led to innovations in shrimp domestication and specific-pathogen-free breeding programmes. The global shrimp industry is now less reliant on harvesting wild resources and better able to manage infectious diseases (49). However, there are also examples where NVS or overarching government policies, or their absence, increase the pressure on PBs. National development strategies that focus on increased animal-source food production for both domestic and international markets, without taking environmental impacts into account, can have a negative impact on PBs, including biosphere integrity, land-system change, freshwater use, chemical pollution and climate change (48). Examples include:

– inappropriate disposal of waste that introduces disease (e.g. the spread of African swine fever via the feeding of contaminated swill) (50), allows access by feral animals, and contaminates environments (sea aquaculture, manure spreading)

– the use of broad-spectrum parasiticides that remove non-target species (e.g. ivermectin and dung beetles) (51, 52, 53)

– veterinary clinical practice use of disposable plastics and expectations of same-day delivery with robust lightweight packaging – all fossil-fuel dependent (54).

Ignoring PBs has long-term consequences with losses in sustainability, viability and profit.

The rapid growth in intensive animal production systems since the 1950s has increased risks to human and environmental health (25, 55), yet animal health regulation and enforcement remain patchy in relation to managing these risks (56). The massive increase in intensive livestock production is reported to be the most significant cause of biodiversity loss in recent decades, with the extinction rate estimated to be 100 to 1,000 times that of pre-industrial levels (18, 57, 58, 59). In addition to contributing to biodiversity loss, the expansion of livestock production, and intensive livestock production systems in particular, has been associated with increased risks of emerging infectious disease, antimicrobial resistance and air pollution due to fine dust and ammonia (25).

How can new sustainability paradigms assist with reviewing and revising national Veterinary Services mandates?

The United Nations (UN) is calling on countries to 'build back better' after the COVID-19 pandemic (60), and the Food and Agriculture Organization of the UN (FAO) (61) promotes 'build forward better' by revitalising agriculture through strengthening natural resource management. This is an opportunity to usher in new national and global frameworks that focus specifically on, and align with, the Sustainable Development Goals (SDGs).

Table III

Examples of the range of positive and negative effects of aquatic and terrestrial animals on Earth processes that could feasibly be influenced by veterinarians and NVS, and can result in either exceeding or staying within planetary boundaries

Includes the effects of changing boundaries on animals

Boundary (i.e. Earth system process) *(Possible actions by individual veterinarians)*	**Positive examples** (i.e. relieving strain on planetary boundaries)	**Negative examples** (i.e. placing strain on planetary boundaries)
1. Biosphere integrity *(Action: be an advocate for productive agriculture within sustainable and diverse ecosystems)*	Sustainable, safe harvesting of animal species well adapted to local environments (I) (12) Adaptation of welfare-friendly livestock production practices that enhance plant and animal biodiversity and ecosystem function (I) (12) Nutrition-sensitive aquatic food production systems (I) (13, 14, 15) Sustainable aquaculture and fisheries management; poly-culture systems farming multiple compatible species adding to diversity and reducing inputs (I) (16) Companion animals that do not kill or otherwise displace indigenous animals and plants (I) (17)	Animal-source food produced by a limited number of species and breeds at the global level (I) (12) Feed demands for intensively raised animals requiring the expansion of livestock and crop production into new landscapes, including forests and wetlands (e.g. for soy and other feed), has frequently led to loss of biodiversity (18) and increased risk of pathogen spillover events from wild animal and bird reservoirs to domestic animals and humans (e.g. avian and swine influenzas and severe acute respiratory syndrome coronavirus 2 or SARS-COV-2) (I) (19) Living conditions of local people are deteriorating as livelihoods, socio-economic institutions and cultural values are affected (I) (18) Environmental and genetic hazards associated with escape of aquatic species into the wild (I) (20) Impact of domestic cats (and feral animals) on indigenous animal and plant species (I) (12, 17) Transboundary movement of aquatic and terrestrial animal diseases with live animal trade and their products (I) (21) Over-harvesting including dynamite or poison harvest techniques for coral fish (I) (22) Disruption of food chain by selective harvesting of predator species (I) (23)
2. Biogeochemical *(Action: consider animal waste and its means of disposal for environmental impact)*	Integrated aquaculture–agriculture closed circular systems (I) (12) Appropriate use of manure for organic fertiliser (I) (12) Maintaining wetlands as part of an integrated aquaculture–agriculture closed circular system and ecological balance of ecosystems (I) (16) Farming seaweeds and filter-feeding marine bivalves (extractive species) benefits the environment by removing waste materials including waste from fed species, thus lowering the nutrient load (I) (16)	Excessive use of nitrogen fertiliser to grow feed for aquatic and terrestrial animals and subsequent spillover/leakage of excess fertiliser into water ways (I) (24) Inefficient and improper management of livestock manure and aquaculture waste generated by intensive production systems (I) (25)
3. Ocean acidification *(Action: reduce atmospheric carbon dioxide and waste run-off into coastal waters)*		Ocean acidification caused by global warming, biogeochemical run-off and atmospheric loading will negatively affect aquatic life and shellfish production (E) (26)
4. Land-use change *(Action: be an advocate for better use of existing agricultural and efficient use of all of the animal carcass)*	Introduction of agro-ecological/regenerative livestock and crop production systems that reduce net greenhouse gas (GHG) emissions and improve overall soil health (I) (16, 27) Greater yields per hectare into the human food chain from livestock in high-income countries – both by weight and nutrient yields – through enhancing animal genetics and husbandry practices and reducing pre-consumer losses, i.e. eating more of the animal, including offal. This leads to less land clearing and fewer flow-on effects (on the biosphere, atmosphere, etc.) (I) (28). NVS surveillance and assistance to producers to economically prevent and minimise pre-consumer losses (I) (29)	Clearing forests for livestock production (30) and coastal mangrove forests for coastal shrimp farming (31) for human and companion animal food chains (I) Arable land, particularly near cities, being built on for housing or industry and becoming urban (I) (32) Poor land/agricultural husbandry practices leading to land degradation, fertility loss (I) (33)
5. Global freshwater use *(Action: be involved in animal selection for long-term survival)*	Selection of animals for heat tolerance and efficient water use (I) (34) Efficient use of water by growing aquatic animals and sea-based food production helps to reduce freshwater footprints and the need for terrestrial animal production (I) (35)	Increased water consumption by animals due to increasing numbers of domestic aquatic and terrestrial animals, and raising animals poorly adapted to local agro-ecological conditions (I) (34)

Boundary (i.e. Earth system process) *(Possible actions by individual veterinarians)*	**Positive examples** (i.e. relieving strain on planetary boundaries)	**Negative examples** (i.e. placing strain on planetary boundaries)
6. Stratospheric ozone depletion *(Action: support and promote low methane animal production systems)*		Skin cancers in animals expected to increase until 2070, in association with ozone layer depletion due to human-made ozone-depleting substances (E) (36)
7. Atmospheric aerosol loading *(Action: consider grazing pressure, species suitability and crop types)*	Silvopasture production systems that reduce ground-level wind speed and enhance soil cover (I) (37) Production systems that conserve soil moisture, reducing the impact of bushfires (I) (38)	Overgrazing, leading to loss of vegetative cover and dust generation by wind (I) (33)
8. Chemical pollution *(Action: contribute to genetic selection of healthy, robust livestock)*	Breeding to reduce livestock pests and diseases (flystrike susceptibility/intestinal worms) and hence reduce pesticide/drench use (I) (39, 40) On-farm biosecurity measures and use of vaccines that reduce the need for veterinary medicines and pesticides (e.g. grazing management to reduce environmental worm burdens, isolating new stock to manage the risk of lice and ticks, selection of specific-pathogen-free seeds for aquaculture) (I) (41, 42) Use of organic fertilisers and soil amendments on land used to grow fodder (I) (43)	Heavy metal pollution affects animal health and the safety of aquatic and terrestrial animal-source foods (I) (44, 45) Some farmed fish have a much higher body burden of natural and human-made toxic substances, e.g. antibiotics, pesticides, heavy metals and persistent organic pollutants, than wild fish (I) (20) Antibiotic pollution of the environment including water ways (I) (46)
9. Climate change *(Action: model good environmental behaviour in transport, purchasing, dining, etc. Adopt healthy and sustainable diets for oneself and promote these to clients)*	Well-managed perennial pasture and silvopasture can sequester carbon, reducing atmospheric levels; good animal husbandry and efficient use of animal products can reduce GHG emissions per unit of production (I) (37) Companion animals with low GHG emission footprints (I) (47) Integrated aquaculture–agriculture and integrated multi-trophic aquaculture could play a significant role in sequestering carbon. Fisheries and aquaculture have a key role to play in feeding a growing world population with nutritious and low-carbon-footprint foods (I) (16)	Emissions of methane and nitrous oxide and the loss of organic carbon in the soil and biomass carbon associated with animal raising and animal feed production and supply lines. Energy consumption associated with heating and cooling intensive rearing enterprises. Transport of feed in and animals out for slaughter (I) (48) Decreased animal welfare due to increased heat stress, pathogen circulation, droughts and bushfires (E) (3)

E: effect of changing planetary boundaries on aquatic and terrestrial animals
I: impact of positive and negative contributions to processes that can result in either exceeding or staying within planetary boundaries
NVS: national Veterinary Services

The SDGs are a blueprint to achieve a better and more sustainable future for all, agreed to by 193 UN Member States (62).

So, how can NVS contribute to this endeavour? Veterinarians are respected thought leaders within their communities and NVS are policy leaders; as such, they have a responsibility to consider the sustainability of new and existing processes. The One Health approach (63) is already familiar to many governments and its application has promoted intersectoral and interdisciplinary collaboration, especially in the control of emerging infectious diseases. Nonetheless, operating effectively in the intersectoral policy space is hugely challenging. This is where communication tools, such as the PBs (4), the 'doughnut' model of social and planetary boundaries, which combines two concentric radar charts to depict both the social and ecological boundaries that underpin human well-being (8), and circular economy and food-system models based on reuse, repair, refurbishing, and recycling of existing materials and products (7), can be very helpful. The data presented in each of these models usually reflect, in a general way, the global situation. However, national data can also be used to generate country-specific illustrations that condense large amounts of data into single images. These images facilitate dialogue and can be updated, monitored over time and taken forward to identify gaps and options. The development of national models will also help to identify data gaps and cost-efficient options for obtaining the required data over time. This will assist in identifying animal systems that are well adapted to local agro-ecological conditions and can help to minimise or reduce pressure on PBs.

Given the vital role of animal-source food in nourishing people efficiently, especially women and children (64), NVS have a responsibility to engage in and contribute to national and global discussions on the transformation of food systems (65). The 2030 Agenda for Sustainable Development, which

produced the SDGs (62), demands that we work to achieve 'healthy people and a healthy planet'. There is general agreement that we should all coalesce on a food systems approach and seek to put culturally acceptable, nutritious, safe, affordable and diverse foods on the plate. National planners must seek to identify the most effective healthy diet that is affordable, accessible, convenient, and climate resilient for different wealth groups and across different geographies (65).

Innovations to accelerate the transition towards future sustainability of food systems must take into account the issues of changing diets, reducing waste and increasing productivity through the lens of PBs. National Veterinary Services have a role to play in achieving UN SDG 12, which aims to ensure sustainable consumption and production (62). For example, in fisheries and aquaculture, it is estimated that 35% of the global harvest is either lost or wasted every year (16, 48). The FAO (65) stated that, from production to wholesale and retail, food losses and waste are generally highest for more perishable, nutritious foods, including fruit, vegetables and animal products. Food loss and waste are important because a reduction in the physical quantity and/or quality of food leads to reduced remuneration from supply-chain activities, wasted energy and natural resources from inefficient food production, lost nutritional resources, pollution including greenhouse gas (GHG) emissions and the depletion of natural resources that could address ongoing chronic malnutrition and reduce pressure on the PBs (14, 65). National Veterinary Services can implement mechanisms to identify the causes of animal-source food losses in the food chain and communicate these to food producers, with advice and support as appropriate, to reduce future occurrences.

Where responsibilities for aquatic food systems lie outside the NVS, strong cooperation and collaboration with national and regional fisheries authorities are essential to promote responsible aquatic food systems transformation within PBs and in line with 'blue growth' and 'blue economy' strategies (16). In such situations, the OIE recommendation that Members nominate OIE Aquatic Focal Points can help to strengthen coordination. Precision production systems (covering a suite of digital and genomic technologies that enable increased production with fewer resources), together with the veterinary profession's enhanced understanding of the environment and human impacts on it, are likely to play a major part in achieving sustainability (16, 65).

As pressures on natural resources increase, NVS are well positioned to play an increasingly vital role in monitoring a wider range of issues relating to domestic animal-source food production, sustainable wildlife harvesting and allied value chains. In relation to food safety (i.e. freedom from biological, chemical and physical contamination), NVS must be authorised and resourced to regularly monitor, analyse and respond to food safety issues associated with production sites, abattoirs and wet markets. In terms of promoting efficient, sustainable aquatic and terrestrial animal production systems, NVS must increasingly engage in intersectoral and interdisciplinary collaboration, in order to monitor, analyse and promote systems that are appropriate to local conditions. The promotion of sustainable aquaculture (66) and soil health and biodiversity through agro-ecological and regenerative extensive and semi-intensive animal production systems on rangeland (i.e. non-arable land) (27) fits within expanded definitions of animal welfare, One Welfare (67), One Health and Planetary Health (68). In regard to intensive animal production, NVS will need to engage in tough debates that ask how food fit for human consumption should best be used. Public health nutritionists have stated that there is no nutritional case for feeding human-edible crops to farmed animals, which reduces calorie and protein supplies directly available for human consumption (69).

With increasing urbanisation and economic growth, the number of companion animals is also increasing and must be considered when assessing food security requirements (70). Companion animals such as cats (obligate carnivores) and dogs (omnivores) require meat-based diets and therefore have greater environmental impacts than herbivores (71). For example, in the United States of America, the energy consumption of companion dogs and cats is approximately 20% of the human population's energy consumption, and animal-source food consumption by dogs and cats alone is responsible for up to 58 ± 14.5 million tonnes of carbon dioxide-equivalent of methane and nitrous oxide, two powerful GHGs (47). Domestic cats and dogs also affect wildlife in multiple ways, including predation, pathogen transmission, hybridisation, competition, and the harvest of wild animals for pet food (72). In the future, NVS will probably see their regulatory role in promoting animal welfare expand to include responsible companion animal ownership that is in line with sustainable development. Beyond food security, the impact of an increasing professional focus on companion animals in high-income settings is leading to the increased use of disposable consumables, non-recyclable packaging and rapid delivery to support companion animal consumer culture. Thought leaders within the human healthcare sector note that their profession has a profound responsibility and opportunity to address climate change by reducing GHG emissions to limit the myriad associated health harms (73). Likewise, veterinarians, NVS and the OIE have an opportunity and an obligation to reduce human pressure on PBs by improving animal health, developing animal health and production systems with a lower GHG footprint, and enhancing locally appropriate wildlife biodiversity activities. These actions will contribute to animal welfare; sustainable local, national and global economies; and human well-being.

Veterinarians must be prepared and resourced to engage in evidence-based debates of the crucial issues presented above. The mandate and regulatory framework of NVS will need to change to ensure that these Services can fully participate in the transition to more sustainable ways of living on our planet.

What structural changes are required to enable efficient national Veterinary Services contributions to a healthy planet?

At present, NVS usually operate within Ministries of Agriculture, Livestock and/or Fisheries and/or Natural Resources. The performance of these Ministries is usually assessed in relation to income generation and contribution to gross domestic product, with few or no direct links to the health of the people or the environment. To increase the efficient use and safety of inputs into aquatic and terrestrial animals, in terms of the health of the planet and its people, the mandates and collaborative and institutional arrangements across sectors must also be transformed. A simple but crucial change will be a shift from measuring gross domestic product to measuring net domestic product, in which the social and environmental impacts of production are also considered. Where animals are raised for food, debates on the benefits and trade-offs in relation to scarce nutrients, land and water, with public health nutritionists within the Ministry of Health and environmental scientists and conservation biologists within the Ministry of the Environment and Forestry, would make it easier to identify production systems that can be directly aligned with human and environmental health. Where animals are kept as companions, NVS could consider collaborating with their public health colleagues to provide harmonised recommendations to consumers and human and companion animal food companies on the best use of available nutrients. For example, currently nutrient-dense pelagic fishes (74) and terrestrial animal offal (28) go to animal and pet feeds in high-income countries, both of which could very efficiently meet the nutritional requirements of humans. Engagement with public health nutrition in relation to healthy and safe animal-source food will also provide an opportunity to discuss tailoring aquatic and terrestrial animal production systems, such as changes to livestock genetics and feed composition, to achieve increased quantities of the final product (e.g. leaner meat) that are suitable for human consumption. For example, current recommendations by the Heart Foundation in Australia suggest eating poultry meat without the skin (75), presumably to reduce the overall fat content, with no mention of consuming offal. This means that significant quantities of nutrients found in the whole chicken are lost to the human food chain. Changes to chicken genetics and nutrition have also contributed to this situation. Wang *et al.* (76) report that, by comparison with the broiler chickens of the 1970s (when physicians recommended eating less fatty red meat and more poultry because it was lean), the modern broiler carcass contains more fat energy compared to protein and significantly less omega-3 fatty acid. Similar findings of the lower overall nutritional quality of farmed fish, when compared to wild fish, have been reported in Bangladesh, with a call to embrace a nutrition-sensitive approach that moves beyond maximising productivity to also consider nutritional quality (77). There are few studies that directly explore the impact of fish feed modification on the nutritional composition of farmed fish and the associated health of human consumers of fish (78). The consumption of calorie-restricted, nutrient-rich diets would also contribute to lowering obesity in humans and companion animals in many countries (79). As nutrition and health become more important to the sustainable development agenda, and as consumers become better informed, attention to feed formulations of all intensively raised animals will become increasingly urgent.

To better manage emerging and re-emerging pathogen risks, the NVS need to coordinate and collaborate with government planning agencies, environmental agencies, health agencies, food safety agencies, the forestry sector and the fisheries sector. As domesticated livestock and companion animal numbers have increased, so too has their contribution to the zoonotic disease burden (30). Pathogen spillover from wildlife is rare but when it occurs it can be very significant. Pathogen transmission from wildlife to humans appears to be influenced by extrinsic factors, such as land-use changes that cause losses in the quality and number of wildlife habitats (30), and agricultural intensification (80). Such factors play a particularly important role in driving the emergence of zoonotic diseases in biodiverse tropical forest regions (81). When human populations expand further into natural habitats (along with their associated activities, such as agriculture and hunting), this leads to increased opportunities for human-to-wildlife contact (82), and increased pathogen transmission at human–livestock–wildlife interfaces (83).

Clearly defining roles and responsibilities across all government agencies, including the NVS, is crucial to both minimising the likelihood of such events occurring and, when such an event does arise, for effective management of the incident. Making full use of the surveillance and reporting systems that NVS already have in place (including veterinary laboratories) facilitates early detection of significant diseases in wildlife, protecting human and livestock health, as well as the health of the wildlife (84). In

addition, as governments introduce agriculture biodiversity policies and programmes (85) that include new and more diverse animal breeds and variability, active collaboration by NVS in the development and monitoring of associated certification schemes involving wildlife will become increasingly important.

How might changes in planetary boundary trends influence the role of the World Organisation for Animal Health?

The OIE has rightly identified that its mandate includes working with NVS to safeguard global health security and the health of the planet (1). As we move forward, this will require expanding the OIE's range of activities to enable NVS to contribute to sustainable aquatic and terrestrial animal development and wildlife conservation. This will likely include:

– increasing veterinary literacy concerning sustainable development and associated Foresight and communication activities

– in collaboration with environmental agencies, monitoring the global biomass of domestic and non-domestic aquatic and terrestrial animals to assist in lowering disease burdens, to increase productivity and to reduce the associated environmental impacts

– the ability to monitor the efficiency of domestic animal raising and the efficient use of food animal carcasses (e.g. what proportion of the edible components of the carcass enter the human food chain)

– in collaboration with environmental agencies, monitoring wildlife health and habitat quality

– guidelines as to how to measure and classify animal species and breeds in relation to their impact on sustainable development in general, and on PBs in particular.

If we simply keep 'growing the economy' using existing structures and approaches, we increasingly risk crossing PBs. Hence, new technologies, policies and engagement processes are needed but these should recognise that the PBs are interconnected and so consideration is required to ensure that improvement in one does not result in the deterioration of others. The OIE's crucial role as a cross-sectoral champion is reflected in the One Health High-Level Expert Council, involving the OIE, FAO, World Health Organization and UN Environment Programme (86), and the active engagement of national governments through the One Health Global Leaders Group on Antimicrobial Resistance (87).

The OIE should continue to work with NVS to support their national veterinary training institutions to ensure that graduates:

a) have a basic knowledge of the status of PBs and SDGs nationally and globally

b) understand the associated impacts of and underlying processes associated with PBs in relation to animal physiology and behaviour

c) are aware of feasible adaptations

d) comprehend the implications for the profession, e.g. in terms of ethics and codes of practice

e) have a basic understanding of how to translate policy objectives into meaningful actions.

Conclusions

Intersectoral and interdisciplinary collaboration are required to achieve the transformation of the framework in which NVS operate. Such transformations cannot be driven by the veterinary profession alone. However, veterinarians have proven very effective operators in the One Health arena. By building on these intersectoral linkages, it will be possible for our profession and NVS to contribute actively to the crucial discussions and transformations required to pull Earth system metrics back within safe boundaries.

Acknowledgements

Mohan V. Chadag was supported by the Consultative Group on International Agricultural Research (CGIAR) Research Program on Fish Agri-Food Systems, led by WorldFish.

Les frontières planétaires et les Services vétérinaires

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Résumé

Les Services vétérinaires nationaux jouent un rôle crucial dans les domaines de la santé animale, de la production animale et du bien-être des animaux. Mais ils sont aussi fortement engagés dans la protection de la sécurité sanitaire mondiale et de la santé de la planète. Le changement climatique est l'une des neuf frontières planétaires existantes, c'est-à-dire les neuf processus du système terrestre qui peuvent nous aider à surveiller les signes vitaux de notre planète vivante.

Les auteurs font le point sur les impacts positifs et négatifs de la gestion par l'homme des animaux aquatiques et terrestres dans la perspective de ces frontières planétaires. S'agissant des Services vétérinaires nationaux, les auteurs donnent un aperçu de l'impact réel des politiques des Services vétérinaires sur les systèmes terrestres ainsi que des possibilités en la matière et font quelques propositions pour que les mandats de ces Services soient repensés et modifiés et la participation des parties prenantes facilitée à la lumière des nouveaux paradigmes de durabilité. Ils évoquent plusieurs occasions au cours desquelles l'Organisation mondiale de la santé animale (OIE) pourrait contribuer aux discussions à l'échelle mondiale sur le rôle des animaux terrestres et aquatiques, tant d'élevage que sauvages, dans le développement durable. En outre, les auteurs estiment qu'un débat plus général est nécessaire concernant l'augmentation récente et significative des populations d'animaux domestiques et les frontières planétaires.

Une collaboration intersectorielle et interdisciplinaire sera nécessaire pour transformer le cadre dans lequel interviennent les Services vétérinaires nationaux. Certes, une transformation de cette nature ne peut être menée par la profession vétérinaire seule, mais les vétérinaires ont déjà fait preuve de l'efficacité de leurs capacités opérationnelles dans l'arène Une seule santé. En s'appuyant sur ces liens intersectoriels, la profession vétérinaire et les Services vétérinaires nationaux seront à même de contribuer activement aux discussions cruciales ainsi qu'aux transformations indispensables pour ramener les variables mesurables de la Terre à l'intérieur de frontières sûres.

Mots-clés

Agro-écologie – Changement climatique – Denrées alimentaires d'origine animale – Frontières planétaires – Processus du système terrestre – Production durable – Régimes alimentaires durables – Services vétérinaires nationaux – Systèmes alimentaires circulaires – Une seule santé.

Límites planetarios y Servicios Veterinarios

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Resumen

La función de los Servicios Veterinarios nacionales, además de ser crucial para la sanidad, la producción y el bienestar animales, guarda estrecha relación con la salvaguarda de la seguridad sanitaria mundial y la salud del planeta. El cambio

climático es solo uno de los nueve límites planetarios, esto es, procesos del sistema terrestre, que cabe utilizar para seguir de cerca los signos vitales del ser vivo que es nuestro planeta.
Los autores exponen los efectos tanto positivos como negativos que en relación con estos límites planetarios trae consigo la gestión antrópica de animales acuáticos y terrestres. Por lo que respecta a los Servicios Veterinarios nacionales, los autores presentan a grandes líneas las repercusiones que las políticas de estos Servicios Veterinarios tienen o pueden tener en los sistemas terrestres y proponen fórmulas para que los nuevos paradigmas de la sostenibilidad ayuden a examinar y revisar el mandato de los Servicios Veterinarios nacionales y a facilitar la participación de los demás interlocutores. También señalan las oportunidades que tiene ante sí la Organización Mundial de Sanidad Animal para contribuir a las deliberaciones mundiales sobre la función de la producción de animales acuáticos y terrestres y de la gestión de la fauna silvestre con vistas al desarrollo sostenible. Los autores, además, consideran necesario un debate más amplio en relación con el reciente y considerable crecimiento de las poblaciones de animales domésticos y los límites planetarios.
Para lograr una transformación de las coordenadas en las que operan los Servicios Veterinarios de los países se requiere una colaboración tanto intersectorial como interdisciplinar. Aunque estos cambios no pueden venir únicamente de la mano de la profesión veterinaria, la labor de los veterinarios en el ruedo de Una sola salud ha demostrado que son agentes muy eficaces. Profundizando en estos vínculos intersectoriales, será posible que nuestra profesión y los Servicios Veterinarios nacionales contribuyan activamente a las cruciales deliberaciones y transformaciones que se necesitan para que el valor de los parámetros del sistema terrestre vuelva a situarse dentro de los márgenes de seguridad.

Palabras clave
Agroecología – Alimento de origen animal – Cambio climático – Límites planetarios – Procesos del sistema terrestre – Producción sostenible – Regímenes alimentarios sostenibles – Servicios Veterinarios nacionales – Sistemas alimentarios circulares – Una sola salud.

References

1. Éloit M. (2020). – Improving Veterinary Services. World Organisation for Animal Health (OIE), Paris, France. Available at: www.oie.int/en/what-we-offer/improving-veterinary-services/ (accessed on 19 July 2021).

2. International Union for Conservation of Nature (IUCN) (2019). – Issues brief: species and climate change. IUCN, Gland, Switzerland, 2 pp. Available at: www.iucn.org/sites/dev/files/species_and_climate_change_issues_brief-2019-12.pdf (accessed on 3 August 2020).

3. Lacetera N. (2019). – Impact of climate change on animal health and welfare. *Anim. Front.*, **9** (1), 26–31. doi:10.1093/af/vfy030.

4. Rockström J., Steffen W. […] & Foley J. (2009). – Planetary boundaries: exploring the safe operating space for humanity. *Ecol. Soc.*, **14** (2), 32. doi:10.5751/ES-03180-140232.

5. Rockström J., Edenhofer O., Gaertner J. & DeClerck F. (2020). – Planet-proofing the global food systems. *Nature Food*, **1**, 3–5. doi:10.1038/s43016-019-0010-4.

6. Steffen W., Rockström J. & Costanza R. (2011). – How defining planetary boundaries can transform our approach to growth. *Solutions J.*, **2** (3), 59–65. Available at: www.researchgate.net/publication/229069964_How_Defining_Planetary_Boundaries_Can_Transform_Our_Approach_to_Growth_Solutions (accessed on 8 February 2021).

7. Jurgilevich A., Birge T., Kentala-Lehtonen J., Korhonen-Kurki K., Pietihäinen J., Saikku L. & Schösler H. (2016). – Transition towards circular economy in the food system. *Sustainability*, **8** (1), 69. doi:10.3390/su8010069.

8. Raworth K. (2017). – A doughnut for the Anthropocene: humanity's compass in the 21st century. *Lancet Planet. Hlth*, **1** (2), e48–e49. doi:10.1016/S2542-5196(17)30028-1.

9. Shyam G. (2015). – The legal status of animals: the world rethinks its position. *Altern. Law J.*, **40** (4), 266–270. doi:10.1177/1037969X1504000411.

10. United States Congress (2006). – House of Representatives (H.R.) 3858 – Pets Evacuation and Transportation Standards Act of 2006. United States Congress, Washington, DC, United States of America. Available at: www.congress.gov/bill/109th-congress/house-bill/3858 (accessed on 10 March 2020).

11. Ministry of the Environment of the Government of Japan (2013). – A guideline for pet rescue and evacuation in case of natural disaster [in Japanese]. Ministry of the Environment, Tokyo, Japan. Available at: www.env.go.jp/nature/dobutsu/aigo/2_data/saigai_guide.html (accessed on 20 July 2020).

12. Food and Agriculture Organization of the United Nations (FAO) (2019). – The state of the world's biodiversity for food and agriculture (J. Bélanger & D. Pilling, eds). FAO Commission on Genetic Resources for Food and Agriculture Assessments, Rome, Italy, 576 pp. Available at: www.fao.org/3/CA3129EN/CA3129EN.pdf (accessed on 25 July 2020).

13. Karim M., Ullah H., Castine S., Islam M.M., Jan Keus H., Kunda M., Thilsted S.H. & Phillips M. (2016). – Carp-mola productivity and fish consumption in small-scale homestead aquaculture in Bangladesh. *Aquacult. Int.*, **25**, 867–879. doi:10.1007/s10499-016-0078-x.

14. Thilsted S.H., Thorne-Lyman A., Webb P., Bogard J.R., Subasinghe R., Phillips M.J. & Allison E.H. (2016). – Sustaining healthy diets: the role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy*, **61**, 126–131. doi:10.1016/j.foodpol.2016.02.005.

15. Castine S.A., Bogard J.R., Barman B.K., Karim M., Hossain M.M., Kunda M., Haque A.B.M.H., Phillips M.J. & Thilsted S.H. (2017). – Homestead pond polyculture can improve access to nutritious small fish. *Food Secur.*, **9**, 785–801. doi:10.1007/s12571-017-0699-6.

16. Food and Agriculture Organization of the United Nations (FAO) (2020). – The state of world fisheries and aquaculture 2020: sustainability in action. FAO, Rome, Italy, 244 pp. doi:10.4060/ca9229en.

17. Olsen P., Silcocks A. & Weston M. (2006). – The state of Australia's birds 2006: invasive species. Supplement to *Wingspan*, **16** (4), 32 pp. Available at: birdlife.org.au/documents/SOAB-2006.pdf (accessed on 3 August 2020).

18. Ceballos G., Ehrlich P.R., Barnosky A.D., García A., Pringle R.M. & Palmer T.M. (2015). – Accelerated modern human-induced species losses: entering the sixth mass extinction. *Sci. Adv.*, **1** (5), e1400253. doi:10.1126/sciadv.1400253.

19. Kock R.A., Karesh W.B., Veas F., Velavan T.P., Simons D., Mboera L.E.G., Dar O., Arruda L.B. & Zumla A. (2020). – 2019-nCoV in context: lessons learned? *Lancet*, **4** (3), e87–e88. doi:10.1016/S2542-5196(20)30035-8.

20. Cole D.W., Cole R., Gaydos S.J., Gray J., Hyland G., Jacques M.L., Powell-Dunford N., Sawhney C. & Au W.W. (2008). – Aquaculture: environmental, toxicological, and health issues. *Int. J. Hyg. Environ. Hlth*, **212** (4), 369–377. doi:10.1016/j.ijheh.2008.08.003.

21. Cartín-Rojas A. (2012). – Transboundary animal diseases and international trade. *In* International trade from economic and policy perspective (V. Bobek, ed.). IntechOpen, London, United Kingdom. doi:10.5772/48151.

22. Coral Reef Alliance (CORAL) (2005). – Coral reefs and exploitive fishing: short-term gain, long-term loss. CORAL, San Francisco, United States of America, 2 pp. Available at: coral.org/wordpress/wp-content/uploads/2014/02/exploitivefishing.pdf (accessed on 16 August 2020).

23. Zhou S. & Smith A.D.M. (2017). – Effect of fishing intensity and selectivity on trophic structure and fishery production. *Mar. Ecol. Prog. Ser.*, **585**, 185–198. doi:10.3354/meps12402.

24. European Commission (2019). – The Nitrates directive. European Commission, Brussels, Belgium. Available at: ec.europa.eu/environment/water/water-nitrates/ (accessed on 1 August 2020).

25. Smit L.A.M. & Heederik D. (2017). – Impacts of intensive livestock production on human health in densely populated regions. *GeoHealth*, **1** (7), 272–277. doi:10.1002/2017GH000103.

26. Union of Concerned Scientists (UoCS) (2019). – CO_2 and ocean acidification: causes, impacts, solutions. UoCS, Cambridge, United States of America. Available at: www.ucsusa.org/resources/co2-and-ocean-acidification (accessed on 22 June 2020).

27. Food and Agriculture Organization of the United Nations (FAO) (2018). – Livestock and agroecology: how they can support the transition towards sustainable food and agriculture. FAO, Rome, Italy, 16 pp. Available at: www.fao.org/3/I8926EN/i8926en.pdf (accessed on 1 August 2020).

28. Wingett K., Allman-Farinelli M. & Alders R. (2019). – Food loss and nutrition security: reviewing pre-consumer loss in Australian sheep meat value chains using a Planetary Health framework. *CAB Rev.*, **13** (33), 1–12. doi:10.1079/PAVSNNR201813033.

29. Varijakshapanicker P., Mckune S., Miller L., Hendrickx S., Balehegn M., Dahl G.E. & Adesogan A.T. (2019). – Sustainable livestock systems to improve human health, nutrition, and economic status. *Anim. Front.*, **9** (4), 39–50. doi:10.1093/af/vfz041.

30. Johnson C.K., Hitchens P.L., Pandit P.S., Rushmore J., Evans T.S., Young C.C.W. & Doyle M.M. (2020). – Global shifts in mammalian population trends reveal key predictors of virus spillover risk. *Proc. Roy. Soc. B, Biol. Sci.*, **287** (1924), 20192736. doi:10.1098/rspb.2019.2736.

31. Osborne C., Cho-Ricketts L. & Salazar J. (2019). – The relationship between resilient mangroves and fish populations in the largest marine reserve in Belize: a case for conservation. *bioRxiv* 719757. Cold Spring Harbor Laboratory, Cold Spring Harbor, United States of America. doi:10.1101/719757.

32. Izakovičová Z., Mederly P. & Petrovič F. (2017). – Long-term land use changes driven by urbanisation and their environmental effects (example of Trnava City, Slovakia). *Sustainability*, **9** (9), 1553. doi:10.3390/su9091553.

33. Henry B., Charmley E., Eckard R., Gaughan J.B. & Hegarty R. (2012). – Livestock production in a changing climate: adaptation and mitigation research in Australia. *Crop Pasture Sci.*, **63** (3), 191–202. doi:10.1071/CP11169.

34. Carabano M.J., Ramón M., Menéndez-Buxadera A., Molina A. & Díaz C. (2019). – Selecting for heat tolerance. *Anim. Front.*, **9** (1), 62–68. doi:10.1093/af/vfy033.

35. Froehlich H.E., Runge C.A., Gentry R.R., Gaines S.D. & Halpern B.S. (2018). – Comparative terrestrial feed and land use of an aquaculture-dominant world. *Proc. Natl Acad. Sci. USA*, **115** (20), 5295–5300. doi:10.1073/pnas.1801692115.

36. Kelfkens G., Bregman A., de Gruijl F.R., van der Leun J.C., Piquet A., van Oijen T., Gieskes W.W.C., van Loveren H., Velders G.J.M., Martens P. & Slaper H. (2002). – Ozone layer – climate change interactions. Influence on UV levels and UV related effects. Dutch National Research Programme on Global Air Pollution and Climate Change Report No. 410 200 112. National Institute for Public Health and the Environment, Bilthoven, the Netherlands, 130 pp. Available at: www.rivm.nl/bibliotheek/rapporten/410200112.pdf (accessed on 17 August 2020).

37. Jose S., Walter W.D. & Kumar B.M. (2019). – Ecological considerations in sustainable silvopasture design and management. *Agrofor. Syst.*, **93** (1), 317–331. doi:10.1007/s10457-016-0065-2.

38. Jehne W. (2020). – Regenerate Australia: the concept. Future Directions International, Dalkeith, Australia, 6 pp. Available at: www.futuredirections.org.au/wp-content/uploads/2020/06/Associate-Paper-Walter-Jenhe-FINAL.pdf (accessed on 5 August 2020).

39. Greeff J.C. & Karlsson L.J.-E. (2006). – Breeding for worm resistance – whole farm benefits. *Int. J. Sheep Wool Sci.*, **54** (2), 102–108.

40. James P.J. (2006). – Genetic alternatives to mulesing and tail docking in sheep: a review. *Aust. J. Experim. Agric.*, **46** (1), 1–18. doi:10.1071/EA05100.

41. Bailey J.N., Walkden-Brown S.W. & Kahn L.P. (2009). – Comparison of strategies to provide lambing paddocks of low gastro-intestinal nematode infectivity in a summer rainfall region of Australia. *Vet. Parasitol.*, **161** (3–4), 218–231. doi:10.1016/j.vetpar.2009.01.016.

42. Cotter J. (2013). – Sheep lice – biosecurity can prevent introduction. Australian Wool Innovation Ltd, Sydney, Australia. Available at: www.liceboss.com.au/sheep-goats/prevention/sheep-lice-biosecurity-can-prevent-introduction.php (accessed on 16 August 2020).

43. Ali W., Nadeem M., Ashiq W., Zaeem M., Gilani S.S.M., Rajabi-Khamseh S., Pham T.H., Kavanagh V., Thomas R. & Cheema M. (2019). – The effects of organic and inorganic phosphorus amendments on the biochemical attributes and active microbial population of agriculture podzols following silage corn cultivation in boreal climate. *Sci. Rep.*, **9**, 17297. doi:10.1038/s41598-019-53906-8.

44. Rajaganapathy V., Xavier F., Sreekumar D. & Mandal P.K. (2011). – Heavy metal contamination in soil, water and fodder and their presence in livestock and products: a review. *J. Environ. Sci. Technol.*, **4** (3), 234–249. doi:10.3923/jest.2011.234.249.

45. Rua-Ibarz A., Bolea-Fernandez E., Maage A., Frantzen S., Sanden M. & Vanhaecke F. (2019). – Tracing mercury pollution along the Norwegian coast via elemental, speciation, and isotopic analysis of liver and muscle tissue of deep-water marine fish (*Brosme brosme*). *Environ. Sci. Technol.*, **53** (4), 1776–1785. doi:10.1021/acs.est.8b04706.

46. Pruden A., Larsson D.G.J. […] & Zhu Y.-G. (2013). – Management options for reducing the release of antibiotics and antibiotic resistance genes to the environment. *Environ. Hlth Perspect.*, **121** (8), 878–885. doi:10.1289/ehp.1206446.

47. Okin G.S. (2017). – Environmental impacts of food consumption by dogs and cats. *PLoS One*, **12** (8), e0181301. doi:10.1371/journal.pone.0181301.

48. Intergovernmental Panel on Climate Change (IPCC) (2019). – Summary for policymakers. *In* Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (P.R. Shukla, *et al.,* eds). IPCC, Geneva, Switzerland. Available at: www.ipcc.ch/srccl/chapter/summary-for-policymakers/ (accessed on 16 August 2020).

49. Walker P.J. & Mohan C.V. (2009). – Viral disease emergence in shrimp aquaculture: origins, impact and the effectiveness of health management strategies. *Rev. Aquacult.*, **1** (2), 125–154. doi:10.1111/j.1753-5131.2009.01007.x.

50. Beltran-Alcrudo D., Falco J.R., Raizman E. & Dietze K. (2019). – Transboundary spread of pig diseases: the role of international trade and travel. *BMC Vet. Res.*, **15**, 64. doi:10.1186/s12917-019-1800-5.

51. González-Tokman D., Martínez I., Villalobos-Ávalos Y., Munguía-Steyer R., Ortiz-Zayas M.D.R., Cruz-Rosales M. & Lumaret J.-P. (2017). – Ivermectin alters reproductive success, body condition and sexual trait expression in dung beetles. *Chemosphere*, **178**, 129–135. doi:10.1016/j.chemosphere.2017.03.013.

52. He Y., Yuan Q., Mathieu J., Stadler L., Senehi N., Sun R. & Alvarez P.J.J. (2020). – Antibiotic resistance genes from livestock waste: occurrence, dissemination, and treatment. *NPJ Clean Water*, **3**, 4. doi:10.1038/s41545-020-0051-0.

53. Martinez-Porchas M. & Martinez-Cordova L.R. (2012). – World aquaculture: environmental impacts and troubleshooting alternatives. *Sci. World J.*, **2012**, 389623. doi:10.1100/2012/389623.

54. West E., Woolridge A. & Ibarrola P. (2020). – How to manage healthcare waste and reduce its environmental impact. *In Practice*, **42** (5), 303–308. doi:10.1136/inp.m1678.

55. Lindahl J.F. & Grace D. (2015). – The consequences of human actions on risks for infectious diseases: a review. *Infect. Ecol. Epidemiol.*, **5** (1), 30048. doi:10.3402/iee.v5.30048.

56. Lam Y., Fry J.P. & Nachman K.E. (2019). – Applying an environmental public health lens to the industrialization of food animal production in ten low- and middle-income countries. *Glob. Hlth*, **15** (1), 40. doi:10.1186/s12992-019-0479-5.

57. Barnosky A.D., Matzke N., Tomiya S., Wogan G.O.U., Swartz B., Quental T.B., Marshall C., McGuire J.L., Lindsey E.L., Maguire K.C., Mersey B.D. & Errer E.A. (2011). – Has the Earth's sixth mass extinction already arrived? *Nature*, **471** (7336), 51–57. doi:10.1038/nature09678.

58. Ceballos G., Ehrlich P.R. & Raven P.H. (2020). – Vertebrates on the brink as indicators of biological annihilation and the sixth mass extinction. *Proc. Natl Acad. Sci. USA*, **117** (24), 13596–13602. doi:10.1073/pnas.1922686117.

59. Pimm S.L., Jenkins C.N., Abell R., Brooks T.M., Gittleman J.L., Joppa L.N., Raven P.H., Roberts C.M. & Sexton J.O. (2014). – The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, **344** (6187), 1246752. doi:10.1126/science.1246752.

60. UN News (2020). – What does 'build back better' really mean? One of the world's top CEOs give us his take. *UN News*, 11 June. Available at: news.un.org/en/story/2020/06/1066152 (accessed on 15 July 2020).

61. Food and Agriculture Organization of the United Nations (FAO) (2020). – Building forward better initiative. FAO, Rome, Italy, 38 pp. Available at: www.fao.org/3/ca9465en/ca9465en.pdf (accessed on 15 August 2020).

62. United Nations (UN) (2019). – The Sustainable Development Goals report 2019. UN, New York, United States of America, 64 pp. Available at: unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf (accessed on 12 July 2020).

63. Centers for Disease Control and Prevention (CDC) (2020). – One Health. CDC, Atlanta, United States of America. Available at: www.cdc.gov/onehealth/index.html (accessed on 5 June 2020).

64. Alonso S., Dominguez-Salas P. & Grace D. (2019). – The role of livestock products for nutrition in the first 1,000 days of life. *Anim. Front.*, **9** (4), 24–31. doi:10.1093/af/vfz033.

65. Food and Agriculture Organization (FAO) (2020). – The state of food security and nutrition in the world 2020: transforming food systems for affordable healthy diets. FAO, Rome, Italy, 320 pp. Available at: www.fao.org/3/ca9692en/CA9692EN.pdf (accessed on 8 August 2020).

66. Stentiford G.D., Bateman I.J. […] & Tyler C.R. (2020). – Sustainable aquaculture through the One Health lens. *Nature Food*, **1**, 468–474. doi:10.1038/s43016-020-0127-5.

67. Garcia Pinillos R., Appleby M.C., Manteca X., Scott-Park F., Smith C. & Velarde A. (2016). – One Welfare – a platform for improving human and animal welfare. *Vet. Rec.*, **179** (16), 412–413. doi:10.1136/vr.i5470.

68. Whitmee S., Haines A. […] & Yach D. (2015). – Safeguarding human health in the Anthropocene epoch: report of the Rockefeller Foundation–Lancet Commission on planetary health. *Lancet*, **386** (10007), 1973–2028. doi:10.1016/S0140-6736(15)60901-1.

69. Berners-Lee M., Kennelly C., Watson R. & Hewitt C.N. (2018). – Current global food production is sufficient to meet human nutritional needs in 2050 provided there is radical societal adaptation. *Elementa*, **6**, 52. doi:10.1525/elementa.310.

70. Alders R., Nunn M., Bagnol B., Cribb J., Kock R. & Rushton J. (2016). – Approaches to fixing broken food systems. Chapter 3.1. *In* Good nutrition: perspectives for the 21st century (M. Eggersdorfer, K. Kraemer, J.B. Cordaro, J. Fanzo, M. Gibney, E. Kennedy, A. Labrique & J. Steffen, eds). Karger, Basel, Switzerland, 132–144. doi:10.1159/000452381.

71. Martens P., Su B. & Deblomme S. (2019). – The ecological paw print of companion dogs and cats. *BioScience*, **69** (6), 467–474. doi:10.1093/biosci/biz044.

72. Twardek W.M., Peiman K.S., Gallagher A.J. & Cooke S.J. (2017). – Fido, Fluffy, and wildlife conservation: the environmental consequences of domesticated animals. *Environ. Rev.*, **25** (4), 381–395. doi:10.1139/er-2016-0111.

73. Salas R.N., Mailbach E., Pencheon D., Watts N. & Frumkin H. (2020). – A pathway to net zero emissions for healthcare. *Br. Med. J.*, **371** (8264), m3785. doi:10.1136/bmj.m3785.

74. Hicks C.C., Cohen P.J., Graham N.A.J., Nash K.L., Allison E.H., D'Lima C., Mills D.J., Roscher M., Thilsted S.H., Thorne-Lyman A.L. & MacNeil M.A. (2019). – Harnessing global fisheries to tackle micronutrient deficiencies. *Nature*, **574** (7776), 95–98. doi:10.1038/s41586-019-1592-6.

75. National Heart Foundation of Australia (Heart Foundation) (2019). – Meat and heart healthy eating. Heart Foundation, Canberra, Australia, 10 pp. Available at: www.heartfoundation.org.au/getmedia/d5b9c4a2-8ccb-4fe9-87a2-d4a34541c272/Nutrition_Position_Statement_-_MEAT.pdf (accessed on 9 August 2020).

76. Wang Y., Lehance C., Ghebremeskel K. & Crawford M.A. (2009). – Modern organic and broiler chickens sold for human consumption provide more energy from fat than protein. *Public Hlth Nutr.*, **13** (3), 400–408. doi:10.1017/S1368980009991157.

77. Bogard J.R., Farook S., Marks G.C., Waid J., Belton B., Ali M., Toufique K., Mamun A. & Thilsted S.H. (2017). – Higher fish but lower micronutrient intakes: temporal changes in fish consumption from capture fisheries and aquaculture in Bangladesh. *PLoS One*, **12** (4), e0175098. doi:10.1371/journal.pone.0175098.

78. Kwasek K., Thorne-Lyman A.L. & Phillips M. (2020). – Can human nutrition be improved through better fish feeding practices? a review paper. *Crit. Rev. Food Sci. Nutr.*, **60** (22), 3822–3835. doi:10.1080/10408398.2019.1708698.

79. Sandøe P., Palmer C., Corr S., Astrup A. & Bjørnvad C.R. (2014). – Canine and feline obesity: a One Health perspective. *Vet. Rec.*, **175** (24), 610–616. doi:10.1136/vr.g7521.

80. Jones B.A., Grace D., Kock R., Alonso S., Rushton J., Said M.Y., McKeever D., Mutua F., Young J., McDermott J. & Pfeiffer D.U. (2013). – Zoonosis emergence linked to agricultural intensification and environmental change. *Proc. Natl Acad. Sci. USA*, **110** (21), 8399–8404. doi:10.1073/pnas.1208059110.

81. Keesing F., Belden L.K. […] & Ostfeld R.S. (2010). – Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, **468** (7324), 647–652. doi:10.1038/nature09575.

82. Han B.A., Kramer A.M. & Drake J.M. (2016). – Global patterns of zoonotic disease in mammals. *Trends Parasitol.*, **32** (7), 565–577. doi:10.1016/j.pt.2016.04.007.

83. Gebreyes W.A., Dupouy-Camet J. [...] & King L.J. (2014). – The global One Health paradigm: challenges and opportunities for tackling infectious diseases at the human, animal, and environment interface in low-resource settings. *PLoS Negl. Trop. Dis.*, **8** (11), e3257. doi:10.1371/journal.pntd.0003257.

84. World Organisation for Animal Health (OIE) (2020). – WAHIS-Wild interface: the OIE worldwide monitoring system for wild animal diseases. OIE, Paris, France. Available at: www.oie.int/en/what-we-do/animal-health-and-welfare/disease-data-collection/world-animal-health-information-system/ (accessed on 17 August 2020).

85. Department of Agriculture, Water and the Environment (Australia) (2020). – Agriculture stewardship package. Department of Agriculture, Water and the Environment, Canberra, Australia. Available at: www.agriculture.gov.au/ag-farm-food/natural-resources/landcare/sustaining-future-australian-farming (accessed on 19 July 2021).

86. United Nations Environment Programme (UNEP) (2020). – UNEP joins three international organizations in expert panel to improve One Health. UNEP, Nairobi, Kenya. Available at: www.unenvironment.org/news-and-stories/story/unep-joins-three-international-organizations-expert-panel-improve-one-health (accessed on 31 December 2020).

87. World Organisation for Animal Health (OIE) (2020). – World leaders join forces to fight the accelerating crisis of antimicrobial resistance. OIE, Paris, France. Available at: www.oie.int/en/for-the-media/press-releases/detail/article/world-leaders-join-forces-to-fight-the-accelerating-crisis-of-antimicrobial-resistance/ (accessed on 31 December 2020).

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 455-468

Digital technologies and implications for Veterinary Services

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Summary

The pace of digital disruption over the past few years has been spectacular, transforming every sector of the economy, including animal production, health and welfare. This paper reviews some advanced digital technologies that may shape the future of Veterinary Services. These technologies are all data driven and are illustrated by three examples that fall under the following categories: a) wireless and mobile technologies for animal health monitoring, disease surveillance, reporting and information sharing; b) advanced data-processing technologies, such as big data and data analytics used to detect patterns, make predictions, find correlations and other information; and c) promising technologies such as blockchain applications, used for effective and efficient management of various input supply chains.

The authors briefly discuss current challenges to increasing the use of these technologies in the animal health sector, along with some implications for Veterinary Services. Digital technologies will have a profound effect on how animal health services are delivered and how animal health systems are managed. It is therefore crucial for Veterinary Services to be proactive and adapt to the ongoing digital transformation. Investment in new technologies and preparing the current and future veterinary workforce with the necessary digital skills and knowledge to stay up to date and at the centre of digital innovation in animal health should be a priority for the years to come.

Keywords

Animal health – Big data – Blockchain – Digital technology – Information and communication technologies – Mobile technology – Veterinary Services.

Introduction

By 2050, the world's population will be around 9.8 billion people (1), and food production will have to increase by 70% to cover additional dietary needs (2). The livestock sector will be called upon to satisfy increasing world demand for animal-source food through sustainable animal production, in ways that promote food security, poverty reduction, public health and food safety (3, 4). To address the new challenges that an increasing population poses, and to achieve the United Nations Sustainable Development Goals (SDGs), technological advances and innovation will play a crucial role in transforming the food and agriculture sector.

In the face of these challenges, Veterinary Services are more essential than ever to improve livestock health and productivity, ensure high-quality food that meets safety standards, and to reduce animal diseases and public health risks across the human–animal–environment continuum. In addition, Veterinary Services must assist in providing solutions to global challenges related to food security, global health, antimicrobial resistance, climate change and shrinking natural resources.

https://doi.org/10.20506/rst.40.2.3237

Science and technological advances have been major drivers of change in the livestock farming and animal health industry over the last century. As they have become integrated into farming practices and animal husbandry, livestock technologies and processes, such as breed selection, improved feed, and milking automation, as well as modern housing and environmental management, have led to the intensification of farming systems and production of more food for growing populations (5, 6). Advances in animal health biotechnologies, such as vaccines, antimicrobials and diagnostic tools, have been fundamental in supporting the intensification of farming systems and the growth of the livestock sector, by reducing the burden of disease and increasing the standards of animal health and welfare and the quality of animal-source products (7).

Today, exponential growth is underpinned by rapidly advancing technologies and innovations in various forms, including cutting-edge biotechnologies, nutritional technologies, digital technologies and more. Digital technology, one of the fastest evolving technologies, is significantly changing the way that people live in modern society, and has gained intense attention in recent years as part of the Fourth Industrial Revolution (Industry 4.0) (8). This revolution is producing disruptive digital technologies and innovations that are transforming almost every sector, and the food and agriculture sector is not exempt (9). The technologies contributing to these developments include mobile applications, the Internet of Things (IoT), Cloud computing, big-data analytics, artificial intelligence, blockchain and many other such advances.

The use of these technologies in agriculture offers new ways and opportunities for better agricultural and livestock policies and practices, leading to more sustainable and resilient food systems (10). As a sub-sector of agriculture, animal health plays a key role in this process and Veterinary Services have the responsibility not only to take part in this technological revolution but also to reassess the organisation of veterinary systems and ensure the appropriate application of new digital technologies for policy-making, decision-making and planning.

In line with its strategy to shape the global governance of animal health and guide Veterinary Services towards better resilience, the World Organisation for Animal Health (OIE) conducted a survey of external factors that have the potential to impact Veterinary Services over the next ten years, and the adaptations required to contribute to sustainable development. Among the most relevant 17 external factors identified by experts and stakeholders was the use of big-data analytics and other advanced technologies, and Veterinary Services should be prepared to respond to this trend (11).

This paper does not aim to give a complete overview of digital technologies that affect animal health, as such reviews can be found elsewhere (12, 13, 14). Rather, it intends to look at some examples of contemporary data-driven technology that will most likely shape the future of Veterinary Services in the years to come. The authors also discuss current challenges to the increased application of digital technologies in the animal health sector, along with some of the implications for Veterinary Services.

Digital technologies to transform Veterinary Services

At the heart of digital technology are new ways of collecting, managing, using and exchanging data, using existing and advanced information and communication technologies (ICTs) and innovations. These technologies are transforming modern economies and entire systems of production, management and governance (15). For example, digital technology has already become an integral part of healthcare in human medicine, as demonstrated by the increasing number of national policies that embrace digital health, including the area known as electronic health (e-health) (16). Similarly, the increased use of ICTs and innovations is driving e-agriculture, improving access to valuable information that can help stakeholders to make the best possible decisions, and enabling the most efficient use of the resources available to deliver economic, social and environmental benefits, through increased productivity, safer products of higher quality, and more cost-effective services (17).

Although much of the digitalisation process has yet to take place, it is expected that the impact of digital technology on animal health and Veterinary Services will be profound in the years to come. Recent developments in ICTs and innovations have created a wealth of new opportunities to improve veterinary practice (18, 19), as well as enhancing the timeliness and accuracy of data collection and reporting for disease surveillance and animal health monitoring (13). The use of new ICTs also makes it easier to map and monitor the spread of infectious diseases and coordinate their management across sectors, as well as to track supplies of drugs and vaccines (16). These developments lead to better, more efficient, and more timely decisions that will considerably enhance the performance and quality of Veterinary Services, enabling them to meet higher standards of animal health and improving welfare practices (20).

The following section covers some digital technology trends that will undoubtedly drive the transformation of Veterinary Services. These technologies are all data driven and will be illustrated by three types of example:

a) mobile technologies and applications

b) big data and big-data analytics

c) blockchain applications.

Together, these technologies are part of the IoT, which is based on the connectivity of machines and devices in collecting, sharing and analysing data. These technologies are among the nine disruptive technology categories identified by the World Economic Forum in 2016 (8), in addition to crowdsourcing, 3-D printing and advanced biotechnology and genomics.

Mobile technologies and applications

Mobile technologies started with the use of simple delivery technologies, such as short message service (SMS) and voice-based systems. With the rapid growth of mobile devices, such as smartphones, tablets and sensors, together with the growth of crowdsourcing platforms, mobile technology is fast evolving and offers the opportunity to share real-time field data for various purposes among large populations of ICT users, including those in developing countries (21).

With the popularity of smartphones and the widespread use of Cloud and Web-based technologies, there has been a proliferation of mobile-phone-based platforms and applications (apps) in every sector of society. In the human health sector, for instance, the use of mobile technologies and applications has rapidly expanded in the implementation of m-health (as part of the broader area of e-health), which is defined as medical and public health practices supported by mobile and wireless devices (22). Mobile technologies are also becoming more abundant in the agriculture sector, offering various agriculture-related m-services to stakeholders, both in developed and developing countries (21, 23).

In animal health, mobile phones were initially used to collect data for animal disease surveillance (24, 25). The mobile technology advances that followed have led to the increased use of mobile apps for the collection, analysis and dissemination of real-time animal health data (13). Specific examples of customised mobile applications used in resource-limited settings include the Event Mobile Application, a mobile app developed by the Food and Agriculture Organization of the United Nations (FAO), for enhancing national capacities in disease reporting, surveillance and early warning (26). Similar mobile applications have been introduced by the Southern African Centre for Infectious Disease Surveillance, for One Health disease surveillance (27), and other pilot projects to improve disease surveillance, diagnosis and control (28, 29, 30, 31). In addition, mobile apps have been used to collect data on animal-based welfare indicators to assess on-farm animal welfare (32).

While the above are only a few examples, most of which remain at the pilot level, the bulk of animal health mobile applications are being developed by national public organisations and local enterprises, in both developing and developed countries. In addition, a wide variety of apps are being offered by mobile apps stores, and these have been developed primarily by large international companies.

Many of these mobile applications may not be validated scientifically, but they illustrate the substantial advantages of integrating mobile technology into various areas of the veterinary domain. There is considerable potential to improve the efficiency of the collection, analysis and dissemination of field data to support planning, decision-making and service provision. However, for this technology to reach its full potential, some basic conditions must be aligned, to remove the existing barriers to widespread adoption by stakeholders at every level, especially in low-resource countries. These conditions include, for example, infrastructure needs, including mobile network availability; the accuracy of the information contained in the applications; and the economic viability of the services they provide (33); in addition to interoperability; the validation of available and new, free, Web-based applications (34); and optimising ease of use.

Big data and big-data analytics

The availability of vast amounts of high-throughput data, often referred to as 'big data', collected from different sources using advanced digital technologies, is a driver of the digital transformation of all sectors of the economy. While many definitions have been proposed by interested parties, there is as yet no unified definition of big data. The most common definition describes big data as possessing three characteristics referred to as the '3 Vs': volume (meaning the vast amounts of data available); variety (referring to the different kinds of data generated, including structured and unstructured data); and velocity (meaning the speed at which the data are created and acted upon). Other definitions also include 'veracity', which refers to the variable quality and uncertainty of data. Additional characteristics mentioned include 'value', referring to the capacity to transform vast amounts of data into information to produce actionable insights, and other features such as volatility and validity (35).

Managing big data not only requires access to large data sets, but also the competence and infrastructure to process

them in a timely manner, and the capacity to recognise valuable insights for the end user. The most commonly used techniques for big-data analytics include modelling and simulation, statistical analysis, geographical information systems, data mining and machine learning. Machine learning technology, a subfield of artificial intelligence (Fig. 1), uses algorithms to build analytical models, helping computers to 'learn' from data (35). It is particularly employed to process massive data sets by running various algorithm models to detect patterns, make predictions and provide a basis for decision-making.

Big data have become an essential tool for the transformation of many sectors. For instance, in human medicine, big data offer a valuable aid in the development and implementation of health policies, for optimisation of the healthcare system and prediction and management of epidemics. The recent COVID-19 crisis, given the multidimensional and intersectoral nature of its impact, has demonstrated the value of big data and artificial intelligence as advanced, efficient and responsive tools to enlighten decision-making in a context of great uncertainty (36, 37).

Big-data applications in agriculture are gaining momentum. In the livestock and animal health sector, digital technologies, such as wearable technologies and sensors, satellite data systems and mobile technologies, are generating large volumes of data to support data-driven farming and animal health monitoring (14, 38, 39). For example, big data applications are increasingly being used in veterinary care and large-scale livestock operations, where digitalisation and automated systems excel in collating and processing large volumes of data to monitor animal health, supporting early detection of animal disease, and preventing adverse health impacts (Table I). Big-data analytics using artificial intelligence and machine-learning models has been applied to mine a large data set generated by sensors to predict infections and diseases in dairy farms (40, 41) and poultry operations (42), and to monitor health in the pig industry (43). Other examples include pilot initiatives to capture and analyse large volumes of animal health data, mostly from veterinary clinics, for the surveillance of diseases in companion animals (44, 45, 46, 47).

In veterinary epidemiology, big-data analytics offers possibilities for spatial and temporal data analysis (48), as well as for a better understanding of animal diseases and health-related risks (49, 50). Big-data analytics is also of great value in fields related to bioinformatics and high-throughput 'omics' data (genomics, transcriptomics, proteomics and metabolomics), which facilitate the understanding of host–pathogen interactions to aid in the development of new diagnostics, therapeutics and vaccines (51, 52).

While big data present opportunities across many industries, including animal health, the increasing availability and use of data to create value also present important challenges and issues that need to be addressed before big-data technology can become a widespread reality (51, 53, 54).

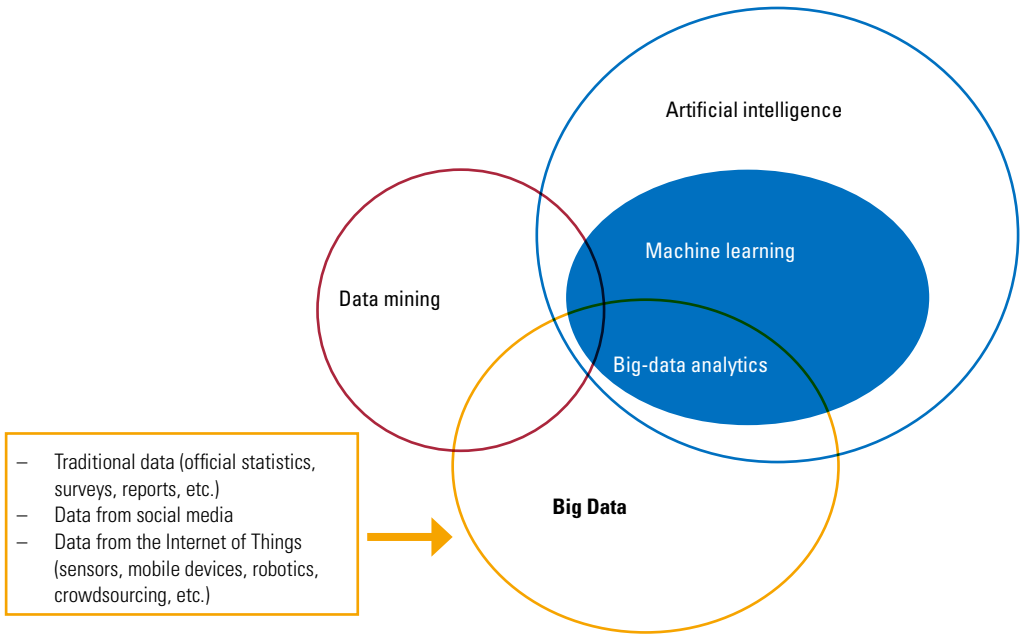

Fig. 1
The big-data ecosystem and links with artificial intelligence, machine learning and data mining
(adapted with permission from 35)

Table I
Examples of big-data applications in animal health reported in primary studies

Application	Reference	Analytic approach	Type of data	Source of data
Surveillance and forecasting of diseases in companion animals	Guernier *et al.*, 2016 (44)	Internet-based surveillance for collection of data and data integration using statistical analysis	Google search data	Internet search engine
			Notifications from passive surveillance	Disease surveillance system
	McGreevy *et al.*, 2017 (45)	Analysis of real-time, clinical veterinary records using natural language processing (NLP) technology	Veterinary clinical records	Veterinary schools
				Primary veterinary care clinics
	Self *et al.*, 2019 (46)	Analysis of disease prevalence data using machine-learning algorithm: Bayesian spatio-temporal Poisson regression model	Disease prevalence data including:	Laboratories
			laboratory data	Veterinary care community
			spatial and temporal data	
	Muellner *et al.*, 2017 (47)	Practice-based surveillance using coded and customised data entry interface	Veterinary clinical data (electronic veterinary medical records)	Primary veterinary care clinics
Monitoring of pig production and the health industry	Faverjon *et al.*, 2019 (43)	Transdisciplinary data collection and integration in a central data repository Data are automatically processed and transformed into a homogeneous interoperable format	Health and laboratory data	Veterinary Services and private veterinarians
			Reproduction data and fattening performance	Producers and marketers
			Transport data	Transport logistics
			Meat inspection and meat quality data	Slaughterhouses
			Feed data	Feed mills
			Climate data	Climate sources
Detection of mastitis on dairy farms	Ebrahimi *et al.*, 2019 (40)	Automatic collection and analysis of milking data using different machine-learning models	Milking parameters generated by automatic milking sensors and systems	Dairy farms
Detection of poultry diseases	Borgonovo *et al.*, 2020 (42)	Analysis of sensor-generated data using data-driven machine-learning algorithms	Data on the concentration of volatile organic compounds in the air on poultry farms	Poultry farms

This is essentially an issue of access to information, since big data generally belong to private companies. Information ownership, data confidentiality, data security and the right to privacy are challenges that must be addressed, in addition to issues related to technical capabilities and adequate infrastructure, particularly in developing countries. However, with the rapid development of efficient data-mining techniques, big-data technology is expected to grow in the coming years. This highlights the need for Veterinary Services to be prepared to use big-data analysis to support planning, decision-making and field operations.

Blockchain applications

Blockchain is an emerging and promising digital technology that has gained significant attention among diverse business sectors in recent years (55). In the simplest terms, a blockchain consists of a linked chain to gather, store, share and track information through a network of public or private computers called 'nodes'. Data are kept in the form of encrypted data-set bases distributed among all participants of the network, without the need for a centralised control (56). The blockchain allows data to be recorded with real-time updates across the network in a way that is designed to be transparent, efficient, unalterable and secure.

In agriculture, blockchain-based applications are being piloted in various agri-food value chains (56, 57, 58).

In the case of the livestock and veterinary sectors, blockchain adoption is still in its infancy. However, blockchain-based systems can potentially be applied to trace livestock (56) and animal product supply chains (59, 60), as well as for the efficient management of various input supply chains, such as animal feed, veterinary drugs, diagnostic kits, and vaccines, especially those that require a cold chain (61). Table II shows an example of an integrated animal product supply chain that can be managed through a blockchain application (58).

Table II
Example of an integrated animal product supply chain that can be managed through a blockchain application, with traceability from the farmer to the consumer
The implications for Veterinary Services as a participating node are included (adapted from 58)

Participating nodes of the network	Data uploading at each node level	Implications for Veterinary Services as a participating node
Producer	Data on feed, breeding, housing condition and sanitation, biosecurity measures, vaccines and treatments, veterinary certificates and others	Uploading data on animal health situation Timely release of electronic animal health reports Efficient tracking and monitoring of non-compliance with international standards Improved ability to monitor and control animal diseases to maintain disease-free status Efficient tracking of contaminated animal food products Issuing of electronic veterinary certificates (veterinary inspection, health certificate, etc.) Issuing of electronic veterinary certification in case of international trade Possible automatic certification based on information associated with the product available in the blockchain network
Processor	Data on storage and slaughter conditions, food safety compliance, lot number, veterinary inspection certificate and other certification	
Distributor	Data on shipment and delivery details, storage and transport conditions, warehouse and vehicle food safety and sanitation measures	
Retailer	Data on delivery details, inventory metrics and sanitation measures, veterinary inspection certificates and other aspects of the products and the supply chain	
Consumer	Receives full information on the product, such as where, when and how it was produced, processed, transported and inspected	

Blockchain technology also has the potential to improve the implementation and monitoring of the technical requirements of trade agreements by Veterinary Services, and to verify and enforce compliance with international animal health standards (58), as well as to scale up the use and implementation of electronic veterinary certification systems. All these applications offer tremendous opportunities for the use of blockchain technology in the animal health sector. However, widespread adoption by Veterinary Services, particularly in developing countries, may not happen in the near future.

Implications of digital technologies for Veterinary Services

In the era of the digitalisation of agriculture and the advent of related concepts, such as e-agriculture and precision agriculture (17), as well as livestock precision farming (62), it would be appropriate to surmise that data-driven technologies and services have the potential to improve the efficiency of animal-source food production and quality throughout the entire food chain. In addition, digital technology may be part of the solution to overcome the impact of global challenges such as population growth, changing land use, climate change and resulting global health threats (9).

The use of data-driven technologies will continue to change production sectors and industries and the animal health sector is no exception. The potential benefits of integrating new digital technologies into animal health are convincing and will likely unlock new models that make national Veterinary Services more effective and efficient at meeting the required standards for animal welfare and health practices. The question remains as to whether Veterinary Services will be able to capture these opportunities and adapt to rapid digital changes.

Achieving the full potential benefit and desired outcomes of the digital transformation is challenging in all sectors. There are hurdles to overcome along the way before digital technologies can be widely adopted by animal health actors, especially in the developing world. These challenges have been extensively reviewed from different perspectives and range from infrastructure requirements, the need for interoperability of digital systems, and policies and regulations to deal with the changing digital environment, to digital skills and competencies and the digital divide (63, 64). The ongoing digital transformation and its challenges will have important implications for Veterinary Services, which must be considered from the perspectives of technology users,

policy-makers, regulators, partners and other stakeholders (13, 19, 53, 65). The following sections deal with some of these implications.

Developing the legislation and policies needed to enable a digital environment

Governments and policy-makers play a primary role in creating the enabling environment needed to support the development and appropriate use of digital technologies. In the agriculture sector, developed countries are already incorporating digital agriculture into some existing policy instruments or developing fully fledged digital agriculture strategies. In developing countries, initiatives and projects for the use of ICTs in the agricultural and associated sectors are increasing in number but have not yet been adopted into a comprehensive national strategy to optimise efficiency gains from the digital transformation (66). Many countries still require institutional support for the development and consolidation of national sectoral digital strategies, while their effective implementation would usually require more resources and capabilities. Governments and policy-makers need to assess their enabling environment and identify the necessary policies, regulations, incentive frameworks and capacity development that would help them to establish an environment conducive to both the supply of and demand for digital technologies, as well as to facilitate technology uptake by stakeholders across the sector. National Veterinary Services will have to actively engage in this process to ensure that they are not left behind in the digital transformation.

There is also a need for the OIE, FAO and other global partners, in collaboration with specialised institutions, to actively support countries in establishing and implementing digital technologies in their agri-food systems, including the animal health sector. For example, one recent global initiative, the International Digital Council for Food and Agriculture, an international platform coordinated by FAO, will provide a policy forum for governments to support digitalisation in the food and agriculture sector, and has the potential to play an increasingly important role in achieving global food security and improving livelihoods, especially in rural areas (67). In addition, FAO is already developing mechanisms to support and facilitate discussion on the adoption and use of new ICTs and to share knowledge on innovation, technology, skills and capacity through a variety of digital approaches and solutions, such as the e-Agriculture Community of Practice (68). This initiative focuses on the exchange of knowledge and resources related to the use of ICTs for sustainable agriculture among United Nations agencies, governments, universities, research organisations, non-governmental organisations, farmers' organisations, the private sector and the wider community.

Developing the digital skills of the veterinary workforce

In a world of rapidly evolving technologies and options, Veterinary Services need to keep up with technological advances to be able to provide the necessary policy advice and technical expertise to their stakeholders. The demand for digital skills is expected to rise in the future within all stakeholder groups of the animal health sector. The introduction of ICTs into formal veterinary education is becoming a reality, not only in developed but also in developing countries. This trend should be reinforced and sustained with the introduction of specific technology-related skills into the curriculum, to ensure a minimum understanding of how new and advanced digital technologies work, along with soft skills such as teamwork, problem-solving and critical thinking, which are also integral to the uptake and implementation of disruptive technologies in the workplace (19).

The veterinary workforce already lives in a connected world and will have ever-greater access to digital technologies in both the public and private spheres. Developing the digital skills of this workforce is essential for wide adoption of the technology. Veterinary Services will have to develop sustainable continuing education programmes to increase access to training in the use of digital technologies and opportunities for attaining the necessary digital skills. Failure to ensure these skills may end up marginalising the veterinary workforce in an increasingly digital world. Specialised training and education programmes showing the advantages of digital technology and its ease of use will be required to ensure that the workforce can use digital technology proficiently in all aspects of the veterinary domain, whether in field operations or animal health planning and management. Specifically, there is a need for more education and training in data science, including statistics and computer science, to develop the necessary knowledge and skills – for example, to mine big data and engage in big-data analytics (48, 50). In addition, Veterinary Services will have to adapt their technical competencies, as well as optimise resources and services by institutionalising interprofessional and multidisciplinary collaboration, to formulate, validate and scale up relevant technologies and promote their adoption across the sector.

National Veterinary Services in developing countries should enlist the support of specialised organisations to develop models of digital skills training aimed at veterinarians and animal health stakeholders so they can learn to assess and implement the best practices and technologies in their work. Assessment of the workforce should also consider the implications for the animal health labour market of introducing digital technologies and their management. Providing the veterinary workforce with knowledge resources, and facilitating their education and training

through digital tools such as e-learning, knowledge sharing and networks, will improve and reinforce skills and competencies in the use of digital technologies.

Fostering public–private partnerships

Digital technologies are being mainly developed and disseminated by the private sector for commercial purposes. The importance of partnerships in veterinary digital solutions has grown over recent years in developed countries, with several initiatives involving veterinary practice, large corporations and innovators in digital products and systems. However, realising the full potential of this digital transformation and extending the benefits to all stakeholders in the animal health sector will require a policy framework with guidelines, to tap into private-sector investment and innovation. It will be fundamental to establish collaborations and strategic partnerships between national Veterinary Services, the private sector, ICT corporations and digital technology innovators, as well as data providers, with clearly defined roles for each actor, so that the opportunities offered by digital animal health can be exploited at all levels. Public–private partnerships (PPPs) in the digital space will become the new norm for the creation of sustainable business models that provide viable digital solutions and support the rapid deployment of digital technologies in veterinary domains. These models should encompass the needs of all stakeholders, as well as the requirements for the development of the necessary infrastructure and processes to support the digital transformation of Veterinary Services. In this regard, the recently developed OIE PPP guidelines (69) could facilitate collaborations and strategic partnerships to expand the capacity of Veterinary Services for digital transformation.

Building robust national and global systems for data management and governance

The digital transformation, fuelled by massive quantities of data being generated by various data-driven technologies, has been impacting data management for the last few years (13). This change offers great opportunities but will also bring challenges, including concerns about who owns, controls, and manages the data being collected and also who will have access to it (e.g. the rights of indigenous people to own their own data, the right to personal privacy). These questions call for robust, secure and scaleable data-management systems that can meet the increasing demands of master data management, data quality and data governance in this new era of digital transformation.

Animal health data management is changing in many countries with a shift to digital data collection systems using various ICTs. Consequently, higher-quality and more accurate data will be available in a more timely manner for decision-making, planning and management. Data will become central to veterinary systems, whether specific and small-scale data customised for routine disease reporting or big data from various sources for the identification of risk factors and trends in disease patterns. It is therefore essential that national Veterinary Services strengthen their capabilities and infrastructures for data use and accessibility through interoperability, harmonisation and optimisation of data distribution to stakeholders (70). It is equally important to develop collaborative models and tools for information sharing beyond the animal health sector, through the exchange of data across sectors and value chains for various purposes (71), and by ensuring interoperability of data systems which must be able to 'talk' to each other (34). Furthermore, translating data into smart and effective action will be crucial, requiring constant dialogue between data collectors, analysers and policy-makers.

At the global level, the OIE is promoting the digital transformation of animal health, particularly for the management of animal disease data, through the new platform of the World Animal Health Information System (OIE–WAHIS). The new interface will allow data to be viewed, analysed and extracted more rapidly, using a variety of analytic programmes. In addition, the new OIE–WAHIS platform will provide straightforward and standardised ways to connect with other international or regional information systems, and become integrated with other valuable data sources, so that users can share and mutually enrich data in collaboration with the OIE. Similarly, FAO is in the process of upgrading its EMPRES Global Animal Disease Information System (EMPRES-i), to support Veterinary Services by facilitating the organisation of and access to data and information at the national, regional and global levels, under the overarching Hand-in-Hand Geospatial Platform (data.apps.fao.org/). These global platforms, along with relevant regional platforms, will play a critical role in the governance, management and use of animal health data at the national and global level, to accompany the digital transformation of Veterinary Services.

Conclusion

The world is changing at a fast pace, with the emergence of an array of cutting-edge digital technologies, which offer great potential to improve food production to feed our growing population, promote more environmentally sustainable agricultural practices, and maintain high-quality sanitary standards. Digital technologies are transforming the agricultural and livestock sector, including in the areas of animal health and welfare. Moreover, this transformation is expected to continue in the years to come, with far-reaching impacts on the veterinary sector in both developed and developing countries. Preparing the current and future veterinary workforce to remain up to date and at the centre of digital innovation in animal health should be a driving force for the future of Veterinary Services.

Les technologies numériques et leurs répercussions sur les Services vétérinaires

A.H. El Idrissi, M. Dhingra, F. Larfaoui, A. Johnson, J. Pinto & K. Sumption

Résumé
L'accélération de la perturbation numérique depuis quelques années est spectaculaire, transformant tous les secteurs de l'économie, y compris la production animale, la santé animale et le bien-être des animaux. Les auteurs s'intéressent à certaines technologies numériques de pointe qui pourraient influencer le devenir des Services vétérinaires. Toutes ces technologies sont orientées données et trouvent leur illustration dans trois exemples qui se répartissent dans les catégories suivantes : a) les technologies sans fil et mobiles appliquées au suivi de la santé animale, à la surveillance des maladies, aux notifications des foyers et à l'échange d'informations ; b) les technologies avancées de traitement des données, dont les mégadonnées et l'analytique de données qui servent à mettre en évidence des structures sous-jacentes, à extraire des schémas prédictifs, à relever des corrélations et à générer d'autres informations ; c) des technologies prometteuses comme les applications *« blockchain »* (chaînes de blocs) utilisées pour une gestion efficace et efficiente de diverses chaînes d'approvisionnement en intrants.
Les auteurs résument brièvement les défis actuels associés au recours accru à ces technologies dans le secteur de la santé animale et en font ressortir certaines répercussions sur les Services vétérinaires. Les technologies numériques vont profondément affecter les modalités de la prestation des services de santé animale ainsi que la gestion des systèmes de santé animale. Par conséquent, il est crucial que les Services vétérinaires anticipent cette évolution et s'adaptent à la transformation numérique en cours. L'investissement dans les nouvelles technologies et les efforts visant à doter les professionnels vétérinaires actuels et futurs des compétences et des connaissances numériques nécessaires pour rester informés et au centre de l'innovation numérique dans le domaine de la santé animale doivent être les priorités des prochaines années.

Mots-clés
Blockchain – Mégadonnées – Santé animale – Services vétérinaires – Technologie mobile – Technologie numérique – Technologies de l'information et de la communication – TIC.

La tecnología digital y sus repercusiones en los Servicios Veterinarios

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Resumen
De unos años a esta parte, el universo digital viene cambiando a un ritmo espectacular y transformando a su estela todos los sectores de la economía, lo que incluye la producción, la sanidad y el bienestar animales. Los autores

pasan revista a algunas avanzadas tecnologías digitales que pueden determinar el porvenir de los Servicios Veterinarios. Para ilustrar estas tecnologías, todas ellas basadas en el uso de datos, ofrecen tres ejemplos correspondientes a otras tantas categorías: a) dispositivos móviles e inalámbricos de seguimiento zoosanitario, vigilancia de enfermedades, notificación e intercambio de información; b) tecnologías avanzadas de tratamiento de datos, como las de macrodatos o las de análisis de datos empleadas para descubrir patrones ocultos, efectuar predicciones, determinar correlaciones u obtener otro tipo de información; y c) tecnologías prometedoras, como las aplicaciones de cadena de bloques utilizadas para gestionar con eficacia y eficiencia varias cadenas de suministro de insumos.

Los autores examinan someramente las dificultades que existen actualmente para aplicar en mayor medida estas tecnologías en el sector de la sanidad animal, así como algunas de las consecuencias que traen consigo para los Servicios Veterinarios. Las tecnologías digitales tendrán un profundo efecto en los modos de prestación de servicios zoosanitarios y de gestión de los sistemas de sanidad animal. Por ello es crucial que los Servicios Veterinarios tomen la iniciativa y se adapten a la transformación digital que ya está en curso. Para los años venideros la prioridad debería cifrarse en invertir en nuevas tecnologías y en aportar al personal veterinario del presente y del futuro los conocimientos teóricos y prácticos sobre cuestiones digitales que necesita no solo para mantenerse al día, sino también para protagonizar la innovación digital en el terreno de la sanidad animal.

Palabras clave

Cadena de bloques – Macrodatos – Sanidad animal – Servicios Veterinarios – Tecnología de la información y la comunicación – Tecnología digital – Tecnología móvil – TIC.

References

1. United Nations Department of Economic and Social Affairs (UNDESA) Population Division (2017). – World population prospects: the 2017 revision, key findings and advance tables. Working Paper No. ESA/P/WP/248. UNDESA, New York, United States of America, 53 pp. Available at: population.un.org/wpp/Publications/Files/WPP2017_KeyFindings.pdf (accessed on 30 April 2021).

2. Food and Agriculture Organization of the United Nations (FAO) (2009). – How to feed the world in 2050. Background paper for the How to Feed the World High-level Expert Forum, 12-13 October, Rome, Italy. FAO, Rome, Italy, 35 pp. Available at: www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf (accessed on 30 April 2021).

3. Food and Agriculture Organization of the United Nations (FAO) (2009). – The state of food and agriculture: livestock in the balance. FAO, Rome, Italy, 180 pp. Available at: www.fao.org/3/i0680e/i0680e.pdf (accessed on 30 April 2021).

4. Tedeschi L.O., Muir J.P., Riley D.G. & Fox D.G. (2015). – The role of ruminant animals in sustainable livestock intensification programs. *Int. J. Sustain. Dev. World Ecol.*, **22** (5), 452–465. doi:10.1080/13504509.2015.1075441.

5. Göncü S. & Güngör C. (2018). – The innovative techniques in animal husbandry. *In* Animal husbandry and nutrition (B. Yucel, ed.). IntechOpen, London, United Kingdom. doi:10.5772/intechopen.72501.

6. Ali W., Ali M., Ahmad M., Dilawar S., Firdous A. & Afzal A. (2020). – Application of modern techniques in animal production sector for human and animal welfare. *Turk. J. Agric. Food Sci. Technol.*, **8** (2), 457–463. doi:10.24925/turjaf.v8i2.457-463.3159.

7. Food and Agriculture Organization of the United Nations (FAO) (2015). – The Second Report on the State of the World's Genetic Resources for Food and Agriculture (B.D. Shearf & D. Pilling, eds). FAO Commission on Genetic Resources for Food and Agriculture Assessment. FAO, Rome, Italy. Available at: www.fao.org/3/i4787e/i4787e00.pdf (accessed on 30 April 2021).

8. World Economic Forum (2016). – The future of jobs: employment, skills and workforce strategy for the fourth industrial revolution. Global Challenge Insight Report. World Economic Forum, Geneva, Switzerland, 167 pp. Available at: www3.weforum.org/docs/WEF_Future_of_Jobs.pdf (accessed on 30 April 2021).

9. Trendov N.M., Varas S. & Zeng M. (2019). – Digital technologies in agriculture and rural areas – status report. Food and Agriculture Organization of the United Nations, Rome, Italy, 152 pp. Available at: www.fao.org/3/ca4985en/ca4985en.pdf (accessed on 30 April 2021).

10. Organisation for Economic Co-operation and Development (OECD) (2019). – Digital technologies for better agricultural policies. OECD Publishing, Paris, France, 234 pp. doi:10.1787/571a0812-en.

11. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K. & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item. *In* Proc. 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France, 28 pp. doi:10.20506/TT.2984.

12. Berckmans D. (2014). – Precision livestock farming technologies for welfare management in intensive livestock systems. *In* Animal welfare: focusing on the future (D.J. Mellor & A.C.D. Bayvel, eds). *Rev. Sci. Tech. Off. Int. Epiz.,* **33** (1), 189–196. doi:10.20506/rst.33.1.2273.

13. Holmstrom L.K. & Beckham T.R. (2017). – Technologies for capturing and analysing animal health data in near real time. *In* Biological threat reduction (T. Beckham, ed.). *Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2), 525–538. doi:10.20506/rst.36.2.2671.

14. Neethirajan S. (2020). – The role of sensors, big data and machine learning in modern animal farming. *Sens. Biosensing Res.*, **29**, 100367. doi:10.1016/j.sbsr.2020.100367.

15. Brennen S. & Kreiss D. (2014). – Digitalization and digitization. *Culture Digitally*, 8 September [group blog]. Available at: culturedigitally.org/2014/09/digitalization-and-digitization (accessed on 30 April 2021).

16. World Health Organization (WHO) (2018). – Digital technologies: shaping the future of primary health care. WHO, Geneva, Switzerland. Available at: apps.who.int/iris/handle/10665/326573 (accessed on 30 April 2021).

17. Food and Agriculture Organization of the United Nations (FAO) & International Telecommunications Union (ITU) (2017). – E-agriculture strategy guide: a summary. FAO, Rome, Italy, 44 pp. Available at: www.fao.org/3/a-i6909e.pdf (accessed on 30 April 2021).

18. Bellet C. (2019). – The future of animal health: how digital technologies reconfigure animal healthcare in farming. *Discover Society*, 7 August. Available at: discoversociety.org/2019/08/07/the-future-of-animal-health-how-digital-technologies-reconfigure-animal-healthcare-in-farming (accessed on 30 April 2021).

19. European Board of Veterinary Specialisation (EBVS) (2019). – European Coordinating Committee on Veterinary Training (ECCVT) workshop – embracing digital technology in veterinary practice, 13 & 14 May, Brussels, Belgium. EBVS, Thessaloniki, Greece. Available at: ebvs.eu/news/eccvt-workshop-embracing-digital-technology-in-veterinary-practice-brussels-13th-14th-may-2019 (accessed on 30 April 2021).

20. Liu J., Toma L., Barnes A.P. & Stott A. (2019). – Farmers' uptake of animal health and welfare technological innovations. Implications for animal health policies. *Front. Vet. Sci.*, **6**, 410. doi:10.3389/fvets.2019.00410.

21. Baumüller H. (2013). – Mobile technology trends and their potential for agricultural development. ZEF Working Paper **123**. University of Bonn, Bonn, Germany, 39 pp. doi:10.2139/ssrn.2359465.

22. World Health Organization (WHO) (2011). – mHealth: new horizons for health through mobile technologies – second global survey on eHealth. WHO, Geneva, Switzerland, 111 pp. Available at: apps.who.int/iris/handle/10665/44607 (accessed on 30 April 2021).

23. Liopa-Tsakalidi A., Tsolis D., Barouchas A., Chantzi A.-E., Koulopoulos A. & Malamos N. (2013). – Application of mobile technologies through an integrated management system for agricultural production. *Procedia Technol.*, **8**, 165–170. doi:10.1016/j.protcy.2013.11.023.

24. Robertson C., Sawford K., Daniel S.L.A., Nelson T.A. & Stephen C. (2010). – Mobile phone-based infectious disease surveillance system, Sri Lanka. *Emerg. Infect. Dis.*, **16** (10), 1524–1531. doi:10.3201/eid1610.100249.

25. Madder M., Walker J.G., Van Rooyen J., Knobel D., Vandamme E., Berkvens D., Vanwambeke S.O. & De Clercq E.M. (2012). – E-surveillance in animal health: use and evaluation of mobile tools. *Parasitology*, **139** (14), 1831–1842. doi:10.1017/S0031182012000571.

26. Food and Agriculture Organization of the United Nations (FAO) (2015). – EMA-i: a mobile app for timely animal disease field reporting to enhance surveillance. FAO, Rome, Italy, 2 pp. Available at: www.fao.org/3/a-i4853e.pdf (accessed on 30 April 2021).

27. Karimuribo E.D., Mutagahywa E., Sindato C., Mboera L., Mwabukus M., Kariuki Njenga M., Teesdale S., Olsen J. & Rweyemamu M. (2017). – A smartphone app (Afyadata) for innovative One Health disease surveillance from community to national levels in Africa: intervention in disease surveillance. *JMIR Public Hlth Surveill.*, **3** (4), e94. doi:10.2196/publichealth.7373.

28. Wamwenje S.A.O., Wangwe I.I., Masila N., Mirieri C.K., Wambua L. & Kulohoma B.W. (2019). – Community-led data collection using Open Data Kit for surveillance of animal African trypanosomiasis in Shimba hills, Kenya. *BMC Res. Notes*, **12**, 151. doi:10.1186/s13104-019-4198-z.

29. Beyene T.J., Eshetu A., Abdu A., Wondimu E., Beyi A.F., Tufa T.B., Ibrahim S. & Revie C.W. (2017). – Assisting differential clinical diagnosis of cattle diseases using smartphone-based technology in low resource settings: a pilot study. *BMC Vet. Res.*, **13**, 323. doi:10.1186/s12917-017-1249-3.

30. Gibson A.D., Mazeri S., Lohr F., Mayer D., Burdon Bailey J.L., Wallace R.M., Handel I.G., Shervell K., Bronsvoort B.M. de C., Mellanby R.J. & Gamble L. (2018). – One million dog vaccinations recorded on mhealth innovation used to direct teams in numerous rabies control campaigns. *PLoS One,* **13** (7), e0200942. doi:10.1371/journal.pone.0200942.

31. Mtema Z., Changalucha J. […] & Hampson K. (2016). – Mobile phones as surveillance tools: implementing and evaluating a large-scale intersectoral surveillance system for rabies in Tanzania. *PLoS Med.,* **13** (4), e1002002. doi:10.1371/journal.pmed.1002002.

32. Battini M., Dalla Costa E. […] & Zanella A.J. (2017). – Mobile apps based on AWIN protocols to assess animal welfare on farm. *In* animal welfare: an asset for livestock production. *OIE Bull.,* **2017** (1), 14–19. doi:10.20506/bull.2017.1.2590.

33. Greenspun H., Coughlin S. & Chang C. (2014). – The four dimensions of effective mHealth: people, places, payment, and purpose. Deloitte Center for Health Solutions, Washington, DC, United States of America, 19 pp. Available at: www2.deloitte.com/content/dam/Deloitte/sg/Documents/life-sciences-health-care/sg-lshc-mhealth-noexp.pdf (accessed on 30 April 2021).

34. PLOS Medicine Editors (2013). – A reality checkpoint for mobile health: three challenges to overcome. *PLoS Med.*, **10** (2), e1001395. doi:10.1371/journal.pmed.1001395.

35. Food and Agriculture Organization of the United Nations (FAO) & International Telecommunications Union (ITU) (2019). – E-agriculture in action: big data for agriculture. FAO & ITU, Bangkok, Thailand, 96 pp. Available at: www.fao.org/3/ca5427en/ca5427en.pdf (accessed on 30 April 2021).

36. Wang C.J., Ng C.Y. & Brook R.H. (2020). – Response to COVID-19 in Taiwan: big data analytics, new technology, and proactive testing. *JAMA*, **323** (14), 1341–1342. doi:10.1001/jama.2020.3151.

37. Lin L. & Hou Z. (2020). – Combat COVID-19 with artificial intelligence and big data. *J. Travel Med.*, **27** (5). doi:10.1093/jtm/taaa080.

38. Morota G., Ventura R.V., Silva F.F., Koyama M. & Fernando S.C. (2018). – Big Data Analytics and Precision Animal Agriculture Symposium: machine learning and data mining advance predictive big data analysis in precision animal agriculture. *J. Anim. Sci.*, **96** (4), 1540–1550. doi:10.1093/jas/sky014.

39. Ouyang Z., Sargeant J., Thomas A., Wycherley K., Ma R., Esmaeilbeigi R., Versluis A., Stacey D., Stone E., Poljak Z. & Bernardo T.M. (2019). – A scoping review of 'big data', 'informatics', and 'bioinformatics' in the animal health and veterinary medical literature. *Anim. Hlth Res. Rev.*, **20** (1), 1–18. doi:10.1017/S1466252319000136.

40. Ebrahimi M., Mohammadi-Dehcheshmeh M., Ebrahimie E. & Petrovski K.R. (2019). – Comprehensive analysis of machine learning models for prediction of sub-clinical mastitis: deep learning and gradient-boosted trees outperform other models. *Comput. Biol. Med.*, **114**, 103456. doi:10.1016/j.compbiomed.2019.103456.

41. Cabrera V.E., Barrientos-Blanco J.A., Delgado H. & Fadul-Pacheco L. (2020). – Symposium review: real-time continuous decision making using big data on dairy farms. *J. Dairy Sci.*, **103** (4), 3856–3866. doi:10.3168/jds.2019-17145.

42. Borgonovo F., Ferrante V., Grilli G., Pascuzzo R., Vantini S. & Guarino M. (2020). – A data-driven prediction method for an early warning of coccidiosis in intensive livestock systems: a preliminary study. *Animals*, **10** (4), 747. doi:10.3390/ani10040747.

43. Faverjon C., Bernstein A., Grütter R., Nathues C., Nathues H., Sarasua C., Sterchi M., Vargas M.E. & Berezowski J. (2019). – A transdisciplinary approach supporting the implementation of a big data project in livestock production: an example from the Swiss pig production industry. *Front. Vet. Sci.*, **6**, 215. doi:10.3389/fvets.2019.00215.

44. Guernier V., Milinovich G.J., Santos M.A.B., Haworth M., Coleman G. & Soares Magalhaes R.J. (2016). – Use of big data in the surveillance of veterinary diseases: early detection of tick paralysis in companion animals. *Parasites Vectors*, **9** (1), 303. doi:10.1186/s13071-016-1590-6.

45. McGreevy P., Thomson P. […] & Hammond J. (2017). – VetCompass Australia: a national big data collection system for veterinary science. *Animals*, **7** (10), 74. doi:10.3390/ani7100074.

46. Self S.C.W., Liu Y., Nordone S.K., Yabsley M.J., Walden H.S., Lund R.B., Bowman D.D., Carpenter C., McMahan C.S. & Gettings J.R. (2019). – Canine vector-borne disease: mapping and the accuracy of forecasting using big data from the veterinary community. *Anim. Hlth Res. Rev.*, **20** (1), 47–60. doi:10.1017/S1466252319000045.

47. Muellner P., Muellner U., Gates M.C., Pearce T., Ahlstrom C., O'Neill D., Brodbelt D. & Cave N.J. (2016). – Evidence in practice – a pilot study leveraging companion animal and equine health data from primary care veterinary clinics in New Zealand. *Front. Vet. Sci*., **3**, 116. doi:10.3389/fvets.2016.00116.

48. Pfeiffer D.U. & Stevens K.B. (2015). – Spatial and temporal epidemiological analysis in the Big Data era. *Prev. Vet. Med*., **122** (1–2), 213–220. doi:10.1016/j.prevetmed.2015.05.012.

49. Asokan G.V. & Asokan V. (2015). – Leveraging 'big data' to enhance the effectiveness of 'One Health' in an era of health informatics. *J. Epidemiol. Glob. Hlth*, **5** (4), 311–314. doi:10.1016/j.jegh.2015.02.001.

50. VanderWaal K., Morrison R.B., Neuhauser C., Vilalta C. & Perez A.M. (2017). – Translating big data into smart data for veterinary epidemiology. *Front. Vet. Sci*., **4**, 110. doi:10.3389/fvets.2017.00110.

51. McCue M.E. & McCoy A.M. (2017). – The scope of big data in One Medicine: unprecedented opportunities and challenges. *Front. Vet. Sci*., **4**, 194. doi:10.3389/fvets.2017.00194.

52. Deblais L., Kathayat D., Helmy Y.A., Closs Jr G. & Rajashekara G. (2019). – Translating 'big data': better understanding of host–pathogen interactions to control bacterial foodborne pathogens in poultry. *Anim. Hlth Res. Rev*., **21** (1), 15–35. doi:10.1017/S1466252319000124.

53. Perez A.M. (2018). – Big data – the language and future of One Medicine, One Science [editorial]. *Front. Vet. Sci*., **5**, 114. doi:10.3389/fvets.2018.00114.

54. Koltes J.E., Cole J.B. […] & Reecy J.M. (2019). – A vision for development and utilization of high-throughput phenotyping and big data analytics in livestock. *Front. Genet*., **10**, 1197. doi:10.3389/fgene.2019.01197.

55. Casino F., Dasaklis T.K. & Patsakis C. (2019). – A systematic literature review of blockchain-based applications: current status, classification and open issues. *Telemat. Inform*., **36**, 55–81. doi:10.1016/j.tele.2018.11.006.

56. Food and Agriculture Organization of the United Nations (FAO) & International Telecommunications Union (ITU) (2019). – E-agriculture in action: blockchain for agriculture – opportunities and challenges (G. Sylvester, ed.). FAO & ITU, Bangkok, Thailand, 72 pp. Available at: www.fao.org/3/ca2906en/ca2906en.pdf (accessed on 30 April 2021).

57. Motta G.A., Tekinerdogan B. & Athanasiadis I.N. (2020). – Blockchain applications in the agri-food domain: the first wave. *Front. Blockchain*, **3**, 6. doi:10.3389/fbloc.2020.00006.

58. Tripoli M. & Schmidhuber J. (2018). – Emerging opportunities for the application of blockchain in the agri-food industry. Food and Agriculture Organization of the United Nations, Rome, Italy; & International Centre for Trade and Sustainable Development, Geneva, Switzerland; 40 pp. Available at: www.fao.org/3/CA1335EN/ca1335en.pdf (accessed on 30 April 2021).

59. Marinello F., Atzori M., Lizi L., Boscaro D. & Pezzuolo A. (2017). – Development of a traceability system for the animal product supply chain based on blockchain technology. *In* Proc. Precision Livestock Farming 2017: papers presented at the 8th European Conference on Precision Livestock Farming (ECPLF) (D. Berckmans & A. Keita, eds), 12–14 September, Nantes, France. Organising Committee of ECPLF 2017, Nantes, France, 258–268. Available at: www.eaplf.eu/wp-content/uploads/ECPLF_17_book.pdf (accessed on 30 April 2021).

60. Makarov E.I., Polyansky K.K., Makarov M.E., Nikolaeva Y.R. & Shubina E.A. (2019). – Conceptual approaches to the quality system of dairy products based on the blockchain technology. *In* Ubiquitous computing and the Internet of Things: prerequisites for the development of ICT. Studies in computational intelligence, Vol. **826** (E.G. Popkova, ed.). Springer, Cham, Switzerland, 1059–1069. doi:10.1007/978-3-030-13397-9_109.

61. Makkar H.P.S. & Costa C. (2020). – Potential blockchain applications in animal production and health sector. *CAB Rev*., **15** (35), 1–8. doi:10.1079/PAVSNNR202015035.

62. Berckmans D. (2017). – General introduction to precision livestock farming. *Anim. Front*., **7** (1), 6–11. doi:10.2527/af.2017.0102.

63. World Bank Group (2019). – Future of food: harnessing digital technologies to improve food system outcomes. World Bank, Washington, DC, United States of America. Available at: hdl.handle.net/10986/31565 (accessed on 30 April 2021).

64. Rotz S., Duncan E., Small M., Botschner J., Dara R., Mosby I., Reed M. & Fraser E.D.G. (2019). – The politics of digital agricultural technologies: a preliminary review. *Sociologia Ruralis*, **59** (2), 203–229. doi:10.1111/soru.12233.

65. AVMA–AAVMC Veterinary Futures Commission (2019). – Executive summary: the future of veterinary medicine. American Association of Veterinary Medical Colleges (AAVMC), Washington, DC, United States of America, 18 pp. Available at: www.aavmc.org/assets/site_18/files/newsletter_files/feb%20vme%20future%20of%20vet%20med.pdf (accessed on 30 April 2021).

66. Food and Agriculture Organization of the United Nations (FAO) (2018). – Status of implementation of e-agriculture in Central and Eastern Europe and Central Asia: insights from selected countries in Europe and Central Asia. FAO Regional Office for Europe and Central Asia, Budapest, Hungary, 64 pp. Available at: www.fao.org/3/I8303EN/i8303en.pdf (accessed on 30 April 2021).

67. Food and Agriculture Organization of the United Nations (FAO) (2020). – Realizing the potential of digitalization to improve the agri-food system: proposing a new International Digital Council for Food and Agriculture – a concept note. FAO, Rome, Italy, 28 pp. Available at: www.fao.org/3/ca7485en/ca7485en.pdf (accessed on 30 April 2021).

68. Food and Agriculture Organization of the United Nations (FAO) (2018). – E-agriculture community of practice now above 14,000. FAO, Rome, Italy. Available at: www.fao.org/e-agriculture/news/e-agriculture-community-practice-now-above-14000 (accessed on 30 April 2021).

69. World Organisation for Animal Health (OIE) (2019). – The OIE PPP handbook: guidelines for public–private partnerships in the veterinary domain. OIE, Paris, France, 64 pp. doi:10.20506/PPP.2965.

70. Contalbrigo L., Borgo S., Pozza G. & Marangon S. (2017). – Data distribution in public veterinary service: health and safety challenges push for context-aware systems. *BMC Vet. Res.*, **13**, 397. doi:10.1186/s12917-017-1320-0.

71. Deloitte (2017). – Smart livestock farming: potential of digitalization for global meat supply – discussion paper. Deloitte Global, London, United Kingdom, 36 pp. Available at: www2.deloitte.com/content/dam/Deloitte/de/Documents/operations/Smart-livestock-farming_Deloitte.pdf (accessed on 30 April 2021).

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 469-481

The importance of animal welfare and Veterinary Services in a changing world

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Summary

Animal welfare is an essential component of the future of sustainable agriculture and the United Nations Sustainable Development Goals. There is growing global recognition of the importance of animal welfare, which must always be considered as part of the decision-making around food and nutrition security. Veterinary Services, encompassing public and private veterinarians and para-veterinarians, are custodians of animal welfare and key players in future actions to improve it. The welfare of animals is everyone's responsibility, from the individual farmer and practitioner to policymakers at the national and intergovernmental level. In this paper, after providing background information about current animal welfare issues and identifying animal welfare risks, the authors make a number of recommendations for action at the institutional and individual level. They do so because while the former is essential to generate change at scale and effective resourcing, the latter can create immediate action at a local level and drive change from the ground up. Without coordinated action from Veterinary Services, opportunities to improve animal welfare, alongside human and environmental health and well-being, may very well be lost, and animal welfare may fail to improve or even be at risk of decline.

Keywords

Animal welfare – Animal well-being – Five domains – One Health – One Welfare – Sustainable Development Goals – Sustainable production – Welfare.

Introduction

This paper discusses global challenges to animal welfare, and suggests how, where and why Veterinary Services can contribute to its improvement. There is a growing demand to improve animal welfare in both low- and middle-income countries (LMICs) and high-income countries (HICs). Achieving this throughout the world will require action from individuals on the ground all the way up to decision-makers at government and intergovernmental levels. Consequently, the veterinary professionals who make up each country's Veterinary Services need to be aware of recent developments in animal welfare; the individuals, communities and institutions seeking change; and those who must participate to achieve it.

This paper begins by describing the current understanding of animal welfare and its relevance globally. It then examines the role of Veterinary Services in maintaining and improving animal welfare, and the challenges they face. Finally, the authors describe the actions that Veterinary Services can take to help facilitate improvements to animal welfare.

https://doi.org/10.20506/rst.40.2.3238

Table I
A set of working definitions to provide a common starting point for discussion

Term	Definition
Animal welfare	According to the OIE, animal welfare is 'the physical and mental state of an animal in relation to the conditions in which it lives and dies' (1) Animal welfare is based on the principle that an animal should be treated in a way that meets its biological, behavioural and affective state needs, giving the animal a good quality of life (2). It can be assessed by using objective and subjective tools to measure how an animal is coping
Animal ethics	A moral and legal framework that is applied to evaluate whether actions proposed, involving the use of animals, should be performed. On a moral level, a person's values will influence their views on animal welfare and acceptability In some research circumstances, even if the welfare of an animal is not compromised, it may not be ethically responsible to conduct the research if the goal is not clear or the study has not been designed to answer the research question adequately
Animal rights	The moral philosophy that animals have interests that cannot be traded (3). Often it is believed that, in many instances, the use of animals for human benefit compromises these rights
3Rs	A framework applied to animals in all research contexts that prioritises the replacement of animals for research (not using animals at all); reduction (reducing the number of animals to the lowest number possible); and refinement (improving the way in which animals are used) in research studies and settings (4)
Five Freedoms	The Five Freedoms focus on experiences that should be avoided so as not to cause animal suffering: freedom from hunger and thirst; freedom from discomfort; freedom from pain, injury and disease; freedom to express normal behaviours; freedom from fear and distress (5, 6). This framework created a solid foundation from which animal welfare science has grown today
Five Domains	A modern animal welfare framework describes the essential components for an animal's quality of life and the balance of positive and negative experiences that define welfare status (7). The first four domains of nutrition, environment, health and behaviour influence the fifth domain of mental state

OIE: World Organisation for Animal Health
3Rs: replacement, reduction and refinement of animal use in research

Animal welfare and its assessment

Animals are sentient, meaning that they experience feelings, so it is important that their basic biological, behavioural and affective state needs are met. This principle underpins both practical and moral concerns when caring for animals and supports the need for a high standard of care, including a humane death. Animal welfare, rights and ethics are separate concepts that need to be interpreted consistently to facilitate discussions of animal welfare (Table I). Welfare can be interpreted as an animal's physical and mental state. Ethics provide the philosophical framework within which this well-being is interpreted and implemented and are influenced by one's moral views. Animal rights are the product of a particular philosophical and moral viewpoint.

Animal health and animal welfare are complementary, but not synonymous, concepts. Without good health, there cannot be good welfare, but good health alone does not guarantee good welfare. Because of this, animal productivity cannot be a proxy for welfare. Animal productivity and welfare are often positively correlated, up to a certain level, in many production systems, including in LMICs. However, higher levels of productivity can compromise animal welfare (8). Background and profession can also influence how a person focuses on animal welfare. Those with an animal production and veterinary background tend to focus on biological indicators of welfare, whereas the general public tend to focus on natural living, and animal welfare science focuses on affective state (2).

Many Veterinary Service personnel are familiar with the 'Five Freedoms' framework for characterising animal welfare (5) (Table I), and the authors suggest building on these Five Freedoms with a next-stage framework. The 'Five Domains' framework for animal welfare comprehensively describes the essential components for an animal's quality of life (7) (Table I), by building on the Five Freedoms while addressing some of their limitations. For example, the Five Freedoms describe an absence of negative experiences, which is not possible (9), and do not recognise the positive experiences needed for an animal to have a 'life worth living' (7).

Animal welfare needs to be assessed to be understood and improved, and the Five Domains concept provides a framework for this evaluation. When we try to understand animal welfare, our assessments should focus on animal-based measures as they directly identify how well an animal is coping in its environment. Adding management and resource evaluation to animal-based measures under the Five Domains comprehensively identifies where actions need to be taken to correct or mitigate welfare issues.

There has been extensive research to develop animal welfare assessment tools, with a strong focus on European environments and high-resource and larger-scale production systems (10, 11). (One exception has been working equids in LMICs.) The authors suggest that these existing tools can be modified to local situations. A guide to considerations for specific situations is given in Figure 1.

Animal welfare as part of a sustainable world

The Food and Agriculture Organization of the United Nations (FAO) links sustainable livestock systems to all 17 of the Sustainable Development Goals (SDGs) (12), and considers animal welfare to be a core component of sustainable livestock production (13). Failing to consider animal welfare can prevent progress towards sustainable development. Animal welfare has financial, nutritional, psychological and health implications for humans, and positive implications for the environment. Demonstrating these relationships is important to create support for animal welfare in situations or circumstances where people may not recognise its intrinsic importance.

Animal welfare and the Sustainable Development Goals

The SDGs are a universal call to action to end poverty and protect the planet without leaving anyone behind (14). The United Nations (UN) 2030 Agenda for Sustainable Development envisages a world where '…other living creatures are protected'. Despite this, animal welfare is not recognised within the goals, and policy recommendations have been made to rectify this omission (15, 16).

The associations between the SDGs and animal welfare are multi-faceted (Fig. 2). One half of the 900 million poor people worldwide, who live on less than US$ 1.90 per day (21), depend directly on livestock for their livelihoods, connecting animal welfare with SDGs 1 and 2: 'No poverty' and 'Zero hunger' (17, 18). Livestock contribute to three major pathways out of poverty by:

a) increasing resilience

b) improving smallholder and pastoral productivity

c) increasing market participation.

In addition, increasing consumption of healthy and nutritious animal-source foods at the household level is a significant contribution to SDG 2 (21).

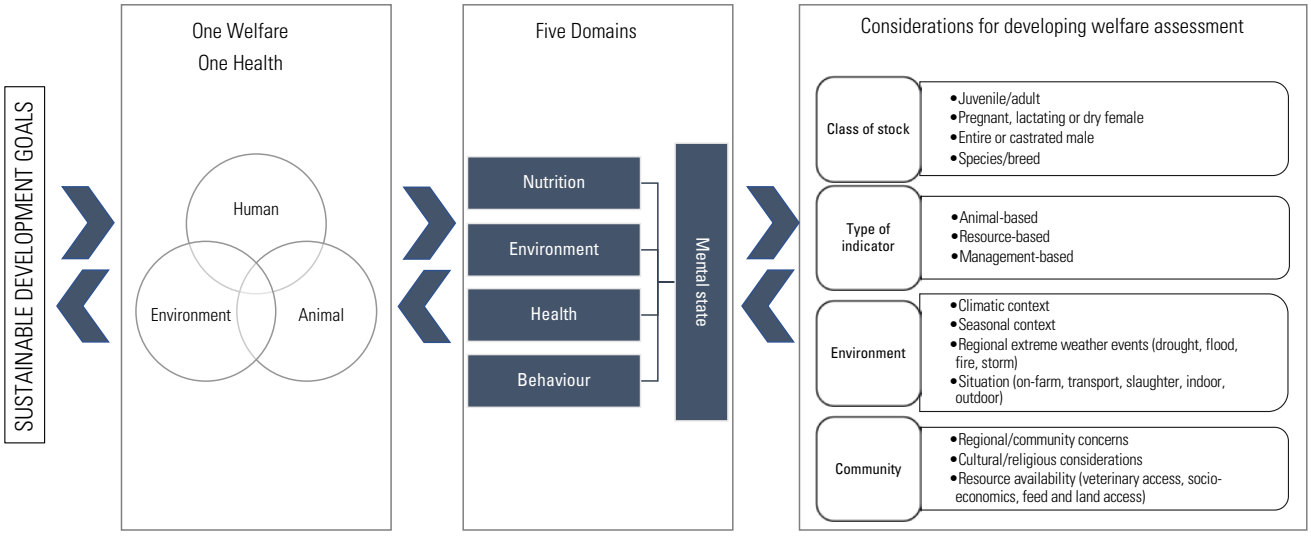

Fig. 1

Connecting the concepts of the United Nations Sustainable Development Goals, One Health and One Welfare, the Five Domains and considerations for developing welfare assessments

From left to right, the diagram shows the increased level of detail needed to address key considerations for animal welfare in relation to the United Nations Sustainable Development Goals (SDGs). The right-to-left arrows reaffirm that this detail is needed to understand and make progress towards these higher-level concepts. Progress to some SDGs can be achieved by applying a One Health and One Welfare framework. When considering animal welfare and health, the Five Domains framework describes the essential components that contribute to an animal's quality of life. In addition to the survival and situation-related factors presented in the Five Domains framework, this list of interdependent considerations on the right-hand side of the figure acts as a checklist when developing a welfare assessment for livestock, working animals and aquaculture. When designing an animal welfare assessment, it should be regional and species-specific

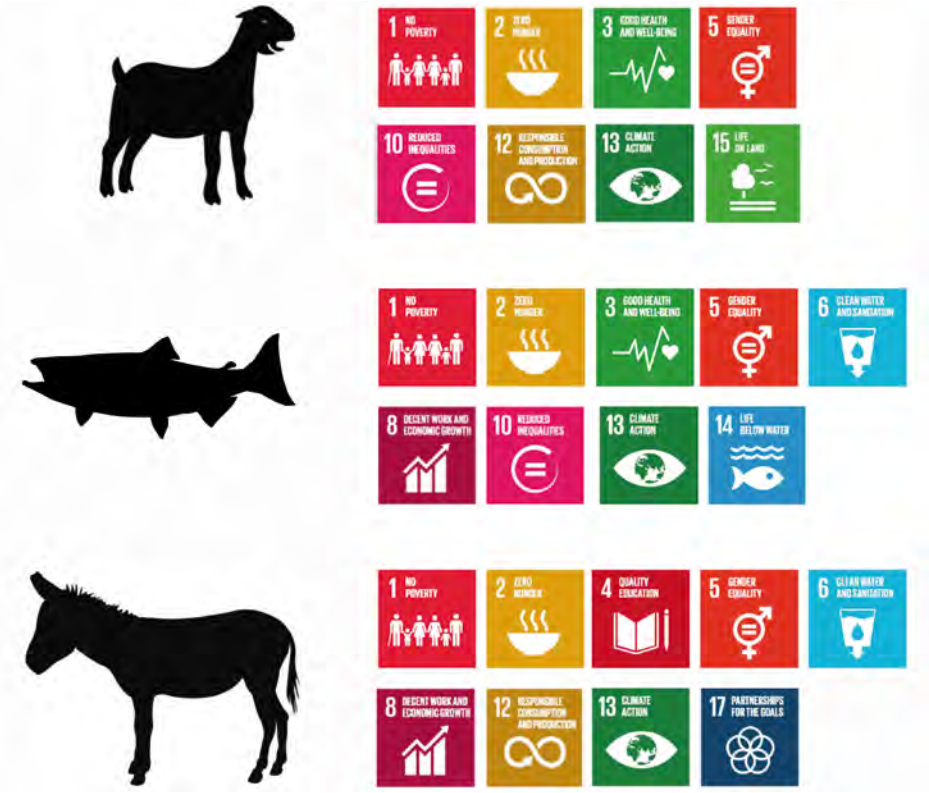

Fig. 2

Proposed links between livestock, aquaculture and working animal welfare and the United Nations Sustainable Development Goals

Summarised from Doyle *et al.* (17), Keeling *et al.* (18), WorldFish (19), and the International Coalition for Working Equids (20). The animal icons represent examples of species within these groups

Approximately 800 million people's livelihoods depend on fisheries/aquaculture worldwide (19), and SDG 14 (life below water) outlines steps for the careful management of this essential global resource. Sustainable Development Goal 14 recognises the need to end overfishing, but makes no reference to fish and invertebrate welfare, particularly that of farmed fish. For wild fish, improving catching methods will improve fish welfare and product quality, and reduce by-catch. In intensive fish farms, welfare can be compromised by overcrowding in poor conditions, starvation, transportation and inhumane slaughter methods (22), and can be a significant source of antibiotic and antiparasitic drugs entering water systems (23). All of these problems threaten our ability to meet SDG 14 targets.

The concepts of One Health and One Welfare (described below) highlight the inextricable links between human health and well-being (SDG 3) and animal and environmental health and welfare. The spillover of zoonotic diseases into humans and overuse of antimicrobials both have their root causes in poor animal welfare (24). Accordingly, improving animal welfare creates an opportunity to reduce the potentially devastating impacts of these events on human well-being.

A largely invisible yet essential contribution to the SDGs comes from working livestock (20). Facilitating farming and transportation, they pull ploughs and carts, deliver goods to market, are essential for water collection for households and other livestock, and provide manure, an important organic fertiliser. Urban uses include construction, the transport of people and goods, and refuse collection (25). A clear connection in policy and practice should be made between working equine welfare and human development.

The livestock and aquaculture sectors are growing at a fast rate. There is an opportunity to steer the direction of this growth to mutually benefit both animal welfare and the attainment of the SDGs, as well as mitigating negative impacts on planetary health (26). One example would be to use current resources more efficiently to produce more animal-source food, or even to reduce the use of these resources. This concept of sustainable intensification can be beneficial to welfare and production when inputs are constrained, but may cause conflict in situations where animal welfare is compromised for other reasons.

One Welfare and One Health

One Health recognises that human, animal and ecosystem health are inextricably linked, and that to achieve sustainable

change and optimal health in any of these areas, all three areas have to be addressed (27). One Welfare highlights connections not just between the health of animals, humans and the environment, but also among other aspects of their well-being, including sustainability (28). The One Health and One Welfare frameworks can be used in conjunction to ensure that concerns for people, animals and the environment have been adequately considered (Fig. 1). Examples of One Welfare connections include human livelihoods, personal empowerment and cultural needs; animal behaviour and opportunities for 'a life worth living' (7); and environmental biodiversity, soil quality, and sustainable food systems.

Corollary impacts of improving animal welfare

The wider impacts that seeking to improve animal welfare may have on animal keepers should be understood in the context of livelihoods and animal production systems, as welfare improvement strategies can disproportionately affect particular communities or even countries. For example, improved animal welfare may be institutionalised through national or international quality assurance and compliance schemes. However, these can create discriminatory trade barriers that particularly disadvantage smallholders and small farms in LMICs and HICs, denying them the opportunity to meet welfare standards and/or provide the evidence required, perhaps because auditing is too expensive or records have not been kept (29, 30, 31). National or regional policies often seek to improve welfare by increasing access to formal Veterinary Services. This can directly or indirectly promote sedentarisation, threatening the traditional livelihoods of pastoralist societies, and the social and ecological benefits and public good that pastoralism brings. A better solution is to improve services and welfare through integrated animal health care (32). At a household level, seeking to improve animal welfare on farms by intensifying production, reducing wastage and improving outputs from animals may unduly burden those who usually care for these livestock. In many small-scale production systems, it is women who tend the livestock, manage their feed, water and environment, take care of vulnerable animals, and clean their home and/or pens. Such well-intentioned aims may cause a heavy increase to women's workloads (33). Avoiding unintended consequences when attempting to improve animal welfare is essential if improvements are to be sustainable, and so diverse consultation, including women and other small-scale farmers, is an essential part of any decision-making process.

Changing global perceptions on animal welfare

A society that increasingly hungers for justice and equality, including progress for women, ethnic minorities and those living with disabilities, has adopted animal welfare as a rapidly evolving social concern. Animal welfare is increasingly recognised by the global community through policy and legislation (34), and there are a broad range of drivers behind this increased demand for improvement. Regional strategies for animal welfare are now available across continents (e.g. 35). Harmonisation of animal welfare policy has been facilitated through the animal welfare standards set out by the World Organisation for Animal Health (OIE), which provide a scientific basis for management practices that aim to maintain an acceptable standard of animal welfare. Whilst legislation is increasingly being put in place across the world, actual enforcement of animal welfare legislation still remains poor and systems to support compliance are scarce and under-resourced, especially in LMICs (36).

Community-led actions often drive animal welfare change and can do so at a faster pace than industry or government. For example, consumer demand for animal products associated with improved welfare has been an important stimulus for changes in animal farming, leading to, for example, widespread adoption of free-range eggs in many HICs (37). This reflects the fact that animal welfare is becoming increasingly important as animal production becomes more intensive. This development is due partly to the emergence of animal welfare science and the body of work on animal sentience (38, 39).

Community-led action can also be a method for engagement, ownership of issues and the development of practical, sustainable strategies for improvement (e.g. 40, 41, 42). These community engagement strategies focus on participatory and representative decision-making and recognise that it is not only knowledge transfer that will achieve change, but an understanding of the motivations and opportunities of communities and individuals (43). While community-led action has improved animal welfare in many cases, it cannot be solely relied upon for animal welfare action. Behavioural changes around animal welfare are complex and multidimensional. However, with 'attitude-behaviour gaps' affecting farmers (44) and consumers (45), participatory approaches are one useful method to bridge the rift between people's values and intentions and the actions they take.

Veterinary Services for animal welfare

The role of Veterinary Services in animal welfare

Veterinary Services – encompassing both veterinarians and veterinary paraprofessionals (VPPs) – are widely recognised

as key custodians of animal welfare and have a key role in maintaining and improving it. Veterinarians who work directly and indirectly with animals are one of the groups in the livestock sector most likely to place importance on good animal welfare, to believe that others would approve of them improving animal welfare (46), and to feel that they are expected by the community to improve animal welfare (47). Veterinarians and VPPs have the ability to support animal welfare through the 'traditional' veterinary activities of diagnosing, preventing and treating disease; understanding and managing pain; conducting welfare assessments; educating stakeholders, including policy-makers, about animal welfare; helping to develop and implement policy; promoting effective welfare assurance schemes; and undertaking scientific work to improve the understanding and practice of animal welfare (48). The scientific training of veterinarians is often identified as important in supporting evidence-based approaches to improving animal welfare (47, 49, 50, 51). Thus, Veterinary Services have both the opportunity and a clear, leading role to promote good animal welfare, locally, nationally and globally (52).

Capacity needs and opportunities

Despite evidence of the value of animal welfare, in many parts of the world animal welfare science is not recognised as a profession in its own right. It is not included within veterinary curricula or taught to a sufficient standard to meet recommended standards for graduating veterinarians (53). Nevertheless, there are good examples of improvement in these areas (54, 55). Similarly, animal welfare is now included in the recommended competencies for continuing VPP training (56). This is an important consideration, because VPPs are often strongly embedded in local production systems, yet their training is often less formal or organised than that of other animal service providers. Animal welfare and welfare assessment should be incorporated into veterinary and para-veterinary curricula and covered in open-source teaching materials for different animal health service providers, with adaptations to ensure that they are relevant to circumstances in different countries. This need is currently being met by animal welfare and veterinary non-governmental organisations in LMICs through irregular training sessions. These training sessions can be effective ways of making rapid changes in local animal welfare education but must be integrated or coordinated with national education systems to guarantee long-term efficacy.

As discussed below, animal welfare priorities will change over time. This must be reflected in continuing reviews of animal welfare content when teaching veterinarians and VPPs, and included in veterinary continuing professional development (CPD). Strong CPD systems also ensure the quality of veterinary services provided by the private sector, which are well-established in HICs and gaining importance in LMICs.

Care and ethics for veterinary professionals

As well as capacity challenges, individual veterinarians and VPPs may face obstacles in acting on animal welfare because of the potential conflict between their obligations to their 'clients' – the owners or managers of animals (including governments) who pay for their services – and to their patients, the animals themselves (57, 58, 59). This may be a particular challenge in HICs, where mutual improvements in welfare and productivity may be less easy to achieve than in LMICs.

Veterinarians may work to implement, or be guided by, legislation that protects animal welfare, but its existence or extent varies widely across the globe (60). 'Top-down' approaches led by government policy and regulation are often used to improve welfare, but this can be hampered by lack of political will or the resources to implement such regulation. This is sometimes particularly the case in LMICs (61), or where legislation is not enforced – an issue in a variety of jurisdictions. Thus, veterinarians may need to work as individuals, in their daily activities, to improve animal welfare. However, this imperative is threatened by the fact that an individual's capacity is limited. Moreover, legislation itself, when it is seen to be enforced, can be an important motivator for individuals and organisations to work to improve animal welfare (62). There may also be subconscious factors influencing a professional's impact on animal welfare. 'Compassion fatigue' is a commonly reported issue that can affect the care provided to the animal, as well as the mental health of the professional (63, 64). Understanding motivations to improve animal welfare, and finding opportunities to incentivise such improvements, will be crucial in creating change.

Future challenges for animal welfare

Changing dietary needs and demands

Identifying global challenges facing animal welfare is important for agile and responsive action at the individual level and through to policy levels. The evolution of the global middle class (31) is changing dietary demands and values, simultaneously threatening animal welfare and providing important opportunities to improve it. Meeting changing consumer demands for higher-quality and safer food products could have positive impacts on animal welfare, especially in relation to disease control and during slaughter. In contrast, the sheer increase in animals needed to meet this dietary demand automatically puts more animals at risk of poor

welfare. Intensification of livestock production (65) has been advocated worldwide as the way to meet this demand, but represents a clear threat to animals if it is not implemented with welfare as one of its operating criteria. A conflict between environmental and animal welfare concerns may also arise, because 'climate-friendly' human diets that are associated with lesser amounts of greenhouse gas generally promote animal-sourced products from intensified production systems, with the associated potential risk to animal welfare (66). For example, chicken meat is considered the most climate-friendly meat, but broiler chicken production is one of the greatest animal welfare concerns globally, due to the widespread occurrence of musculoskeletal lesions in birds (67) and the enormous number of broilers reared.

Table II
Recommendations for action to improve animal welfare by Veterinary Services at an institutional/policy level and an individual/local level

Action area	High-level policy & institutional action	Individual & local action
Sustainable production & SDGs	Incorporate specific animal welfare targets and indicators in the relevant Sustainable Development Goals (SDGs) Design programmes to achieve SDGs with a One Health and One Welfare focus, to recognise synergies between improving animal welfare and other production and livelihood outcomes, and to minimise trade-offs	Use a One Health and One Welfare approach to identify the best methods for simultaneously improving animal welfare, production and livelihoods, e.g. making the connection between workplace satisfaction and animal handling can help workers to understand animal welfare issues and identify opportunities for improvement
Training	OIE/UN Member States should integrate open-source teaching materials on animal welfare into Veterinary Services curricula, and encourage states to tailor material, including welfare assessment, to suit their circumstances and situation Include animal welfare training in veterinary and VPP curricula with appropriate resourcing, including relevant 'Day 1' graduate skills consistent with OIE or other international accreditation standards Include high-quality animal welfare learning content in Veterinary Services capacity building and the continuing professional development initiatives of international agencies, government and the private sector Recognising animal welfare as a professional skill/profession will encourage training and continuous education	Use self/local reflection to generate awareness of ethical challenges and possible biases that can affect the care provided to animals Include animal welfare in continuing professional development activities, including accessing free online resources Include animal welfare when engaging with stakeholders and delivering training to identify its inherent value
Diverse engagement	Seek broad consultation with diverse stakeholders (gender, ethnicity, socio-economics, education, livelihood activities, etc.) before action is taken to achieve equitable impact Any action on animal welfare needs to accommodate public expectations, and can include wildlife and other non-owned animals	Understand the capacity, opportunities and motivations of animal owners/stakeholders when recommending action on animal welfare Empower animal owners and other stakeholders to create their own plans and accountability for animal welfare improvements (using techniques such as motivational interviewing)
Practical action & welfare assessment	Develop and implement national animal welfare laws, guidelines and policies that are internationally harmonised with OIE standards Implement systems for monitoring and enforcing animal welfare standards, including continual improvement processes, using evidence-based, objective criteria and assessment frameworks	Evaluate animal welfare at individual and group levels. Consider the individual animal when evaluating welfare Apply the Five Domains and specific-context needs when evaluating welfare (Fig. 1) Encourage the publication of clear and transparent welfare assessment data from industries and organisations to act as a process for continuous improvement
Future focus	Use country and regional projections of animal-source food demands as guidelines to help prepare for future animal welfare and Veterinary Services' needs, including capacity and regulation Include animal welfare and community needs and expectations when developing strategies for food and nutrition security Embed animal welfare and ethical considerations in disaster preparedness and disease outbreak action plans	Anticipate future trends, needs and opportunities for animal welfare and veterinary ethics Create opportunities for continuous education and improvement of animal welfare in professional activities

OIE: World Organisation for Animal Health
SDGs: Sustainable Development Goals
UN: United Nations
VPP: veterinary paraprofessional

Environment and climate change

Environment-related welfare risks are likely to become more frequent and extreme as the impacts of climate change are felt. Extreme weather, heatwaves, an increase in the average and range of temperatures, changed rainfall patterns, droughts, emerging diseases and changing patterns of disease spread, and changes in plant growth and flora biodiversity are just some examples. Climate-related disasters such as fires and floods are also likely to increase. For example, the 2019–2020 bushfires in Australia were thought to have killed 69,000 head of livestock, burned millions of hectares of productive farmland and resulted in the death of one billion wild animals (68). The UN Sendai Framework for Disaster Risk Reduction (69) explicitly recognises the need to accommodate livestock and working animals, and the Livestock Emergency Guidelines and Standards (70) provide guidelines for rapid and slow-onset disasters.

Global pandemics and disease outbreaks

The impact of global disease outbreaks, such as COVID-19 and African swine fever in Asia (71), will continue to be felt in industries worldwide. Preventing or mitigating future pandemics must focus on animal management. Strategies include stopping or improving the world wildlife trade, using One Health approaches to manage animals and deliver veterinary services (72), increasing food safety, modifying industrial agricultural production practices to reduce intensity and increase scale, and improving farm biosecurity. Animal welfare may be improved by default or design in these strategies. There is also a risk that welfare will be compromised by 'closed systems' for biosecurity, which may lack transparency or promote mass slaughter and wastage during outbreaks, due to poor preparedness (73), or provide inadequate responses when disease outbreaks occur (74).

Looking forwards: opportunities for action and conclusions

The authors make a number of recommendations for action at an institutional and policy level, alongside individual and community actions, that seek to improve animal welfare through Veterinary Services (Table II). Veterinary Services that are working effectively to improve animal welfare are essential to achieve large-scale change at the national level, whilst the actions of individuals can create immediate change at the local level.

Veterinary Services have a key role in supporting improved animal welfare along with food and nutrition security. Without action from Veterinary Services to improve animal welfare, global human and environmental health and well-being may very well be at risk.

Acknowledgements

The authors wish to thank Kate Fletcher (The Brooke) and Carolina Munoz (University of Melbourne) for their comments on the manuscript.

L'importance du bien-être animal et des Services vétérinaires dans un monde en mutation

R.E. Doyle, B. Wieland, K. Saville, D. Grace & A.J.D. Campbell

Résumé

Le bien-être animal est une composante essentielle de l'agriculture durable de demain ainsi que des objectifs de développement durable des Nations Unies. La question du bien-être animal fait l'objet d'une attention croissante dans le monde et la nécessité de le prendre en compte lors des décision relatives à la sécurité alimentaire et nutritionnelle est désormais bien perçue. Les Services vétérinaires, qui recouvrent les vétérinaires et les paraprofessionnels vétérinaires du secteur public et privé sont les garants du bien-être animal ainsi que les principaux acteurs des activités futures pour l'améliorer. Il relève de la responsabilité de chacun, depuis l'éleveur et le praticien de terrain jusqu'aux décideurs politiques de niveau national et intergouvernemental, de veiller dès aujourd'hui à l'amélioration du

bien-être des animaux partout où cela est nécessaire, et de tracer le chemin d'une amélioration continue à l'avenir. Après avoir décrit dans leurs grandes lignes les problématiques actuelles du bien-être animal et identifié les risques dans ce domaine, les auteurs formulent un certain nombre de recommandations sur les mesures qui peuvent être prises à l'échelle institutionnelle et individuelle. Ils considèrent que les institutions sont essentielles pour générer un changement de vaste envergure grâce à une mobilisation efficace des ressources, tandis que l'individu de son côté peut passer à l'action de manière immédiate au niveau local et impulser le changement à partir de rien. À défaut d'une action coordonnée par les Services vétérinaires, on risque de passer à côté de certaines possibilités d'améliorer le bien-être animal en même temps que la santé et le bien-être humains et environnementaux, ce qui se traduirait par un ralentissement des avancées en matière de bien-être animal, voire par un recul.

Mots-clés
Bien-être – Bien-être animal – Cinq domaines – Objectifs de développement durable – Production durable – Protection des animaux – Un seul bien-être – Une seule santé.

Importancia del bienestar animal y los Servicios Veterinarios en un mundo en plena transformación

R.E. Doyle, B. Wieland, K. Saville, D. Grace & A.J.D. Campbell

Resumen
El bienestar animal es un componente esencial de la agricultura sostenible del futuro y de los Objetivos de Desarrollo Sostenible fijados por las Naciones Unidas. Su importancia está cada vez más clara en todo el mundo. El bienestar de los animales debe ser siempre tenido en cuenta en los procesos decisorios que tocan a la seguridad alimentaria y nutricional. Los Servicios Veterinarios, que comprenden tanto a los veterinarios públicos y privados como al personal paraveterinario, son custodios del bienestar animal y agentes clave de toda acción futura encaminada a mejorarlo. Para lograr que el bienestar animal mejore desde ahora mismo, allí donde haga falta, y asegurar que siga un rumbo de constante progreso en el futuro, es preciso que todos los interlocutores, desde los productores y cuidadores hasta los planificadores de políticas de ámbito nacional e intergubernamental, hagan suya esta responsabilidad. Tras presentar información básica sobre los actuales problemas de bienestar animal y señalar los riesgos existentes en la materia, los autores formulan una serie de recomendaciones para actuar tanto desde las instituciones como a título individual, sabedores de que el primer nivel es fundamental para inducir cambios a gran escala y movilizar recursos eficazmente, mientras que el segundo puede generar inmediatamente acciones a escala local e impulsar desde ahí cambios en sentido ascendente. A falta de una labor coordinada de los Servicios Veterinarios, es muy posible que se pierdan oportunidades para mejorar el bienestar animal, junto con la salud y el bienestar de personas y ecosistemas, y que los niveles de bienestar animal no mejoren o, incluso, corran peligro de deterioro.

Palabras clave
Bienestar – Bienestar animal – Cinco dominios – Objetivos de Desarrollo Sostenible – Producción sostenible – Un solo bienestar – Una sola salud.

References

1. World Organisation for Animal Health (OIE) (2004). – Terrestrial Animal Health Code, 13th Ed. OIE, Paris, France, 556 pp. Available at: doc.oie.int/dyn/portal/index.seam;jsessionid=d36aead3cc7a045f74003c54b0e2?page=alo&aloId=23734&menu=DO16&cid=2694.

2. Fraser D., Weary D.M., Pajor E.A. & Milligan B.N. (1997). – A scientific conception of animal welfare that reflects ethical concerns. *Anim. Welf.,* **6** (3), 187–205. Available at: www.wellbeingintlstudiesrepository.org/cgi/viewcontent.cgi?article=1000&context=ethawel (accessed on 8 June 2021).

3. Singer P. (2015). – Animal liberation: the definitive classic of the animal movement. Open Road Media, New York, United States of America, 452 pp.

4. World Organisation for Animal Health (OIE) (2012). – Chapter 7.8. Use of animals in research and education. *In* Terrestrial Animal Health Code, 21st Ed. OIE, Paris, France. Available at: doc.oie.int/dyn/portal/index.seam?page=alo&aloId=24142&menu=DO16&cid=2726.

5. Farm Animal Welfare Council (FAWC) (2007). – Five Freedoms. FAWC, London, United Kingdom. Available at: webarchive.nationalarchives.gov.uk/20121007104210/http:/www.fawc.org.uk/freedoms.htm (accessed on 4 February 2021).

6. Webster J. (1995). – Animal welfare: a cool eye towards Eden. Blackwell Science, Oxford, United Kingdom, 284 pp.

7. Mellor D.J. & Beausoleil N.J. (2015). – Extending the 'Five Domains' model for animal welfare assessment to incorporate positive welfare states. *Anim. Welf.,* **24** (3), 241–253. doi:10.7120/09627286.24.3.241.

8. Dawkins M.S. (2017). – Animal welfare and efficient farming: is conflict inevitable? *Anim. Prod. Sci.,* **57** (2), 201–208. doi:10.1071/AN15383.

9. Korte S.M., Olivier B. & Koolhaas J.M. (2007). – A new animal welfare concept based on allostasis. *Physiol. Behav.,* **92** (3), 422–428. doi:10.1016/j.physbeh.2006.10.018.

10. Blokhuis H.J., Veissier I., Miele M. & Jones B. (2010). – The Welfare Quality® project and beyond: safeguarding farm animal well-being. *Acta Agric. Scand. A, Anim. Sci.,* **60** (3), 129–140. doi:10.1080/09064702.2010.523480.

11. Animal Welfare Indicators Project (AWIN) (2015). – AWIN welfare assessment protocol for sheep. AWIN, 72 pp. doi:10.13130/AWIN_sheep_2015.

12. Food and Agriculture Organization of the United Nations (FAO) (2016). – Synthesis: livestock and the Sustainable Development Goals – Global Agenda for Sustainable Livestock. FAO, Rome, Italy, 12 pp. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2016/Panama/FAO-AGAL_synthesis_Panama_Livestock_and_SDGs.pdf (accessed on 26 November 2020).

13. Food and Agriculture Organization of the United Nations (FAO) (2018). – Shaping the future of livestock sustainably, responsibly, efficiently. FAO, Rome, Italy, 20 pp. Available at: www.fao.org/publications/card/en/c/I8384EN/ (accessed on 26 November 2020).

14. United Nations (UN) (2015). – Transforming our world: the 2030 Agenda for Sustainable Development. UN, New York, United States of America, 41 pp. Available at: sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed on 26 November 2020).

15. Cox J. & Bridgers J. (2018). – Why is animal welfare important for sustainable consumption and production? *Perspectives*, issue No. **34**. United Nations Environment Programme, Nairobi, Kenya, 14 pp. Available at: hdl.handle.net/20.500.11822/28159 (accessed on 4 February 2021).

16. Ghislain S. (2019). – Policy brief: animal welfare, trade and sustainable development goals. Eurogroup for Animals, Brussels, Belgium, 28 pp. Available at: www.eurogroupforanimals.org/sites/eurogroup/files/2020-02/E4A-SDG-and-AW_Report_03-2019-screen.pdf (accessed on 26 November 2020).

17. Doyle R.E., Wieland B., Roesel K. & Grace D. (2018). – Animal welfare and the Sustainable Development Goals. PowerPoint presentation. *In* Proc. UFAW 2018: Animal Welfare Across Borders, 25–26 October, Hong Kong, Special Administrative Region of the People's Republic of China. Universities Federation for Animal Welfare (UFAW), Wheathampstead, United Kingdom. Available at: www.slideshare.net/ILRI/animal-welfare-sdgs (accessed on 4 February 2021).

18. Keeling L.J., Tunón H., Olmos Antillón G., Berg C.L., Jones M., Stuardo L., Swanson J., Wallenbeck A., Winckler C. & Blokhuis H. (2019). – Animal welfare and the United Nations Sustainable Development Goals. *Front. Vet. Sci.,* **6**, 336. doi:10.3389/fvets.2019.00336.

19. WorldFish (2020). – WorldFish and the Sustainable Development Goals. WorldFish, Penang, Malaysia. Available at: www.worldfishcenter.org/landing-page/worldfish-and-sustainable-development-goals (accessed on 26 November 2020).

20. International Coalition for Working Equids (ICWE) (2019). – Achieving Agenda 2030: how the welfare of working animals delivers for development. ICWE, 7 pp. Available at: www.icweworkingequids.org/wp-content/themes/icwe/pdf/sdg-brochure.pdf (accessed on 26 November 2020).

21. World Bank (2019). – PovcalNet: an online analysis tool for global poverty monitoring. World Bank, Washington, DC, United States of America. Available at: iresearch.worldbank.org/PovcalNet/home.aspx (accessed on 4 February 2021).

22. Lara E. & Boyland N. (2019). – Fish welfare: an NGO's point of view [in Spanish]. *Derecho Anim.*, **10** (4), 77–84. doi:10.5565/rev/da.462.

23. Miranda C.D., Godoy F.A. & Lee M.R. (2018). – Current status of the use of antibiotics and the antimicrobial resistance in the Chilean salmon farms. *Front. Microbiol.,* **9**, 1284. doi:10.3389/fmicb.2018.01284.

24. De Passillé A. & Rushen J. (2005). – Food safety and environmental issues in animal welfare. *In* Animal welfare: global issues, trends and challenges (A.C.D. Bayvel, S.A. Rahman & A. Gavinelli, eds). *Rev. Sci. Tech. Off. Int. Epiz.,* **24** (2), 757. doi:10.20506/rst.24.2.1599.

25. Vallette D. (2014). – Invisible helpers: women's views on the contributions of working donkeys, horses and mules to their lives. The Brooke, London, United Kingdom, 25 pp. Available at: www.thebrooke.org/sites/default/files/Advocacy-and-policy/Invisible-helpers-voices-from-women.pdf (accessed on 26 November 2020).

26. High Level Panel of Experts on Food Security and Nutrition (HLPE) (2016). – Sustainable agricultural development for food security and nutrition: what roles for livestock? A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. HLPE, Rome, Italy, 140 pp. Available at: www.fao.org/3/a-i5795e.pdf (accessed on 26 November 2020).

27. Zinsstag J., Schelling E., Waltner-Toews D. & Tanner M. (2011). – From "one medicine" to "one health" and systemic approaches to health and well-being. *Prev. Vet. Med.,* **101** (3–4), 148–156. doi:10.1016/j.prevetmed.2010.07.003.

28. García Pinillos R., Appleby M.C., Manteca X., Scott-Park F., Smith C. & Velarde A. (2016). – One welfare – a platform for improving human and animal welfare. *Vet. Rec.,* **179** (16), 412–413. doi:10.1136/vr.i5470.

29. Narrod C., Tiongco M. & Costales A. (2007). – Global poultry sector trends and external drivers of structural change. *In* Poultry in the 21st century: avian influenza and beyond (O. Thieme & D. Pilling, eds). Proc. International Poultry Conference, 5–7 November, Bangkok, Thailand. FAO Animal Production and Health Proceedings No. **9**. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 21–48. Available at: www.fao.org/3/i0323e/i0323e.pdf (accessed on 4 February 2021).

30. More S.J., Hanlon A., Marchewka J. & Boyle L. (2017). – Private animal health and welfare standards in quality assurance programmes: a review and proposed framework for critical evaluation. *Vet. Rec.,* **180** (25), 612. doi:10.1136/vr.104107.

31. Hazell P. & Wood S. (2008). – Drivers of change in global agriculture. *Philos. Trans. Roy. Soc. Lond. B, Biol. Sci.,* **363** (1491), 495–515. doi:10.1098/rstb.2007.2166.

32. Zinsstag J., Bonfoh B., Zinsstag G., Crump L., Alfaroukh I., Abakar M., Kasymbekov J., Baljinnyam Z., Liechti K., Seid M.A. & Schelling E. (2016). – A vision for the future of pastoralism. *In* The future of pastoralism (J. Zinsstag, E. Schelling & B. Bonfoh, eds). *Rev. Sci. Tech. Off. Int. Epiz.,* **35** (2), 693–699. doi:10.20506/rst.35.2.2550.

33. Kristjanson P., Waters-Bayer A., Johnson N., Tipilda A., Njuki J., Baltenweck I., Grace D. & MacMillan S. (2014). – Livestock and women's livelihoods. *In* Gender in agriculture (A. Quisumbing, R. Meinzen-Dick, T. Raney, A. Croppenstedt, J. Behrman & A. Peterman, eds). Springer, Dordrecht, the Netherlands, 209–233. doi:10.1007/978-94-017-8616-4_9.

34. Buller H., Blokhuis H., Jensen P. & Keeling L. (2018). – Towards farm animal welfare and sustainability. *Animals,* **8** (6), 81. doi:10.3390/ani8060081.

35. African Union–Inter-African Bureau for Animal Resources (AU–IBAR) (2017). – Animal welfare strategy in Africa (AWSA). AU–IBAR, Nairobi, Kenya, 32 pp. Available at: worldanimal.net/images/stories/documents/Africa/AWSA.pdf (accessed on 26 November 2020).

36. World Animal Protection (2020). – Animal Protection Index. World Animal Protection, London, United Kingdom. Available at: api.worldanimalprotection.org/ (accessed on 4 February 2021).

37. Pettersson I.C., Weeks C.A., Wilson L.R.M. & Nicol C.J. (2016). – Consumer perceptions of free-range laying hen welfare. *Br. Food J.,* **118** (8), 1999–2013. doi:10.1108/BFJ-02-2016-0065.

38. Tamioso P.R., Rucinque D.S., Miele M., Boissy A. & Molento C.F.M. (2018). – Perception of animal sentience by Brazilian and French citizens: the case of sheep welfare and sentience. *PLoS One,* **13** (7), e0200425. doi:10.1371/journal.pone.0200425.

39. Futureye (2018). – Australia's shifting mindset on farm animal welfare. Futureye, Windsor, Australia, 103 pp. Available at: futureye.com/resources/ (accessed on 4 February 2021).

40. Van Dijk L., Pritchard J.C., Pradhan S.K. & Wells K.L. (2011). – Sharing the load: a guide to improving the welfare of working animals through collective action. Practical Action Publishing, Rugby, United Kingdom, 256 pp. doi:10.3362/9781780440675.000.

41. The Brooke (2019). – Compassionate handling for life. The Brooke, London, United Kingdom, 3 pp. Available at: www.thebrooke.org/sites/default/files/Animal%20Welfare/Compassionate-Handling-for-Life.pdf (accessed on 26 November 2020).

42. Doyle R.E., Lemma M., Mulema A., Wieland B. & Mekonnen M. (2019). – Community conversation on animal welfare: a guide to facilitators. International Livestock Research Institute, Nairobi, Kenya, 34 pp. Available at: cgspace.cgiar.org/bitstream/handle/10568/106206/Animal_welfare_guide.pdf?sequence=4 (accessed on 26 November 2020).

43. Michie S., van Stralen M.M. & West R. (2011). – The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement. Sci.,* **6**, 42. doi:10.1186/1748-5908-6-42.

44. Munoz C.A., Coleman G.J., Hemsworth P.H., Campbell A.J.D. & Doyle R.E. (2019). – Positive attitudes, positive outcomes: the relationship between farmer attitudes, management behaviour and sheep welfare. *PLoS One,* **14** (7), e0220455. doi:10.1371/journal.pone.0220455.

45. Cornish A., Jamieson J., Raubenheimer D. & McGreevy P. (2019). – Applying the behavioural change wheel to encourage higher welfare food choices. *Animals,* **9** (8), 524. doi:10.3390/ani9080524.

46. Sinclair M. & Phillips C.J.C. (2019). – Asian livestock industry leaders' perceptions of the importance of, and solutions for, animal welfare issues. *Animals,* **9** (6), 319. doi:10.3390/ani9060319.

47. Edwards J.D. (2004). – The role of the veterinarian in animal welfare – a global perspective. *In* Proc. Global Conference on Animal Welfare: an OIE initiative. World Organisation for Animal Health (OIE), Paris, France; & European Commission, Brussels, Belgium, 27–32. Available at: www.oie.int/doc/ged/D706.pdf (accessed on 4 February 2021).

48. World Veterinary Association (WVA) (2016). – World Veterinary Association policy on the role of the veterinarian in animal welfare. WVA, Brussels, Belgium, 2 pp. Available at: www.worldvet.org/uploads/docs/wva_position_on_aw_2016.pdf (accessed on 26 November 2020).

49. Bayvel A.C.D. (2004). – Science-based animal welfare standards: the international role of the Office International des Epizooties. *Anim. Welf.,* **13** (Suppl. 1), S163–S169. Available at: www.ingentaconnect.com/content/ufaw/aw/2004/00000013/a00101s1/art00024 (accessed on 4 February 2021).

50. Vieira A.D. & Anthony R. (2020). – Recalibrating veterinary medicine through animal welfare science and ethics for the 2020s. *Animals,* **10** (4), 654. doi:10.3390/ani10040654.

51. Mayer E. (1994). – Animal welfare (well-being), the veterinary profession and Veterinary Services. *In* Animal welfare and Veterinary Services (R. Moss, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **13** (1), 13–30. doi:10.20506/rst.13.1.757.

52. Bayvel A.C.D. & Cross N. (2010). – Animal welfare: a complex domestic and international public-policy issue – who are the key players? *J. Vet. Med. Educ.,* **37** (1), 3–12. doi:10.3138/jvme.37.1.3.

53. World Organisation for Animal Health (OIE) (2012). – OIE recommendations on the competencies of graduating veterinarians ('Day 1 Graduates') to assure national Veterinary Services of quality. OIE, Paris, France, 16 pp. Available at: www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/Vet_Edu_AHG/DAY_1/DAYONE-B-ang-vC.pdf (accessed on 4 February 2021).

54. Mota-Rojas D., Orihuela A., Strappini-Asteggiano A., Cajiao-Pachón M.N., Agüera-Buendía E., Mora-Medina P., Ghezzi M. & Alonso-Spilsbury M. (2018). – Teaching animal welfare in veterinary schools in Latin America. *Int. J. Vet. Sci. Med.,* **6** (2), 131–140. doi:10.1016/j.ijvsm.2018.07.003.

55. De Briyne N., Vidovi- J., Morton D.B. & Magalhães-Sant'Ana M. (2020). – Evolution of the teaching of animal welfare science, ethics and law in European veterinary schools (2012–2019). *Animals*, **10** (7), 1238. doi:10.3390/ani10071238.

56. World Organisation for Animal Health (OIE) (2019). – OIE curricula guidelines for veterinary paraprofessionals. OIE, Paris, France, 56 pp. Available at: www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/docs/pdf/AF-CoreCV-ANG.pdf (accessed on 26 November 2020).

57. Arkow P. (1998). – Application of ethics to animal welfare. *Appl. Anim. Behav. Sci.,* **59** (1–3), 193–200. doi:10.1016/S0168-1591(98)00133-6.

58. Kipperman B.S. (2015). – The role of the veterinary profession in promoting animal welfare. *JAVMA,* **246** (5), 502–504. doi:10.2460/javma.246.5.502.

59. Whiting T.L., Brennan S.C. & Wruck G.C. (2006). – The veterinary profession's role in policing animal welfare. *Can. Vet. J.,* **47** (11), 1065–1072. Available at: www.ncbi.nlm.nih.gov/pmc/articles/PMC1624913/ (accessed on 8 June 2021).

60. Vapnek J. & Chapman M.S. (2010). – Legislative and regulatory options for animal welfare. FAO Legislative Study No. **104**. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 34 pp. Available at: www.fao.org/3/i1907e/i1907e01.pdf (accessed on 4 February 2021).

61. Molomo M. & Mumba T. (2014). – Drivers for animal welfare policies in Africa. *In* Animal welfare: focusing on the future (D.J. Mellor & A.C.D. Bayvel, eds). *Rev. Sci. Tech. Off. Int. Epiz.,* **33** (1), 47–53. doi:10.20506/rst.33.1.2265.

62. Sinclair M., Zito S., Idrus Z., Yan W., van Nhiem D., Lampang P.N. & Phillips C.J.C. (2017). – Attitudes of stakeholders to animal welfare during slaughter and transport in SE and E Asia. *Anim. Welf.,* **26** (4), 417–425. doi:10.7120/09627286.26.4.417.

63. Rohlf V.I. (2018). – Interventions for occupational stress and compassion fatigue in animal care professionals – a systematic review. *Traumatology,* **24** (3), 186–192. doi:10.1037/trm0000144.

64. Figley C.R. & Roop R.G. (2006). – Compassion fatigue in the animal-care community. Humane Society Press, Washington, DC, United States of America, 139 pp. Available at: www.wellbeingintlstudiesrepository.org/ebooks/5/ (accessed on 4 February 2021).

65. Garnett T., Appleby M.C. [...] & Godfray H.C.J. (2013). – Sustainable intensification in agriculture: premises and policies. *Science,* **341** (6141), 33–34. doi:10.1126/science.1234485.

66. Willett W., Rockström J. [...] & Murray C.J.L. (2019). – Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. *Lancet,* **393** (10170), 447–492. doi:10.1016/S0140-6736(18)31788-4.

67. Granquist E.G., Vasdal G., de Jong I.C. & Moe R.O. (2019). – Lameness and its relationship with health and production measures in broiler chickens. *Animal,* **13** (10), 2365–2372. doi:10.1017/S1751731119000466.

68. Condon J. (2020). – Bushfire livestock loss estimates downgraded. *Beef Central*, 23 January 2020. Available at: www.beefcentral.com/news/bushfire-livestock-loss-estimates-downgraded/ (accessed on 26 November 2020).

69. Pearson L. & Pelling M. (2015). – The UN Sendai Framework for Disaster Risk Reduction 2015–2030: negotiation process and prospects for science and practice. *J. Extreme Events,* **2** (1), 1571001. doi:10.1142/S2345737615710013.

70. Watson C. (2011). – Protecting livestock, protecting livelihoods: the Livestock Emergency Guidelines and Standards (LEGS). *Pastoralism,* **1**, 9. doi:10.1186/2041-7136-1-9.

71. World Organisation for Animal Health (OIE) (2019). – Situational updates of ASF in Asia and the Pacific. OIE, Tokyo, Japan. Available at: rr-asia.oie.int/en/projects/asf/situational-updates-of-asf/ (accessed on 4 February 2021).

72. The Brooke (2020). – Action for animal health. The Brooke, London, United Kingdom. Available at: www.actionforanimalhealth.org (accessed on 26 November 2020).

73. Kevany S. (2020). – Millions of US farm animals to be culled by suffocation, drowning and shooting. *Guardian*, 19 May, 2020. Available at: www.theguardian.com/environment/2020/may/19/millions-of-us-farm-animals-to-be-culled-by-suffocation-drowning-and-shooting-coronavirus (accessed on 26 November 2020).

74. Mutua B.M. (2018). – Challenges facing indigenous chicken production and adoption levels of biosecurity measures in selected areas of Makueni County, Kenya. MSc thesis. South Eastern Kenya University, Kitui, Kenya, 136 pp. Available at: 41.89.55.71/bitstream/handle/123456789/4126/Mutua_Challenges%20facing%20indigenous%20chicken%20production%20and%20adoption%20levels%20of%20biosecurity%20measures%20in%20selected%20areas%20of%20Makueni%20county%2C%20Kenya.pdf?sequence=1&isAllowed=y (accessed on 26 November 2020).

How can we realise the full potential of animal health systems for delivering development and health outcomes?

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Summary

Animal health services play an essential role in supporting livestock production, with the potential to address the challenges of hunger, poverty, health, social justice and environmental health as part of the path towards the Sustainable Development Goal (SDG) defined in the United Nations, 2030 Agenda. However, the provision of animal health services remains chronically underfunded. Although the aspiration that 'no one will be left behind' is core to the SDG agenda, animal health service provision still fails to meet the basic needs of many of the poorest livestock owners. This review draws largely on experience from Tanzania and highlights the obstacles to equitable provision of animal health services, as well as identifying opportunities for improvement. Delivery models that rely on owners paying for services, whether through the private sector or public–private partnerships, can be effective for diseases that are of clear economic importance to animal keepers, particularly in more market-orientated production systems, but are currently constrained by issues of access, affordability, availability and quality. Substantial challenges remain when attempting to control diseases that exert a major burden on animal or human health but are less well recognised, as well as in the delivery of veterinary public health or other public good interventions. Here, the authors propose solutions that focus on: improving awareness of the potential for animal health services to address the SDGs, particularly those concerning public and environmental health; linking this more explicitly with advocacy for increased investment; ensuring that the voices of stakeholders are heard, particularly those of the rural poor; and embracing a cross-cutting and expanded vision for animal health services to support more adaptive development of livestock systems.

Keywords

Agro-pastoral – Animal health sciences – Animal health services – Pastoral – Sustainable development goals – Tanzania – Veterinary public health – Veterinary Services.

Introduction

Livestock are central to the lives and livelihoods of millions of the rural poor in low- and middle-income countries. In Tanzania, for example, 60% of rural households derive income from livestock, which comprises 22% of total household income (1). However, livestock fulfil multiple additional roles, providing nutritious animal-source protein, social capital, household insurance, and manure for soil fertilisation, as well as the security to pursue potentially riskier activities, such as crop production, that rely on rainfall. Supporting livestock production among the poor can provide an important route towards sustainable development, equitable livelihoods, and household health and welfare, as shown in this issue of the *Review* and elsewhere (2).

https://doi.org/10.20506/rst.40.2.3239

The World Organisation for Animal Health (OIE) describes Veterinary Services as 'a global public good playing a vital role in the security and the economic and social wellbeing of humanity', as well as being of fundamental importance for countries engaging in international trade (3, 4). In many countries, the capacity for public good Veterinary Services has diminished over past decades with resources dwarfed by those available for human public health services. Within agriculture, which itself receives relatively little international development, animal health has also been neglected, with livestock production receiving only a very small proportion of the total global development assistance for agriculture (5).

Structural adjustment policies that emphasise private-sector delivery models have undoubtedly contributed to a reduction in the capacity of animal health services over past decades. These models have not been effective in meeting the needs of the poor (6), yet, despite long-standing warnings of the problem and growing advocacy for investment in Veterinary Services (4), the problems remain entrenched.

The broad and cross-cutting elements of the Sustainable Development Goals (SDGs) provide an important opportunity for an expanded and more integrated vision for animal health services. They also represent a chance to realise the huge untapped potential for animal health services to address the challenges of hunger, poverty, health, social justice, climate and environmental degradation (2, 4). However, these problems are multi-dimensional and the linkages with animal health are often complex. The extent to which animal health services can effectively contribute to meeting SDG targets depends on interacting social, economic, environmental and political factors that affect the demand for, access to and quality of services, and these still need to be better understood.

Core to the sustainable development agenda is the aspiration that 'no one will be left behind', which is reflected in the SDG target on universal health coverage (7). Although it is well understood that the health of millions of the world's poorest people is dependent on animal health (8, 9), the provision of essential animal health services is rarely considered within this framework. Animal health services are affected by many of the same social, economic and geographic inequities that affect access to human health services, with many of those living in these under-served areas at high risk of being 'left behind'. For many rural populations, the provision of services is beset by challenges arising from remote locations, limited transport infrastructure, lack of cold-chain facilities, reluctance of veterinarians to work in remote areas, and the limited resources available.

Inequities in access to services are also associated with closely linked factors underpinning a higher disease risk among more impoverished and disadvantaged sectors of society, a concept framed as 'structural violence' (10, 11). This is clearly recognised for human diseases, but can also be seen in the human and animal health burden of zoonoses, which falls disproportionately on the billion poorest livestock keepers (12). These intersecting human and animal health inequalities appear closely associated with different agricultural production systems. For example, in Tanzania, communities defined as 'pastoral' and 'agro-pastoral' appear particularly vulnerable to human and animal health problems, with households reporting much higher levels of hunger than those classified as 'smallholder', as well as higher levels of disease and mortality in livestock (13). Fewer than 30% of livestock-keeping households in Tanzania report using animal vaccination (1), with significant heterogeneities in vaccine use across livestock production systems (13).

Recent investments in the livestock sector in eastern Africa have tended to focus on pre-commercial smallholder systems and improved market access to drive agricultural transformation and poverty reduction (14). These models aim to address the problems of economic sustainability that often beset state- or donor-funded programmes, but are less able to support subsistence-orientated and traditional production systems, which almost by definition include the poorest livestock keepers. Furthermore, over-reliance on approaches based on market access could divert attention from the need for investments in public Veterinary Services that could deliver on a broader range of animal health and SDG outcomes.

This paper examines challenges and constraints in the provision of animal health services, focusing on eastern Africa and drawing particularly on experiences from Tanzania. The authors also attempt to identify solutions with relevance not only for this region but for other low- and middle-income countries that are facing similar challenges. The terms 'Veterinary Services' and 'animal health services' are often used interchangeably. In this paper, the term 'Veterinary Services' is used to mean the predominantly state-funded responsibility for veterinary public health, food safety, disease control and trade (15). The authors use 'animal health services' to encompass the entire provision of services, products and advice by veterinarians or other personnel to do with animal or veterinary public health, including husbandry, nutrition and fertility. However, as the examples below illustrate, this distinction is not always clear.

Who provides animal health services?

Privatisation and cost-recovery systems for animal health services began abruptly in many countries in the mid-

1980s, triggered by the adoption of structural adjustment programmes. These were based on the premise that animal health costs that predominantly provide a private good, such as endemic disease control, should be borne by livestock keepers and that privatisation would bring benefits in the quality and coverage of services (16). The reduction in government-funded support created a gap that the private sector was expected to fill. However, with little transition period or incentivisation to enable this process, the degree to which the private sector has developed has varied. Privatisation has proved a successful model of delivery in several systems and settings, including more intensive livestock production systems (17) and smallholder dairy (18); however, the benefits for the poor have been variable (19).

In most current models, animal health services are provided by both the private and state sector. State veterinarians primarily have responsibility for the centrally funded prevention and control of diseases that have the potential to result in high production losses, affect the export trade, or pose a threat to public health and food safety, as well as for animal disease surveillance. State veterinarians are assisted by livestock extension workers: government-registered para-professionals who also provide advice to livestock keepers on wider animal health. Private veterinarians may provide advice directly for a fee, but more commonly generate income from drug sales. In reality, the boundaries between private and state-funded services are often blurred, with state veterinarians and livestock extension workers also offering private services (18).

Despite these provisions, livestock keepers in rural areas still struggle to access services from qualified animal health professionals (20, 21); the Tanzanian government estimates that only 20% of livestock keepers are able to obtain extension services (22). The number of veterinary professionals in Africa is extremely low and the deficit in rural areas is particularly acute, with most private veterinarians preferring to work in urban areas and challenges facing state Veterinary Services in retaining veterinary expertise in rural areas (17, 21). Livestock extension workers commonly represent the only source of professional advice available (23), but even then, access is difficult. For example, in Simanjiro District, Tanzania, the ratio of veterinary personnel (veterinary officer and livestock extension workers) to livestock is 1:22,000, with each person serving an area of over 600 km^2. This far exceeds the recommended targets of 1:10,000, or 200 km^2, set by the Veterinary Council of Tanzania (24). Lack of personnel means that extension workers trained in agriculture (crop production) rather than livestock health often provide livestock extension services (23, 25). A review of health-seeking behaviours in response to livestock illness in northern Tanzania revealed that livestock keepers are largely treating animals themselves, primarily due to the inaccessibility of formal services (A. Davis, unpublished data).

Given the scarcity of animal health service provision from veterinarians and extension workers, it is not surprising that many livestock farmers cite agro-veterinary shops as their main source of information on animal health (26, 27). Animal keepers frequently purchase drugs from these shops, other shops or livestock markets. However, this does not adequately fill the gaps in provision of either veterinary products or advice. In remote areas, animal keepers may incur significant transport costs to access these sources, which often have low choice and poor availability (23). Staff selling drugs are not always qualified, with animal health professionals making up only 40% of staff in agro-veterinary shops and 0% at other outlets in a study in Kenya (27). In pastoral and agro-pastoral areas of Kenya and Tanzania, animal owners cite the unavailability of commercial medicines and the lack of veterinary services as the major constraint on animal health (23, 27, 28).

It is important to note that lack of resources to pay for drugs, diagnostics or other services is rarely cited by animal keepers as the most important limitation on accessing animal health services; animal owners, even those in subsistence-orientated production systems, are willing to invest in animal health. For example, livestock keepers in tsetse-infested areas spend a substantial amount of money on trypanocides and insecticides, but the efficacy of trypanosomosis control is limited by poor availability and choice of drugs and lack of access to trained personnel for advice (Box 1). East Coast fever vaccination has been reported by 39% of pastoral farmers in Kenya (29). Willingness-to-pay studies in Tanzania demonstrate the demand for vaccines against diseases perceived to be important, including foot and mouth disease (30) and malignant catarrhal fever (31), with decision-making strongly influenced by vaccine efficacy and safety, and trust in the vaccine providers. A recent study of agro-pastoralists also highlighted the importance of trust, revealing that past negative experiences, such as animals becoming sick after vaccination, represented a particular cause for mistrust (32). Mistrust is likely to represent a major barrier to uptake of animal health services but is poorly understood.

International and government animal health policies have long advocated strengthening the private sector to support the livestock sector, including the establishment of public–private partnerships, as existing government resources are too limited for effective delivery of animal health services. These models span several different typologies which address a wide range of challenges and draw on a range of private-sector capacities, for example, technical expertise, equipment and resources (34). Several successful public–private partnerships are helping to address market failures by subsidising research and development and improving

Box 1
Will the same old problems limit the potential of new drugs? Controlling animal African trypanosomosis

Animal African trypanosomosis (AAT) remains a major constraint on livestock health in the large parts of sub-Saharan Africa where the tsetse fly vector (*Glossina*) persists. Livestock keepers commonly use trypanocides and insecticides to prevent and treat trypanosome infections in their livestock. This has added benefits in reducing the transmission of human African trypanosomosis (33).

Livestock keepers can purchase trypanocides without restriction, and most commonly buy them from agro-veterinary shops or from stalls at livestock markets. While there are government guidelines on trypanocide use, many people do not receive any advice from livestock extension officers. In tsetse fly areas, the use of trypanocides and treatment of AAT is frequently cited as the area of animal health where livestock keepers would most like to be better informed. Lack of veterinary services and unavailability of drugs were the two most commonly cited concerns by farmers about AAT control (28), rather than lack of resources to pay for it. Indeed, whilst there is a lack of data on relative expenditure, it is clear that many farmers are spending a substantial amount of money on trypanocides.

Since diagnostics are very rarely available, the use of trypanocides depends on a livestock keeper's ability to correctly recognise clinical signs of AAT. Although new 'pen-side' diagnostics are being developed, until they are cheaper than the cost of drugs (a sachet of diminazene diaceturate to treat one adult cow costs less than US$ 0.50), they will not be widely adopted. Livestock keepers frequently report treatment failure. Inappropriate treatment (i.e. where the animal did not have AAT), incorrect administration and resistance are all known to occur but their relative contributions to treatment failure have not been quantified.

Livestock keepers are heavily dependent on trypanocides and the current investment in candidates for new drug development is essential and welcome. However, the current challenges of ineffective usage, lack of information and poor availability will need to be addressed to maximise the potential benefits of any new drugs.

access of small-scale livestock farmers to quality animal health products. Projects supported by organisations such as GALVmed (www.galvmed.org), with funding from government and non-governmental organisation (NGO) donors, address market failures by reducing the financial risk from the research and development of animal health products for use in low-income countries and developing commercial markets. This approach aims at sustainable delivery of animal health services, with products purchased by small-scale livestock producers at market prices. Several such projects have resulted in notable improvements in livestock productivity and economic outcomes for small-scale farmers, particularly in the poultry sector (35). Another example is that of Sidai Africa Ltd, a social enterprise in Kenya, where a franchise model provides animal health products and technical advice to farmers and pastoralists. These outlets were found to be run by better-trained staff and to provide a wider range of services and more advice than agro-veterinary shops, and were viewed by smallholder dairy farmers and pastoralists as having improved animal health service provision (27, 36).

Despite encouraging improvements in access to and the quality of animal health services provided through public–private partnership, major gaps remain. In the absence of donor support, the ability of the private sector to deliver veterinary drugs is limited by the complex logistics required to get products into remote areas. High costs and low profit margins, as well as competition from cheap international imports, make investment unappealing. Basic constraints, such as a lack of instructions in local languages, suggest a disinclination of veterinary pharmaceutical companies to engage with rural livestock-keeping communities.

The creation of community animal health workers (CAHWs) was also a donor-led effort to address the institutional vacuum of private-sector delivery in rural areas. Community animal health workers were created with the aim of providing services for the poor, specifically, and to improve community health over all (37). They received training in basic animal health care and carried out a limited range of veterinary tasks for members of the community (38). Community animal health workers were usually local to the area, thus reducing transaction costs, and were livestock keepers themselves. The role of CAHWs remains widely debated. Community animal health workers have been shown to provide accessible, cost-effective animal health services to the rural poor (39) and, in agro-pastoral communities in Tanzania, livestock owners expressed a preference for using CAHWs because of the perception that they possessed adequate knowledge and treatment capabilities, where owners themselves were lacking (32). However, because the training of CAHWs has been primarily a donor-led effort, it has been difficult to sustain. Remaining CAHWs are largely unsupported by state veterinary institutions who do not regard them as viable providers of animal health care, and they are usually overlooked in policy legislation (40, 41). As a result, the potential of CAHWs to provide more equitable access to animal health services in rural areas is hindered by barriers to institutional participation.

Who chooses the priorities?

The efforts of international agencies and donors focus predominantly on transboundary livestock diseases, and those of global public health concern. In regard to zoonoses, highly pathogenic avian influenza and viral haemorrhagic fevers are often prioritised for international investment, whilst national priority-setting exercises for zoonotic diseases consistently identify endemic zoonoses, such as rabies, brucellosis, trypanosomosis and anthrax, as the highest priorities (42, 43, 44). This more broadly reflects the uneven and inequitable aspects of global health, in that the biopolitical concerns of wealthy nations often supersede those of poorer nations, and endemic zoonoses of local concern to communities may be neglected by national authorities who respond more readily to global priorities (41). These global influences, combined with a view that endemic animal diseases can be controlled through private-sector delivery, has meant that national government funding is rarely prioritised to control endemic zoonoses that impose high burdens of disease in the poorest communities (12).

Disease exceptionalism, where specific diseases are singled out for attention and international investment, is a recognised feature of global health. This exceptionalism can have adverse effects on already fragile health systems, and risk diverting attention from strengthening health systems more broadly (45). However, benefits for local health need not be mutually exclusive from those for global health. A focus on tackling locally relevant diseases that are of immediate concern to affected communities has enormous potential for strengthening disease surveillance and response, with benefits for both endemic and emerging disease control (46). Coronavirus disease 2019 (COVID-19) leaves us in no doubt about the need for responsive and flexible health systems to effectively combat complex and emerging disease threats. But these systems cannot be developed through theoretical principles alone. Core competencies and response capabilities have to be established, and the best way to do this may be to tackle disease problems that are an ongoing concern to people in affected communities. For animal-keeping communities, addressing the problems of endemic zoonoses and other animal diseases could be a highly effective starting point for strengthening cross-sectoral capacity for surveillance and response, as well as building trust between health professionals and communities, all of which will be essential in preparing for emerging disease threats.

For example, action to improve rabies surveillance has resulted in more effective engagement of front-line human and animal workers in the detection and reporting of cases, with the deployment of rapid diagnostic tests and development of more integrated data management systems across human and animal health (47). An example of how this capability has been transferred to an emerging disease threat comes from Kenya, where teams with expertise in using contact-tracing to identify rabies cases and human exposures have been at the forefront of developing contact-tracing systems for COVID-19 (48). Improved provision of the human rabies vaccine, and scaling up of mass dog rabies vaccination programmes, the two key actions needed to achieve human rabies elimination (48), could also strengthen capability in many of the critical areas identified by the World Health Organization for improving readiness for COVID-19 vaccination, including planning, procurement and supply-chain management, communications and community engagement (49).

Despite the potential of the private sector for managing animal health problems of direct economic benefit to farmers, this delivery route is unlikely to be effective for veterinary public health or other public good interventions at the scale that would be needed for effective disease control. In low-income countries, it is often advocated that cost recovery should be imposed for the delivery of veterinary interventions to achieve public health outcomes, but this seems paradoxical when zoonoses disproportionately affect the poorest communities, and cost-recovery models have generally not been imposed in high-income settings. For example, the control and elimination of brucellosis has been achieved in Europe through state-supported veterinary interventions or through European Union co-funding initiatives (50). While substantial investments are being made in the research and development of safe and effective brucellosis vaccines for use in low-income countries (brucellosisvaccine.org), little attention has yet been given to how these vaccines will be delivered at scale to achieve public health outcomes. Even if it is assumed that farmers will pay for a product that improves livestock productivity, these approaches are unlikely to be effective for brucellosis as the 'visible' benefits to the family, in terms of both human health and livestock productivity, will be difficult to recognise (51, 52).

Market-led approaches are also less likely to be effective in more subsistence-orientated production systems, including pastoral communities, where the human health burden of brucellosis is particularly high (53, 54, 55). Gaps still remain in our understanding of the epidemiology of *Brucella* species in Africa, but growing evidence suggests that sheep and goats are important sources of transmission in East Africa (56, 57), and this will likely exacerbate the economic and social challenges in delivering large-scale vaccination campaigns. Not only will the lower economic value of sheep and goats constrain farmers' willingness to pay, but farmers' perceptions of disease risk and disease losses in sheep and goats can also differ substantially from those in cattle, with consequences for the uptake of vaccines and other veterinary products.

In human disease elimination programmes, such as polio and measles, it is generally unquestioned that vaccines should be administered to people free of charge. However, many still advocate charging fees for administering dog vaccines for the control and elimination of human rabies. Across these programmes, the goals are the same – elimination of a deadly human disease – and strategies are based on similar interventions involving mass vaccination campaigns. Yet cost recovery for public health vaccination campaigns is only invoked when the intervention involves veterinary service delivery. This may seem to be the only available solution to the scarcity of Veterinary Services when budgets are so limited. But, in low-income settings, imposing charges for dog vaccination has resulted in vaccination coverage that is too low to control rabies (58). Greater investments will be needed if veterinary interventions, such as dog vaccination, are to deliver human health benefits for the poor. In order to make the investment case, in terms of cost-effective health and development outcomes, advocacy from both the Veterinary Services and the medical sector will be essential, building on the strong evidence base available (59).

What are the solutions?

In 2002, the Food and Agriculture Organization of the United Nations wrote: 'there is increasing realization that a balance needs to be struck between developing a robust private veterinary sector [and] providing animal healthcare services to the vulnerable poor groups' (60). While the issues discussed here are clearly not new, there is little evidence that the provision of animal health services to the rural poor has improved since this was written, despite significant investment in other aspects of animal health. Veterinary Services remain significantly under-resourced (4) and the gaps in service provision are not filled by the private sector. The case for investment is clear, with positive returns through the benefits to animal and public health, animal welfare, reduction of poverty and facilitating trade, as well as a wide range of societal benefits (4), although there is a need for more data to better quantify the trans-sectoral nature of these benefits. However, the lack of access to animal health services in rural poor communities is widespread.

This issue is not addressed effectively by current livestock policies. To meet global demands on food security, emphasis is placed on intensification and modernisation of livestock production, often assuming that strategies should follow those in industrialised countries. However, global attention is now shifting towards more environmentally sustainable livestock production, such as agroforestry and silvo-pastoral systems (61). This provides an important opportunity to examine assumptions around the optimal trajectory for the development of livestock systems in Africa.

Policies for intensification and modernisation often also include strategies for genetic improvement. While these investments are likely to yield important benefits in some sectors, such as dairy production, the more critical need in subsistence-orientated sectors is to address the huge unmet demand to support the basics of livestock production, including primary animal health services (62). Cattle herds in traditional systems in East Africa are already managed to maintain diversity in key traits that balance productivity and adaptability, which is needed if herds are to survive in precarious and highly variable environments (63). As climate becomes increasingly unpredictable in East Africa (64), strategies for maintaining herd diversity will become ever more important.

In developing appropriate models for livestock modernisation in East Africa, there needs to be a better understanding of where and how benefits accrue, but also a greater appreciation of the values and benefits provided by more traditional production systems (65), particularly those which address the social and environmental dimensions of the SDGs. Rather than being constrained to deliver only within preconceived pathways of livestock development, animal health services could play a vital role in facilitating and supporting ongoing adaptation and, potentially, the emergence of new systems of production.

To better encompass these wider aspects of animal health service provision, the authors conclude that considering these services within the framework of 'animal health systems' would be helpful. Animal health systems are defined as: 'the organisation of people, institutions and resources that deliver healthcare services to animals and their owners [that]…includes animal health practitioners (veterinarians and veterinary paraprofessionals), veterinary medicines, surveillance and diagnostics of disease as well as the legal framework and financing of health services' (66). This also provides the animal health sector with a useful parallel to the more recognised dialogue around strengthening human health systems, and may be valuable in promoting discussion around the real needs of livestock-dependent communities for access to animal health services.

In identifying solutions that provide more equitable access to services, particularly in supporting the essential health and welfare needs of the most vulnerable livestock-dependent communities, there is a need to:

– recognise the full scope of the potential contribution of animal health systems to development and become advocates for increased investment

– expand the vision for animal health services

– ensure that efforts to improve the private-sector provision of animal health services bring benefits to poor communities

– increase awareness of the demand for animal health services from affected communities

– increase recognition of opportunities for private veterinarians within state- or donor-funded programmes.

Recognising the potential contribution of animal health systems to development

Experience has shown that animal health services cannot be adequately provided to the rural poor by the private sector. Yet, the provision of essential animal health services must improve if livestock-dependent communities are to achieve basic nutritional and health needs, analogous to universal healthcare coverage. The Abuja Declaration of 2001 set targets for all African nations to invest 15% of their national budget into the health sector (67). While translating increased investment into increased healthcare coverage remains challenging, this high-level advocacy has had some success (68). The case for investing in animal health services is clear; similar incentives to encourage and commit to investment are needed.

Expanding the vision for animal health services

Supporting animal health provision is a good candidate for donor programmes, and public–private partnerships have had some success in enhancing access to animal health services and improving their quality. But an adapted and expanded vision of health service provision could be considered to better meet the needs of the poorest farmers within subsistence-orientated livestock systems. Including more holistic views of animal health, rather than focusing on single disease interventions, and working with local knowledge/belief systems, where appropriate, would help to address a broader suite of SDGs. More inclusive discussions around appropriate pathways for livestock development that draw on expertise and experience from other sectors, actors and disciplines would enable better adaptation of animal health systems in response to environmental, economic and social change.

Ensuring that efforts to improve private-sector provision of animal health services bring benefits to poor communities

Efforts are being made to address obstacles to market access, including building regulatory capacity, encouraging market entry and investment, and promoting the registration of products, particularly through collaborations between industry, non-governmental organisations and the research sector. These projects focus on removing the barriers to animal health investment in Africa. However, further consideration is needed to understand and address the constraints that limit the poor's access to markets, particularly in rural areas, to avoid perpetuating current inequalities. Efforts to recognise CAHWs and their role in providing animal health services to the rural poor could prove beneficial here.

Increasing awareness of the demand for animal health services from affected communities

Making sure that the voices of people in affected communities, particularly the rural poor, are heard by policy-makers is important in ensuring that the services provided are appropriate and available. This would be strengthened by encouraging the grassroots engagement of veterinary policy-makers with the problems that affect rural communities, and facilitating the involvement of local and regional authorities in programmes that generate tangible benefits, which are recognised and appreciated by these communities.

Increasing recognition of opportunities for private veterinarians within state- or donor-funded programmes

The delivery of mass dog rabies vaccination campaigns is an example of the large untapped potential for private veterinarians to engage with donor- or state-funded programmes to improve primary animal health care. Although there is a widespread perception that free delivery of dog rabies vaccines could undermine private animal health services, the opposite is likely to be true. Dog vaccination campaigns provide opportunities for private veterinarians to access and develop potential markets, since many dog owners attending such campaigns are likely to be interested in primary healthcare services that could be offered through the private sector.

To conclude, despite their potential to improve animal and public health outcomes, animal health systems suffer from chronic under-investment and inequitable access. Opportunities exist for action and investment but these must be prioritised to ensure that animal keepers in under-served communities are not 'left behind'.

Acknowledgements

H. Auty's research on trypanosomosis is supported by the United Kingdom (UK) Biotechnology and Biological Sciences Research Council (BB/S000143/2), the UK Zoonoses and Emerging Livestock Systems (ZELS) initiative (BB/S01375X/1), and the Soulsby Foundation. S. Cleaveland, E. Swai, A. Davis, J. Virhia, W. de Glanville, F. Lankester, T. Kibona and G. Shirima were supported by the ZELS initiative (grants BB/L018926/1, BB/S0103857/1 and BB/N503563/1) and G. Shirima by the ZELS brucellosis project (BB/J010367). F. Lankester's rabies research is funded by the Department of Health and Human Services of

the National Institutes of Health (R01AI141712) and MSD Animal Health. Research was approved through ethical clearance certificate 2028 (NIMR/HQ/R.8a/vol. ix/2028) and the Tanzania Commission for Science and Technology (Ref: 2019-103-NA-2005-141). This paper is the result of many discussions with colleagues from across the ZELS programme, with particular thanks to Dr Jo Halliday for inputs on brucellosis control and to the Social, Economic and Environmental Drivers of Zoonoses in Tanzania team, particularly Prof. Jo Sharp, Dr John Claxton, Prof. John Crump and Prof. Blandina Mmbaga, for wide-ranging insights on equitable delivery of animal health services and public health interventions. The content is solely the responsibility of the authors and does not necessarily represent the official views of any of the funders mentioned. This paper was published with permission from the Director of Veterinary Services and the National Institute for Medical Research, Tanzania.

Comment réaliser tout le potentiel des systèmes de santé animale afin de contribuer avec des résultats tangibles au développement et à la santé ?

H. Auty, E. Swai, J. Virhia, A. Davis, W.A. de Glanville, T. Kibona, F. Lankester, G. Shirima & S. Cleaveland

Résumé

Les services de santé animale accomplissent une fonction essentielle en faveur de la production animale tout en ayant un potentiel d'action pour relever les défis de la faim, de la pauvreté, de la santé, de la justice sociale et de la santé dans la perspective des objectifs de développement durable (ODD) définis dans l'Agenda 2030 des Nations Unies. Toutefois, la prestation de services de santé animale souffre d'un sous-financement chronique. Bien que l'aspiration de « ne laisser personne pour compte » soit au cœur du programme des ODD, à ce jour la prestation de services de santé animale ne parvient pas encore à répondre aux besoins fondamentaux de nombreux propriétaires de bétail parmi les plus pauvres. Les auteurs s'appuient largement sur l'expérience de la Tanzanie pour mettre en évidence les obstacles à une prestation équitable de services de santé animale, et relever des perspectives d'amélioration. Les modèles de prestation assurés dans le cadre du secteur privé ou de partenariats public-privé et reposant sur le paiement des services par les propriétaires se révèlent efficaces lorsqu'il s'agit de maladies qui ont une importance économique évidente pour les détenteurs d'animaux, en particulier dans les systèmes de production orientés vers le marché, mais ils sont actuellement limités par des problèmes d'accès, de coût, de disponibilité de l'offre et de qualité. Des difficultés encore plus grandes subsistent lorsqu'il s'agit de lutter contre des maladies moins connues bien qu'ayant un impact important sur la santé animale ou humaine, ou d'assurer des services de santé publique vétérinaire ou d'autres interventions relevant du bien public. Les auteurs proposent des solutions centrées sur : une meilleure sensibilisation concernant le potentiel des services de santé animale à réaliser les ODD, en particulier ceux qui portent sur la santé publique et la santé environnementale ; la mise en place de liens plus explicites avec les plaidoyers en faveur d'investissements accrus ; des mesures garantissant que les voix de toutes les parties prenantes soient entendues, en particulier celles des pauvres

du monde rural ; l'adoption d'une stratégie transversale et de grande ampleur pour les services de santé animale en faveur d'un développement plus adaptatif des systèmes d'élevage.

Mots-clés
Agropastoralisme – Objectifs de développement durable – Pastoralisme – Santé publique vétérinaire – Science de la santé animale – Services de santé animale – Services vétérinaires – Tanzanie.

¿Cómo aprovechar al máximo el potencial de los sistemas de sanidad animal para obtener resultados sanitarios y de desarrollo?

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Resumen
Los servicios de sanidad animal cumplen una esencial función de apoyo a la producción ganadera, potencialmente útil para abordar problemas relacionados con el hambre, la pobreza, la salud, la justicia social y la salud ambiental como parte del camino hacia los Objetivos de Desarrollo Sostenible (ODS) marcados en la Agenda 2030 de las Naciones Unidas. Sin embargo, la prestación de servicios zoosanitarios está lastrada por un déficit crónico de financiación. Aunque en la base misma de los ODS late la aspiración de «no dejar a nadie atrás», la prestación estos servicios aún no alcanza para responder a las necesidades básicas de muchos de los propietarios de ganado más pobres. Los autores, basándose principalmente en la experiencia de Tanzania, destacan los obstáculos que dificultan una prestación equitativa de servicios zoosanitarios y señalan las posibilidades existentes para progresar al respecto. Los modelos de prestación que requieren que el propietario pague por los servicios recibidos, ya sea del sector privado o de alianzas publicoprivadas, pueden resultar eficaces en el caso de enfermedades que revisten una clara importancia económica para los productores, especialmente en sistemas productivos con una marcada orientación comercial, aunque actualmente se ven lastrados por problemas de acceso, asequibilidad, disponibilidad y calidad. Por otro lado, subsisten dificultades de gran calado a la hora de combatir enfermedades menos reconocidas, aunque estas entrañen una pesada carga sanitaria o zoosanitaria, y también a la hora de implantar medidas de salud pública veterinaria u otras intervenciones de interés público. Los autores proponen soluciones centradas en: dar mejor a conocer el potencial que encierran los servicios de sanidad animal para perseguir los ODS, sobre todo los relacionados con la salud pública y ambiental; vincular más explícitamente esto último a la labor de sensibilización para lograr inversiones más cuantiosas; hacer oír la voz de todos los interesados, en especial la de los pobres de zonas rurales; y adoptar una visión más amplia y transversal de los servicios zoosanitarios para favorecer un desarrollo más flexible de los sistemas ganaderos.

Palabras clave
Agropastoral – Ciencias de la sanidad animal – Objetivos de Desarrollo Sostenible – Pastoral – Salud pública veterinaria – Servicios Veterinarios – Servicios zoosanitarios – Tanzania.

References

1. Covarrubias K., Nsiima L. & Zezza A. (2012). – Livestock and livelihoods in rural Tanzania: a descriptive analysis of the 2009 National Panel Survey [English]. World Bank Group, Washington, DC, United States of America, 57 pp. Available at: documents.worldbank.org/curated/en/141341468132878632/Livestock-and-livelihoods-in-rural-Tanzania-a-descriptive-analysis-of-the-2009-national-panel-survey (accessed on 3 March 2021).

2. Food and Agriculture Organization of the United Nations (FAO) (2018). – World livestock: transforming the livestock sector through the Sustainable Development Goals. FAO, Rome, Italy, 228 pp. Available at: www.fao.org/3/CA1201EN/ca1201en.pdf (accessed on 3 March 2021).

3. Thomson G.R., Tambi E.N., Hargreaves S.K., Leyland T., Catley A., van't Klooster G.G.M. & Penrith M.L. (2004). – International trade in livestock and livestock products: the need for a commodity-based approach. *Vet. Rec.*, **155** (14), 429–433.

4. World Organisation for Animal Health (OIE) (2019). – Strengthening Veterinary Services through the OIE PVS Pathway: the case for engagement and investment. OIE, Paris, France, 40 pp. Available at: www.oie.int/fileadmin/Home/eng/Media_Center/docs/pdf/SG2018/PVS_BUSINESS_CASE_FINAL.pdf (accessed on 3 March 2021).

5. Pradère J.-P. (2014). – Improving animal health and livestock productivity to reduce poverty. *Rev. Sci. Tech. Off. Int. Epiz.*, **33** (3), 735–744. doi:10.20506/rst.33.3.2315.

6. Perry B.D. & Sones K. (2008). – Strengthening demand-led animal health services in pastoral areas of the IGAD region. Intergovernmental Authority on Development (IGAD) Livestock Policy Initiative (LPI) Working Paper No. **09–08**. Food and Agriculture Organization of the United Nations, Rome, Italy, 24 pp. Available at: www.researchgate.net/profile/Brian-Perry-5/publication/242153272_Strengthening_Demand-Led_Animal_Health_Services_in_Pastoral_Areas_of_the_IGAD_Region/links/00b7d51d82f6022fc8000000/Strengthening-Demand-Led-Animal-Health-Services-in-Pastoral-Areas-of-the-IGAD-Region.pdf (accessed on 3 March 2021).

7. United Nations (UN) (2015). – Transforming our world: the 2030 Agenda for Sustainable Development. UN, New York, United States of America, 41 pp. Available at: sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (accessed on 3 March 2021).

8. Herrero M., Grace D., Njuki J., Johnson N., Enahoro D., Silvestri S. & Rufino M.C. (2013). – The roles of livestock in developing countries. *Animal*, **7** (Suppl. 1), S3–S18. doi:10.1017/S1751731112001954.

9. Thornton P.K. (2010). – Livestock production: recent trends, future prospects. *Philos. Trans. Roy. Soc. Lond., B, Biol. Sci.*, **365** (1554), 2853–2867. doi:10.1098/rstb.2010.0134.

10. Farmer P. (2001). – Infections and inequalities: the modern plagues. University of California Press, Berkeley, United States of America, 424 pp. Available at: www.ucpress.edu/book/9780520229136/infections-and-inequalities (accessed on 3 March 2021).

11. Farmer P. (2004). – Pathologies of power: health, human rights, and the new war on the poor. University of California Press, Berkeley, United States of America, 438 pp. Available at: www.ucpress.edu/book/9780520243262/pathologies-of-power (accessed on 3 March 2021).

12. Grace D., Mutua F. […] & Ogutu F. (2012). – Mapping of poverty and likely zoonoses hotspots. Zoonoses Project **4**. Report to the UK Department for International Development. International Livestock Research Institute, Nairobi, Kenya, 119 pp. Available at: hdl.handle.net/10568/21161 (accessed on 3 March 2021).

13. de Glanville W.A., Davis A. […] & Cleaveland S. (2020). – Classification and characterisation of livestock production systems in northern Tanzania. *PLoS One*, **15** (12), e0229478. doi:10.1371/journal.pone.0229478.

14. Kilelu C., Klerkx L., Omore A., Baltenweck I., Leeuwis C. & Githinji J. (2017). – Value chain upgrading and the inclusion of smallholders in markets: reflections on contributions of multi-stakeholder processes in dairy development in Tanzania. *Eur. J. Dev. Res.*, **29** (5), 1102–1121. doi:10.1057/s41287-016-0074-z.

15. World Organisation for Animal Health (OIE) (2015). – Veterinary Services. OIE, Paris, France, 23 pp. Available at: www.oie.int/fileadmin/Home/eng/Media_Center/docs/pdf/VS-FINAL-EN.pdf (accessed on 3 March 2021).

16. Umali D.L., Feder G. & de Haan C. (1994). – Animal health services: finding the balance between public and private delivery. *World Bank Res. Obs.*, **9** (1), 71–96. doi:10.1093/wbro/9.1.71.

17. Ilukor J., Birner R., Rwamigisa P.B. & Nantima N. (2015). – The provision of veterinary services: who are the influential actors and what are the governance challenges? A case study of Uganda. *Exp. Agric.*, **51** (3), 408–434. doi:10.1017/S0014479714000398.

18. Oruko L.O., Upton M. & McLeod A. (2000). – Restructuring of animal health services in Kenya: constraints, prospects and options. *Dev. Policy Rev.*, **18** (2), 123–138. doi:10.1111/1467-7679.00103.

19. Ahuja V. (2004). – The economic rationale of public and private sector roles in the provision of animal health services. *In* Veterinary institutions in the developing world: current status and future needs (C. de Haan, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **23** (1), 33–45. doi:10.20506/rst.23.1.1464.

20. Zablon K.L. (2014). – Animal health governance and services: a case of pastoralists in Ngorongoro District, Tanzania. Master's thesis. Sokoine University of Agriculture, Morogoro, Tanzania, 103 pp. Available at: publicationslist.org/data/malaysian_journal_of_medical.biological_research/ref-21/3.1%20Thesis.pdf (accessed on 3 March 2021).

21. Makundi A.E., Mchuni M.N. & Sultan J. (2012). – Studies on animal health delivery systems in pastoral areas in Manyara, Tanzania. *Huria J. Open Univ. Tanzan.,* **10** (1), 43–53. Available at: www.ajol.info/index.php/huria/article/view/110855 (accessed on 3 March 2021).

22. Ministry of Livestock and Fisheries Development (2015). – Tanzania Livestock Modernisation Initiative. Ministry of Livestock and Fisheries Development, Dodoma, United Republic of Tanzania, 40 pp. Available at: agriprofocus.com/upload/post/Tanzania_Livestock_Modernization_Initiative1437567817.pdf (accessed on 3 March 2021).

23. Gustafson C.R., VanWormer E., Kazwala R., Makweta A., Paul G., Smith W. & Mazet J.A.K. (2015). – Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania. *Pastoralism*, **5**, 1. doi:10.1186/s13570-014-0022-5.

24. Swai E.S. & Masaaza S. (2012). – Where there is no conventional veterinary health delivery services what are the capabilities of community animal health workers? *Livest. Res. Rural Dev.*, **24** (7), 114. Available at: www.lrrd.org/lrrd24/7/swai24114.htm (accessed on 3 March 2021).

25. Ilukor J. (2017). – Improving the delivery of veterinary services in Africa: insights from the empirical application of transaction costs theory in Uganda and Kenya. *In* The economics of animal health (J. Rushton, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 279–289. doi:10.20506/rst.36.1.2628.

26. Mugambi J.M., Wesonga F.D. & Ndungu S.G. (2012). – Ticks and tick-borne disease control in a pastoral and an agro-pastoral farming systems in Kenya. *Livest. Res. Rural Dev.*, **24** (5), 78. Available at: www.lrrd.org/lrrd24/5/muga24078.htm (accessed on 3 March 2021).

27. Higham L.E., Ongeri W., Asena K. & Thrusfield M.V. (2016). – Characterising and comparing animal-health services in the Rift Valley, Kenya: an exploratory analysis (part I). *Trop. Anim. Hlth Prod.*, **48** (8), 1621–1632. doi:10.1007/s11250-016-1136-0.

28. Ngumbi A.F. & Silayo R.S. (2017). – A cross-sectional study on the use and misuse of trypanocides in selected pastoral and agropastoral areas of eastern and northeastern Tanzania. *Parasit. Vectors*, **10**, 607. doi:10.1186/s13071-017-2544-3.

29. Marsh T.L., Yoder J., Deboch T., McElwain T.F. & Palmer G.H. (2016). – Livestock vaccinations translate into increased human capital and school attendance by girls. *Sci. Adv.*, **2** (12), e1601410. doi:10.1126/sciadv.1601410.

30. Railey A.F., Lembo T., Palmer G.H., Shirima G.M. & Marsh T.L. (2018). – Spatial and temporal risk as drivers for adoption of foot and mouth disease vaccination. *Vaccine*, **36** (33), 5077–5083. doi:10.1016/j.vaccine.2018.06.069.

31. Decker C., Hanley N., Czajkowski M., Morrison T.A., Keyyu J., Munishi L., Lankester F. & Cleaveland S. (2020). – Predicting uptake of a malignant catarrhal fever vaccine by pastoralists in northern Tanzania: opportunities for improving livelihoods and ecosystem health. Working Paper **2020–26**. Faculty of Economic Sciences, University of Warsaw, Warsaw, Poland. Available at: ideas.repec.org/p/war/wpaper/2020-26.html (accessed on 3 March 2021).

32. Virhia J. (2019). – Healthy animals, healthy people: lived experiences of zoonotic febrile illness in northern Tanzania. PhD thesis. University of Glasgow, Glasgow, Scotland, 240 pp. Available at: theses.gla.ac.uk/79058/1/Virhia2020phd.pdf (accessed on 3 March 2021).

33. Galière M., Peyre M., Muñoz F., Poupaud M., Dehove A., Roger F. & Dieuzy-Labaye I. (2019). – Typological analysis of public–private partnerships in the veterinary domain. *PLoS One*, **14** (10), 1–22. doi:10.1371/journal.pone.0224079.

34. Lord J.S., Lea R.S. […] & Auty H.K. (2020). – Assessing the effect of insecticide-treated cattle on tsetse abundance and trypanosome transmission at the wildlife–livestock interface in Serengeti, Tanzania. *PLoS Negl. Trop. Dis.*, **14** (8), e0008288. doi:10.1101/2020.04.14.040873.

35. Bessell P.R., Woolley R., Stevenson S., Al-Riyami L., Opondo P., Lai L. & Gammon N. (2020). – An analysis of the impact of Newcastle disease vaccination and husbandry practice on smallholder chicken productivity in Uganda. *Prev. Vet. Med.*, **177**, 104975. doi:10.1016/j.prevetmed.2020.104975.

36. Higham L.E., Ongeri W., Asena K. & Thrusfield M.V. (2016). – Characterising and comparing drug-dispensing practices at animal health outlets in the Rift Valley, Kenya: an exploratory analysis (part II). *Trop. Anim. Hlth Prod.*, **48** (8), 1633–1643. doi:10.1007/s11250-016-1137-z.

37. Catley A., Leyland T., Mariner J.C., Akabwai D.M.O., Admassu B., Asfaw W., Bekele G. & Hassan H.S. (2004). – Para-veterinary professionals and the development of quality, self-sustaining community-based services. *In* Veterinary institutions in the developing world: current status and future needs (C. de Haan, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **23** (1), 225–252. doi:10.20506/rst.23.1.1476.

38. Vétérinaires Sans Frontières (VSF) (2018). – Community-based animal health workers (CAHWs): guardians for quality, localised animal health services in the global South. VSF, Brussels, Belgium, 8 pp. Available at: vsf-international.org/project/community-based-animal-health-workers-policy-brief/ (accessed on 3 March 2021).

39. Leyland T., Lotira R., Abebe D., Bekele G. & Catley A. (2014). – Community-based animal health workers in the Horn of Africa: an evaluation for the U.S. Office of Foreign Disaster Assistance. Feinstein International Center, Tufts University, Africa Regional Office, Addis Ababa, Ethiopia; & Vetwork UK, Great Holland, United Kingdom, 92 pp. Available at: fic.tufts.edu/publication-item/community-based-animal-health-workers-in-the-horn-of-africa/ (accessed on 3 March 2021).

40. Rutabanzibwa A.P. (2002). – Veterinary legal reform in Tanzania. *In* Primary animal health care in the 21st century: shaping the rules, policies and institutions (K. Sones & A. Catley, eds). Proc. Int. Conf. held in Mombasa, Kenya, 15–18 October 2002. African Union/Interafrican Bureau for Animal Resources, Nairobi, Kenya, 69 pp. Available at: fic.tufts.edu/wp-content/uploads/Rutabanzibwa-Mombasa.pdf (accessed on 3 March 2021).

41. Davis A. & Sharp J. (2020). – Rethinking One Health: emergent human, animal and environmental assemblages. *Soc. Sci. Med.*, **258**, 113093. doi:10.1016/j.socscimed.2020.113093.

42. Munyua P., Bitek A., Osoro E., Pieracci E.G., Muema J., Mwatondo A., Kungu M., Nanyingi M., Gharpure R., Njenga K. & Thumbi S.M. (2016). – Prioritization of zoonotic diseases in Kenya, 2015. *PLoS One*, **11** (8), e0161576. doi:10.1371/journal.pone.0161576.

43. Pieracci E.G., Hall A.J., Gharpure R., Haile A., Walelign E., Deressa A., Bahiru G., Kibebe M., Walke H. & Belay E. (2016). – Prioritizing zoonotic diseases in Ethiopia using a One Health approach. *One Hlth*, **2**, 131–135. doi:10.1016/j.onehlt.2016.09.001.

44. Sekamatte M., Krishnasamy V. […] & Behravesh C.B. (2018). – Multisectoral prioritization of zoonotic diseases in Uganda, 2017: a One Health perspective. *PLoS One*, **13** (5), e0196799. doi:10.1371/journal.pone.0196799.

45. Benton A. & Dionne K.Y. (2015). – International political economy and the 2014 West African Ebola outbreak. *Afr. Stud. Rev.*, **58** (1), 223–236. doi:10.1017/asr.2015.11.

46. Halliday J.E.B., Hampson K., Hanley N., Lembo T., Sharp J.P., Haydon D.T. & Cleaveland S. (2017). – Driving improvements in emerging disease surveillance through locally relevant capacity strengthening. *Science*, **357** (6347), 146–148. doi:10.1126/science.aam8332.

47. Lushasi K., Steenson R. […] & Hampson K. (2020). – One Health in practice: using integrated bite case management to increase detection of rabid animals in Tanzania. *Front. Public Hlth*, **8**, 13. doi:10.3389/fpubh.2020.00013.

48. World Health Organization (WHO) Rabies Modelling Consortium (2019). – The potential effect of improved provision of rabies post-exposure prophylaxis in Gavi-eligible countries: a modelling study. *Lancet Infect. Dis.*, **19** (1), 102–111. doi:10.1016/S1473-3099(18)30512-7.

49. World Health Organization (WHO) (2021). – COVID-19 vaccine country readiness and delivery. WHO, Geneva, Switzerland. Available at: www.who.int/initiatives/act-accelerator/covax/covid-19-vaccine-country-readiness-and-delivery (accessed on 3 March 2021).

50. European Commission Directorate General for Health and Consumers (DG SANCO) (2011). – Report on the outcome of the EU co-financed animal disease eradication and monitoring programmes in the MS and EU as a whole. DG SANCO, Brussels, Belgium, 248 pp. Available at: ec.europa.eu/food/system/files/2016-12/cff_animal_vet-progs_eval_report-other_fcec_erad-monitor_2005-9.pdf (accessed on 29 June 2021).

51. Roth F., Zinsstag J., Orkhon D., Chimed-Ochir G., Hutton G., Cosivi O., Carrin G. & Otte J. (2003). – Human health benefits from livestock vaccination for brucellosis: case study. *Bull. WHO*, **81** (12), 867–876. doi:10.1590/S0042-96862003001200005.

52. Halliday J.E.B., Allan K.J., Ekwem D., Cleaveland S., Kazwala R.R. & Crump J.A. (2015). – Endemic zoonoses in the tropics: a public health problem hiding in plain sight. *Vet. Rec.*, **176** (9), 220–225. doi:10.1136/vr.h798.

53. McDermott J.J. & Arimi S.M. (2002). – Brucellosis in sub-Saharan Africa: epidemiology, control and impact. *Vet. Microbiol.*, **90** (1–4), 111–134. doi:10.1016/S0378-1135(02)00249-3.

54. Bodenham R.F., Lukambagire A.H.S. […] & Halliday J.E.B. (2020). – Prevalence and speciation of brucellosis in febrile patients from a pastoralist community of Tanzania. *Sci. Rep.*, **10** (1), 7081. doi:10.1038/s41598-020-62849-4.

55. Kiambi S.G., Fèvre E.M., Omolo J., Oundo J. & de Glanville W.A. (2020). – Risk factors for acute human brucellosis in Ijara, north-eastern Kenya. *PLoS Negl. Trop. Dis.*, **14** (4), e0008108. doi:10.1371/journal.pntd.0008108.

56. Osoro E.M., Munyua P. […] & Guerra M. (2015). – Strong association between human and animal *Brucella* seropositivity in a linked study in Kenya, 2012–2013. *Am. J. Trop. Med. Hyg.*, **93** (2), 224–231. doi:10.4269/ajtmh.15-0113.

57. Viana M., Shirima G.M., John K.S., Fitzpatrick J., Kazwala R.R., Buza J.J., Cleaveland S., Haydon D.T. & Halliday J.E.B. (2016). – Integrating serological and genetic data to quantify cross-species transmission: brucellosis as a case study. *Parasitol.*, **143** (7), 821–834. doi:10.1017/S0031182016000044.

58. Jibat T., Hogeveen H. & Mourits M.C.M. (2015). – Review on dog rabies vaccination coverage in Africa: a question of dog accessibility or cost recovery? *PLoS Negl. Trop. Dis.*, **9** (2), e0003447. doi:10.1371/journal.pntd.0003447.

59. Cleaveland S. & Hampson K. (2017). – Rabies elimination research: juxtaposing optimism, pragmatism and realism. *Proc. Roy. Soc. Lond., B, Biol. Sci.*, **284** (1869), 20171880. doi:10.1098/rspb.2017.1880.

60. Food and Agriculture Organization of the United Nations (FAO) (2002). – Improved animal health for poverty reduction and sustainable livelihoods. FAO Animal Production and Health Paper **153**. FAO, Rome, Italy. Available at: www.fao.org/3/y3542e/y3542e00.htm (accessed on 3 March 2021).

61. Campanhola C. & Pandey S. (eds) (2019). – Sustainable food and agriculture: an integrated approach, 1st Ed. Academic Press, Cambridge, United States of America, 594 pp. Available at: www.elsevier.com/books/sustainable-food-and-agriculture/campanhola/978-0-12-812134-4 (accessed on 3 March 2021).

62. Pica-Ciamarra U. (2005). – Livestock policies for poverty alleviation: theory and practical evidence from Africa, Asia and Latin America. Food and Agriculture Organization of the United Nations, Rome, Italy, 67 pp. Available at: www.fao.org/3/bp207e/bp207e.pdf (accessed on 3 March 2021).

63. Kaufmann B.A., Lelea M.A. & Hülsebusch C.G. (2016). – Diversity in livestock resources in pastoral systems in Africa. *In* The future of pastoralism (J. Zinsstag, E. Schelling & B. Bonfoh, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **35** (2), 445–459. doi:10.20506/rst.35.2.2535.

64. Nicholson S.E. (2017). – Climate and climatic variability of rainfall over eastern Africa. *Rev. Geophys.*, **55** (3), 590–635. doi:10.1002/2016RG000544.

65. Lankester F. & Davis A. (2016). – Pastoralism and wildlife: historical and current perspectives in the East African rangelands of Kenya and Tanzania. *In* The future of pastoralism (J. Zinsstag, E. Schelling & B. Bonfoh, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **35** (2), 473–484. doi:10.20506/rst.35.2.2536.

66. The Brooke (2021). – Our work in strengthening animal health systems. The Brooke, London, United Kingdom. Available at: www.thebrooke.org/our-work/animal-health-systems (accessed on 3 March 2021).

67. Organization of African Unity (OAU) (2001). – Abuja Declaration on HIV/AIDS, tuberculosis and other related infectious diseases. *In* Proc. African Summit on HIV/AIDS, Tuberculosis and Other Related Infectious Diseases, 24–27 April. OAU/SPS/ABUJA/3. OAU, Addis Ababa, Ethiopia, 8 pp. Available at: docplayer.net/20856142-Abuja-declaration-on-hiv-aids-tuberculosis-and-other-related-infectious-diseases.html (accessed on 29 June 2021).

68. World Health Organization (WHO) (2016). – Public financing for health in Africa: from Abuja to the SDGs. WHO/HIS/HGF/Tech.Report/16.2. WHO, Geneva, Switzerland, 89 pp. Available at: docplayer.net/20856142-Abuja-declaration-on-hiv-aids-tuberculosis-and-other-related-infectious-diseases.html (accessed on 29 June 2021).

Epidemic disease risks and implications for Veterinary Services

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The views and opinions expressed in this article are the authors' own and do not necessarily reflect the official policy or position of the United States Agency for International Development, the government of the United States of America, or the Food and Agriculture Organization of the United Nations.

Summary
Growth in the livestock sector is associated with heightened risk for epidemic diseases. The increasing spillover of new diseases from wildlife is being driven by wide-scale anthropogenic changes allowing for more frequent and closer wildlife–human and wildlife–livestock contacts. An increasing number of epidemics in livestock are associated with rapid transition of livestock systems from extensive to intensive, and local to global movement of livestock and their products through value chain networks with weak biosecurity. Major livestock epidemics in the past two decades have had substantial economic impacts, and the COVID-19 pandemic highlights the devastating socio-economic consequences that spillovers can have when not identified and controlled early in the process of emergence. This highlights the importance of Veterinary Services to integrated, whole-of-society efforts to control infectious diseases in animals. Emphasis within Veterinary Services must be placed on prevention and preparedness. The authors suggest four areas for continued improvement in Veterinary Services to meet this challenge. These are a) continued development of staff capacity for risk assessment and value chain analysis, together with improved policies and communication, b) appropriate adaptation of approaches to prevention and control in resource-poor settings, c) improved multi-sectoral and transboundary cooperation, which enables the sharing of resources and expertise, and d) systematic approaches that enable Veterinary Services to influence decision-making for trade, markets, business, public health, and livelihood development at the national and regional levels.

Keywords
Emerging infectious disease – Epidemic – One Health – Risk-based approach – Systems approach – Transboundary cooperation – Veterinary Services.

https://doi.org/10.20506/rst.40.2.3240

Introduction

Global growth in the livestock sector is driven by population growth, economic growth, urbanisation, and technological advancements, with much of the increased demand for livestock-derived foods occurring in low- and middle-income countries (LMICs). Positive consequences of this so-called 'Livestock Revolution' have included improved nutrition for children and the poor and improved income and livelihoods, while negative consequences have included environmental degradation, contributions to changing climatic conditions, and increased risk of the spread of endemic and epidemic infectious diseases (1, 2, 3, 4).

The geospatial distribution and host dynamics of animal diseases are changing and new diseases are emerging, particularly at the livestock–wildlife interface (5, 6, 7). The recent global increase in reporting of epidemic livestock diseases is likely due, at least in part, to improved surveillance, wider and faster information-sharing, and increased public awareness (8).

Due to data scarcity, the impacts of epidemic livestock diseases are difficult to quantify (9). In 2009, the World Organisation for Animal Health (OIE) estimated that disease in general reduced global food animal production by 20% (10), while a 2014 meta-analysis by Pradère (11) found that the overall disease mortality rate for livestock in low-income countries was 18%.

Under-resourced Veterinary Services continue to struggle to prepare for, prevent, detect, and respond to disease epidemics. Veterinary Services play an important role in delivering direct and indirect economic, health, food security, and other societal benefits. At the same time, they face a number of threats and challenges that often extend far beyond their immediate control.

This paper focuses on the drivers and risks of infectious disease epidemics, and how Veterinary Services can best manage existing and future threats. To illustrate the need for strong Veterinary Services as part of preparedness for dynamic risks, the authors examine the impacts and implications of seven livestock-associated diseases that are emerging or have caused major epidemics in the past two decades.

Drivers of disease emergence

Emerging infectious diseases (EIDs), which include diseases that are zoonotic, vector-borne and drug-resistant, are associated with a) newly identified pathogens, b) known pathogens with significantly increased incidence or expanded geographic presence, or c) pathogens that have become established in new susceptible host species. Among the key components of EID risk are exposure practices that allow for spillover of pathogens to other species and facilitate their spread. These exposures are often broadly characterised as domestic animal–human, wildlife–human, or wildlife–domestic animal.

Wildlife-origin pathogens make up over 70% of the number of infectious zoonoses that emerged between 1940 and 2006 (12). While substantial progress has been made in strengthening coordination and risk management strategies for zoonotic disease threats linked to domestic animals, attention to the role of wildlife and environmental determinants is limited and there is a lack of appropriate risk reduction strategies to date, with the overall field of wildlife health poorly developed in terms of capacity and operations. There are several broad reasons why the number of zoonotic disease emergence events related to wildlife is increasing at a faster rate than the number of events related to livestock. These include human coexistence with domestic animals over millennia, the relatively high surveillance efforts in domestic animals compared to wild species, and, critically, the increasing frequency and changing types of wildlife–human and wildlife–domestic animal exposures associated with wide-scale anthropogenic changes (5, 13).

Mapping disease emergence events in recent decades and correcting for surveillance bias indicates that there are hotspots for the emergence of infectious diseases (Fig. 1). For disease emergence from wildlife specifically, hotspots are broadly associated with areas of high mammalian biodiversity, expanding human populations, and land-use change, signifying environmental and anthropogenic changes that increase the likelihood of spillover (5, 12). These hotspots can provide a general geographic guide to aid in global preparedness and prioritisation; however, all countries should consider possible sources of risk with hotspot characteristics. Analyses of the sharing of viruses among humans and various genera or species of mammals have identified some viral families (among them *coronaviridae*, *filoviridae*, *orthomyxoviridae*, and *paramyxoviridae*) and mammalian and bird groups (particularly, bats, rodents and non-human primates) which are of greatest concern for emerging zoonoses globally (14). In the process of disease emergence, livestock can serve as amplifier hosts, either remaining asymptomatic or developing disease themselves (15).

Livestock disease epidemic risks

Risk factors for epidemics of infectious diseases in livestock include human population growth and changing prosperity. These factors create increasing demand for livestock-derived

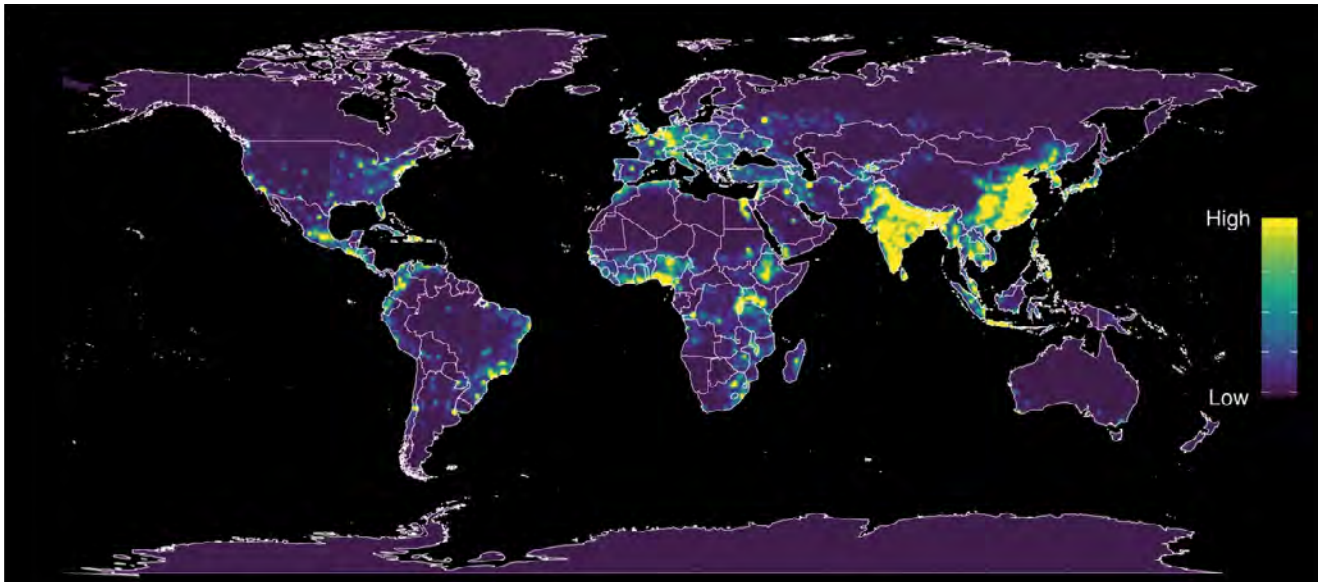

Fig. 1
Predicted distribution of the relative risk of zoonotic disease emergence from wildlife
Adjusted for reporting bias. Lighter colours represent higher relative risk (13)

foods, resulting in increases in the global production and movement of livestock and livestock products. The intensification of livestock production, which was made possible in part by the control of endemic infectious diseases, represents one of the greatest risks for the spread of epidemic diseases, particularly in concentrated animal populations linked by networks of service providers (8). Genetically homogenous naive animal populations reared in high densities in intensified systems promote increased selection of key mutations as the pathogen transmits through the population, which may lead to the evolution of highly pathogenic variants (16). Conversely, extensive farming practices with complex networks of animals moving to and from numerous small- to medium-size producers and markets also facilitate disease spread and complicate surveillance and response efforts.

Ecological disturbance creates conditions for epidemics of otherwise rare or low-level endemic diseases (8). Of particular interest is natural habitat fragmentation due to agricultural expansion, as this can increase the type and amount of interaction at the wildlife–livestock interface and facilitate the spread of pathogens. Changing climatic patterns also facilitate the spread of some diseases, or the shift of some diseases; for example, as some disease vectors have expanded their range northward into areas which were previously unsuitable for them, the incidence of vector-borne disease in these areas has increased (17). At the same time, the suitability of some ranges will contract owing to changing precipitation patterns, potentially reducing disease risk and prevalence in some instances (see Stephen *et al.*, this issue, for greater coverage on climate-related disease trends [18]). The changing pattern of disease spread, along with other possible effects of a warming climate on livestock production (e.g. extreme heat and dwindling sources of feed and water), underscores the importance of preparedness.

The movement of livestock and their products is an important risk for the domestic and transboundary spread of infectious diseases. Livestock markets have been shown to be important nodes for disease spread, and associated value chains are often connected across borders. The infectious pathogens can be spread both directly by animals themselves and indirectly, i.e. on clothes, on the surfaces of equipment such as vehicles and crates, and through insect vectors accompanying animals and equipment.

Major epidemics associated with livestock in the 21st century

Table I shows seven diseases that are emerging or have caused recent major epidemics. The authors consider how the drivers and risks referred to above influenced emergence, spread, and impact, and consider their implications for Veterinary Services in order to support risk-based approaches.

In low-income countries, more than one in seven livestock keepers is infected with a zoonotic disease (29). The economic sense of zoonotic disease prevention was demonstrated in a recent paper by Dobson *et al.* (30).

Table I
Seven diseases that are emerging or have caused major epidemics in the 21st century

Disease	Risk factors for spillover to livestock or people	Main risk factors for epidemic spread	Impacts of note	Implications/ recommendations for Veterinary Services
African swine fever (ASF)	Spillover/spillback between wild and domestic suids	Trade in livestock and contaminated pork products Pig production systems with low biosecurity Movement of wild suids	Severe losses to pig production in China after 2018 detection, and significant increase in pork price; spread to many other countries in Asia and the Pacific	– Import screening – Livestock and wildlife surveillance to determine pathways of introduction and spread – Risk-based approaches for domestic and international trade restrictions – Improved biosecurity focusing on backyard and small-scale settings
Avian influenza (AI)	Wild–domestic bird mixing	Re-assortment or genetic drift of virus strains Inadequate/ inappropriate vaccination strategies Low biosecurity in poultry value chains Long-distance spread via infected wild birds	Major epidemics in the past 10 years have included the H5N8 2014–2015 epidemic in turkeys and chickens in the United States of America (19), and the 2016–2017 H5N8 epidemic in domestic and wild birds in Europe affecting 30 countries (20)	– Biosecurity measures to reduce wildlife–livestock exposures – Monitoring of domestic and wild bird strains – Poultry sector investments in low-risk geographic areas – Appropriate vaccination strategies – Transition to safer practices (e.g. away from live animal markets where viral amplification may occur)
Crimean–Congo haemorrhagic fever (CCHF)	Transmission to humans via infected ticks or animal blood	Domestic or international spread via animal trade	No/negligible clinical impact(s) on livestock Estimates of ≥1,500 human cases per year (21), with case fatality rate up to 40%	– Tick control measures – Surveillance reporting to public health services – Promote biosafety measures for animal handlers and laboratory workers
Lumpy skin disease (LSD)	n/a	International spread via livestock trade Introduction and spread by blood-feeding insect vectors	Major reductions in milk production (22) threaten food security and nutrition (23) Spread to major bovine producing countries, i.e. India and China	– Mass vaccination across countries, combined with strict movement control, modified stamping out, and awareness campaigns – Trade risk analysis
Middle East respiratory syndrome (MERS)	Other ruminant or human contact with infected camels	Domestic or international spread via livestock trade (mainly camel trade)	Negligible clinical impacts on camels Approximately 2,500 human cases to date and 850 deaths since first detection in 2012; US$ 12 billion in losses from human introduction into the Republic of Korea (24)	– Trade risk analysis – Import screening – Reporting of emerging infections – Promote biosafety measures for animal handlers
Nipah	Swine or human contact with infected bat secretions Human contact with infected swine	Domestic or international spread via trade Human–human transmission	Over 1 million pigs lost to control >100 human deaths US$ 671 million in losses Spread to Singapore (25)	– Designate safe areas for livestock production – Biosecurity measures to reduce wildlife–livestock exposures (e.g. distancing of orchard trees and livestock holding areas) – Promote biosafety measures for animal handlers – Ensure access to laboratory facilities for novel pathogen screening
Rift Valley fever (RVF)	Ecological disruption and/or changing climatic conditions creating new habitat for mosquito vectors Potential introduction of vectors beyond current range Human contact with blood/ tissues of infected animals	Domestic or international spread via live animal trade Low vaccine coverage or prior immunity levels	A ban on livestock imports imposed by Middle East countries on the Horn of Africa in 1998–1999 caused losses amounting to US$ 109 million (26) US$ 32 million in losses in Kenya in 2006/2007 (27) Up to 11,958 human disability-adjusted life years lost in 2005 (28)	– Vaccination and screening requirements for traded animals from endemic regions – Develop early warning systems for vaccine deployment, and other risk reduction measures – Reporting of animal disease to inform public health risk analysis – Promote biosafety measures for animal handlers – Develop infrastructure to prevent and prepare for climate-sensitive diseases

The World Bank (25) found that losses from outbreaks of Nipah, West Nile fever, severe acute respiratory syndrome (SARS), highly pathogenic avian influenza (HPAI), Rift Valley fever (RVF), and bovine spongiform encephalopathy from 1997 to 2009 were at least US$ 80 billion. Prevention would have avoided losses of US$ 6.7 billion per year. This is substantially more than the estimated US$ 1.9–3.4 billion needed for investment in human and animal health systems for zoonotic disease prevention and control in 139 LMICs. Clearly, animal disease epidemics have substantial direct and indirect health, social, and economic consequences. This highlights the importance of Veterinary Services within a more integrated whole-of-society response that recognises these linkages and potential direct and indirect effects.

Veterinary Services and epidemic prevention and control

Emphasis must be placed on prevention, given the impacts of epidemic diseases and the difficulty of achieving control once they are established. Nevertheless, epidemics will occur and therefore preparedness for effective early detection and control is needed. The importance of prevention and preparedness is evidenced in the public health systems of Asian countries that have experienced SARS. Several Asian countries were better prepared for COVID-19 because they had put in place measures for early detection and response to EID outbreaks. Preparedness for early detection and control allowed for appropriate opening of these economies once COVID-19 was under control, and for a more rapid economic recovery than much of the rest of the world.

Following the large-scale epidemics of H5N1 HPAI in Southeast Asia in 2004–2005 there were calls for improved prevention, detection, response and control efforts for infectious animal diseases, specifically by adapting tools and approaches to the contexts of LMICs. This led to improved surveillance and emergency preparedness capacity in LMICs, particularly in Southeast, South, and East Asia (31). However, in many other countries, capacity has remained limited or specific to selected diseases, supported by donor-funded programmes. The implications of this have been demonstrated by the introduction of African swine fever (ASF) to the same geographic region in 2018, which resulted in rapid spread to many countries and enormous socio-economic consequences. These experiences highlight advances that have been made, but also suggest four areas for continued improvement in Veterinary Services that will allow for better epidemic prevention, preparedness, and control, namely: risk analysis, adaptations in LMICs, transboundary cooperation, and the One Health approach.

Risk analysis

The risk analysis framework was first promoted by the OIE in the 1980s in support of livestock-associated trade between countries. Since then, the central role of risk assessment has been recognised for facilitating an evidence-based prioritisation of disease prevention and control within countries, and even for individual farms. Risk assessment plays an important role in informing risk mapping, risk-based surveillance, movement control and trade restrictions, zoning, and compartmentalisation. The risk assessment approach has been strengthened by recognising the importance of understanding the value chains that are relevant for a particular disease or commodity, as these value chains inform the identification of risk pathways. In addition, understanding the role of anthropogenic and economic factors in generating, perpetuating, and amplifying disease risks is important. The challenge for national Veterinary Services now is to continue developing their national capacity for risk assessment and value chain analysis, and then link them with policies. It is notable that decision-makers often struggle to separate risk into its components of likelihood and consequences, and fail to understand how important each is when it comes to deciding on acceptable risk or any risk mitigation measures. Furthermore, the inherent uncertainty associated with risk estimates is difficult for decision-makers to consider when formulating their policies.

Another area of focus has been in the area of surveillance systems, where the value of risk-based surveillance has been recognised by the OIE in order to promote the implementation of targeted, and potentially more cost-effective, animal health surveillance (32). Risk-based surveillance will be an extremely useful approach for LMICs, but it requires sound risk assessment to inform the design of surveillance systems. Improving local capacity for risk-based surveillance, in particular community-based approaches, ensures relevance to local contexts (33, 34). For surveillance to be useful, it needs to be complemented by the capacity to conduct outbreak investigations that generate meaningful data which can inform prevention and control activities. Unfortunately, this is still an area where more investment into the development of staff capacity is required.

The COVID-19 pandemic highlights the importance of effective risk communication and community engagement (RCCE) to disease prevention and control, not only for informing decision-makers but for guiding and influencing public behaviours. The COVID-19 'infodemic' spread rapidly, facilitated by the spread via social media of misinformation challenging effective public health messaging and costing lives (35). Effective RCCE includes transparency, the presentation of trusted evidence by authoritative voices, and the clear articulation of knowns

and unknowns to help the public understand the nature of a risk and respond appropriately. In 2003 at the start of the H5N1 HPAI epidemic, poor and inconsistent messaging led to global consumer fears about poultry consumption (36); similarly, poorly formulated messages about risks associated with meat consumption contributed to steep drops in demand for meat during the 2006/2007 and 2018 RVF outbreaks in East Africa, with subsequent economic impacts (37).

Appropriate adaptations in low- and middle-income countries

It is still common that prevention and control approaches that work in high-income countries are promoted in LMICs. This can be inappropriate in settings with very heterogenous livestock production structures, where value chain actors have limited technical knowledge and fewer means or incentives for making improvements to facilities or processes. Veterinary Services are often constrained by limited resources, poor infrastructure, lack of a chain of command, insufficient and/or aging technical capacity, and ineffective regulatory enforcement ability. It is in these environments where epidemic risks are most often generated and, therefore, it is in these environments that there is a need to develop more effective prevention and control approaches that are adapted to the transitioning production systems of LMICs. For example, broad-scale culling measures may be impractical and understandably met with resistance, not only due to the economic costs for farmers and society, but also because of the apparent waste of animal protein and the adverse environmental impact of having to dispose of large numbers of carcasses. Within high-risk or endemically infected areas, the concept of compartmentalisation is now likely to play an increasing role when dealing with diseases such as ASF, since it allows individual businesses using high biosecurity standards to continue to operate; it may, therefore, also reduce or even prevent the need for broad-scale culling in the surrounding areas.

The impacts of increasingly frequent outbreaks of epidemic animal diseases demonstrate the importance and urgency of shifting animal health policies from targeting single diseases towards multi-hazard detection and response. A key element of such strategies has to be improved animal husbandry, including biosecurity, but also a reversal of the continuing trend towards intensified meat production and land use changes, as they can provide new pathways for known and novel disease pathogens. Some of the Sustainable Development Goals (SDG) define important targets in this regard, with those of most relevance to livestock production being SDG 1 (No poverty), SDG 2 (Zero hunger), SDG 3 (Good health and wellbeing) and SDG 12 (Responsible consumption and production).

In resource-poor settings, recent innovations in digital surveillance offer opportunities for increasing data capture from remote areas and widening the surveillance network to include animal health providers, livestock owners, actors involved in the wildlife trade, and consumers (38). In Kenya, community disease reporters are using a smartphone app for syndromic surveillance to report disease outbreaks to Veterinary Services (39). Thailand has been an innovation hotbed of smartphone apps for crowdsourcing One Health surveillance, such as the participatory One Health Disease Detection app (40).

To assist countries with strategic and systematic capacity development, globally accepted standards and tools have been developed by the OIE and the Food and Agriculture Organization of the United Nations (FAO). The main international standards for animal health and zoonoses are contained in the OIE *Terrestrial Animal Health Code* and *Aquatic Animal Health Code* (standards for disease prevention/control and trade) and the *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* and *Manual of Diagnostic Tests for Aquatic Animals* (biological standards) (41). These standards are enforced under the World Trade Organization and they require countries to report any occurrence of any of the 117 OIE-listed diseases, infections or infestations.

To target animal health investments, the OIE's Performance of Veterinary Services (PVS) Evaluation serves as an independent external evaluation to identify gaps and weaknesses in countries' capacity to comply with OIE standards. The PVS Evaluation is typically followed up with a PVS Gap Analysis, a quantitative and costed evaluation of a country's needs and priorities (42). Similarly, the World Health Organization's Joint External Evaluation helps countries identify gaps in both human and animal health services to improve public health response capacities (43), serving as a basis for multi-sectoral national action planning for health security. The One Health Assessment for Planning and Performance tool allows national One Health platforms to assess their own coordination performance and capacity (44).

Other key tools for assessing capacity include FAO's Laboratory Mapping Tool and its Surveillance Evaluation Tool (45, 46). Countries are also encouraged to increase their resilience to animal health threats through FAO Good Emergency Management Practice workshops, which guide them in developing preparedness and response plans (47). While these tools support animal health capacity assessment processes and progressive improvements towards standards, they are primarily focused on domestic animals, and a gap remains in supporting Veterinary Services in wildlife epidemic disease prevention and control.

Transboundary cooperation

Given the increasingly transboundary nature of epidemics, coordination between Veterinary Services of different countries is necessary for effective disease prevention and

control, as it allows services challenged by resource scarcity to improve their networks, share information, and mobilise expertise. The Global Framework for the Progressive Control of Transboundary Animal Diseases (GF-TADs) coordinates guidance, resources, and other technical assistance to progressively control and reduce the impact of regional and global priority diseases (48). Perhaps the best example of regional and global collaboration between Veterinary Services was the Global Rinderpest Eradication Programme established in 1994, which led to the successful eradication of the disease and declaration of global freedom in 2011 (49). Key to eradication were institutional changes that allowed Veterinary Services to share information, target interventions, and adopt public–private–community partnerships for disease surveillance and control (50). Additional examples include the Progressive Control Pathway for Foot and Mouth Disease, and the more recent GF-TADs initiative for the global control of ASF, which supports regional alliances, partnerships, and progressive disease elimination (51).

The engagement of Veterinary Services in regional trade initiatives, such as the African Continental Free Trade Area, which came into effect in 2019 for 28 countries (52), is also necessary to ensure that economic and livelihood benefits are realised while transparent control of animal diseases is maintained. Regional Economic Communities play crucial roles in fostering regional cooperation, policy dialogues, and ownership amongst member states. For example, in Southeast Asia, several regional strategies and action plans were developed after a statement was issued by the Ministers of Agriculture and Forestry of the Association of Southeast Asian Nations (ASEAN). The statement highlighted the importance of ASEAN cooperation on animal health and zoonoses (53) and led to improved regional coordination and a reduction in cases of animal diseases such as H5N1 HPAI.

One Health

The complex drivers, risks, and resulting impacts of epidemics underscore the importance for global and national organisations to adopt a One Health approach to risk governance. Animal diseases (including EIDs, zoonoses, and diseases that impact human nutrition, food security, and wellbeing) require holistic approaches to the development of prevention and control policies. That means truly integrated policies that consider human, animal, and environmental factors, as well as social, economic, ethical, and judicial ones. Veterinary Services can address the economic and wider societal impacts of epidemics through linkages between economic and veterinary policies. In many countries, the responsibility to prevent and control zoonoses is spread across several agencies, and collaboration amongst them is often neither promoted nor rewarded. Currently, government departments may consult with each other when it comes to disease response, but rarely develop integrated approaches that optimise prevention and detection upstream. Mandates, information sources, resources, stakeholders, and policies are required to design more comprehensive strategies for every element of risk management, from risk assessment to risk reduction.

A systems approach needs to be mastered if the next livestock or zoonotic epidemic is to be prevented or at least controlled more effectively, with Veterinary Services engaging in risk-based linkages with other sectors, particularly wildlife and environmental services. The Animal and Human Health for the Environment and Development programme exemplifies the One Health approach to linking Veterinary Services and other sectors, particularly wildlife and environmental services. The programme emphasises the importance of a sustainable livelihoods approach that addresses the socio-economic and disease priorities – both human and animal – of frontline communities (54, 55). A growing number of national One Health multi-sectoral coordination mechanisms are linking Veterinary Services with critical counterparts in public health, wildlife, and environmental services for joint evaluation, planning, and disease prevention and control (56, 57). The One Health Workforce approach in Southeast Asia and Central and Eastern Africa is creating future capacity for cross-sectoral approaches to training, disease surveillance, and outbreak response (58).

Conclusions

The COVID-19 pandemic serves as a reminder of the importance of investing in epidemic prevention and preparedness, and it has led to calls for systematic approaches in areas such as risk assessment and One Health. Such challenges are global, but particularly acute in LMICs. If Veterinary Services in these countries are to meet the challenges posed by epidemic diseases, they must share innovations and resources at national and regional levels, and they need support from regional and international collaboration and alliances.

Recent experiences with epidemic disease emergence and spread highlight the risks posed by our increasingly globalised and industrialised livestock production systems and by the expansion of extensive and intensive livestock production at the wildlife interface. Interactions and dynamics are not unidirectional, as seen with wildlife epidemics linked to disease introduction from livestock. These epidemics have the potential to be devastating to wildlife conservation efforts; for example, the mass die-off of saiga antelope in Mongolia in 2016–2017, linked to peste des petits ruminants that spilled over from unvaccinated livestock, caused a saiga population decline estimated at 80% or greater (59).

Improvements in our understanding of epidemic disease drivers, including economic and anthropogenic drivers, and the bolstering of Veterinary Services' capacity have supported advances in reducing epidemic disease, but they warrant additional attention. Moving forward, emphasis must be placed on risk-based approaches to the targeting of scarce resources. Ultimately, these approaches will need to be moved further upstream for cost-effective prevention and early detection. There needs to be greater attention to the wildlife, environmental, and climate-sensitive dimensions of animal health risks, in line with a One Health approach. Other sectors (e.g. social sciences) can add insights into private-sector incentives and motivation for uptake of prevention, reporting, and impact mitigation strategies. It is also important to recognise that changes in socio-economic systems can happen very rapidly, as demonstrated during the COVID-19 pandemic, which is taking us into a highly uncertain and potentially very different future. This has enormous implications for emerging infectious disease risks and the essential role of national, regional, and global One Health risk governance, since it requires truly integrated risk management policies that can be developed rapidly and are informed by a highly effective interface between interdisciplinary science and policy.

Knowledge of EID hotspots and of the drivers of EID emergence provides an initial indication of areas that require greater attention and capacity enhancement, especially in the context of changing climatic patterns. When designing prevention, detection, and response efforts, it is necessary to determine the high-risk practices to target ('the what'), the taxonomic groups to target (the 'which') and the countries or regions to target (the 'where'), and hotspot information can be helpful in prioritising the latter. As more information is collected, hotspots maps and other predictive tools can be refined and downscaled to finer-scale resolutions.

As noted in a number of World Bank reports (23, 60, 61), in terms of its impact on epidemic and pandemic risk mitigation, strengthening animal and human health systems provides a high return on investment (it is worth noting, however, that the wildlife dimensions of risk mitigation have continued to be a largely neglected area of focus). Operationalisation of One Health, which will include developing better incentives for multi-agency collaboration, is a priority moving forward.

Animal disease epidemics have substantial direct and indirect economic consequences. To meet these challenges from both known and novel threats, Veterinary Services must emphasise cooperation, integrate their plans with those of other sectors, and take the broader economic context into account when making decisions in order to ensure sufficient coordination with trade, markets, business, public health, and livelihood development at the national and regional levels.

Les risques de maladies épidémiques et leurs conséquences pour les Services vétérinaires

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Résumé

La croissance du secteur de l'élevage est associée à un risque accru de maladies épidémiques. Les changements anthropiques à grande échelle sont à l'origine du nombre croissant de maladies émergentes atteignant de nouvelles espèces réceptives (*spillover*) à partir de réservoirs sauvages, à la faveur de contacts plus fréquents et plus rapprochés entre la faune sauvage et les humains, d'une part, et entre la faune sauvage et les animaux domestiques, d'autre part. On considère qu'un nombre croissant d'épidémies affectant le bétail sont dues à la transition rapide des systèmes d'élevage extensif vers des systèmes intensifs, et aux mouvements du bétail et des produits de l'élevage de l'échelle locale à l'échelle mondiale par le biais de réseaux de chaînes de valeur dotés d'un faible niveau de biosécurité. Au cours des deux dernières décennies, d'importantes épidémies affectant le bétail

ont eu un impact économique considérable ; en outre, la pandémie de COVID-19 a mis en évidence les conséquences socio-économiques dévastatrices des atteintes de nouvelles espèces réceptives par des agents pathogènes, lorsque ces maladies ne sont pas détectées et maîtrisées dès le processus d'émergence. Cela souligne l'importance cruciale des Services vétérinaires dans les efforts de lutte contre les maladies infectieuses chez les animaux, qui doivent être intégrés et mobiliser la société entière. Les Services vétérinaires doivent mettre un accent particulier sur la prévention et la préparation. Les auteurs proposent quatre aspects d'amélioration continue pour que les Services vétérinaires puissent relever ce défi. Il s'agit : a) du développement permanent des compétences des personnels vétérinaires en matière d'évaluation du risque et d'analyse des chaînes de valeur, et leur articulation avec de meilleures politiques et une communication plus performante ; b) une adaptation adéquate des méthodes de prévention et de contrôle dans les configurations faiblement dotées en ressources ; c) une meilleure coopération multisectorielle et transfrontalière afin de partager les ressources et les compétences ; d) des dispositifs systémiques permettant aux Services vétérinaires d'influencer les prises de décision en matière d'échanges internationaux, de marchés, de commerce, de santé publique et de développement des moyens de subsistance, à l'échelle nationale et régionale.

Mots-clés
Coopération transfrontalière – Épidémie – Maladie infectieuse émergente – Méthode basée sur le risque – Méthode systémique – Services vétérinaires – Une seule santé.

Riesgos de enfermedad epidémica y consecuencias para los Servicios Veterinarios

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Resumen
El crecimiento del sector pecuario está condicionado por la existencia de un mayor riesgo de enfermedades epidémicas. La creciente diseminación de nuevas enfermedades a partir de animales silvestres es consecuencia de transformaciones antrópicas a gran escala que posibilitan un contacto más frecuente y estrecho de la fauna silvestre con el ser humano y el ganado. Cada vez son más las epidemias del ganado que tienen que ver con la rápida transición de los sistemas pecuarios de un régimen de producción extensiva a otro de producción intensiva y con el paso de la dimensión local a la mundial de la circulación de animales y sus derivados a través de redes de cadenas de valor que presentan una endeble seguridad biológica. En los últimos dos decenios ha habido grandes epidemias que han afectado al ganado y tenido importantes consecuencias económicas. La pandemia de COVID-19 es un elocuente ejemplo de los devastadores efectos socioeconómicos que puede tener la extensión de un patógeno cuando no se detecta y controla en un momento lo bastante precoz del proceso de emergencia. Ello pone de relieve la importancia que revisten los Servicios Veterinarios para que toda la sociedad pueda reaccionar de forma integrada a la hora de combatir las enfermedades infecciosas de los animales. Dentro de los Servicios Veterinarios, conviene poner el acento en la prevención

y la preparación. Para lograr este objetivo los autores señalan cuatro ámbitos que exigen una constante mejora: a) el desarrollo continuo de la capacidad del personal en materia de determinación de riesgos y análisis de cadenas de valor, ligado a la mejora de las políticas y la comunicación; b) la adecuada adaptación de los métodos de prevención y control en contextos de escasos recursos; c) una mejor cooperación multisectorial y transfronteriza, que permita poner en común recursos y competencias técnicas; y d) enfoques sistemáticos que hagan posible que los Servicios Veterinarios influyan en los procesos decisorios relativos al desarrollo del comercio, los mercados, las empresas, la salud pública y los medios de sustento a escala tanto nacional como regional.

Palabras clave
Cooperación transfronteriza – Enfermedad infecciosa emergente – Enfoque por riesgos – Enfoque sistémico – Epidemia – Servicios Veterinarios – Una sola salud.

References

1. MacLachlan I. (2015). – Evolution of a revolution, meat consumption and livestock production in the developing world. *In* Political ecologies of meat (J. Emel & H. Neo, eds). Routledge, London, United Kingdom, 21–41.

2. Herrero M. & Thornton P.K. (2013). – Livestock and global change: emerging issues for global food systems. *Proc. Natl. Acad. Sci. U.S.A.*, **110** (52), 20878–20881. doi:10.1073/pnas.1321844111.

3. Food and Agriculture Organization of the United Nations (FAO) (2006). – Livestock's long shadow: environmental issues and options. FAO, Rome, Italy, 416 pp. Available at: www.fao.org/3/a0701e/a0701e.pdf (accessed on 31 August 2020).

4. Delgado C., Rosegrant M., Steinfeld H., Ehui S. & Courbois C. (1999). – Livestock to 2020: the next food revolution. Food, Agriculture, and the Environment Discussion Paper **28**. International Food Policy Research Institute, Washington, DC, United States of America, 83 pp. Available at: idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/30755/121863.pdf?sequence=1 (accessed on 31 August 2020).

5. Allen T., Murray K.A., Zambrana-Torrelio C., Morse S.S., Rondinini C., Di Marco M., Breit N., Olival K.J. & Daszak P. (2017). – Global hotspots and correlates of emerging zoonotic diseases. *Nat. Comm.*, **8**, Article No. 1124. doi:10.1038/s41467-017-00923-8.

6. Wiethoelter A.K., Beltrán-Alcrudo D., Kock R. & Mor S.M. (2015). – Global trends in infectious diseases at the wildlife–livestock interface. *Proc. Natl. Acad. Sci. U.S.A.*, **112** (31), 9662–9667. doi:10.1073/pnas.1422741112.

7. Morse S.S., Mazet J.A., Woolhouse M., Parrish C.R., Carroll D., Karesh W.B., Zambrana-Torrelio C., Lipkin W.I. & Daszak P. (2012). – Prediction and prevention of the next pandemic zoonosis. *Lancet*, **380** (9857), 1956–1965. doi:10.1016/S0140-6736(12)61684-5.

8. Perry B.D., Grace D. & Sones K. (2013). – Current drivers and future directions of global livestock disease dynamics. *Proc. Natl. Acad. Sci. U.S.A.*, **110** (52), 20871–20877. doi:10.1073/pnas.1012953108.

9. Rushton J., Bruce M., Bellet C., Torgerson P., Shaw A., Marsh T., Pigott D., Stone M., Pinto J., Mesenhowski S. & Wood P. (2018). – Initiation of global burden of animal disease program. *Lancet*, **392** (10147), 538–540. doi:10.1016/S0140-6736(18)31472-7.

10. Vallat B. (2009). – One World, One Health. World Organisation for Animal Health, Paris, France. Available at: www.oie.int/en/one-world-one-health/ (accessed on 21 July 2021).

11. Pradère J.-P. (2014). – Improving animal health and livestock productivity to reduce poverty. *Rev. Sci. Tech. Off. Int. Epiz*, **33** (3), 735–744. doi:10.20506/rst.33.3.2315.

12. Jones K.E., Patel N.G., Levy M.A., Storeygard A., Balk D., Gittleman J.L. & Daszak P. (2008). – Global trends in emerging infectious diseases. *Nature*, **451** (7181), 990–993. doi:10.1038/nature06536.

13. EcoHealth Alliance (2019). – Infectious disease emergence and economics of altered landscapes – IDEEAL (P. Daszak *et al.*, eds). EcoHealth Alliance, New York, United States of America, 88 pp. Available at: www.ecohealthalliance.org/wp-content/uploads/2019/09/IDEEAL_report_final.pdf (accessed on 31 August 2020).

14. Olival K.J., Hosseini P.R., Zambrana-Torrelio C., Ross N., Bogich T.L. & Daszak P. (2017). – Host and viral traits predict zoonotic spillover from mammals. *Nature*, **546** (7660), 646–650. doi:10.1038/nature22975 [published correction appears in *Nature*, **548** (7669), 612, doi:10.1038/nature23660].

15. Morand S., McIntyre K.M. & Baylis M. (2014). – Domesticated animals and human infectious diseases of zoonotic origins: domestication time matters. *Infect. Genet. Evol.*, **24**, 76–81. doi:10.1016/j.meegid.2014.02.013.

16. Dhingra M.S., Artois J., Dellicour S., Lemey P., Dauphin G., Von Dobschuetz S., Van Boeckel T.P., Castellan D.M., Morzaria S. & Gilbert M. (2018). – Geographical and historical patterns in the emergence of novel highly pathogenic avian influenza (HPAI) H5 and H7 viruses in poultry. *Front. Vet. Sci.,* **5**, Article No. 84. doi:10.3389/fvets.2018.00084.

17. Grace D., Bett B., Lindahl J. & Robinson T. (2015). – Climate and livestock disease: assessing the vulnerability of agricultural systems to livestock pests under climate change scenarios. CCAFS Working Paper No. 116. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark, 29 pp. Available at: hdl.handle.net/10568/66595 (accessed on 5 March 2021).

18. Stephen C. & Soos C. (2021). – The implications of climate change for Veterinary Services. *In* Veterinary Services in a changing world: climate change and other external factors (D. Grace Randolph, H.S. Lee & J. Smith, eds). *Rev. Sci. Tech. Off. Int. Epiz.*, **40** (2), 421–430. doi:10.20506/rst.40.2.3234.

19. Ramos S., MacLachlan M. & Melton A. (2017). – Impacts of the 2014-2015 highly pathogenic avian influenza outbreak on the US poultry sector. A report from the Economic Research Service (ERS), LDPM-282-02. ERS, United States Department of Agriculture, Washington, DC, United States of America, 20 pp. Available at: www.ers.usda.gov/webdocs/outlooks/86282/ldpm-282-02.pdf?v=169 (accessed on 25 June 2021).

20. Napp S., Majó N., Sánchez-Gónzalez R. & Vergara-Alert J. (2018). – Emergence and spread of highly pathogenic avian influenza A(H5N8) in Europe in 2016–2017. *Transbound. Emerg. Dis.*, **65** (5), 1217–1226. doi:10.1111/tbed.12861.

21. Burki T.K. (2012). – Ticks and turkey. *Lancet*, **380** (9857), 1897–1898. doi:10.1016/s0140-6736(12)62097-2.

22. Kiplagat S.K., Kitala P.M., Onono J.O., Beard P.M. & Lyons N.A. (2020). – Risk factors for outbreaks of lumpy skin disease and the economic impact in cattle farms of Nakuru County, Kenya. *Front. Vet. Sci.*, **7**, Article No. 259. doi:10.3389/fvets.2020.00259.

23. Kumar A., Staal S.J. & Singh D.K. (2011). – Smallholder dairy farmers' access to modern milk marketing chains in India. *Agric. Econ. Res. Rev.*, **24** (2), 243–254. doi:10.22004/ag.econ.118232.

24. World Health Organization (WHO) (2019). – Worldwide reduction in MERS cases and deaths since 2016. WHO, Geneva, Switzerland. Available at: www.who.int/news/item/08-07-2019-worldwide-reduction-in-mers-cases-and-deaths-since-2016 (accessed on 21 July 2021).

25. World Bank (2012). – People, pathogens and our planet: the economics of One Health. World Bank, Washington, DC, United States of America, 65 pp. Available at: openknowledge.worldbank.org/handle/10986/11892 (accessed on 31 August 2020).

26. Cagnolati V., Tempia S. & Abdi A.M. (2006). – Economic impact of Rift Valley fever on the Somali livestock industry and a novel surveillance approach in nomadic pastoral systems. *In* Proc. of the 11th International Symposium on Veterinary Epidemiology and Economics, Cairns, Australia. New Zealand Veterinary Association, Wellington, New Zealand. Available at: www.sciquest.org.nz/elibrary/download/64159/T5-5.4.1+-+Economic+impact+of+Rift+Valley+fever+on+the+Somali+livestock+industry (accessed on 5 March 2021).

27. Rich K.M. & Wanyoike F. (2010). – An assessment of the regional and national socio-economic impacts of the 2007 Rift Valley fever outbreak in Kenya. *Am. J. Trop. Med. Hyg.*, **83** (Suppl. 2), 52–57. doi:10.4269/ajtmh.2010.09-0291.

28. LaBeaud A.D., Bashir F. & King C.H. (2011). – Measuring the burden of arboviral diseases: the spectrum of morbidity and mortality from four prevalent infections. *Popul. Health Metr.*, **9**, Article No. 1. doi:10.1186/1478-7954-9-1.

29. Grace D., Mutua F. […] & Ogutu F. (2012). – Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. International Livestock Research Institute, Nairobi, Kenya, 119 pp. Available at: cgspace.cgiar.org/handle/10568/21161 (accessed on 31 August 2020).

30. Dobson A.P., Pimm S.L. […] & Vale M.M. (2020). – Ecology and economics for pandemic prevention. *Science*, **369** (6502), 379–381. doi:10.1126/science.abc3189.

31. Food and Agriculture Organization of the United Nations (FAO) (2011). – Approaches to controlling, preventing and eliminating H5N1 highly pathogenic avian influenza in endemic countries. Animal Production and Health Paper No. **171**. FAO, Rome, Italy, 97 pp. Available at: www.fao.org/3/i2150e/i2150e00.htm (accessed on 31 August 2020).

32. World Organisation for Animal Health (OIE) (2019). – Chapter 1.4. Animal health surveillance. *In* Terrestrial Animal Health Code, 28th Ed. OIE, Paris, France. Available at: www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmfile=chapitre_surveillance_general.htm (accessed on 31 July 2020).

33. Halliday J.E.B., Hampson K., Hanley N., Lembo T., Sharp J.P., Haydon D.T. & Cleaveland S. (2017). – Driving improvements in emerging disease surveillance through locally relevant capacity strengthening. *Science*, **357** (6347), 146–148. doi:10.1126/science.aam8332.

34. Jost C.C., Mariner J.M., Roeder P.L., Sawitri E. & Macgregor-Skinner G.J. (2007). – Participatory epidemiology in disease surveillance and research. *Rev. Sci. Tech. Off. Int. Epiz.*, **26** (3), 537–547. doi:10.20506/rst.26.3.1765.

35. World Health Organization (WHO) (2020). – Coronavirus disease (COVID-19) advice for the public: mythbusters. WHO, Geneva, Switzerland. Available at: www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public/myth-busters (accessed on 31 August 2020).

36. Taha F.A. (2007). – How highly pathogenic avian influenza (H5N1) has affected world poultry-meat trade. A report from the Economic Research Service (ERS), LDP-M-159-02. ERS, United States Department of Agriculture, Washington, DC, United States of America, 27 pp. doi:10.22004/ag.econ.7360.

37. Ng'ang'a C.M., Bukachi S.A. & Bett B.K. (2016). – Lay perceptions of risk factors for Rift Valley fever in a pastoral community in northeastern Kenya. *BMC Public Health*, **16**, Article No. 32. doi:10.1186/s12889-016-2707-8.

38. Chunara R., Smolinski M.S. & Brownstein J.S. (2013). – Why we need crowdsourced data in infectious disease surveillance. *Curr. Infect. Dis. Rep.*, **15**, 316–319. doi:10.1007/s11908-013-0341-5.

39. Bett B., Long'or B. & Kihara A. (2018). – Mobile phone-based syndromic surveillance system for early detection and control of livestock diseases [PowerPoint presentation]. Presented at the CGIAR Platform for Big Data in Agriculture Convention, Nairobi, Kenya, 3–5 October. International Livestock Research Institute, Nairobi, Kenya. Available at: hdl.handle.net/10568/97619 (accessed on 31 August 2020).

40. Yano T., Phornwisetsirikun S. […] & Srikitjakarn L. (2018). – A participatory system for preventing pandemics of animal origins: pilot study of the participatory One Health disease detection (PODD) system. *JMIR Public Health Surveill.*, **4** (1), Article No. e25. doi:10.2196/publichealth.7375.

41. World Organisation for Animal Health (OIE) (2020). – International standards. OIE, Paris, France. Available at: www.oie.int/en/what-we-do/standards/ (accessed on 21 July 2021).

42. World Organisation for Animal Health (OIE) (2020). – OIE PVS Pathway. OIE, Paris, France. Available at: www.oie.int/solidarity/pvs-pathway/ (accessed on 31 July 2020).

43. World Health Organization (WHO) (2018). – Joint External Evaluation Tool: International Health Regulations, 2nd Ed. WHO, Geneva, Switzerland, 119 pp. Available at: www.who.int/ihr/publications/WHO_HSE_GCR_2018_2/en/ (accessed on 31 August 2020).

44. One Health Assessment for Planning and Performance (OH-APP) (2020). – OH APP Resources. Available at: www.onehealthapp.org/resources (accessed on 18 August 2020).

45. Food and Agriculture Organization of the United Nations (FAO) (2019). – Surveillance evaluation tool (SET). FAO, Rome, Italy. Available at: www.fao.org/ag/againfo/programmes/en/empres/tools_SET.html (accessed on 31 July 2020).

46. Food and Agriculture Organization of the United Nations (FAO) (2016). – Sharing FAO tools for veterinary laboratory assessment. FAO, Rome, Italy. Available at: www.fao.org/ag/againfo/programmes/en/empres/news_231216b.html (accessed on 31 July 2020).

47. Food and Agriculture Organization of the United Nations (FAO) (2011). – Good emergency management practices: the essentials (N. Honhold, I. Douglas, W. Geering, A. Shimshoni & J. Lubroth, eds). FAO Animal Production and Health Manual No. **11**. FAO, Rome, Italy, 131 pp. Available at: www.fao.org/3/a-ba0137e.pdf (accessed on 31 August 2020).

48. Food and Agriculture Organization of the United Nations (FAO) & World Organisation for Animal Health (OIE) (2004). – The global framework for the progressive control of transboundary animal diseases (GF-TADs). FAO, Rome, Italy & OIE, Paris, France, 40 pp. Available at: www.fao.org/3/a-ak136e.pdf (accessed on 31 July 2020).

49. Roeder P.L. (2011). – Rinderpest: the end of cattle plague. *Prev. Vet. Med.*, **102** (2), 98–106. doi:10.1016/j.prevetmed.2011.04.004.

50. Mariner J.C., House J.A., Mebus C.A., Sollod A.E., Chibeu D., Jones B.A., Roeder P.L., Admassu B. & van't Klooster G.G.M. (2012). – Rinderpest eradication: appropriate technology and social innovations. *Science*, **337** (6100), 1309–1312. doi:10.1126/science.1223805.

51. Food and Agriculture Organization of the United Nations (FAO) & World Organisation for Animal Health (OIE) (2020). – Global control of African swine fever: a GF-TADs initiative. FAO, Rome, Italy & OIE, Paris, France, 17 pp. Available at: www.fao.org/3/ca9164en/ca9164en.pdf (accessed on 25 August 2020).

52. African Union (2020). – African Continental Free Trade Area. African Union, Addis Ababa, Ethiopia. Available at: au.int/en/cfta (accessed on 18 August 2020).

53. Association of Southeast Asian Nations (ASEAN) (2010). – ASEAN ministerial statement on 'ASEAN cooperation on animal health and zoonoses: avian influenza and beyond'. ASEAN, Jakarta, Indonesia. Available at: asean.org/?static_post=the-thirty-second-meeting-of-the-asean-minsters-on-agriculture-and-forestry-32nd-amaf-phnom-penh-23-october-2010 (accessed on 31 August 2020).

54. Animal & Human Health for the Environment and Development (AHEAD). (2020). – Welcome to AHEAD: Animal & human health for the environment and development. Available at: wcs-ahead.org/index.html (accessed on 18 August 2020).

55. Osofsky S.A., Cleaveland S., Karesh W.B., Kock M.D., Nyhus P.J., Starr L. & Yang A. (eds) (2005). – Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland, 239 pp. Available at: www.iucn.org/content/conservation-and-development-interventions-wildlifelivestock-interface-implications-wildlife-livestock-and-human-health-proceedings-southern-and-east-african-experts-panel-designing-successful (accessed on 31 August 2020).

56. Machalaba C.C., Salerno R.H. […] & Wannous C. (2018). – Institutionalizing One Health: from assessment to action. *Health Secur.*, **16** (Suppl. 1), S37–S43. doi:10.1089/hs.2018.0064.

57. Kitua A.Y., Scribner S., Rasmuson M., Kambarage D., Mghamba J., Mwakapeje E.R., Chinyuka H., Bernard J., Zimmerman K., Duale S. & Mutonga D. (2019). – Building a functional national One Health platform: the case of Tanzania. *One Health Outlook*, **1**, Article No. 3. doi:10.1186/s42522-019-0003-0.

58. One Health Workforce (OHW) (2020). – What is a One Health Workforce? A One Health Workforce planning guide. Available at: medium.com/one-health-workforce/what-is-a-one-health-workforce-cc5d3f9e9db5 (accessed on 18 August 2020).

59. Pruvot M., Fine A.E. […] & Shiilegdamba E. (2020). – Outbreak of peste des petits ruminants among critically endangered Mongolian saiga and other wild ungulates, Mongolia, 2016–2017. *Emerg. Infect. Dis.*, **26** (1), 51–62. doi:10.3201/eid2601.181998.

60. World Bank (2017). – From panic and neglect to investing in health security: financing pandemic preparedness at a national level. World Bank Group, Washington, DC, United States of America. Available at: documents.worldbank.org/curated/en/979591495652724770/From-panic-and-neglect-to-investing-in-health-security-financing-pandemic-preparedness-at-a-national-level (accessed on 31 August 2020).

61. Berthe F.C.J., Bouley T., Karesh W.B., Le Gall F.G., Machalaba C.C., Plante C.A. & Seifman R.M. (2018). – Operational framework for strengthening human, animal and environmental public health systems at their interface. World Bank Group, Washington, DC, United States of America. Available at: documents.worldbank.org/curated/en/703711517234402168/Operational-framework-for-strengthening-human-animal-and-environmental-public-health-systems-at-their-interface (accessed on 31 August 2020).

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 511-521

Antimicrobial resistance at the livestock–human interface: implications for Veterinary Services

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Summary

The emergence of antimicrobial resistance (AMR) is a major global public health issue, but it also jeopardises the effectiveness of antimicrobials as a means of curing infections in animals that threaten their health, welfare and productivity. Several reports show that infections in humans caused by antimicrobial-resistant pathogens may be linked to antimicrobial use (AMU) and AMR in food-producing animals; however, to what extent this happens is unknown. Use of antimicrobials drives the emergence of AMR, therefore, their extensive over-use and misuse in livestock is of concern.

Robust AMU and AMR data are important to monitor the progress of interventions aiming to reduce AMR in the livestock sector. However, not all countries have complete data on antibiotic sales or use, so our current knowledge of global AMU is primarily based on modelling estimates. Antimicrobial resistance prevalence data are limited, particularly in low- and middle-income countries, but in some high-income regions fairly robust data are available. It should also be noted that monitoring guidelines and protocols are available to provide globally harmonised AMR data.

Using antimicrobials rationally and not using them for disease prevention purposes is key to reducing AMU. To ensure that these drugs are used appropriately we must ensure that: a) veterinary services are accessible and affordable for farmers; b) antibiotics are only sold on prescription; c) veterinarians earn no revenue linked to the sale or prescription of antibiotics; d) veterinarians have substantial skills in preventive medicine (good animal husbandry, efficient biosecurity and vaccinology); and e) the benefits of preventive measures must appeal to farmers so that they are willing to pay for them.

Keywords

Animal husbandry – Antibiotics – Antimicrobial resistance – Antimicrobial use – Biosecurity – Farmers – Livestock – Vaccination – Veterinary service.

Introduction

Antimicrobial resistance (AMR) is a major global public health issue that is getting increasing attention. Given that the use of antimicrobials drives the emergence of resistance, the extensive use in the livestock sector of antibiotics, the sub-set of antimicrobials effective against bacteria, is under scrutiny (1, 2, 3). The widespread use in livestock is attributable to various kinds of prophylactic use and use as growth promoters, mostly administered as a feed additive. Similar practices are rare in human medicine. There are several reports on how resistant bacteria from animals have infected humans (4). To what extent this happens, or how much the livestock sector contributes to the overall prevalence of resistant microbes in humans, is largely unknown. The livestock–human connection within AMR is of most concern with respect to resistance to antibiotics. This is because humans and livestock share pathogenic as well as commensal bacteria and because the same classes of antibiotics are used in both human and veterinary medicine. Antibiotic resistance jeopardises the effectiveness of antibiotics in curing animals of bacterial infections that threaten their health, welfare and productivity (5). The

https://doi.org/10.20506/rst.40.2.3241

extensive use of antibiotics in the livestock sector for growth promotion and disease prevention, compensating for poor animal husbandry and biosecurity, should be stopped. This is challenging for Veterinary Services, but will, if wisely handled, contribute positively to human and animal health.

Here, the authors begin by providing an overview of antimicrobial use (AMU) as well as AMR across the world. They then assess the over-arching impact of AMR on animal health and discuss the link between resistance in livestock populations and in humans. Finally, they present ways in which antibiotics can be used in livestock in a more prudent and medically rational manner – an area where Veterinary Services play a key role.

Antimicrobial use and antimicrobial resistance in livestock

Antimicrobial use in the livestock sector

It has been estimated that 73% of global AMU is in livestock, and a 2017 study comprising sales data from 41 countries from all regions in the world projected that their use would increase by 11.5% by 2030, primarily in Asia (6, 7). This increase is being driven by intensification of livestock farming to meet the growing demand for animal protein, particularly in low- and middle-income countries (LMICs), where AMU is poorly regulated and antimicrobials are used irrationally to compensate for poor animal husbandry practices (7, 8, 9, 10).

Antibiotics are veterinary medicines used in livestock to treat bacterial infections, to prevent disease in a herd and, at sub-therapeutic concentrations, to promote growth. They are administered either orally via feed or in drinking water, or parenterally. Antibiotics are ranked in importance for human medicine (11) and veterinary medicine (12). In the few cases where the same antibiotic class is critically important to both sectors, e.g. fluroquinolones and third- and fourth-generation cephalosporins, recommendations for veterinary use are provided by the World Organisation for Animal Health (OIE). These recommendations are as follows:

a) these antibiotics should not be used for metaphylaxis (preventing specific disease outbreaks)

b) they should not to be used as a first line treatment unless justified, and their use should be guided by antimicrobial susceptibility testing

c) off-label use should be limited and reserved for when no alternatives are available

d) they should not to be used as growth promoters (13).

A key objective of many national and international action plans, including those of the OIE (3), the Food and Agriculture Organization of the United Nations (FAO) (2), and the World Health Organization (WHO) (1), is prudent antibiotic use, which is connected to monitoring of antibiotic consumption patterns and understanding drivers of use. High-income countries, typically those in Europe and North America, have national monitoring programmes that capture antibiotic prescriptions in animals, with the data sometimes stratified by animal species, age and disease indication (14). This information is important to a) identify areas for targeted interventions, and b) evaluate the impact of AMU/AMR-reducing interventions (15). However, only 6% of LMICs monitor AMU in animals (16), as they do not have the capacity or resources to establish and sustain a nationwide surveillance system; consequently, there is a general scarcity of data at the detailed level on the extent to which antibiotics are used and for what purpose.

In an attempt to obtain robust and harmonised global AMU data in food animals, the OIE has asked its Member Countries to submit AMU data annually since October 2015 (currently, the data are aggregated at the regional level only [17]). Moreover, the OIE has developed standards on monitoring AMU and AMR in livestock (Chapters 6.9 and 6.8 in the *Terrestrial Animal Health Code*) (18).

Banning the use of sub-therapeutic antimicrobials for growth promotion is key to reducing AMR, and many regions have introduced regulations to this effect. In the European Union, regulations came into effect in 2006, and subsequent measures, such as improved biosecurity, vaccinations, etc., led to a 20% reduction in antimicrobial consumption in the region between 2011 and 2016 (19). Similarly, in the United States of America, in 2017, antibiotic sales fell by 33% when use of antimicrobial growth promoters was restricted and limits were imposed on the use of antibiotics such that they could only be used under the supervision of a veterinarian (20). Studies have shown that the negative impact of these bans on animal productivity was temporary and could be mitigated with increased biosecurity and better herd management (21, 22, 23).

Clear regulations that ban the use of antibiotics as growth promoters are also in place in LMICs such as Bangladesh, Indonesia, India and Thailand (24), but enforcement is challenging. Moreover, there are no economic impact analyses conducted specifically in the LMIC livestock production context that assess the effect of restricting antimicrobial growth promoters, or the costs and benefits of alternatives to antibiotics, such as improved animal husbandry (9, 10, 25).

Antimicrobial resistance in livestock

One of the most important issues to consider when addressing AMR is surveillance, and it is a key pillar in the Global Action Plan on AMR led by the Tripartite (FAO, OIE and WHO), in the AMR strategies of the individual organisations, and in national AMR action plans. In human medicine, the WHO's Global Antimicrobial Resistance Surveillance System collects AMR data for selected indicator bacteria to estimate the global burden of AMR (16). As yet, no such global system exists for animals, but, in Europe, AMR data in zoonotic and indicator bacteria from food animals and their products are collected annually by countries in selected food animal species and age groups. In the latest report for 2017–2018, some promising trends were noted in food animals: a) there was decrease in the prevalence of extended-spectrum beta-lactamase-/AmpC-producing *Escherichia coli;* b) there was a significant increase in the proportion of fully susceptible *E. coli* (approximately 25% in some Member States); c) resistance to colistin was uncommon; and d) carbapenemase-producing *E. coli* were not detected in poultry (26). In North America, similar monitoring of AMR in animals has been implemented. However, in LMICs, only 10% of countries reported monitoring AMR in animals (27). In the absence of national or regional AMR data, Van Boekel *et al.* (28) reviewed point prevalence surveys carried about between 2000 and 2018 to provide a snapshot of AMR levels in animals and animal food products in LMICs. The review focused on four bacterial species: *E. coli, Campylobacter* spp., non-typhoidal *Salmonella* spp. and *Staphylococcus aureus*. Some of the key observations from this study were that: a) there is geographical variation in the number of studies performed (fewer studies conducted in Africa compared to Asia); b) there has been an overall increase in AMR levels over time in different livestock commodities; and c) geographical differences in AMR levels and patterns of resistance appear to be associated with regional antimicrobial consumption patterns.

Impact of antimicrobial resistance on animal health and the interaction with human health

Impact of antimicrobial resistance on animal health

The impact of AMR on animal health has been given far less attention than its impact on human health, but the effects are similar. As in humans, AMR in animals will lead to infections that would not have otherwise occurred, increased frequency of treatment failures, and increased severity of infections (29). Furthermore, losing treatment options, either through the occurrence of resistance or through restrictions on their use, will also have consequences for animal health and welfare (3). For owners of food and commodity-producing animals, AMR may lead to financial losses both directly, through higher mortality, and indirectly, through reduced production and growth, decreased feed conversion, and early culling of breeding and production animals. Eventually this may increase the price of commodities and food from animal production for the end consumer (29, 30).

As food animals and food of animal origin are traded worldwide, resistant bacteria selected by antimicrobial usage in one country may cause problems in several other countries, for example, cephalosporin-resistant *E. coli* was spread from broiler parents exported from England, through Sweden, to Denmark, where it was detected in the broiler meat (22, 31). Output and trade in livestock and livestock products are especially vulnerable to AMR impacts (32). In a 2017 World Bank report, it was estimated that, by 2050, global livestock production will fall by 3% to 8% each year due to AMR (25). A number of different AMR-impact scenarios were considered in the report, and it was estimated that the high-impact scenario would lead to an 11% loss in livestock production by 2050, with the highest decline expected in low-income countries (25). Furthermore, in countries that experience a higher burden of infectious disease, and which therefore use a larger amount of antimicrobials, the impact of AMR is likely to be greater. In the small- and medium-sized farming systems commonly found in LMICs, animals are in frequent and close contact with humans and biosecurity is limited, which allows AMR to spread between farms and from livestock to humans (33). Weaker AMR surveillance systems and less regulation of antimicrobials which are more likely to be substandard, falsified or unregistered add to the negative impact of AMR in these countries (24, 33).

Although beyond the scope of this review, it is worth noting that, in animals kept for social reasons, sports, or breeding (such as dogs, cats, horses and exotic animals) there are other challenges in managing emerging AMR. These animals are likely to receive advanced veterinary care in animal clinics or hospitals that have a high animal density and which, like human hospitals, frequently use antibiotics to combat nosocomial infections (30, 34, 35).

Impact of antimicrobial resistance seen from a One Health perspective

Solid scientific evidence is available showing that humans can become infected with resistant microbes as a result of AMU in food-producing and companion animals (4, 36). Depending on the species and production system in

question, AMR genes or microbes are transferred to humans via contact with animals or animal products colonised by resistant organisms, or by ingesting food that is incompletely cooked (30, 36) (Fig. 1). Antimicrobial resistant microbes from animals can also spread from animal waste. In addition, manure or urine from livestock used as fertilizers may excrete unmetabolised antibiotics that contribute to the overall emergence of AMR (37, 38). There are, as yet, too many gaps in the data to be able to determine the extent of this zoonotic transmission.

Antimicrobial resistance is considered an increasingly serious threat, and one that that may undermine the progress made in global health and development, hinder the attainment of the Sustainable Development Goals (39) and widen the inequity gap within and between countries. In the European Union alone, AMR is estimated to cause 25,000 human deaths annually, and several studies project that, should AMR continue to increase, the economic cost will be substantial (25, 40, 41). It is estimated that by 2050, the economic costs of AMR may comprise as much as 1.1% to 3.8% of the global GDP and result in 10 million lives lost a year, with a cumulative US$ 100 trillion of economic output at risk (25, 42, 43).

Medically rational use of antibiotics in livestock

A key pillar in curbing AMR in livestock is improving the way in which antibiotics are used (2, 3). Antibiotics should be used in a medically rational way, i.e., as efficiently as possible and only when needed. They should only be used in cases where not to do so would jeopardise animal health and welfare.

Reducing the need for antibiotics

The need for antibiotics in livestock can be reduced by improving overall animal husbandry and applying disease preventive measures in a herd. This has been demonstrated in countries where the use of antibiotics as growth promoters or for prophylaxis was phased out several decades ago (5). Phasing out must, however, be done carefully and be accompanied by appropriate measures to maintain animal health. Recommended measures have been summarised for the pig, poultry, beef and dairy sectors (44). These measures can be divided into three categories and organised in a hierarchical order (Fig. 2). The first category is good animal husbandry, which includes ensuring sufficient access to water and nutritious feed, appropriate shelter

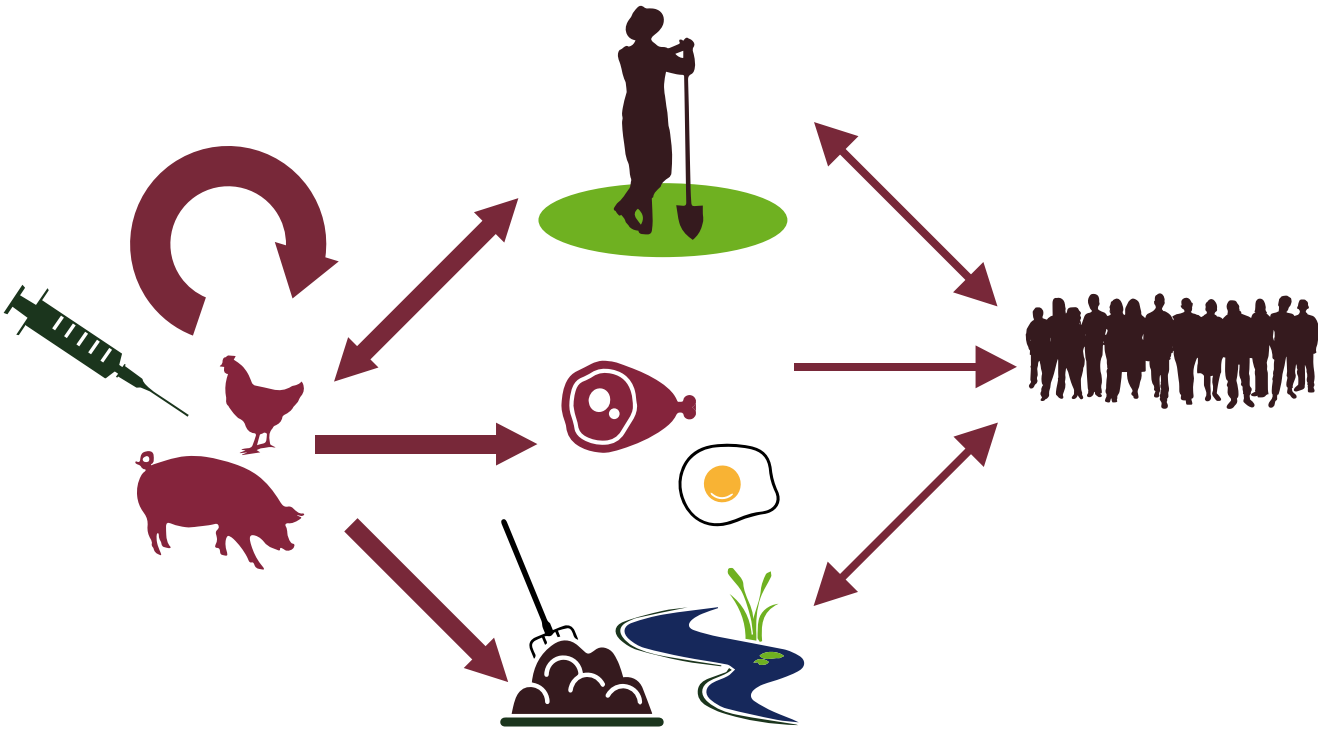


Fig. 1
Possible routes of transmission of resistant bacteria and resistance genes from livestock to the general population
Antimicrobial resistance may be transmitted from livestock to the general human population via farmers working with the animals, via the food chain or via manure and the environment. The relative importance of these various routes is largely unknown

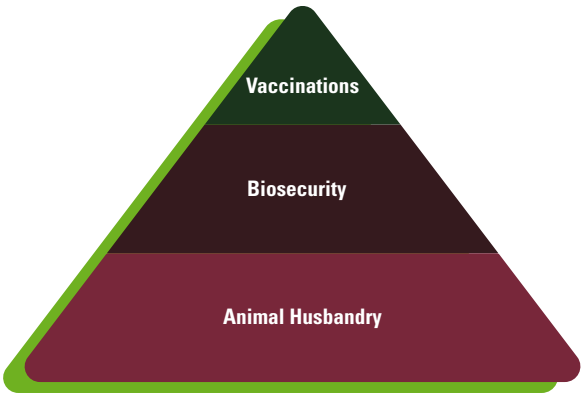


Fig. 2
The key means of disease prevention in hierarchical order
Firstly, good animal husbandry helps to ensure that animals are robust; secondly, effective biosecurity serves as a general barrier, protecting the herd from introduction of infectious diseases; and thirdly, vaccinations protect the individual animal from specific pathogens

and housing, proper hygiene, etc., all of which promote robust and generally disease-resistant animals. The second category is efficient biosecurity, i.e. measures to protect the animals from any kind of infection. These include measures designed to a) prevent infections being introduced to the farm by restricting the number of animals or humans entering the farm (i.e. external biosecurity) and b) hinder the transmission of infections from one group of animals to another group within the farm by placing restrictions on the movement of animals and personnel inside the farm (i.e. internal biosecurity). The third category is vaccination, which involves implementing relevant vaccination schemes against specific infectious diseases that are hazardous for the farm. Many of these preventive measures depend on good management skills alone, but others also need financial and material resource investment. Veterinary Services must be competent to provide correct and implementable advice on all three categories of disease preventive measures, which can be a challenge in both high-income countries and LMICs.

Quality of antibiotics

Access to good quality antimicrobials with proper labelling is a challenge in some parts of the world. The widespread use of substandard and falsified veterinary products causes harm and treatment failure and may lead to loss of confidence in animal health service providers. There are several reports on the use of falsified or substandard pharmaceuticals, especially from LMICs, where health systems are weaker (45). Stronger regulations, improved standards, better reporting systems and greater enforcement by competent authorities can limit the circulation and use of these drugs.

How to use antibiotics in a medically rational way

There are several international initiatives that advocate phasing out the excessive use of antibiotics for growth promotion and prophylaxis, which is often in place to compensate for poor animal management (2, 3). But we should also restrict the use of antibiotics to cure sick animals, and, if antibiotics are truly necessary, we should strive to treat only the affected animals in order to reduce the total amount of antibiotics used (23, 46). Importantly, antibiotics should be used only after a proper diagnosis by a veterinarian, and the prescribed dose, treatment intervals and treatment length must be adhered to (18, 46). A professional clinical or post-mortem diagnosis may be the most feasible; laboratory diagnosis, including susceptibility testing if the causative agent is a bacterium, is desirable, but may not always be possible due to urgency or lack of infrastructure. Obviously, it is important to use an antibiotic to which the diagnosed bacteria are susceptible and to use them at the right time, at the right dose, and for the right length of time. Notably, the use of antibiotics listed as critically important in human medicine by WHO (6) should be avoided. In some countries, these antibiotics are banned for use in veterinary practice or are approved only under certain circumstances.

How to change the use of antibiotics

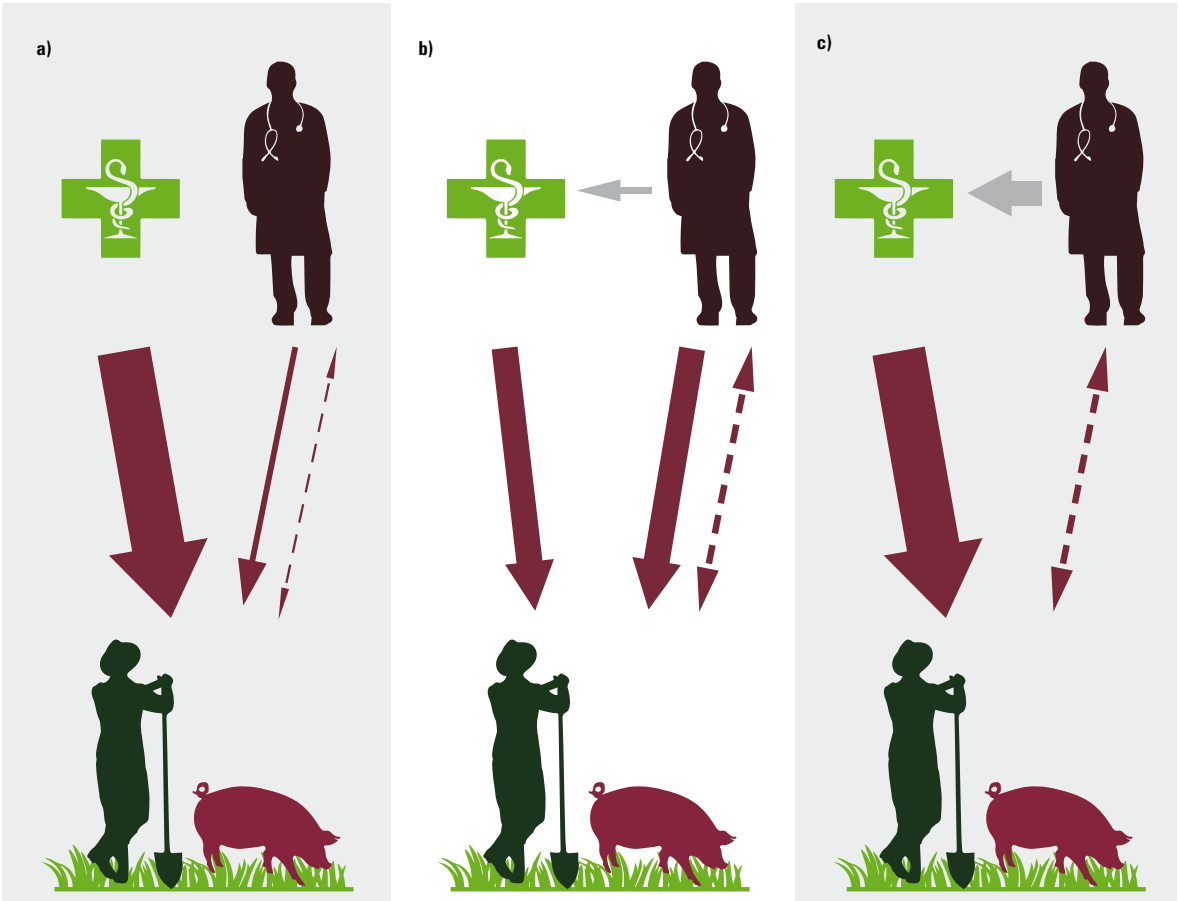
To alter the use of antimicrobials in the livestock sector and ensure that they are used in a more medically rational way, farmers must trust that this kind of use is equally as good and cost-efficient as over-use or misuse, if not more so. Also, the entire livestock and animal health sectors must take responsibility and be aware that, in the long run, inappropriate use will reduce the effectiveness of antibiotics for curing disease, in both humans and animals, and ultimately may stigmatise the livestock sector. Effective Veterinary Services are at the core of efforts to reduce AMU and they must provide farmers with alternatives to antibiotics without jeopardising the incomes of veterinarians or the Veterinary Service as an organisation. Even though more and more countries are banning the use of antibiotics as growth promoters (8), this is not the case everywhere; moreover, in many countries, antibiotics are still available without prescription over the counter (Table I). In these countries, the advisory role commonly played by veterinarians is increasingly being taken over by the salespersons of companies, pharmacies and agrochemical stores that sell their products directly to farmers (38). In countries where veterinarians retain their advisory role, there can still be an issue with the over-use of antimicrobials if veterinarians receive a substantial part of their income from selling these drugs (48). The additional income can serve as an incentive and drive the use of antibiotics. In some countries where a prescription

Table I
Responses to a European Union (EU) survey in which 70 non-EU countries were asked to indicate whether or not a prescription was required to use antimicrobials in animals (47)

World Bank income groups	Yes, in all cases	Yes, in some cases	No	No. of countries
High income	42%	42%	16%	12
Upper-middle income	48%	26%	26%	11
Lower-middle income	20%	45%	35%	20
Low income	10%	45%	45%	27

is required, antimicrobials are allowed to be dispensed through pharmacies only (Fig. 3).

If countries introduce restrictions on veterinarians receiving an income from the sale of antibiotics, veterinarians who earn a large part of their income this way may need to expand their skills in preventive medicine so that they can offer services other than diagnosis and antibiotic treatment, e.g., vaccination and advice on herd management (44). When a cap on veterinarians' profits from antibiotic sales was introduced in the Scandinavian countries, the incentive for veterinarians to prescribe antimicrobials was removed and the use of antibiotics fell accordingly, but the livestock sector is still highly productive and the veterinary profession has remained economically viable (48).



Solid purple arrow: distribution of antibiotics, the thickness of the arrow reflects the share of antibiotics distributed this way.
Dotted purple arrow: diagnostic/consultation with a veterinarian
Grey arrow: prescription of antibiotics

Fig. 3
Three different ways to distribute antibiotics to a livestock farmer
a) in a country where antibiotics can be dispensed without a veterinary prescription and which has weak Veterinary Services (mostly in low-income countries)
b) in a country where antibiotics cannot be dispensed without a veterinary prescription, but the veterinarian is allowed to sell antibiotics directly to the farmer (common in middle- and high-income countries)
c) in a country where antibiotics cannot be dispensed without a veterinary prescription and the veterinarian is not allowed to sell antibiotics directly to the farmer (some high-income countries)

Conclusions

In summary, by using antimicrobials rationally, the animal health sector can reduce AMU in livestock and thereby make a major contribution to the global AMR fight. To encourage a more medically rational use of antibiotics, the sector must ensure that: a) veterinary services are available and affordable for farmers; b) antibiotics are sold only on prescription; *c)* veterinarians do not receive any income from the sale or prescription of antibiotics; d) veterinarians have well-grounded skills in preventive medicine (vaccinology, good animal husbandry, efficient biosecurity) in addition to conventional diagnostic competence; and e) the benefits of preventive medicine must be made clear to farmers so they are willing to pay for them.

La résistance aux agents antimicrobiens à l'interface animaux d'élevage–humains : conséquences pour les Services vétérinaires

U. Magnusson, A. Moodley & K. Osbjer

Résumé

L'émergence de la résistance aux agents antimicrobiens (RAM) constitue un problème majeur de santé publique à l'échelle mondiale, qui compromet également l'efficacité des agents antimicrobiens utilisés chez les animaux pour traiter les infections menaçant leur santé, leur bien-être et leur productivité. Plusieurs rapports montrent que les infections humaines par des agents pathogènes résistants aux agents antimicrobiens sont probablement liées à l'utilisation d'agents antimicrobiens (UAM) et à la RAM chez les animaux servant à la production de denrées alimentaires ; toutefois, on ignore la portée exacte de ce phénomène. L'utilisation d'agents antimicrobiens étant à l'origine de l'émergence de la RAM, l'utilisation excessive ou le mauvais usage de ces produits chez les animaux d'élevage sont des sujets de préoccupation.

Il est important de disposer de données solides sur l'UAM et la RAM afin de suivre les progrès des interventions visant à réduire la RAM dans le secteur de l'élevage. Plusieurs pays ont des données incomplètes sur les ventes ou l'utilisation d'antibiotiques au niveau national et nos connaissances actuelles sur l'UAM à l'échelle mondiale proviennent principalement d'estimations basées sur des modélisations. Les données sur la prévalence de la résistance aux agents antimicrobiens sont souvent éparses, en particulier dans les pays à revenu faible ou intermédiaire tandis que dans d'autres régions à revenu élevé, les données disponibles sont assez solides. Il convient à cet égard de signaler l'existence de lignes directrices et de protocoles de surveillance permettant de fournir des données harmonisées sur la RAM à l'échelle mondiale.

Pour réduire l'UAM, il est essentiel d'appliquer des méthodes de prévention des maladies qui ne fassent pas appel aux agents antimicrobiens, et de n'utiliser ces derniers qu'en suivant des principes rationnels. Cela suppose de faire en sorte que : a) les services vétérinaires soient accessibles et abordables pour les éleveurs ; b) les antibiotiques ne soient vendus que sur ordonnance ; c) les vétérinaires ne tirent pas de revenus de la vente ou de la prescription d'antibiotiques ; d) les vétérinaires praticiens soient dotés de compétences solides en médecine préventive, y compris concernant les bonnes pratiques d'élevage, les mesures efficaces de biosécurité et la vaccinologie ; e) la valeur ajoutée de ces mesures soit bien perçue par les éleveurs afin qu'ils soient disposés à payer pour ces services.

Mots-clés

Animaux d'élevage – Antibiotique – Biosécurité – Élevage – Éleveurs – Résistance aux agents antimicrobiens – Services vétérinaires – Utilisation des agents antimicrobiens – Vaccination.

Resistencia a los antimicrobianos en la interfaz del ganado con el ser humano y sus consecuencias para los Servicios Veterinarios

U. Magnusson, A. Moodley & K. Osbjer

Resumen

La aparición de resistencias a los antimicrobianos no solo supone un importante problema de salud pública mundial, sino que también puede restar eficacia a los antimicrobianos para curar infecciones que amenazan la salud, el bienestar y la productividad de los animales. Varios informes han dejado patente que las infecciones humanas causadas por patógenos resistentes a los antimicrobianos pueden guardar relación con el uso de estos fármacos y la resistencia a ellos en animales de producción alimentaria, aunque se ignora la amplitud del fenómeno. Dado que el uso de antimicrobianos provoca la aparición de resistencias, su utilización excesiva o incorrecta en el ganado, tan extendida, resulta preocupante. Para seguir de cerca el progreso de las intervenciones destinadas a reducir la resistencia a los antimicrobianos en el sector ganadero es importante disponer de datos robustos sobre la utilización de estos fármacos y las resistencias a ellos. Varios países tienen datos incompletos sobre las ventas o el uso de antibióticos, de tal modo que lo que hoy sabemos sobre el uso de antimicrobianos a escala mundial reposa principalmente en estimaciones obtenidas por modelización. Los datos sobre la prevalencia de resistencias a los antimicrobianos son fragmentarios, especialmente en los países de renta baja o mediana, pero en algunas regiones de renta alta existen datos bastante robustos. Conviene señalar también la existencia de directrices y protocolos de seguimiento que permiten disponer de datos mundialmente armonizados en la materia.

Para reducir las resistencias a los antimicrobianos, dos factores clave son la prevención de enfermedades sin recurrir a estos fármacos y el uso racional de los mismos, factores que pasan por lo siguiente: a) servicios veterinarios accesibles y asequibles para los productores; b) venta de antibióticos únicamente con receta; c) los veterinarios no deben percibir ingresos ligados a la venta o prescripción de antibióticos; d) los veterinarios deben contar con sólidos conocimientos de medicina preventiva, lo que incluye cuestiones de buena producción animal, seguridad biológica eficaz y vacunología; y e) tales medidas deben aportar un valor añadido que resulte atractivo para los ganaderos, de forma que estén dispuestos a pagar por ese servicio.

Palabras clave

Antibióticos – Ganaderos – Ganado – Producción animal – Resistencia a los antimicrobianos – Seguridad biológica – Servicio veterinario – Uso de antimicrobianos – Vacunación.

References

1. World Health Organization (WHO) (2015). – Global action plan on antimicrobial resistance. WHO, Geneva, Switzerland, 28 pp. Available at: apps.who.int/iris/bitstream/handle/10665/193736/9789241509763_eng.pdf?sequence=1 (accessed on 17 August 2020).

2. Food and Agriculture Organization of the United Nations (FAO) (2016). – FAO action plan on antimicrobial resistance: 2016–2020. FAO, Rome, Italy, 25 pp. Available at: www.fao.org/3/a-i5996e.pdf (accessed on 18 August 2020).

3. World Organisation for Animal Health (OIE) (2016). – The OIE strategy on antimicrobial resistance and the prudent use of antimicrobials. OIE, Paris, France, 12 pp. Available at: www.oie.int/fileadmin/Home/eng/Media_Center/docs/pdf/PortailAMR/EN_OIE-AMRstrategy.pdf (accessed on 18 August 2020).

4. Hoelzer K., Wong N., Thomas J., Talkington K., Jungman E. & Coukell A. (2017). – Antimicrobial drug use in food-producing animals and associated human health risks: what, and how strong, is the evidence? *BMC Vet. Res.*, **13**, Article No. 211. doi:10.1186/s12917-017-1131-3.

5. Bengtsson B. & Wierup M. (2006). – Antimicrobial resistance in Scandinavia after ban of antimicrobial growth promoters. *Anim. Biotechnol.*, **17** (2), 147–156. doi:10.1080/10495390600956920.

6. Van Boeckel T.P., Brower C., Gilbert M., Grenfell B.T., Levin S.A., Robinson T.P., Teillant A. & Laxminarayan R. (2015). – Global trends in antimicrobial use in food animals. *Proc. Natl Acad. Sci. USA*, **112** (18), 5649–5654. doi:10.1073/pnas.1503141112.

7. Tiseo K., Huber L., Gilbert M., Robinson T.P. & Van Boeckel T.P. (2020). – Global trends in antimicrobial use in food animals from 2017 to 2030. *Antibiotics*, **9** (12), Article No. 918. doi:10.3390/antibiotics9120918.

8. Klein E.Y., Van Boeckel T.P., Martinez E.M., Pant S., Gandra S., Levin S.A., Goossens H. & Laxminarayan R. (2018). – Global increase and geographic convergence in antibiotic consumption between 2000 and 2015. *Proc. Natl Acad. Sci. USA*, **115** (15), E3463–E3470. doi:10.1073/pnas.1717295115.

9. Van Boeckel T.P., Glennon E.E., Chen D., Gilbert M., Robinson T.P., Grenfell B.T., Levin S.A., Bonhoeffer S. & Laxminarayan R. (2017). – Reducing antimicrobial use in food animals. *Science*, **357** (6358), 1350–1352. doi:10.1126/science.aao1495.

10. Schar D., Sommanustweechai A., Laxminarayan R. & Tangcharoensathien V. (2018). – Surveillance of antimicrobial consumption in animal production sectors of low- and middle-income countries: optimizing use and addressing antimicrobial resistance. *PLoS Med.*, **15** (3), Article No. e1002521. doi:10.1371/journal.pmed.1002521.

11. World Health Organization (WHO) (2019). – Critically important antimicrobials for human medicine, 6th revision. WHO, Geneva, Switzerland, 45 pp. Available at: www.who.int/foodsafety/publications/antimicrobials-sixth/en/ (accessed on 12 June 2020).

12. World Organisation for Animal Health (OIE) (2018). – OIE annual report on antimicrobial agents intended for use in animals. OIE, Paris, France, 131 pp. Available at: www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/AMR/Annual_Report_AMR_3.pdf (accessed on 12 June 2020).

13. World Organisation for Animal Health (OIE) (2019). – OIE list of antimicrobial agents of veterinary importance. OIE, Paris, France, 9 pp. Available at: www.oie.int/fileadmin/Home/eng/Our_scientific_expertise/docs/pdf/AMR/A_OIE_List_antimicrobials_July2019.pdf (accessed on 10 August 2020).

14. Sanders P., Vanderhaeghen W. […] & Dewulf J. (2020). – Monitoring of farm-level antimicrobial use to guide stewardship: overview of existing systems and analysis of key components and processes. *Front. Vet. Sci.*, **7**, Article No. 540. doi:10.3389/fvets.2020.00540.

15. Ferreira J.P. (2017). – Why antibiotic use data in animals needs to be collected and how this can be facilitated. *Front. Vet. Sci.*, **4**, Article No. 213. doi:10.3389/fvets.2017.00213.

16. World Health Organization (WHO) (2021). – Global Antimicrobial Resistance and Use Surveillance Systems (GLASS). WHO, Geneva, Switzerland. Available at: www.who.int/initiatives/glass (accessed on 15 July 2021).

17. Góchez D., Raicek M., Pinto Ferreira J., Jeannin M., Moulin G. & Erlacher-Vindel E. (2019). – OIE Annual report on antimicrobial agents intended for use in animals: methods used. *Front. Vet. Sci.*, **6**, Article No. 317. doi:10.3389/fvets.2019.00317.

18. World Organisation for Animal Health (OIE) (2019). – Terrestrial Animal Health Code, 28th Ed. OIE, Paris, France. Available at: www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/ (accessed on 26 July 2021).

19. European Medicines Agency (EMA) (2018). – Sales of veterinary antimicrobial agents in 30 European countries in 2016. Eighth Report of the European Surveillance of Veterinary Antimicrobial Consumption Project (EMA/275982/2018). EMA, London, United Kingdom, 184 pp. Available at: www.ema.europa.eu/documents/report/sales-veterinary-antimicrobial-agents-30-european-countries-2016-trends-2010-2016-eighth-esvac_en.pdf (accessed on 18 August 2020).

20. Food and Drug Administration (FDA) (2018). – 2017 Summary report on antimicrobials sold or distributed for use in food-producing animals. FDA, Silver Spring, MD, United States of America, 52 pp. Available at: www.fda.gov/media/119332/download (accessed on 18 August 2020).

21. Wierup M. (2001). – The Swedish experience of the 1986 year ban of antimicrobial growth promoters, with special reference to animal health, disease prevention, productivity, and usage of antimicrobials. *Microb. Drug Resist.*, **7** (2), 183–190. doi:10.1089/10766290152045066.

22. Aarestrup F.M. (2015). – The livestock reservoir for antimicrobial resistance: a personal view on changing patterns of risks, effects of interventions and the way forward. *Philos. Trans. Roy. Soc. Lond., B, Biol. Sci.*, **370** (1670), Article No. 20140085. doi:10.1098/rstb.2014.0085.

23. Tang K.L., Caffrey N.P., Nóbrega D.B., Cork S.C., Ronksley P.E., Barkema H.W., Polachek A.J., Ganshorn H., Sharma N., Kellner J.D., Checkley S.L. & Ghali W.A. (2019). – Comparison of different approaches to antibiotic restriction in food-producing animals: stratified results from a systematic review and meta-analysis. *BMJ Glob. Health*, **4**, Article No. e001710. doi:10.1136/bmjgh-2019-001710.

24. Goutard F.L., Bordier M., Calba C., Erlacher-Vindel E., Góchez D., de Balogh K., Benigno C., Kalpravidh W., Roger F. & Vong S. (2017). – Antimicrobial policy interventions in food animal production in South East Asia. *BMJ*, **358** (Suppl. 1), Article No. j3544. doi:10.1136/bmj.j3544.

25. Jonas O.B., Irwin A., Berthe F.C.J., Le Gall F.G. & Marquez P.V. (2017). – Drug-resistant infections: a threat to our economic future (Vol. 2): final report. HNP/Agriculture Global Antimicrobial Resistance Initiative. World Bank Group, Washington, DC, United States of America. Available at: documents.worldbank.org/curated/en/323311493396993758/final-report (accessed on 10 August 2020).

26. European Food Safety Agency (EFSA) & European Centre for Disease Prevention and Control (ECDC) (2020). – The European Union summary report on antimicrobial resistance in zoonotic and indicator bacteria from humans, animals and food in 2017/2018. *EFSA J.*, **18** (3), Article No. e06007. doi:10.2903/j.efsa.2020.6007.

27. World Health Organization (WHO) (2020). – Global database for the Tripartite antimicrobial resistance (AMR) country self-assessment survey: AMR self-assessment survey responses 2018/2019. WHO, Geneva, Switzerland. Available at: amrcountryprogress.org (accessed on 18 August 2020).

28. Van Boeckel T.P., Pires J. Silvester R., Zhao C., Song J., Criscuolo N.G., Gilbert M., Bonhoeffer S. & Laxminarayan R. (2019). – Global trends in antimicrobial resistance in animals in low- and middle-income countries. *Science*, **365** (6459), Article No. eaaw1944. doi:10.1126/science.aaw1944.

29. Bengtsson B. & Greko C. (2014). – Antibiotic resistance: consequences for animal health, welfare, and food production. *Ups. J. Med. Sci.*, **119** (2), 96–102. doi:10.3109/03009734.2014.901445.

30. Catry B., Van Duijkeren E. […] & Torren-Edo J. (2010). – Reflection paper on MRSA in food-producing and companion animals: epidemiology and control options for human and animal health. *Epidemiol. Infect.*, **138** (5), 626–644. doi:10.1017/S0950268810000014.

31. Agersø Y., Jensen J.D., Hasman H. & Pedersen K. (2014). – Spread of extended spectrum cephalosporinase-producing *Escherichia coli* clones and plasmids from parent animals to broilers and to broiler meat in a production without use of cephalosporins. *Foodborne Pathog. Dis.*, **11** (9), 740–746. doi:10.1089/fpd.2014.1742.

32. Food and Agriculture Organization of the United Nations (FAO) (2016). – Drivers, dynamics and epidemiology of antimicrobial resistance in animal production. FAO, Rome, Italy, 68 pp. Available at: www.fao.org/3/a-i6209e.pdf (accessed on 17 August 2020).

33. Ashley E.A., Recht J. & Chua A. (2017). – Antimicrobial resistance in low and middle income countries: an analysis of surveillance networks. Available at: www.iddo.org/amr-networks (accessed on 10 August 2020).

34. Köck R., Daniels-Haardt I., Becker K., Mellmann A., Friedrich A.W., Mevius D., Schwarz S. & Jurke A. (2018). – Carbapenem-resistant *Enterobacteriaceae* in wildlife, food-producing, and companion animals: a systematic review. *Clin. Microbiol. Infect.*, **24** (12), 1241–1250. doi:10.1016/j.cmi.2018.04.004.

35. Van Duijkeren E., Catry B., Greko C., Moreno M.A., Pomba M.C., Pyörälä S., Ružauskas M., Sanders P., Threlfall E.J., Torren-Edo J. & Törneke K. (2011). – Review on methicillin-resistant *Staphylococcus pseudintermedius*. *J. Antimicrob. Chemother.*, **66** (12), 2705–2714. doi:10.1093/jac/dkr367.

36. Tang K.L., Caffrey N.P., Nóbrega D.B., Cork S.C., Ronksley P.E., Barkema H.W., Polachek A.J., Ganshorn H., Sharma N., Kellner J.D. & Ghali W.A. (2017). – Restricting the use of antibiotics in food-producing animals and its associations with antibiotic resistance in food-producing animals and humans: a systematic review and meta-analysis. *Lancet Planet. Health*, **1** (8), e316–e327. doi:10.1016/S2542-5196(17)30141-9.

37. Rushton J. (2015). – Anti-microbial use in animals: how to assess the trade-offs. *Zoonoses Public Health*, **62** (Suppl. 1), 10–21. doi:10.1111/zph.12193.

38. Wu Z. (2019). – Antibiotic use and antibiotic resistance in food producing animals in China. Paper discussed at the 75th session of the Working Party on Agricultural Policies and Markets, Paris, France, 13–15 November 2018. Organisation for Economic Co-operation and Development, Paris, France, 32 pp. Available at: www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=TAD/CA/APM/WP(2018)19/FINAL&docLanguage=En (accessed on 11 August 2020).

39. World Health Organization (WHO) (2017). – Fact sheets on the Sustainable Development Goals – health targets. Antimicrobial resistance. WHO, Geneva, Switzerland, 7 pp. Available at: www.euro.who.int/__data/assets/pdf_file/0005/348224/Fact-sheet-SDG-AMR-FINAL-07-09-2017.pdf?ua=1 (accessed on 7 August 2020).

40. Naylor N.R., Atun R., Zhu N., Kulasabanathan K., Silva S., Chatterjee A., Knight G.M. & Robotham J.V. (2018). – Estimating the burden of antimicrobial resistance: a systematic literature review. *Antimicrob. Resist. Infect. Control*, **7**, Article No. 58. doi:10.1186/s13756-018-0336-y.

41. Cassini A., Högberg L.D. […] & Burden of AMR Collaborative Group (2019). – Attributable deaths and disability-adjusted life-years caused by infections with antibiotic-resistant bacteria in the EU and the European Economic Area in 2015: a population-level modelling analysis. *Lancet Infect. Dis.*, **19** (1), 56–66. doi:10.1016/S1473-3099(18)30605-4.

42. O'Neill J. *et al*. (2016). – Tackling drug-resistant infections globally: final report and recommendations. Wellcome Trust, London, United Kingdom, 84 pp. Available at: amr-review.org/sites/default/files/160525_Final%20paper_with%20cover.pdf (accessed on 11 August 2020).

43. Cecchini M., Langer J. & Slawomirski L. (2015). – Antimicrobial resistance in G7 countries and beyond: economic issues, policies and options for action. Organisation for Economic Co-operation and Development, Paris, France, 75 pp. Available at: www.oecd.org/els/health-systems/Antimicrobial-Resistance-in-G7-Countries-and-Beyond.pdf (accessed on 11 August 2020).

44. Magnusson U. (2020). – Prudent and effective antimicrobial use in a diverse livestock and consumer's world. *J. Anim. Sci.*, **98** (Suppl. 1), S4–S8. doi:10.1093/jas/skaa148.

45. Kelesidis T. & Falagas M.E. (2015). – Substandard/counterfeit antimicrobial drugs. *Clin. Microbiol. Rev.*, **28** (2), 443–464. doi:10.1128/CMR.00072-14.

46. Magnusson U., Sternberg S., Eklund G. & Rozstalnyy A. (2019). – Prudent and efficient use of antimicrobials in pigs and poultry. FAO Animal Production and Health Manual No. 23. Food and Agriculture Organization of the United Nations, Rome, Italy, 44 pp. doi:10.4060/CA6729EN.

47. European Commission Directorate-General for Health and Food Safety (2017). – Overview report of the responses to a questionnaire sent to non-EU countries regarding national policies and measure taken to combat the development of antimicrobial resistance. Publications Office of the European Union, Luxembourg, 33 pp. doi:10.2772/60954.

48. Maron D.F., Smith T.J.S. & Nachman K.E. (2013). – Restrictions on antimicrobial use in food animal production: an international regulatory and economic survey. *Glob. Health*, **9**, Article No. 48. doi:10.1186/1744-8603-9-48.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 523-532

Global nutrition security: the role of Veterinary Services

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Summary

Disparities in nutrition security and the harmful health effects of malnutrition are pronounced as the world's population continues to rise and nutrition-related development falls short of targets. This paper discusses the importance of animal source foods (ASFs) in global nutrition security and the roles that Veterinary Services play in enhancing availability of and equitable access to ASFs.

The first section of this paper reviews the nutritional value of ASFs and disparities in global consumption patterns. It also presents the biological basis for ASF-derived nutrition, its importance throughout the human lifecycle and the negative effects of both under- and overnutrition. The second section discusses the various roles of Veterinary Services along the pathway from terrestrial livestock production to positive outcomes in nutrition security. It addresses the importance of Veterinary Services in improving production efficiencies in extensive livestock systems as well as the contributions of Veterinary Services to integrated approaches for improved human and livestock health and security. Gaps between ASF availability and nutrition security are then discussed along with the importance of closing these gaps by targeting smallholders and women. The paper concludes with recommendations for incorporating targeted, nutrition-sensitive approaches in Veterinary Services to help populations vulnerable to nutrition insecurity gain more equitable access to ASFs as part of sustainable healthy diets.

Keywords

Animal source foods – Global nutrition security – Smallholder livestock – Sustainable healthy diets – Veterinary Services.

Introduction

Disparities in food and nutrition security are becoming increasingly pronounced as the world's population grows toward a projected 9.7 billion by 2050, with most growth occurring in low- and middle-income countries (LMICs) (1). It is estimated that 8.9% of the global population is undernourished, and nearly 750 million suffer severe food insecurity (2). Furthermore, an estimated 21.3% of children under the age of 5 years have stunted growth, while over 250 million of children in this age group experience impaired cognition and development. Over the next five to ten years, reductions in levels of stunting are projected to fall short of targets set by the World Health Assembly (2). Many of those most affected by these nutritional shortcomings reside in LMICs, where populations are particularly vulnerable to the effects of exacerbating external factors including climate change, conflicts and global crises such as the COVID-19 pandemic.

Animal source foods (ASFs) have the potential to substantially reduce global nutrition insecurity and the morbidity and mortality associated with malnutrition. Animal source foods (meat, fish, eggs and milk) supply approximately 15.4% of the global daily calories consumed per capita, with important differences by country income level. In high-income countries, 22.9% of daily calories per capita are from ASFs. In low-income countries, this number falls to 5.7% (2). Animal source foods provide bioavailable micronutrients that are critical for early childhood growth and development, maternal health, and health throughout the lifecycle. However, ASF consumption has been concurrently associated with the global obesity epidemic and conditions such as cardiovascular disease, diabetes and cancer (3).

https://doi.org/10.20506/rst.40.2.3242

While global livestock production levels have increased in tandem with a growing population, certain regions, including sub-Saharan Africa and South Asia, have experienced lower per capita livestock production due to rapidly expanding human populations and low production per animal (2, 4). Demand for ASFs is expected to increase in the coming decades, with the greatest growth expected in LMICs (5). Increasing consumption of ASFs is often critiqued as unsustainable and contributing to climate change, yet these critiques tend to focus on large, intensive systems rather than smallholder and mixed systems, which supply over half of the world's food and are vital to feeding undernourished populations (6).

Veterinary Services play a pivotal role in optimising global ASF systems, particularly among smallholders and populations vulnerable to food and nutrition insecurity. Four pillars are recognised as forming the basis of food security: availability, access, stability and utilisation (4). Nutrition security builds on this definition, adding access to high-quality diets and the full range of essential nutrients necessary for optimal growth, development and health in populations. Most directly, Veterinary Services can help increase the availability of, and potentially access to, ASFs in low-income settings through optimised livestock production efficiencies and improved livelihoods. Veterinary Services also have an important place in integrated One Health approaches aimed at enhancing equitable access to, safety and security of and overall utilisation of ASFs. Ultimately, by targeting vulnerable households, Veterinary Services can positively impact nutrition security along the pathway from livestock to improved, sustainable diets.

This paper will describe the nutritional value of ASFs in the diet and variations in global consumption patterns. It will then present pathways through which Veterinary Services can enhance the availability of and access to ASFs and mitigate risks associated with them. It will conclude with a discussion of the larger role of Veterinary Services in optimising global food and, importantly, nutrition security.

Animal source foods and nutrition

Nutritional value of animal source foods

Animal source foods contain several essential nutrients in bioavailable forms that are important for human growth, development, cognition and maintenance of health throughout the lifecycle. Evidence suggests increases in dietary ASFs occurred at important junctures of hominin evolution and were associated with brain development and other important physiological changes (7). Animal source foods are particularly important among low-income and nutrition-insecure populations where a modest amount of ASF consumption can lead to greater nutritional gains compared to a diet of plant-based foods alone (8).

Eggs and milk are considered 'first foods', providing a complete suite of nutrition to young children (9). Eggs are a good source of macronutrients and micronutrients as well as immune and endocrine factors. They are considered a perfect protein source, containing all nine essential amino acids as well as essential omega-3 and omega-6 fatty acids. Choline, an essential nutrient present in high concentrations in eggs, is a phospholipid precursor crucial for cell growth and division and is vital to proper neural development and transmission, gene expression and numerous growth pathways (10). Eggs are also an important source of bioavailable selenium, iron and zinc, as well as vitamins A, B12, D and E and folate (9).

Milk supplies nutritional and bioactive factors known to support childhood growth and development. It contains high-quality protein, including whey and casein, and has a high mineral and micronutrient content (11). There is evidence that milk increases circulating levels of insulin-like growth factor-1, which increases amino acid uptake in bone tissue and promotes linear growth in children (12). Cow's milk has low iron and zinc content compared to meat and egg products (13) but is rich in A and B vitamins, including B12 (14).

Like eggs, terrestrial animal meats (muscle foods and organ tissue) are high-quality sources of protein that provide all essential amino acids as well varying ratios of monounsaturated, saturated and polyunsaturated fatty acids. Meat is a major source of vitamin B12, which is only naturally found in ASFs. Meat not only supplies iron in the bioavailable heme form, but also enhances the bioavailability of nonheme iron sources in the diet. It is a rich source of potassium, phosphorus, copper, zinc and selenium and also contains fat-soluble vitamins, though in less abundance than plant foods (15).

Aquatic foods (fin fish, crustaceans and molluscs, among others) account for 17% of global animal protein supply. Global fish consumption increased by an average of 3.2% annually between 1961 and 2016. Aquaculture has been the world's fastest-growing food production sector for over four decades (16). Aquatic foods are an especially rich source of omega-3 fatty acids and essential minerals such as zinc, calcium, iron and selenium, as well proteins and other critical vitamins (17). Consumption of the whole bodies of small fish delivers a particularly high concentration of micronutrients (18). Fish consumption has been associated with health benefits including long-term weight loss, reduced mortality from heart disease, and reduced overall morbidity and mortality (19).

Nutrition from animal source foods through the lifecycle

Bioavailable ASF-derived nutrition is important during all stages of the human lifecycle and is particularly critical during childhood and pregnancy/lactation. The complementary feeding period from 6 to 24 months of age is when children are especially vulnerable to malnutrition and subsequent stunting (11). The smaller gastrointestinal capacity of young children combined with a period of rapid growth and development necessitates highly bioavailable nutrients. Starch-based staple diets in many low-resource settings are inefficient at providing critical nutrients such as iron, zinc and vitamin A that are abundantly supplied through relatively small quantities of ASFs (11). Studies examining the effects of terrestrial and aquatic ASFs on stunting and growth have shown mixed results, though interventional trials provide compelling evidence of positive effects on childhood growth and development (20, 21).

Pregnancy and lactation are also nutritionally demanding periods that require digestible and bioavailable ASF-derived nutrients, particularly in low-resource settings where sufficient supplements and/or fortified foods may not be readily available. Deficiencies in micronutrients such as iron, zinc, iodine, vitamin D and calcium can have severe impacts on maternal health and fetal development (22). Similarly, healthy neural function, bone heath and muscle mass throughout adulthood and aging may be difficult to maintain in resource-limited areas without sufficient access to ASFs (23, 24).

Global consumption patterns of animal source foods

Consumption patterns of ASFs vary widely around the world and, consequently, major disparities in food security and nutritional status exist. There has been an overall increase in global per capita ASF consumption over recent decades, a trend that is projected to continue through mid-century, particularly in LMICs (25). Yet some areas of sub-Saharan Africa and South Asia, already characterised by low ASF consumption, have experienced declines in consumption (4). Egg consumption varies by region, with the highest levels in Latin America and the Caribbean and the lowest levels in Africa (9). Per capita milk consumption has experienced a decades-long increase in LMICs except in sub-Saharan Africa (14).

Variations in ASF consumption have resulted in global health crises from both under- and overconsumption. There is evidence of associations between low rates of ASF consumption and stunting, cognitive deficits, anaemia and developmental disorders (6). At the same time, ASF overconsumption in high-income countries has been linked to higher rates of cardiovascular disease, colorectal cancer, diabetes, obesity and other health problems. Reasons for these associations are complex and may be linked to higher rates of processed meat consumption (25). From a global health perspective, emphasis should be placed on narrowing the disparities in ASF consumption by ensuring that populations vulnerable to nutrition insecurity have more equitable access to high-quality ASFs during all life stages.

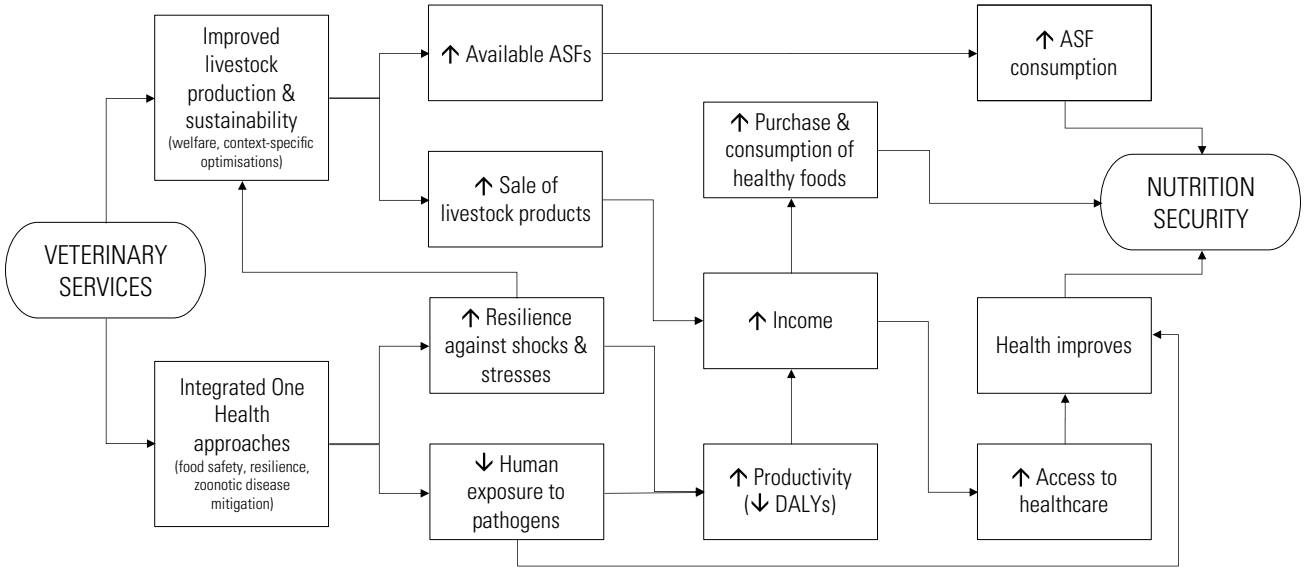
From livestock production to nutrition security: the roles of Veterinary Services

Sustainable livestock production, particularly among smallholder, mixed and other extensive systems, plays a vital role in providing food and nutrition security to those most vulnerable to undernutrition. Extensive livestock production, as opposed to intensive, is characterised by relatively low per-animal productivity and inputs relative to land area used. These systems provide ASFs directly to producer households, communities and local market chains in addition to serving as a source of income and direct farm inputs. Smallholder systems in particular tend to have lower per-animal output and are especially vulnerable to disease and climate extremes.

Veterinary Services can play critical roles along the pathway from livestock production to positive nutrition outcomes by enhancing the availability of and access to ASFs, the stability of these foods through sustainable practices, and the health of communities. Figure 1 outlines several of these positive impact pathways. This section focuses on the role of Veterinary Services in extensive terrestrial livestock systems with emphasis on the unique needs of smallholder producers. Though aquaculture is not specifically covered, it is crucial to acknowledge the concurrent importance of aquatic systems to global nutrition security and the necessity of Veterinary Services contributions to animal health and welfare in this sector.

Optimising livestock production and sustainability

Animal welfare is ranked as one of the top five priorities of the World Organisation for Animal Health (OIE) Member Countries, but one with a low level of Member preparedness (26). Deficiencies in animal health and welfare at the herd level result in acute to chronic production losses that can be detrimental to the nutrition security and livelihoods of smallholder producers (27). Improving the welfare of livestock mitigates many factors related to morbidity and



ASF: Animal source food

DALY: Disability-adjusted life year

Fig. 1
Positive impact pathways of Veterinary Services on nutrition security

mortality in young stock and mature animals, lowers herd susceptibility to disease outbreaks, and can reduce waste and downstream losses from condemnation or downgrading during slaughter and processing (4). By filling the gap in preparedness for animal welfare, Veterinary Services can enhance productivity gains in extensive systems, thus improving the quality and quantity of ASFs produced.

Production performance can also be enhanced through strategic improvements in feeding practices of smallholder and mixed-system producers, a strategy that may be overlooked by Veterinary Services in extensive production systems. Proper nutrition and supplementation for animals can help optimise production for a particular setting. Locally available plants and supplements have been used to enhance the productivity of ruminants and improve the nutritional profile of eggs (28). For example, inclusion of Moringa oleifera leaf meal, a drought-tolerant plant grown throughout the tropics, in the diets of lactating goats was found to enhance ruminal fermentation and nutrient digestibility and to increase milk yield (29). Additionally, livestock can contribute positively to total food availability in a community when raised in marginal areas, where they graze off land unsuitable for crop production, or in mixed systems, where they add reciprocal value to the crops grown by consuming post-harvest residues and providing manure and traction (4). These feeding strategies also have planetary health implications, as livestock production is often labelled as unsustainable due to land use and emissions associated with feed production and transportation (8, 30).

Genetic optimisation of extensively farmed livestock is another method of enhancing performance that has received much research interest but may be underutilised by Veterinary Services in settings that could benefit from it (31). Not all breeds of livestock perform equally well in all settings. Native breeds, though often considered less productive than commercial breeds when raised in intensive systems, may perform better in extensive systems due to natural adaptation to the local climate and resistance to endemic diseases, thus requiring fewer veterinary inputs. For example, *Bos taurus* breeds of cattle, such as the indigenous Sheko of Ethiopia, are more resistant to the pathologic effects of African trypanosome parasites. Researchers found that knowledge of trypanosomiasis transmission and tolerance traits among different cattle breeds was lacking among Ethiopian livestock keepers although a majority were positive about wanting to buy more tolerant breeds (32). Veterinary Services' involvement in strategic genetic improvement programmes and education campaigns can facilitate the selection of desired traits in these native breeds to enhance their health and productivity for smallholders (31).

It is essential that Veterinary Services support research and initiatives aimed at improving animal welfare and optimising feed and genetic selection for a particular setting's biogeographical, cultural and nutritional context, with concurrent extension services to educate smallholders about the benefits of these optimisations. Sustainable and efficient extensive production systems can reduce the planetary footprint of livestock and promote positive

downstream nutrition outcomes for producers and their communities.

Integrated One Health approaches

Food safety is a major concern for global Veterinary Services and has considerable relevance to nutrition outcomes, particularly among low-income populations. A survey of OIE Member Countries revealed foodborne disease to be an issue of high importance with low preparedness, highlighting a critical gap that Veterinary Services must address (26). Animal source foods are estimated to cause 35% of the global burden of all foodborne disease (33). Diarrhoeal and other gastrointestinal illnesses resulting from ASF consumption can cause acute to chronic nutrient loss and reduced nutrient absorption, thus impeding nutrition gains (34). In addition, illness caused by ASFs often leads to fear and reluctance to consume these foods, meaning their nutritional benefits are sacrificed (35).

At the national level, public funding is essential for the functioning of Veterinary Services operations and infrastructure necessary to provide adequate disease and food safety surveillance, yet only 15 of 84 OIE-Member LMICs report adequate funding for operations and capital investment. Based on estimates of disability-adjusted life years (DALYs) resulting from ASF-related foodborne disease among countries in sub-Saharan Africa, nations with adequate operational funding for Veterinary Services had an average of 361 fewer lost DALYs than nations with inadequate Veterinary Services funding (36), revealing a clear association between adequate Veterinary Services funding and improved food safety.

While involvement of Veterinary Services in national food safety policy and operations is essential, this may largely exclude smallholders and other small-scale producers who rely heavily on informal market chains (37). Therefore, ensuring preparedness for ASF-derived foodborne disease outbreaks by strengthening Veterinary Services funding and capacity for prevention, surveillance and response among smallholders and the markets they serve is essential to improving downstream nutrition outcomes.

International- and national-level Veterinary Services can also have an important local effect on smallholders by improving resilience against shocks and stresses such as large-scale disease outbreaks or droughts. Enhanced resilience increases ASF stability in communities and along market chains (26). Deficits in national Veterinary Services, organisation, particularly in LMICs, may include inadequacies in biosecurity protocols, vaccination and drug distribution campaigns, animal disease surveillance, animal disease reporting and traceability systems, laboratory capacity and transboundary disease contingency plans (36, 38).

It is also imperative that Veterinary Services be on the frontlines of integrated efforts to uncover and mitigate the drivers of emerging and endemic zoonoses, which may disproportionately affect smallholders with limited access to Veterinary Services and public health systems. A strong association exists between zoonoses, livestock keeping, poverty and hunger. Countries such as India, Nigeria, Ethiopia, Bangladesh and the Democratic Republic of Congo have particularly high densities of poor livestock keepers as well as zoonoses burden (39). A major barrier to controlling zoonoses is substantial under-reporting of these diseases in LMICs, a gap that Veterinary Services must help fill.

Inadequacies in these integrated approaches have significant downstream effects on food chains, with negative consequences for populations that depend on ASFs for their nutritional needs (27). Strengthening of Veterinary Services operations as part of multidisciplinary approaches to livestock and public health helps build short- and long-term resilience to shocks among smallholders, therefore promoting more secure ASF availability to those most at risk for undernourishment.

Closing the gaps in nutrition security

Improving the production and availability of ASFs does not necessarily translate into equitable access for those most in need of ASF-based nutrition. It is estimated that the overall global availability of ASFs is sufficient to feed the current human population; however, disparities in access are the underlying driver of food insecurity (4). Access to high-quality ASFs involves a complex web of economic and sociocultural factors, and ASFs tend to be considered luxury goods in low-income countries (40). In these settings, relatively high prices of ASFs compared to other foods are likely linked to supply constraints due to poor productivity (41). Poor smallholders may thus sell off ASFs in order to feed their households with lower-cost starchy staples. The decision of smallholders over which animal products they will either consume or sell is highly household dependent. It is essential that Veterinary Services help optimise smallholders' abilities to make these choices by enhancing the productivity and sustainability of their livestock systems.

In order to ensure that populations at risk for nutrition insecurity benefit from Veterinary Services, access to these services needs to be improved and strategically targeted. Particular emphasis should be placed on smallholders and women in low-resource settings. Smallholders are particularly vulnerable in situations where increasing privatisation of Veterinary Services has resulted in gaps in extension services (4). These gaps make smallholders more vulnerable to devastating disease outbreaks, famine, welfare and food safety concerns, and poor productivity due to insufficient or inefficient inputs.

Additionally, evidence indicates that nutrition outcomes are more likely to be improved when livestock interventions

target women (35). In many regions, women are the primary caretakers of small livestock but have more limited access to animal production and health trainings, information about animal disease control measures, and other veterinary extension services (42). Small livestock such as poultry and small ruminants provide a continuous source of eggs or milk and reproduce quickly, increasing household ASF availability. They also require lower capital investment, survive in harsher conditions and can be sold quickly, generating income and providing added security against acute crises (43). Providing women and other smallholders with access to the appropriate animal health resources as well as public- and private-sector extension services can therefore help increase household and community access to high-quality ASFs.

Conclusions

Animal source foods are essential sources of high-quality nutrition for much of the world's population, particularly those most vulnerable to food insecurity and undernutrition. Veterinary Services are a key contributor on this pathway from livestock production to positive nutrition outcomes. It is critical that the design of Veterinary Services take into consideration a nutrition-sensitive lens and the global movement toward more sustainable diets and food systems (27, 44).

Efforts to strategically close gaps in Veterinary Services in LMICs are integral to improving human and animal health as well as mitigating environmental impacts at a global level. These gaps are largely context specific and may extend to animal welfare, production efficiencies for mixed and extensive livestock systems, public funding of Veterinary Services, food safety, resilience against shocks and stresses, zoonotic disease preparedness and more. Smallholders and women should be targeted as they are most vulnerable to poverty and malnutrition and also provide much of the ASF to the world's poor.

National and local Veterinary Services programming with defined nutrition objectives should be implemented using an integrated approach that is sensitive to the local context. Such an approach may include interdisciplinary training and response at the national level, incorporation of nutrition education into animal health services, and improvement in access to public and private extension services targeted at women, smallholders and populations vulnerable to malnutrition.

Finally, investigators in the Veterinary Services field should be actively involved in multidisciplinary research efforts to continue building evidence for the role of ASFs in sustainable healthy diets. Further insights into the constraints facing livestock-based food production systems are critical to informing optimal policies and evidence-based solutions. One Health approaches are vital to an understanding of how Veterinary Services can enhance global nutrition security at all points along the farm-to-fork pathway.

As threats to planetary health such as climate change, pandemics and poverty grow, Veterinary Services are increasingly recognised for the role they play in building a sustainable future. Strengthening Veterinary Services as part of integrated public health and One Health efforts will support enhanced availability of and equitable access to ASF-based nutrition, thus achieving more sustainable healthy diets around the globe.

Sécurité nutritionnelle mondiale : le rôle des Services vétérinaires

J.H. Carag, C.K. Lesorogol & L.L. Iannotti

Résumé

À mesure que la population mondiale s'accroît, les disparités d'accès à la sécurité nutritionnelle et les effets nocifs pour la santé de la malnutrition s'accentuent, tandis que les évolutions en lien avec la nutrition demeurent en deçà des objectifs. Les auteurs examinent l'importance des denrées alimentaires d'origine animale pour la sécurité nutritionnelle mondiale ainsi que le rôle joué par les Services vétérinaires pour garantir une meilleure disponibilité et un accès équitable à ces denrées.

Dans la première partie de leur article, les auteurs soulignent la valeur nutritionnelle des denrées alimentaires d'origine animale et font le point sur les disparités des structures de consommation dans le monde. Ils expliquent également la base biologique de l'apport nutritionnel des denrées d'origine animale ainsi que l'importance de ces dernières à chaque étape de la vie humaine, en analysant les effets négatifs induits tant par la sous-nutrition que par la surnutrition. Dans la deuxième partie, ils examinent les divers rôles des Services vétérinaires le long du processus allant de la production d'animaux d'élevage terrestres à l'obtention de résultats favorables en termes de sécurité nutritionnelle. Leur analyse souligne l'importance des Services vétérinaires dans l'amélioration des performances des systèmes d'élevage extensifs ainsi que leur contribution à la mise en œuvre de méthodes intégrées visant à améliorer la santé et la sécurité des populations humaines et des cheptels. Les auteurs examinent ensuite les écarts entre la disponibilité des denrées alimentaires d'origine animale et la sécurité nutritionnelle, ainsi que l'importance de résorber ces écarts au moyen d'interventions ciblées visant spécifiquement les petits exploitants et les femmes. Les auteurs concluent en recommandant que les Services vétérinaires intègrent des méthodes ciblées et axées sur les priorités nutritionnelles afin que les populations exposées à l'insécurité nutritionnelle puissent accéder de manière plus équitable aux denrées alimentaires d'origine animale, dans le cadre d'une alimentation saine et durable.

Mots-clés
Alimentation saine et durable – Denrées alimentaires d'origine animale – Petits élevages – Sécurité nutritionnelle mondiale – Services vétérinaires.

Función de los Servicios Veterinarios de cara a la seguridad nutricional mundial

J.H. Carag, C.K. Lesorogol & L.L. Iannotti

Resumen
Hoy, a la vez que la población mundial sigue creciendo y que aún quedan lejos las metas de desarrollo vinculadas a la nutrición, se acentúan las disparidades de seguridad nutricional y las negativas consecuencias sanitarias de la malnutrición. Los autores exponen la importancia que revisten los alimentos de origen animal para la seguridad nutricional mundial y las funciones que cumplen los Servicios Veterinarios a la hora de mejorar la disponibilidad de alimentos de origen animal y potenciar un acceso equitativo a ellos.
En la primera sección, los autores exponen el valor nutricional de los alimentos de origen animal y la disparidad existente en el mundo en cuanto a regímenes alimentarios. También presentan la base biológica de una nutrición derivada de alimentos de origen animal, su importancia a lo largo del ciclo vital de las personas y los efectos perjudiciales que tienen tanto la desnutrición como la sobrealimentación. En la segunda sección presentan las diversas funciones que incumben a los Servicios Veterinarios en el proceso que va de la producción de ganado terrestre a la obtención de resultados positivos de seguridad nutricional. Así, destacan la importancia de los Servicios Veterinarios para mejorar la eficiencia productiva de los sistemas de ganadería extensiva, así como su contribución a planteamientos integrados que aporten un mayor grado de salud y seguridad a personas y animales. Después exponen el desfase existente entre la disponibilidad de alimentos de origen animal y la seguridad nutricional, así

como la importancia de corregir estas deficiencias, apuntando selectivamente a los pequeños productores y las mujeres. A modo de conclusión, formulan recomendaciones para que los Servicios Veterinarios incorporen lógicas de trabajo por objetivos que tengan en cuenta las cuestiones de nutrición, a fin de ayudar a las poblaciones expuestas a la inseguridad nutricional a lograr un acceso más equitativo a alimentos de origen animal como parte de una alimentación sana sostenible.

Palabras clave
Alimentación sana sostenible – Alimentos de origen animal – Seguridad nutricional mundial – Ganado de minifundio –Servicios Veterinarios.

References

1. United Nations Department of Economic and Social Affairs (UN DESA) (2019). – World population prospects 2019: highlights. UN DESA, New York, New York, United States of America. Available at: www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html (accessed on 12 August 2020).

2. Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), United Nations International Children's Emergency Fund (UNICEF), World Food Programme (WFP) & World Health Organization (WHO) (2020). – The state of food security and nutrition in the world 2020: Transforming food systems for affordable healthy diets. FAO, Rome, Italy, 320 pp. doi:10.4060/ca9692en.

3. Swinburn B.A., Kraak V.I. […] & Dietz W.H. (2019). – The global syndemic of obesity, undernutrition, and climate change: *The Lancet* Commission report. *Lancet*, **393** (10173), 791–846. doi:10.1016/S0140-6736(18)32822-8.

4. Food and Agriculture Organization of the United Nations (FAO) (2011). – World livestock 2011: livestock in food security. FAO Rome, Italy, 130 pp. Available at: www.fao.org/3/i2373e/i2373e00.htm (accessed on 6 August 2020).

5. Alexandratos N. & Bruinsma J. (2012). – World Agriculture towards 2030/2050: the 2012 Revision. ESA Working Paper No. **12-03**, FAO, Rome, Italy, 154 pp. Available at: www.fao.org/3/a-ap106e.pdf (accessed on 17 August 2020).

6. Adesogan A.T., Havelaar A.H., McKune S.L., Eilitta M. & Dahl G.E. (2020). – Animal source foods: sustainability problem or malnutrition and sustainability solution? Perspective matters. *Glob. Food Sec.*, **25**, Article No. 100325. doi:10.1016/j.gfs.2019.100325.

7. Kuipers R.S., Joordens J.C.A. & Muskiet F.A.J. (2012). – A multidisciplinary reconstruction of Palaeolithic nutrition that holds promise for the prevention and treatment of diseases of civilisation. *Nutr. Res. Rev.*, **25** (1), 96–129. doi:10.1017/S0954422412000017.

8. Eisler M.C., Lee M.R.F. […] & Winter M. (2014). – Agriculture: Steps to sustainable livestock. *Nature*, **507**, 32–34. Available at: www.nature.com/news/agriculture-steps-to-sustainable-livestock-1.14796 (accessed on 12 August 2020).

9. Iannotti L.L., Lutter C.K., Bunn D.A. & Steward C.P. (2014). – Eggs: the uncracked potential for improving maternal and young child nutrition among the world's poor. *Nutr. Rev.*, **72** (6), 355–368. doi:10.1111/nure.12107.

10. Iannotti L.L., Lutter C.K. […] & Stewart C.P. (2017). – Eggs early in complementary feeding increase choline pathway biomarkers and DHA: a randomized controlled trial in Ecuador. *Am. J. Clin. Nutr.*, **106** (6), 1482–1489. doi:10.3945/ajcn.117.160515.

11. Iannotti L.L. (2018). – The benefits of animal products for child nutrition in developing countries. *In* The contribution of animals to human welfare (T. Grandin, ed.). *Rev. Sci. Tech. Off. Int. Epiz.,* **37** (1), 37–46. doi:10.20506/rst.37.1.2738.

12. Dror D.K. & Allen L.H. (2011). – The importance of milk and other animal-source foods for children in low-income countries. *Food Nutr. Bull.*, **32** (3), 227–243. doi:10.1177/156482651103200307.

13. Michaelsen K.F., Hoppe C., Lauritzen L. & Mølgaard C. (2007). – Whole cow's milk: why, what and when? *Nestlé Nutr. Inst. Workshop Ser. Pediatr. Program*, **60**, 201–219. doi:10.1159/000106370.

14. Food and Agriculture Organization of the United Nations (FAO) (2013). – Milk and dairy products in human nutrition. FAO, Rome, Italy, 404 pp. Available at: www.fao.org/3/i3396e/i3396e.pdf (accessed on 5 July 2021).

15. Lofgren P. (2013). – Meat, poultry, and meat products: nutritional value. *In* Encyclopedia of Human Nutrition, 3rd Ed. (B. Caballero, ed.). Academic Press, Amsterdam, the Netherlands, 160–167.

16. Food and Agriculture Organization of the United Nations (FAO) (2018). – The state of world fisheries and aquaculture 2018: meeting the sustainable development goals. FAO, Rome, Italy, 227 pp. Available at: www.fao.org/documents/card/en/c/I9540EN/ (accessed on 19 August 2020).

17. Tacon A.G.J. & Metian M. (2013). – Fish matters: importance of aquatic foods in human nutrition and global food supply. *Rev. Fish. Sci.*, **21** (1), 22–38. doi:10.1080/10641262.2012.753405.

18. Kawarazuka N. & Béné C. (2011). – The potential role of small fish species in improving micronutrient deficiencies in developing countries: building evidence. *Public Health Nutr.*, **14** (11), 1927–1938. doi:10.1017/S1368980011000814.

19. Thilsted S.H., Thorne-Lyman A., Webb P., Bogard J.R., Subasinghe R., Phillips M.J. & Allison E.H. (2016). – Sustaining healthy diets: the role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy*, **61**, 126–131. doi:10.1016/j.foodpol.2016.02.005.

20. Eaton J.C., Rothpletz-Puglia P., Dreker M.R., Iannotti L., Lutter C., Kaganda J. & Rayco-Solon P. (2019). – Effectiveness of provision of animal-source foods for supporting optimal growth and development in children 6 to 59 months of age. *Cochrane Database Syst. Rev.*, **2** (2), Article No. CD012818. doi:10.1002/14651858.CD012818.pub2.

21. Shapiro M.J., Downs S.M., Swartz H.J., Parker M., Quelhas D., Kreis K., Kraemer K., West Jr K.P. & Fanzo J. (2019). – A systematic review investigating the relation between animal-source food consumption and stunting in children aged 6–60 months in low- and middle-income countries. *Adv. Nutr.*, **10** (5), 827–847. doi:10.1093/advances/nmz018.

22. Black R.E., Victora C.G., Walker S.P., Bhutta Z.A., Christian P., de Onis M., Ezzati M., Grantham-McGregor S., Katz J., Martorell R., Uauy R. & Maternal and Child Nutrition Study Group (2013). – Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet*, **382** (9890), 427–451. doi:10.1016/S0140-6736(13)60937-X.

23. Lonnie M., Hooker E., Brunstrom J.M., Corfe B.M., Green M.A., Watson A.W., Williams E.A., Stevenson E.J., Penson S. & Johnstone A.M. (2018). – Protein for life: review of optimal protein intake, sustainable dietary sources and the effect on appetite in ageing adults. *Nutrients*, **10** (3), Article No. 360. doi:10.3390/nu10030360.

24. Goyal M.S., Iannotti L.L. & Raichle M.E. (2018). – Brain nutrition: a life span approach. *Annu. Rev. Nutr.*, **38**, 381–399. doi:10.1146/annurev-nutr-082117-051652.

25. Godfray H.C.J., Aveyard P., Garnett T., Hall J.W., Key T.J., Lorimer J., Pierrehumbert R.T., Scarborough P., Springmann M. & Jebb S.A. (2018). – Meat consumption, health, and the environment. *Science*, **361** (6399), Article No. eaam5324. doi:10.1126/science.aam5324.

26. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K., & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item In *Proc.* 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France, 28 pp. doi:10.20506/TT.2984.

27. Bonnet P., Lancelot R., Seegers H. & Martinez D. (2011). – Contribution of veterinary activities to global food security for food derived from terrestrial and aquatic animals. Technical Item In *Proc.* presented at 79th General Session of the World Organisation for Animal Health (OIE), 22–27 May. OIE, Paris, France, 15 pp. Available at: www.oie.int/doc/ged/D10451.PDF (accessed on 12 August 2020).

28. Jafari S., Meng G.Y., Rajion M.A. & Ebrahimi M. (2020). – The use of plant by-products as non-conventional feedstuff for livestock feeding with reference to rumen methanogenesis. *Agroforest. Syst.*, **94**, 1491–1500. doi:10.1007/s10457-019-00426-z.

29. Kholif A.E., Gouda G.A., Morsy T.A., Salem A.Z.M., Lopez S. & Kholif A.M. (2015). – *Moringa oleifera* leaf meal as a protein source in lactating goat's diets: feed intake, digestibility, ruminal fermentation, milk yield and composition, and its fatty acids profile. *Small Ruminant Res.*, **129**, 129–137. doi:10.1016/j.smallrumres.2015.05.007.

30. Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A. & Tempio G. (2013). – Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy, 139 pp. Available at: www.fao.org/3/a-i3437e.pdf (accessed on 27 August 2020).

31. Marshall K., de Haan N. & Galiè A. (2019). – Integrating gender considerations into livestock genetic improvement programs in low to middle income countries. *In* Proc. 23rd Conference of the Association for the Advancement of Animal Breeding and Genetics (AAABG), 27 October – 1 November, Armidale, Australia. AAABG, Armidale, Australia, 171–174. Available at: www.aaabg.org/aaabghome/AAABG23papers/43Marshall23171.pdf (accessed on 21 August 2020).

32. Stein J., Ayalew W., Rege E., Mulatu W., Lemecha H., Tadesse Y., Tekle T. & Philipsson J. (2011). – Trypanosomosis and phenotypic features of four indigenous cattle breeds in an Ethiopian field study. *Vet. Parasitol.*, **178** (1–2), 40–47. doi:10.1016/j.vetpar.2010.12.025.

33. Li M., Havelaar A.H., Hoffmann S., Hald T., Kirk M.D., Torgerson P.R. & Devleesschauwer B. (2019). – Global disease burden of pathogens in animal source foods, 2010. *PLoS One*, **14** (6), Article No. e0216545. doi:10.1371/journal.pone.0216545.

34. Kotloff K.L. (2017). – The burden and etiology of diarrheal illness in developing countries. *Pediatr. Clin. North Am.*, **64** (4), 799–814. doi:10.1016/j.pcl.2017.03.006.

35. Grace D., Dominguez-Salas P., Alonso S., Lannerstad M., Muunda E., Ngwili N., Omar A., Khan M. & Otobo E. (2018). – The influence of livestock-derived foods on nutrition during the first 1,000 days of life. ILRI Research Report 44. International Livestock Research Institute, Nairobi, Kenya, 82 pp. Available at: hdl.handle.net/10568/92907 (accessed on 5 July 2021).

36. Jaffee S., Henson S., Unnevehr L., Grace D. & Cassou E. (2019). The safe food imperative: accelerating progress in low- and middle-income countries. World Bank, Washington DC, United States of America, 168 pp. doi:10.1596/978-1-4648-1345-0.

37. Grace D., Makita K., Kang'Ethe E.K. & Bonfoh B. (2010). – Safe food, fair food: participatory risk analysis for improving the safety of informally produced and marketed food in sub-Saharan Africa. *Rev. Afri. Santé Prod. Anim.*, **8** (S), 3–11. Available at: hdl.handle.net/10568/4175 (accessed on 5 July 2021).

38. World Organisation for Animal Health (OIE) (2019). – Terrestrial Animal Health Code, 28th Ed. OIE, Paris, France. Available at: www.oie.int/standard-setting/terrestrial-code/ (accessed on 12 February 2021).

39. Grace D., Mutua F. […] & Ogutu F. (2012). – Mapping of poverty and likely zoonoses hotspots. Zoonoses Project 4. Report to the UK Department for International Development. International Livestock Research Institute, Nairobi, Kenya, 119 pp. Available at hdl.handle.net/10568/21161 (accessed on 5 July 2021).

40. Dominguez-Salas P. (2015). – Realizing the potential of animal source foods for human nutrition in the developing world: report on an ILRI/IFPRI workshop, London, 2–3 February 2015. International Livestock Research Institute, Nairobi, Kenya, 28 pp. Available at: hdl.handle.net/10568/91528 (accessed on 5 July 2021).

41. Headey D.D. & Alderman H.H. (2019). – The relative caloric prices of healthy and unhealthy foods differ systematically across income levels and continents. *J. Nutr.*, **149** (11), 2020–2033. doi:10.1093/jn/nxz158.

42. Quisumbing A.R., Meinzen-Dick R.S. & Smith L.C. (2004). – Increasing the effective participation of women in food and nutrition security in Africa. 2020 Africa Conference Brief 4. International Food Policy Research Institute, Washington DC, United States of America, 6 pp. Available at: www.ifpri.org/publication/increasing-effective-participation-women-food-and-nutrition-security-africa (accessed on 20 August 2020).

43. Otte J., Costales A. & Upton M. (2005). – Smallholder livestock keepers in the era of globalization. Pro-Poor Livestock Policy Initiative Research Report. FAO, Rome, Italy, 18 pp. Available at: www.fao.org/3/a-bp328e.pdf (accessed on 20 August 2020).

44. Ruel M.T. & Alderman H. (2013). – Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *Lancet*, **382** (9891), 536–551. doi:10.1016/S0140-6736(13)60843-0.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 533-544

Animal health and food safety risk assessments

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Summary

Animal health risk assessment is one of the key tasks of Veterinary Services. There are well-established protocols created by the World Organisation for Animal Health and Codex Alimentarius Commission for assessing risk. They cover terrestrial and aquatic animals and zoonotic infectious diseases, food safety, and the environment, taking into consideration the connections between them.

Significant effort has been made in developing methods to estimate the probability, and consequences, of infectious disease incursion in disease-free countries through legal or illegal trade or via the movements of insects and wildlife. Additional efforts have been made in the design of prevention strategies and contingency plans. Concerns about possible pandemics of avian influenza continue to be important motivation for monitoring viruses for selection of vaccine candidate strains. The recent COVID-19 pandemic was zoonotic in nature and caused extensive disruption throughout the world. Tools are becoming available for quantitative food safety risk assessments for bacteria, toxins, viruses, and antimicrobial resistance genes, including tools that allow simulations for the selection of effective control options. Applying participatory techniques facilitates the conduct of risk analysis in low- and middle-income countries. In internationally established frameworks, risk assessment is the first step towards elimination of important infectious diseases in endemic countries and it is an important contributor to the reduction of disease risks. Quantitative and qualitative socio-economic and behavioural studies have been developed to design risk management options that are acceptable and sustainable for actors throughout value chains.

Keywords

Animal health – Aquatic animal – Food safety – Risk analysis – Risk assessment – Terrestrial animal.

Introduction

Animal health risk assessment is one of the key tasks of Veterinary Services. Risk assessment is about determining the probability that an event will occur and predicting how big the impact is likely to be (1), and it is a highly useful concept for management of terrestrial and aquatic animal diseases and zoonotic diseases. Trade in livestock and commodities of animal origin is vital to the global economy and leads to intensification of the livestock systems of exporting countries. However, an importing country faces the risk that disease will be introduced into domestic animal populations and that foodborne diseases (FBDs) will be introduced into the domestic human population; such risks must be carefully assessed before approval of importation. These risks are encountered even when working within the legal framework for import/export trade. For instance, a recent risk assessment report suggested that the spread of African swine fever (ASF) into western and eastern European countries was due to legal trade in pigs and to the movement of wild boar, respectively (2). However, the virus is principally introduced illegally, often in contaminated pork products carried in the luggage of international travellers, as demonstrated by detection at customs check points in the international airports of several ASF-free countries (3). While penal regulations are tightened globally, illegal importation still continues (3) and the risk of disease introduction should not be underestimated. The risk from illegal importation of meat and meat products is not new; for example, outbreaks of ASF, foot and mouth disease (FMD), classical swine fever (CSF), and swine vesicular disease in countries formerly free from these diseases have long been attributed to the feeding of illegally imported waste meat to domestic pigs (4, 5, 6, 7, 8).

https://doi.org/10.20506/rst.40.2.3243

Over 60% of pathogens that infect humans are zoonotic (9), and terrestrial and aquatic animal-source foods are the most important causes of FBDs in humans. Health authorities are generally responsible for the prevention and control of FBDs, but under the One Health concept Veterinary Services are important stakeholders in conducting food safety risk assessments, particularly at the production phase. The global threat of antimicrobial resistance (AMR) is associated with FBDs, because the causal antimicrobial-resistant bacteria may be selected by the use of antimicrobial drugs in food animals. Risk assessment for FBDs is a complex exercise that considers contamination of food items, patterns of consumption, and probability of infection and disease. Antimicrobial resistance in FBDs is a much more complex problem than only dealing with FBDs, due to relationships with antimicrobial use (AMU) in animals, mobile genetic elements, and factors related to humans, such as travel, antimicrobial availability, nosocomial infections, and immune status.

Hereafter, the author discusses risk assessment frameworks, their challenges and benefits, and the latest developments in this field.

Frameworks for risk assessment

There are useful frameworks for risk analysis that Veterinary Services can use in designing, implementing, and evaluating risk management. One such framework is the World Organisation for Animal Health (OIE) import risk analysis framework, which covers hazard identification, risk assessment, risk management, and risk communication (Fig. 1) (10).

Hazard identification involves identifying the pathogenic agents that could potentially produce adverse consequences if they were to be introduced through the importation of a commodity. Risk assessment comprises four steps:

– release assessment (or entry assessment): assessing the probability of introduction of the agent with the commodity

– exposure assessment: assessing the probability that the animal population of the importing country will be exposed to the agent

– consequence assessment: assessing the magnitude of the possible impact on the importing country (e.g. expected final size of the infection, number of animals to be culled, or economic damage)

– risk estimation: an integration of the three assessments.

The assessment results can be presented either qualitatively (for example, 'extremely high', 'high', 'medium', 'low', 'extremely low', and 'negligible') or quantitatively. When the qualitative approach is taken, overall risk can be assessed using a risk estimation matrix, by identifying the cell where the probability row and the consequence column meet (Fig. 2). There is no uniform format for conducting a risk assessment, and the approaches can be flexible.

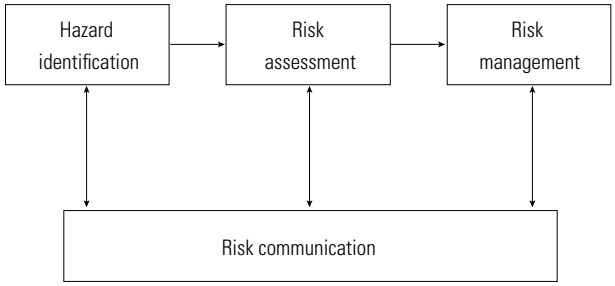

Fig. 1
The four components of the World Organisation for Animal Health import risk analysis framework (10)

The OIE import risk analysis framework has been applied to the risks associated with AMR (11). In the risk assessment for AMR, release assessment evaluates the probability of selection of antimicrobial-resistant bacteria as a result of the use of antimicrobials on a farm; exposure assessment examines the probability that an individual ingests the resistant bacteria in animal-source food; and consequence assessment shows the effect of AMR in reducing the efficacy of the antimicrobials that a physician may prescribe for a patient infected with the agent. The consequences can include an increase in days of illness, or an increase in the number of deaths.

Another useful framework is the food safety risk analysis framework of the Codex Alimentarius Commission (CAC), which is a joint body of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). This framework comprises three components: risk assessment, risk management, and risk communication, as summarised in Figure 3. The risk assessment starts when a food safety problem with an associated hazard is identified and a health authority decides to commission an assessment, which requires a clear statement of the specific purpose of the analysis. The risk assessment consists of four steps: hazard identification, hazard characterisation, exposure assessment, and risk characterisation. Hazard identification is the identification of biological, chemical, and physical agents that are capable of causing adverse health effects, and that may be present in a particular food or group of foods covered by the assessment. Hazard characterisation is the qualitative and/or quantitative evaluation of the nature (e.g. severity and duration) of the adverse health effects associated with those agents. If data are available, a dose–response assessment should be performed. Exposure assessment is

Probability							
	High	Negligible	Very low	Low	Moderate	High	Extreme
	Moderate	Negligible	Very low	Low	Moderate	High	Extreme
	Slight	Negligible	Very low	Low	Moderate	High	Extreme
	Low	Negligible	Negligible	Very low	Low	Moderate	High
	Very low	Negligible	Negligible	Negligible	Very low	Low	Moderate
	Extremely low	Negligible	Negligible	Negligible	Negligible	Very low	Low
	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very low
		Negligible	**Very low**	**Low**	**Moderate**	**High**	**Extreme**
		Consequence					

Fig. 2
An example of a risk estimation matrix

the qualitative and/or quantitative evaluation of the likely intake of the agent via food, as well as exposures from other sources, if relevant. The quantitative information may include the frequency with which the population ingests the food and the volume ingested. The prevalence and concentration of the agent gives the actual frequency and volume of the agent consumed. Risk characterisation is based on the previous three steps and is the qualitative and/or quantitative estimation, including uncertainties, of both the probability of occurrence and the severity of known or potential adverse health effects in a given population (13). The CAC has also published guidelines for AMR risk analysis (14). In this framework, AMU at farms, selection of AMR bacteria, and ingestion of the bacteria are included in the exposure assessment.

Challenges and benefits of risk assessment frameworks

Risk assessment frameworks are powerful tools for identifying and understanding how a disease event occurs in animal and/or human populations. Usually, a qualitative assessment may be conducted at the beginning of a risk assessment. This exercise is very useful for identifying knowledge gaps before proceeding to quantitative analysis, and for discussing what the risk assessment should cover, even if the risk question has been stated clearly. A quantitative risk assessment can then be carried out to provide the relevant authorities with a quantitative prediction of the risk, of the reduction of disease burden, and of the costs

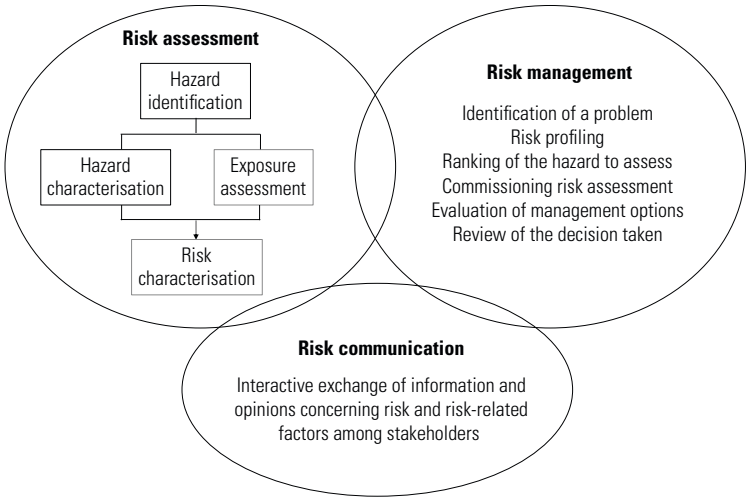

Fig. 3
Codex Alimentarius Commission risk analysis ([12], based on [13])

and time taken, with *a priori* uncertainty (credible interval of the estimated risk) for designed control options.

Risk assessment is complicated by several common challenges. One of these challenges is a lack of information. Shortcomings may include: unintroduced surveillance and monitoring schemes (due to financial limitations), failure to reliably maintain data collection during surveillance, illegal and informal activities that escape legal monitoring frameworks, and gaps in biological and technical knowledge. A second challenge is the high level of quantitative skills required for reliable quantitative risk assessment. As research progresses on biology, socio-economics, and ecology, we are discovering more evidence associated with risks. The findings can be complex, but they are very useful for risk assessments. Risk assessors must always be developing new approaches to facilitate the needs of the risk manager, who, in turn, must be aware of the latest scientific developments and international discussions. This challenge also requires the risk manager to remain up to date with technical developments in the field. A third challenge is that of assembling a good risk assessment team, one that includes high-level experts of different backgrounds who can respond to the changing needs of risk managers. A fourth challenge is ensuring that risks assessors have the opportunity to engage with diverse real-world conditions, through table-top experiments and/or fieldwork, in order to facilitate realistic risk assessment, which can provide the authorities with information for practical considerations in risk management. Finally, an excellent risk assessment may not result in effective risk management programmes unless careful and dedicated risk communication with stakeholders, which sometimes include the general population, is undertaken. All of these challenges are associated with resource availability in each country. International cooperation between countries of all income levels is critically important for reducing global disease risk.

Latest developments in animal health and food safety risk assessments

The OIE import risk analysis framework can be implemented in any OIE Member Country to manage the risks from hazards associated with the formal trade in animals and livestock products. However, the illegal import of livestock, meat and meat products can pose significant risks to the livestock industry and public health, and a framework of quantitative risk assessment to evaluate the risks posed by this illegal trade was proposed in 2006 (15); this framework was applied soon thereafter to assess the risks from illegal importation to the United Kingdom (UK) of meat contaminated with FMD (4). The risk from illegally imported bushmeat has also been the subject of attention (8), as wild animals are a large and uncharacterised reservoir of unknown zoonotic and non-zoonotic disease agents (16). To overcome the lack of information on the numbers of illegal importation events and the lack of detailed travel records, Japan and the United States of America (USA) have used the estimated weight of pork products in air passenger's luggage to calculate the risk of ASF and CSF being introduced into the country (3, 17).

Infectious disease modelling has had a long history since the development of the Kermack and McKendrick susceptible/infectious/recovered (SIR) model (18). Detailed predictive models were developed during the 2001 FMD outbreaks in the UK to understand the patterns of disease spread, and to plan and evaluate proposed control policies (19, 20, 21). Later, simulation models for FMD were used to assess the consequences of FMD virus entry into FMD-free countries (22), and a spatial and stochastic computer programme, InterSpread Plus, became available for epidemic contingency planning for infectious diseases such as FMD, avian influenza, and CSF (23). More recent transmission network models have combined genomic and epidemiological data to reconstruct transmission patterns (who infected whom) during infectious disease outbreaks (24).

Bluetongue (BT) is prevalent in regions where the insect vector, *Culicoides*, is present (25), and the qualitative risk assessment for BT virus entry into the UK considered scenarios that incorporated the incursion and overwintering of the vector, as well as the spread of the virus in animal populations in central and northern Europe (26). The use of detailed entomological and ecological study results may increase precision and preparedness in risk management for vector-borne diseases, including BT (27). Additional scenarios, including future predictions of the effects of climate change on disease distribution, are becoming available (28).

Risk assessments for diseases that can cause pandemics, such as coronavirus disease and highly pathogenic avian influenza (HPAI), are vital. Similarities in genome sequences suggest that SARS-coronavirus-2 may have originated in animals such as pangolins (29) and bats (30), and protecting animal health is critically important in preparing for future pandemics in humans. Highly-pathogenic avian influenza has caused several pandemics in the recent past, and the Centers for Disease Control and Prevention in the USA has developed the Influenza Risk Assessment Tool (IRAT) to assess the potential pandemic risk posed by influenza A viruses that are not currently circulating in people, thus facilitating decision-making for pre-pandemic vaccine production (31). The IRAT consists of ten evaluation criteria

across three categories – properties of the virus, attributes of the population, and ecology and epidemiology (31) – and it involves assessments of both animals and humans. The influenza A virus that IRAT rates as having the greatest potential to cause a pandemic is the Asian lineage H7N9 virus, which has been causing human infections in the People's Republic of China since 2013 (usually associated with exposure to birds in live bird markets) (32). The H7N9 viruses isolated in Hong Kong, Special Administrative Region of the People's Republic of China, and Shanghai in 2016 and 2017 were assessed as posing a moderate-high pandemic risk (33). In 2016, following the development of IRAT, the World Health Organization launched the Tool for Influenza Pandemic Risk Assessment (TIPRA), which involves the assessments of three components (the hazard, the possible exposure to the hazard, and the context in which the event is occurring) (34). It is intended to provide a standardised and transparent approach that will facilitate assessment of the risks posed by influenza viruses with pandemic potential.

Understanding the value chain greatly helps in predicting disease spread, and network analysis is useful here. For example, a social network analysis in poultry market chains in southern China was found to be useful in risk-based surveillance for avian influenza (35). In Vietnam, to calculate the probability of infection at live bird markets and the probability of subsequent virus spread, network analysis has been elaborated further to take into consideration the dynamics of poultry movement in the country (36). The volume of poultry trade varies seasonally, and changes in the risk of avian influenza spread in poultry in Thailand has been analysed using exponential random graph models (37). In other work, a combination of network analysis of the poultry value chain and genome analysis has provided a clear picture of the risk of avian influenza spread in China (38).

Risk analysis, particularly OIE import risk analysis, has been used in the management of aquatic animal health for international trade. More specifically, it has been used to assess the risk of disease emergence and disease transmission, including transmission from farmed animals to wildlife, vertical transmission, and transmission between rivers (39, 40). Ecological risk assessments have been conducted for antibiotics applied in fish farms and antibiotics derived from hospital waste, looking at the effects on aquatic bacteria, green algae, invertebrates, and fish (41, 42). Contamination of the oceans with plastics is a global issue, and risk assessments have been conducted for physical and chemical toxicity in humans through ingestion of microplastics in seafood (43).

Animal health risk assessment is also used for reducing disease risks in endemic countries. The Progressive Control Pathway for FMD, for example, starts with risk assessment, including value chain analysis, and then, based on the results, a national control programme is designed and implemented. The goal is to achieve and maintain freedom from FMD without vaccination. This process is jointly supported by the FAO, the OIE, and the Global Framework for the Progressive Control of Transboundary Animal Diseases (44).

It is worth noting at this point that disease control in outbreaks of infectious animal diseases such as FMD has both social and psychological impacts on farmers (45, 46) and veterinarians (47, 48), and assessment tools are available to assess these effects. These include the Impact of Event Scale-Revised, which assesses post-traumatic stress disorder (49), and the Kessler Psychological Distress Scale (both K10 and the slightly shorter K6) (50). Both these tools, which are based on a self-administered questionnaire about associated symptoms, have been used to assess the psychological impacts of animal disease outbreaks, including outbreaks of FMD (46, 47).

Alongside FMD risk assessment, a large number of cost-benefit analysis studies have been conducted for FMD control and eradication programmes (51). Similarly, for rabies, assessments of risk have been carried out alongside assessment of the cost-benefit ratio of control options. In Japan, for example, which is rabies free, a risk assessment and cost–benefit analysis were carried out to evaluate the risk of a rabies incursion and assess whether or not the policy of mandatory dog rabies vaccination was economically efficient (52, 53). In a rabies-endemic country, Chad, a cost-effectiveness study comparing the average cost per disability-adjusted life year (DALY) averted of different control options showed that, after six years, a policy of implementing rabies vaccination in dogs alongside post-exposure prophylaxis (PEP) in humans is profitable, and that, over a period of longer than seven years, it becomes more cost-effective than the current policy of relying solely on PEP (54).

Risk assessment has been used in discussions about creating a multi-state policy on administering PEP after dog-bite injuries in western Europe. The countries of western Europe were declared free of rabies in non-flying mammals in 2015; however, the practice of administering PEP following dog-bites continued because of concerns about dog rabies cases being imported from endemic countries. In 2016, risk assessors found that the risk that a given pet in western Europe was contagious for rabies was very low, and argued that costly post-exposure prophylaxis could be avoided, permitting optimisation of resource allocation (55).

Food safety risk analysis has evolved since the CAC adopted the Principles and Guidelines for the Conduct of Microbiological Risk Assessment in 1999 (56). These principles were developed to help countries

meet the requirements of the World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS), which came into force in 1995. In 2020, to respond to increasing international need for advice on meeting the obligations of the SPS Agreement and on reducing the risk of foodborne illness to consumers, FAO and WHO undertook a programme of quantitative microbiological risk assessment (QMRA) for three pathogens: *Salmonella* Enteritidis in eggs, *Salmonella* in broiler chickens, and *Listeria monocytogenes* in ready-to-eat foods (57). The QMRA methodology was established following two years of international efforts to collect data (data used for analysing the dose–response relationship were obtained from outbreak investigation records in Japan since 1997) (57). Since the establishment of this methodology, many QMRAs have been conducted; however, such risk assessments are challenging in countries where informal food chains dominate the food supply and surveillance data are scarce. In these countries, participatory approaches to QMRA have offered a new paradigm to bring communities and food safety implementers together in assessing and managing risks in informally marketed animal-source foods (58). Using participatory techniques, and taking gender and socio-economic considerations into account, structures of formal and informal value chains have been identified. Participatory QMRAs have suggested points of intervention at the farm, processing, distribution, and household levels (59, 60, 61). For example, a participatory QMRA for staphylococcal food poisoning through consumption of raw dairy milk and homemade yoghurt found that traditional fermentation reduced the risk by 93.7% and that interventions at the farm, such as mastitis control and milking hygiene, were effective (59). In Vietnam, a participatory QMRA for salmonellosis in smallholder pig value chains in urban areas, involving risk factor analysis and an experiment, identified a number of intervention points: weak biosecurity at farms, lack of clear separation between lairage and the slaughter area in slaughterhouses, presence of flies and wiping pork with a cloth at pork shops, and use of the same cutting board for both raw and cooked pork in households (61, 62, 63). Quantitative risk assessment has been applied for toxins (64) using the OIE framework, and for viruses (65) using the CAC framework, although finding sound dose–response relationships is a challenge. In low- and middle-income countries, prior to the introduction of QMRA, foodborne diseases had not received as much attention as infectious diseases. In 2015, WHO estimated the global burden of foodborne diseases in 2010 as 33 million DALYs. For comparison, a 2012 report estimated the burden of each of the 'big three' infectious diseases as follows: HIV/AIDS (92 million DALYs), malaria (55 million DALYs), and tuberculosis (44 million DALYs) (66).

The first quantitative risk assessment for AMR used a linear relationship between the proportion of chicken meat contaminated with fluoroquinolone-resistant *Campylobacter* and the number of human cases of fluoroquinolone-resistant *Campylobacter* infection (67). However, AMR involves complex resistance mechanisms, including mobile resistance genes, and risk assessments needed to address them. The OIE risk assessment framework has been used to qualitatively assess the risks of pleuromutilin use in swine in Denmark, and this assessment incorporated co-selection of bacteria that are resistant to other antimicrobials and covered multiple pathogens and different transmission routes, including human-to-human transmission, foodborne transmission (enterococci) and occupational exposure (methicillin-resistant *Staphylococcus aureus*) (68). A large number of AMR risk assessments have been conducted using the CAC framework as well (69). Mathematical modelling has started to be used to quantify the behaviour of resistance genes (70); however, it has been argued that existing gaps in our knowledge of AMR biology preclude the accurate use of such techniques (71). An individual-based simulation model was used for the quantitative release assessment of *mcr*-mediated colistin-resistant *Escherichia coli* from pigs, which enabled *a priori* assessments of intervention effects of different management options (72).

While guidelines and techniques for quantitative risk assessments continue to advance rapidly, the science related to the relevant behaviour of humans is also being developed; such behavioural analyses are expected to reduce the risks. Systems approaches consider resource allocation, cost-effectiveness, and the behaviour of actors along the livestock supply chain. These behaviours can change dynamically, in non-linear ways, over time (73, 74), and reviewing them can help to predict the feasibility of intervention programmes. At the farm level, analyses have been conducted to evaluate decision-making processes in the context of farm biosecurity; such an approach may help in designing targeted intervention programmes (75). The 'nudge' theory, which describes how individuals can be encouraged to act in ways that produce net social benefits without restricting freedom of choice, has been used to design intervention programmes for the actors along the pork value chain in Vietnam to reduce the burden of FBD in that country (76).

In the near future, risk assessment may include a combination of QMRA, mathematical modelling, genome sequencing, quantitative and qualitative socio-economics, and even artificial intelligence. This will improve animal and public health while enhancing community participation as well as the participation of actors in the livestock and animal industries.

Les évaluations des risques pour la santé animale et la sécurité sanitaire des aliments

K. Makita

Résumé

L'évaluation des risques pour la santé animale constitue l'une des tâches centrales des Services vétérinaires. L'Organisation mondiale de la santé animale et la Commission du Codex Alimentarius ont élaboré à cet effet des protocoles d'évaluation des risques désormais bien établis. Ces protocoles recouvrent les maladies infectieuses des animaux terrestres et aquatiques, les zoonoses, la sécurité sanitaire des aliments ainsi que l'environnement, en prenant en compte leurs connexions réciproques.

Beaucoup d'efforts ont été déployés pour mettre au point des méthodes permettant d'estimer la probabilité (et les conséquences) d'une incursion de maladie infectieuse dans des pays indemnes, à la faveur d'échanges commerciaux licites ou illicites ou de déplacements d'insectes ou d'animaux sauvages. Des efforts additionnels ont été consacrés à la conception de stratégies de prévention et de plans d'urgence. Les craintes suscitées par le risque de futures pandémies d'influenza aviaire constituent une incitation importante pour continuer à surveiller les virus afin de sélectionner les souches candidates pour l'élaboration de vaccins. La récente pandémie de COVID-19, dont la nature est zoonotique, a occasionné des perturbations considérables dans le monde entier. Des outils sont progressivement mis au point permettant d'effectuer des évaluations quantitatives des risques pour la sécurité sanitaire des aliments associés à des bactéries, des toxines, des virus ainsi que les gènes de la résistance aux agents antimicrobiens, y compris des outils de simulation pour étayer le choix des stratégies de lutte les plus efficaces. Le recours à des techniques participatives facilite la réalisation d'analyses du risque dans les pays à revenu faible et intermédiaire. Dans les cadres mis en place à l'échelle internationale, l'évaluation du risque est la première étape du processus visant à éliminer des maladies infectieuses majeures dans les pays où celles-ci sévissent à l'état endémique ; de ce fait, elle est une composante importante de la stratégie d'atténuation des risques de maladie. Des études quantitatives et qualitatives portant sur les aspects socio-économiques et sur les comportements ont été réalisées afin d'élaborer des stratégies de gestion du risque qui soient à la fois acceptables et applicables durablement par les acteurs intervenant à chaque point des chaînes de valeur.

Mots-clés

Analyse des risques – Animaux aquatiques – Animaux terrestres – Évaluation des risques – Santé animale – Sécurité sanitaire des aliments.

Determinación del riesgo en materia de sanidad animal y de inocuidad de los alimentos

K. Makita

Resumen

La determinación del riesgo zoosanitario es uno de los principales cometidos de los Servicios Veterinarios. Ya existen arraigados protocolos de determinación del riesgo, elaborados por la Organización Mundial de Sanidad Animal y la Comisión

del Codex Alimentarius, que abarcan desde los animales terrestres y acuáticos hasta las enfermedades infecciosas zoonóticas, pasando por las cuestiones ambientales y de inocuidad de los alimentos, y tienen en cuenta las conexiones existentes entre todos estos factores.
Se ha dedicado un gran esfuerzo a dar con métodos para calcular la probabilidad y las consecuencias de que una enfermedad infecciosa penetre en un país exento de ella a resultas del comercio, ya sea legal o ilegal, o del desplazamiento de insectos o animales silvestres. También se ha trabajado para concebir estrategias de prevención y planes de contingencia. La inquietud por una posible pandemia de influenza aviar sigue suponiendo una poderosa motivación para vigilar a los virus con objeto de seleccionar cepas candidatas para vacunas. La reciente pandemia de COVID-19, de carácter zoonótico, causó una profunda conmoción en todo el mundo. Ahora empieza a haber herramientas para efectuar determinaciones cuantitativas del riesgo de insalubridad de los alimentos a causa de bacterias, toxinas, virus y genes de resistencia a antimicrobianos, entre ellas algunas que permiten hacer simulaciones para seleccionar fórmulas eficaces de lucha. La aplicación de técnicas participativas facilita la realización de análisis de riesgos en países de renta baja o mediana. En los mecanismos ya establecidos a nivel internacional, la determinación del riesgo es el primer paso para eliminar importantes enfermedades infecciosas en los países donde son endémicas y resulta de gran ayuda para reducir los riesgos de enfermedad. Se han elaborado asimismo estudios cuantitativos y cualitativos del medio socioeconómico y del comportamiento para dar con fórmulas de gestión del riesgo que puedan ser aceptables y sostenibles para los agentes que operan a lo largo de las cadenas de valor.

Palabras clave
Análisis de riesgos – Animal acuático – Animal terrestre – Determinación del riesgo – Inocuidad de los alimentos – Sanidad animal.

References

1. Vose D. (2008). – Risk analysis: a quantitative guide, 3rd Ed. John Wiley & Sons Ltd, Chichester, United Kingdom. Available at: www.wiley.com/en-us/Risk+Analysis%3A+A+Quantitative+Guide%2C+3rd+Edition-p-9780470512845 (accessed on 24 March 2021).

2. Taylor R.A., Condoleo R., Simons R.R.L., Gale P., Kelly L.A. & Snary E.L. (2020). – The risk of infection by African swine fever virus in European swine through boar movement and legal trade of pigs and pig meat. *Front. Vet. Sci.*, **6**, Article No. 486. doi:10.3389/fvets.2019.00486.

3. Ito S., Jurado C., Sánchez-Vizcaíno J.M. & Isoda N. (2020). – Quantitative risk assessment of African swine fever virus introduction to Japan via pork products brought in air passengers' luggage. *Trans. Emerg. Dis.*, **67** (2), 894–905. doi:10.1111/tbed.13414.

4. Harnett E., Adkin A., Seaman M., Cooper J., Watson E., Coburn H., England T., Marooney C., Cox A. & Woodbridge M. (2007). – A quantitative assessment of the risks from illegally imported meat contaminated with foot and mouth disease virus to Great Britain. *Risk Anal.*, **27** (1), 187–202. doi:10.1111/j.1539-6924.2006.00869.x.

5. Bironf P., Castryck F. & Leunen J. (1987). – An epizootic of African swine fever in Belgium and its eradication. *Vet. Rec.*, **120** (18), 432–434. doi:10.1136/vr.120.18.432.

6. Mansley L.M., Dunlop P.J., Whiteside S.M. & Smith R.G.H. (2003). – Early dissemination of foot-and-mouth disease virus through sheep marketing in February 2001. *Vet. Rec.*, **153** (2), 43–50. doi:10.1136/vr.153.2.43.

7. Mansley L.M., Donaldson A.I., Thrusfield M.V. & Honhold N. (2011). – Destructive tension: mathematics versus experience: the progress and control of the 2001 foot and mouth disease epidemic in Great Britain. *In* Models in the management of animal diseases (P. Willeberg, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **30** (2), 483–498. doi:10.20506/rst.30.2.2054.

8. Falk H., Dürr S., Hauser R., Wood K., Tenger B., Lörtscher M. & Schüpbach-Regula G. (2013). – Illegal import of bushmeat and other meat products into Switzerland on commercial passenger flights. *Rev. Sci. Tech. Off. Int. Epiz.*, **32** (3), 727–739. doi:10.20506/rst.32.2.2221.

9. Taylor L.H., Latham S.M. & Woolhouse M.E.J. (2001). – Risk factors for human disease emergence. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, **356** (1411), 983–989. doi:10.1098/rstb.2001.0888.

10. World Organisation for Animal Health (OIE) (2017). – Section 2. Risk analysis. *In* Terrestrial Animal Health Code, 27th Ed. OIE, Paris, France. Available at: www.oie.int/en/what-we-do/standards/codes-and-manuals/terrestrial-code-online-access/?id=169&L=1&htmfile=titre_1.2.htm (accessed on 25 August 2021).

11. World Organisation for Animal Health (OIE) (2019). – Risk analysis for antimicrobial resistance arising from the use of antimicrobials in animals. Chapter 6.11. *In* Terrestrial Animal Health Code, 27th Ed. OIE, Paris, France. Available at: www.oie.int/fileadmin/Home/eng/Health_standards/tahc/current/chapitre_antibio_risk_ass.pdf (accessed on 17 July 2021).

12. Makita K., de Haan N., Nguyen-Viet H. & Grace D. (2019). – Assessing food safety risks in low and middle-income countries. *In* Encyclopedia of food security and sustainability, 1st Ed. (P. Ferranti, E. Berry & A. Jock, eds). Elsevier, Amsterdam, the Netherlands, 448–453. doi:10.1016/B978-0-08-100596-5.21576-X

13. Codex Alimentarius Commission (CAC) (2013). – Codex Alimentarius Commission Procedural Manual, 21st Ed. CAC, Rome, Italy, 214 pp. Available at: www.fao.org/3/i3243e/i3243e.pdf (accessed on 24 March 2021).

14. Codex Alimentarius Commission (CAC) (2011). – Guidelines for risk analysis of foodborne antimicrobial resistance (CAC/GL 77-2011). CAC, Rome, Italy, 29 pp. Available at: www.fao.org/input/download/standards/11776/CXG_077e.pdf (accessed on 24 March 2021).

15. Woodridge M.H.E., Cox A. & Seaman M. (2006). – Quantitative risk assessment case study: smuggled meats as disease vectors. *In* Biological disasters of animal origin. The role and preparedness of veterinary and public health services (M. Hugh-Jones, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **25** (1), 105–117. doi:10.20506/rst.25.1.1651.

16. Wolfe N.D., Daszak P., Kilpatrick A.M. & Burke D.S. (2005). – Bushmeat hunting, deforestation, and prediction of zoonotic disease. *Emerg. Infect. Dis.*, **11** (12), 1822–1827. doi:10.3201/eid1112.040789.

17. Jurado C., Paternoster G., Martinez-Lopez B., Burton K. & Mur L. (2018). – Could African swine fever and classical swine fever viruses enter into the United States via swine products carried in air passengers' luggage? *Trans. Emerg. Dis.*, **66** (1), 166–180. doi:10.1111/tbed.12996.

18. Kermack W.O. & McKendrick A.G. (1927). – A contribution to the mathematical theory of epidemics. *Proc. Roy. Soc. Lond., A*, **115** (772), 700–721. doi:10.1098/rspa.1927.0118.

19. Ferguson N.M., Donnelly C.A. & Anderson R.M. (2001). – The foot-and-mouth epidemic in Great Britain: pattern of spread and impact of interventions. *Science*, **292** (5519), 1155–1160. doi:10.1126/science.1061020.

20. Keeling M.L., Woolhouse M.E., Shaw D.J., Matthews L., Chase-Topping M., Haydon D.T., Cornell S.J., Kappey J., Wilesmith J. & Grenfell B.T. (2001). – Dynamics of the 2001 UK foot and mouth epidemic: stochastic dispersal in a heterogeneous landscape. *Science*, **294** (5543), 813–817. doi:10.1126/science.1065973.

21. Morris R.S., Wilesmith J.W., Stern M.W., Sanson R.L. & Stevenson M.A. (2001). – Predictive spatial modelling of alternative control strategies for the foot-and-mouth disease epidemic in Great Britain, 2001. *Vet. Rec.*, **149** (5), 137–144. doi:10.1136/vr.149.5.137.

22. Carpenter T.E., Christiansen L.E., Dickey B.F., Thunes C. & Hullinger P.J. (2007). – Potential impact of an introduction of foot-and-mouth disease into the California State Fair. *J. Am. Vet. Med. Assoc.*, **231** (8), 1231–1235. doi:10.2460/javma.231.8.1231.

23. Stevenson M.A., Sanson R.L., Stern M.W., O'Leary B.D., Sujau M., Moles-Benfell N. & Morris R.S. (2013). – InterSpread Plus: a spatial and stochastic simulation model of disease in animal populations. *Prev. Vet. Med.*, **109** (1–2), 10–24. doi:10.1016/j.prevetmed.2012.08.015.

24. Firestone S.M., Hayama Y., Bradhurst R., Yamamoto T., Tsutsui T. & Stevenson M.A. (2019). – Reconstructing foot-and-mouth disease outbreaks: a methods comparison of transmission network models. *Sci. Rep.*, **9**, Article No. 4809. doi:10.1038/s41598-019-41103-6.

25. World Organisation for Animal Health (OIE) (2020). – Bluetongue. OIE, Paris, France. Available at: www.oie.int/en/animal-health-in-the-world/animal-diseases/bluetongue/ (accessed on 5 August 2020).

26. Department for Environment, Food and Rural Affairs (DEFRA) (2015). – Risk assessment for bluetongue virus (BTV) entry into the United Kingdom: qualitative risk assessment. DEFRA, London, United Kingdom, 25 pp. Available at: assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/437167/qra-btv-europe-201506.pdf (accessed on 8 January 2021).

27. Jacquet S., Huber K. […] & Garros C. (2016). – Range expansion of the bluetongue vector, *Culicoides imicola*, in continental France likely due to rare wind-transport events. *Sci. Rep.*, **6**, Article No. 27247. doi:10.1038/srep27247.

28. Jones A.E., Turner J., Caminade C., Heath A.E., Wardesh M., Kluiters G., Diggle P.J., Morse A.P. & Baylis M. (2019). – Bluetongue risk under future climates. *Nat. Clim. Chang.*, **9** (2), 153–157. doi:10.1038/s41558-018-0376-6.

29. Lam T.T.-Y., Jia N. […] & Cao W.-C. (2020). – Identifying SARS-Cov-2-related coronaviruses in Malayan pangolins. *Nature*, **583**, 282–285. doi:10.1038/s41586-020-2169-0.

30. Dabravolski S.A. & Kavalionak Y.K. (2020). – SARS-CoV-2: Structural diversity, phylogeny, and potential animal host identification of spike glycoprotein. *J. Med. Virol.*, **92** (9), 1690–1694. doi:10.1002/jmv.25976.

31. Cox N.J., Trock S.C. & Burke S.A. (2014). – Pandemic preparedness and the Influenza Risk Assessment Tool (IRAT). *In* Influenza pathogenesis and control, Vol. I. (R. Compans & M.B.A. Oldstone, eds). *Curr. Top. Microbiol. Immunol.*, **385**. Springer, Cham, Switzerland.

32. World Health Organization (WHO) (2017). – Analysis of recent scientific information on avian influenza A(H7N9) virus, 10 February. WHO, Geneva, Switzerland. Available at: www.who.int/influenza/human_animal_interface/avian_influenza/riskassessment_AH7N9_201702/en/ (accessed on 6 August 2020).

33. Centers for Disease Prevention and Control (CDC) (2020). – Summary of Influenza Risk Assessment Tool (IRAT) results. CDC, Atlanta, United States of America. Available at: www.cdc.gov/flu/pandemic-resources/monitoring/irat-virus-summaries.htm (accessed on 6 August 2020).

34. World Health Organization (WHO) (2016). – Tool for Influenza Pandemic Risk Assessment (TIPRA). Version 1 Release. WHO, Geneva, Switzerland, 60 pp. Available at: www.who.int/influenza/publications/TIPRA_manual_v1/en/ (accessed on 29 March 2021).

35. Martin V., Zhou X., Marshall E., Jia B., Fusheng G., FrancoDixon M.A., DeHaan N., Pfeiffer D.U., Soares Magalhães R.J. & Gilbert M. (2011). – Risk-based surveillance for avian influenza control along poultry market chains in South China: the value of social network analysis. *Prev. Vet. Med.*, **102** (3), 196–205. doi:10.1016/j.prevetmed.2011.07.007.

36. Fournié G., Tripodi A., Nguyen T.T.T., Nguyen V.T., Tran T.T., Bisson A., Pfeiffer D.U. & Newman S.H. (2016). – Investigating poultry trade patterns to guide avian influenza surveillance and control: a case study in Vietnam. *Sci. Rep.*, **6**, Article No. 29463. doi:10.1038/srep29463.

37. Poolkhet C., Makita K., Thongratsakul S. & Leelehapongsathon K. (2018). – Exponential random graph models to evaluate the movement of backyard chickens after the avian influenza crisis in 2004–2005, Thailand. *Prev. Vet. Med.*, **158**, 71–77. doi:10.1016/j.prevetmed.2018.07.015.

38. Yang Q., Zhao X., Lemey P., Suchard M.A., Bi Y., Shi W., Liu D., Qi W., Zhang G., Stenseth N.C., Pybus O.G. & Tian H. (2020). – Assessing the role of live poultry trade in community-structured transmission of avian influenza in China. *Proc. Nat. Acad. Sci. USA*, **117** (11), 5949–5954. doi:10.1073/pnas.1906954117.

39. Peeler E.J., Murray A.G., Thebault A., Brun E., Giovaninni A. & Thrush M.A. (2007). – The application of risk analysis in aquatic animal health management. *Prev. Vet. Med.*, **81** (1–3), 3–20. doi:10.1016/j.prevetmed.2007.04.012.

40. Arthur J.R. & Bondad-Reantaso M.G. (2012). – Risk analysis for movements of live aquatic animals: An introductory training course. Food and Agriculture Organization Sub-Regional Office for the Pacific Islands, Apia, Samoa, 176 pp. Available at: www.fao.org/3/i2571e/i2571e.pdf (accessed on 29 March 2021).

41. Andrieu M., Rico A., Phu T.M., Huong D.T.T., Phuong N.T. & Van den Brink P.J. (2015). – Ecological risk assessment of the antibiotic enrofloxacin applied to *Pangasius* catfish farms in the Mekong Delta, Vietnam. *Chemosphere*, **119**, 407–414. doi:10.1016/j.chemosphere.2014.06.062.

42. Ashfaq M., Khan K.N., Rasool S., Mustafa G., Saif-Ur-Rehman M., Nazar M.F., Sun Q. & Yu C.-P. (2016). – Occurrence and ecological risk assessment of fluoroquinolone antibiotics in hospital waste of Lahore, Pakistan. *Environ. Toxicol. Pharmacol.*, **42**, 16–22. doi:10.1016/j.etap.2015.12.015.

43. Smith M., Love D.C., Rochman C.M. & Neff R.A. (2018). – Microplastics in seafood and the implications for human health. *Curr. Environ. Health Rep.*, **5** (3), 375–386. doi:10.1007/s40572-018-0206-z.

44. Food and Agriculture Organization of the United Nations (FAO), World Organisation for Animal Health (OIE) & European Commission for the Control of Foot-and-Mouth Disease (EuFMD) (2018). – The Progressive Control Pathway for Foot-and-Mouth Disease control (PCP-FMD): principles, stage descriptions and standards, 2nd Ed. FAO, Rome, Italy, 25 pp. Available at: www.fao.org/eufmd/global-situation/pcp-fmd/en/ (accessed on 8 January 2021).

45. Crimes D. & Enticott G. (2019). – Assessing the social and psychological impacts of endemic animal disease amongst farmers. *Front. Vet. Sci.*, **6**, Article No. 342. doi:10.3389/fvets.2019.00342.

46. Kadowaki H., Kayano T., Tobinaga T., Tsutsumi A., Watari M. & Makita K. (2016). – Analysis of factors associated with hesitation to restart farming after depopulation of animals due to 2010 foot-and-mouth disease epidemic in Japan. *J. Vet. Med. Sci.*, **78** (8), 1251–1259. doi:10.1292/jvms.15-0559.

47. Hibi J., Kurosawa A., Watanabe T., Kadowaki H. & Watari M. (2015). – Post-traumatic stress disorder in participants of foot-and-mouth disease epidemic control in Miyazaki, Japan, in 2010. *J. Vet. Med. Sci.*, **77** (8), 953–959. doi:10.1292/jvms.14-0512.

48. Makita K., Tsuji A., Iki Y., Kurosawa A., Kadowaki H., Tsutsumi A., Nogami T. & Watari M. (2015). – Mental and physical distress of field veterinarians during and soon after control of the 2010 foot and mouth disease outbreak in Miyazaki, Japan. *Rev. Sci. Tech. Off. Int. Epiz.*, **34** (3), 699–712. doi:10.20506/rst.34.3.2387.

49. Beck J.G., Grant D.M., Read J.P., Clapp J.D., Coffey S.F., Miller L.M. & Palyo S.A. (2008). – The Impact of Event Scale-Revised: psychometric properties in a sample of motor vehicle accident survivors. *J. Anxiety Disord.*, **22** (2), 187–198. doi:10.1016/j.janxdis.2007.02.007.

50. Kessler R.C., Andrews G., Colpe L.J., Hiripi E., Mroczek D.K., Normand S.L.T., Walters E.E. & Zaslavsky A.M. (2002). – Short screening scales to monitor population prevalences and trends in non-specific psychological distress. *Psychol. Med.*, **32** (6), 959–976. doi:10.1017/s0033291702006074.

51. Knight-Jones T.J.D. & Rushton J. (2013). – The economic impacts of foot and mouth disease – what are they, how big are they and where do they occur? *Prev. Vet. Med.*, **112** (3–4), 161–173. doi:10.1016/j.prevetmed.2013.07.013.

52. Kwan N.C.L., Yamada A. & Sugiura K. (2018). – Benefit-cost analysis of the policy of mandatory annual rabies vaccination of domestic dogs in rabies-free Japan. *PLoS One*, **13** (12), Article No. e0206717. doi:10.1371/journal.pone.0206717.

53. Kadowaki H., Hampson K., Tojinbara K., Yamada A. & Makita K. (2018). – The risk of rabies spread in Japan: a mathematical modelling assessment. *Epidemiol. Infect.*, **146** (10), 1245–1252. doi:10.1017/S0950268818001267.

54. Zinsstag J., Dürr S., Penny M.A., Mindekem R., Roth F., Menendez Gonzalez S., Naissengar S. & Hattendorf J. (2009). – Transmission dynamics and economics of rabies control in dogs and humans in an African city. *Proc. Nat. Acad. Sci. USA*, **106** (35), 14996–15001. doi:10.1073/pnas.0904740106.

55. Ribadeau-Dumas F., Cliquet F., Gautret P., Robardet E., Le Pen C. & Bourhy H. (2016). – Travel-associated rabies in pets and residual rabies risk, western Europe. *Emerg. Infect. Dis.*, **22** (7), 1268–1271. doi:10.3201/eid2207.151733.

56. Codex Alimentarius Commission (CAC) (1999). – Principles and guidelines for the conduct of microbiological risk assessment. CAC/GL-30. CAC, Rome, Italy. Available at: www.fao.org/3/Y1579E/y1579e05.htm (accessed on 28 July 2021).

57. World Health Organization (WHO) & Food and Agriculture Organization of the United Nations (FAO) (2002). – Risk assessments of *Salmonella* in eggs and broiler chickens: interpretative summary. Microbiological Risk Assessment Series 1. WHO, Geneva, Switzerland & FAO, Rome, Italy, 70 pp. Available at: www.who.int/foodsafety/publications/salmonella/en/ (accessed on 8 January 2021).

58. Grace D., Randolph T., Olawoye J., Dipelou M. & Kang'ethe E. (2008). – Participatory risk assessment: a new approach for safer food in vulnerable African communities. *Devel. Prac.*, **18** (4–5), 611–618. doi:10.1080/09614520802181731.

59. Makita K., Desissa F., Teklu A., Zewde G. & Grace D. (2012). – Risk assessment of staphylococcal poisoning due to consumption of informally-marketed milk and home-made yoghurt in Debre Zeit, Ethiopia. *Int. J. Food Microbiol.*, **153** (1–2), 135–141. doi:10.1016/j.ijfoodmicro.2011.10.028.

60. Oguttu J.W., McCrindle C.M.E., Makita K. & Grace D. (2014). – Investigation of the food value chain of ready-to-eat chicken and the associated risk for staphylococcal food poisoning in Tshwane Metropole, South Africa. *Food Control*, **45**, 87–94. doi:10.1016/j.foodcont.2014.04.026.

61. Sinh D.-X., Hung N.-V., Unger F., Phuc P.-D., Grace D., Ngan T.-T., Barot M., Ngoc P.-T. & Makita K. (2017). – Quantitative risk assessment of human salmonellosis in the smallholder pig value chains in urban of Vietnam. *Int. J. Pub. Health*, **62** (Suppl. 1), S93–S102. doi:10.1007/s00038-016-0921-x.

62. Dang-Xuan S., Nguyen-Viet H., Pham-Duc P., Grace D., Unger F., Nguyen-Hai N., Nguyen-Tien T. & Makita K. (2018). – Simulating cross-contamination of cooled pork with *Salmonella enterica* from raw pork through home kitchen preparation in Vietnam. *Int. J. Environ. Res. Pub. Health*, **15** (10), Article No. 2324. doi:10.3390/ijerph15102324.

63. Dang-Xuan S., Nguyen-Viet H., Pham-Duc P., Unger F., Tran-Thi N., Grace D. & Makita K. (2019). – Risk factors associated with *Salmonella* spp. prevalence along smallholder pig value chains in Vietnam. *Int. J. Food Microbiol.*, **290**, 105–115. doi:10.1016/j.ijfoodmicro.2018.09.030.

64. Sirma A.J., Makita K., Randolph D.G., Senerwa D. & Lindahl J.F. (2019). – Aflatoxin exposure from milk in rural Kenya and the contribution to the risk of liver cancer. *Toxins*, **11** (8), Article No. 469. doi:10.3390/toxins11080469.

65. Sarno E., Martin A., McFarland S., Johne R., Stephan R. & Greiner M. (2016). – Estimated exposure to hepatitis E virus through consumption of swine liver and liver sausages. *Food Cont.*, **73** (B), 821–828. doi:10.1016/j.foodcont.2016.09.030.

66. Havelaar A.H., Kirk M.D. […] & WHO Foodborne Disease Burden Epidemiology Reference Group (2015). – World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med.*, **12** (12), Article No. e1001923. doi:10.1371/journal.pmed.1001923.

67. Food and Drug Administration (FDA) Center for Veterinary Medicine (2000). – Human health impact of fluoroquinolone resistant *Campylobacter* attributed to the consumption of chicken. FDA, Silver Spring, United States of America, 109 pp. Available at: fda.report/media/76429/Human-Health-Impact-of-Fluoroquinolone-Resistant-Campylobacter-Attributed-to-the-Consumption-of-Chicken.pdf (accessed on 30 March 2021).

68. Alban L., Ellis-Iversen J., Andreasen M., Dahl J. & Sönksen U.W. (2017). – Assessment of the risk to public health due to use of antimicrobials in pigs – an example of pleuromutilins in Denmark. *Front. Vet. Sci.*, **4**, Article No. 74. doi:10.3389/fvets.2017.00074.

69. Caffrey N., Invik J., Waldner C.L., Ramsay D. & Checkley S.L. (2019). – Risk assessments evaluating foodborne antimicrobial resistance in humans: a scoping review. *Microbial Risk Anal.*, **11**, 31–46. doi:10.1016/j.mran.2018.08.002.

70. Lopatkin A., Meredith H.R., Srimani J.K., Pfeiffer C., Durrett R. & You L. (2017). – Persistence and reversal of plasmid-mediated antibiotic resistance. *Nat. Commun.*, **8**, Article No. 1689. doi:10.1038/s41467-017-01532-1.

71. Knight G.M., Davies N.G. […] & Atkins K.E. (2019). – Mathematical modelling for antibiotic resistance control policy: do we know enough? *BMC Infect. Dis.*, **19**, Article No. 1011. doi:10.1186/s12879-019-4630-y.

72. Makita K., Fujimoto Y., Sugahara N., Miyama T., Usui M., Asai T., Kawanishi M., Ozawa M. & Tamura Y. (2020). – Quantitative release assessment of *mcr*-mediated colistin-resistant *Escherichia coli* from Japanese pigs. *Food Saf.*, **8** (2), 13–33. doi:10.14252/foodsafetyfscj.D-20-00004.

73. Rich K.M., Denwood M.J., Stott A.W., Mellor D.J., Reid S.W.J. & Gunn G.J. (2013). – Systems approaches to animal disease surveillance and resource allocation: methodological frameworks for behavioral analysis. *PLoS One,* **8** (11), e82019. doi:10.1371/journal.pone.0082019.

74. Rich K.M., Dizyee K., Nguyen T.T.H., Duong N.H., Pham V.H., Nguyen T.D.N., Unger F. & Lapar M.L. (2018). – Quantitative value chain approaches for animal health and food safety. *Food Microbiol.*, **75**, 103–113. doi:10.1016/j.fm.2017.09.018.

75. Makita K., Steenbergen E., Haruta L., Hossain S., Nakahara Y., Tamura Y., Watanabe T., Kadowaki H. & Asakura S. (2020). – Quantitative understanding of the decision-making process for farm biosecurity among Japanese livestock farmers using the KAP-Capacity framework. *Front. Vet. Sci.*, **7**, Article No. 614. doi:10.3389/fvets.2020.00614.

76. Hennessey M., Kim S., Unger F., Nguyen-Viet H., Dang-Xuan S., Nguyen-Thi T. & Häsler B. (2020). – Exploring the potential of using nudges to promote food hygiene in the pork value chain in Vietnam. *Prev. Vet. Med.*, **181**, Article No. 105003. doi:10.1016/j.prevetmed.2020.105003.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 545-553

Managing institutional risk for Veterinary Services

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Summary
The use of institutional risk assessment and management, considered best practice in management sciences, is not systematically used across public Veterinary Services. Chief Veterinary Officers and their teams often lack exposure to or training in the application of this type of institutional risk assessment. This paper describes the essential elements of institutional risk assessment and how it might be applied within the context of Veterinary Services.

Keywords
Risk management – Institutional risk – Veterinary Services.

Introduction

A recent survey of how Veterinary Services perceive external factors affecting their future priorities, roles and performance highlighted the role of strengthening assessment of such factors as part of institutional planning by, for example, making better use of Foresight and risk assessment (1). It is important to differentiate between the type of epidemiological risk assessment that Veterinary Services undertake to evaluate the threat of a disease being introduced or transmitted, and the type of institutional risk assessment and management that is now considered best practice in management sciences. Methods and protocols for epidemiological risk analysis, such as those described by MacDiarmid and Pharo (2), are well-defined and are routinely applied to transboundary diseases in trade and to issues of food safety. Veterinary Services often have capacity in-house to undertake limited epidemiological risk analysis, and they also draw from academic expertise, as they did, for example, during the highly pathogenic avian influenza outbreaks in the first decade of the 2000s, when veterinary epidemiologists from local universities in several countries assisted Veterinary Services in conducting risk assessments to help assess the evolving situation. This type of technical, typically quantitative, risk analysis – the results of which are often published – should not be confused with institutional risk management, a management process that leadership teams undertake internally to improve their focus and effectiveness in reaching strategic objectives. In the survey mentioned above, carried out by Grace *et al.* (1), a majority (59%) of the 86 national Veterinary Services participating reported conducting analyses of institutional risk, but discrepancies in answers suggested some confusion between the epidemiological and institutional approaches. Only a subset of 25 country services appeared to have applied institutional risk assessment systematically. It would appear, therefore, that institutional risk assessment and management is still limited across public Veterinary Services, which is not surprising, given that professional advancement in these services has conventionally focused on technical expertise or political considerations rather than management skill sets. Chief Veterinary Officers and their teams often lack exposure to or training in the application of this type of institutional risk assessment. This has been borne out by many of the recent assessments of public Veterinary Services undertaken using the World Organisation for Animal Health (OIE) Tool for the Evaluation of Performance of Veterinary Services (PVS Tool), which have found Veterinary Service management is usually highly bureaucratic and focused on administrative tasks rather than strategic planning (3). In the survey conducted by Grace *et al*. (1), national Veterinary Services indicated that they felt they needed to strengthen their capacity in this area in order to better manage increasing uncertainty associated with a range of external factors. This paper describes the essential elements of institutional risk assessment and how it might be applied within the context of Veterinary Services.

The development of institutional enterprise-wide risk management

All types of organisations face uncertainty due to external or internal factors which may have a negative or positive effect on the organisation's ability to reach its objectives. In the

https://doi.org/10.20506/rst.40.2.3244

International Organization for Standardization (ISO) 31000 international standard on risk management (4), the effect of this uncertainty on objectives is defined as 'risk'. Therefore, dealing with risk when setting the strategy and working towards objectives has become increasingly accepted as an integral part of managing any organisation. The set of coordinated activities that can be followed to direct and control an organisation with regard to risk is defined as 'risk management'.

Historically, risk management activities were associated mainly with the insurance industry aiming to protect companies and individuals from losses related to accidents. Over the last fifty years, risk management has also been introduced in financial management to hedge against risks and reduce regulatory capital (5). Over the last two decades, there has been a major shift in how the role of risk management is perceived by corporate leaders and stakeholders. Today, across institutions and businesses, risk management is seen as an enabler to create value as well as protecting it (Fig. 1). Moreover, strategic failures, disruption of established business models, corporate governance scandals, global financial crises, human-made or natural disasters and the interconnectedness of risks have highlighted the need for an enterprise-wide approach to institutional risk management. This approach takes a holistic view of risks the organisation faces rather than seeing risk as something to be dealt with in isolation within separate departments and functional areas. It is also important to stress that risk management is much more than simply creating an inventory of risks that the organisation faces: it should start with objectives; it should be reflected in the operational strategy; there should be a culture of risk management across the organisation and be integrated into the organisation's practices at all levels. All staff should have the capability to participate in risk management activities, and the organisation should continually monitor the effectiveness of its risk management as an indicator of its organisational performance (6).

Fig. 1
Risk management targets: supporting compliance and preserving and creating value

One of the key benefits of successful implementation of risk management is that organisations can take better-informed strategic decisions regarding opportunities and risks. Another benefit is increased ability to reach objectives in an effective and consistent way. Risk management can also assist in enhancing confidence in the organisation by providing transparency and visibility on key risks the organisation faces and the actions to manage those risks. Additionally, by proactively identifying and managing risks, an organisation can improve efficiency in maintaining legal and regulatory compliance in relation to evolving and forthcoming changes.

How risk management can be applied

As is made clear in the principles set out in the ISO 31000 international standard on risk management (4), for risk management to succeed it needs to be integrated into organisational activities rather than operate in a standalone mode. It must also follow a structured and comprehensive approach and be customised and proportionate to the organisation's internal and external environment. Key stakeholders must be efficiently and effectively engaged along the process, which must remain dynamic to anticipate, and address in a timely manner, any changes in the risk landscape. Risk management is based on the best available information and should always account for human behaviour and the influence of culture. Risk management should improve continuously.

An illustration of the risk management process and its key components is set out in Figure 2.

To support the risk management process, it is necessary to define the risk framework in terms of risk architecture, strategy and protocols, key elements of which are shown in Figure 3 (7).

Prior to looking at the different components of the process, the importance of communication to promote awareness of institutional risk management should be emphasised. Equally important is the engagement with stakeholders to ensure that there is accurate and timely exchange of information on risks ('communicate and consult' element in Figure 2).

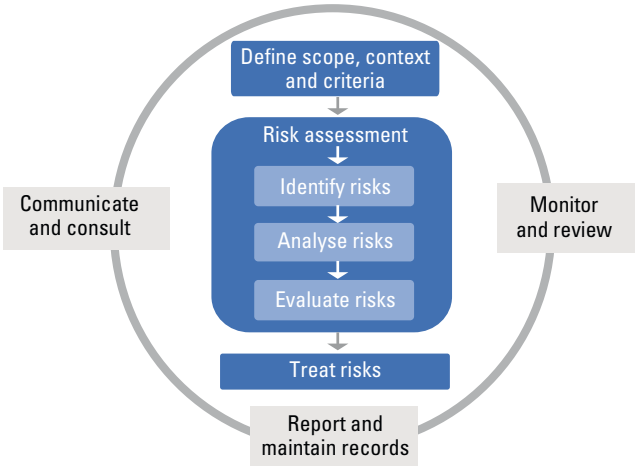

Fig. 2
Risk management process, adapted from ISO 31000:2018, the international standard on risk management (4)

The following sections elaborate further on the components of the risk management process in Figure 2.

Define the scope, context and criteria of risk activities

This component is about understanding the organisation's internal and external environment and setting the scope of the risk management activities. It includes defining criteria in relation to the amount and type of risk the organisation is willing to accept (risk appetite) in pursuit of its strategic objectives and creation of value. It also includes defining terminology and metrics to ensure consistency in the process. Finally, it involves identifying the areas in which management activities can deliver the most value for stakeholders, and demonstrating how the activities will contribute to the achievement of the organisation's strategic objectives.

Risk assessment to identify, analyse and evaluate risks

Risk identification

There are various ways in which risks can be determined. For example, they can be identified by implementing surveys/questionnaires or carrying out analyses of strengths, weaknesses, opportunities and threats. They can also be identified during scenario analysis sessions and at workshops with cross-functional representation. It is important that risk identification does not take place only during planned risk assessment activities but is integrated into team, unit or management discussions within other performance monitoring and management processes. To facilitate discussions, risks may often be grouped into different categories, which will vary depending on the organisation's internal and external environment. For example, risks may be categorised as strategic, financial, operational, legal/regulatory, reputational, or as relating to health and safety.

Risk analysis

Following risk identification, an analysis of causes, effects, likelihood and impact should be carried out, as should an analysis of existing controls and mitigation measures.

Risk evaluation

Risk evaluation is about deciding on further actions needed. Options may vary and should be guided by the risk criteria set earlier in the process. For example, the organisation may decide to accept, reduce or increase current levels of risk according to its risk appetite or even to reconsider objectives set.

Treat risks

The specific actions to achieve the agreed level of risk should consider factors such as feasibility, timeframe and the impact on costs or resources.

Risk framework and architecture	**Risk strategy**	**Risk protocols**
Roles and responsibilities of individuals and committees that support the risk management process	Risk strategy and risk activities scope	Risk guidelines that include rules, procedures, methodologies, tools and techniques to implement the risk strategy
Risk communication and reporting structure	Risk appetite	
	Attitudes and philosophy (defined in the risk management policy for the organisation)	

Fig. 3
Preliminary inputs required when introducing risk management

Monitor and review

Reviewing and monitoring risks, as well as the risk management process and its deliverables, is important to ensure that risks are managed and the process remains dynamic and fit for purpose. Lessons learned should be considered to improve the process itself and to improve decision-making, both in terms of strategic decisions and decisions on risk treatment.

Report and maintain records

Reporting the outcomes and steps followed is important to enhance risk accountability, to provide visibility to different audiences in relation to decision-making, and to give stakeholders the opportunity to offer an independent assessment of the organisation's risk management processes. To facilitate reporting, organisations usually maintain a risk register; an example is provided in Appendix 1. In larger organisations, each division or function within the organisation typically maintains a register of risks relating to its area of operation, the top items of which are shared and reviewed cross-functionally/divisionally by management.

Figure 4 provides an overview of a monitoring and reporting mechanism that can be followed throughout the year to review top (principal) risks and other risks (to be adjusted based on the organisation's risk strategy). These reviews should be integrated into the organisation's performance review cycle rather than held in a standalone mode.

Actions that can be taken to strengthen risk management capacity

The following actions could be undertaken to further strengthen risk management capacity within an organisation.

a) Agree on the scope and objective of risk management – Agree on the scope and objective of risk management for the overall organisation with key stakeholders, and set priorities and a related timeframe.

b) Define the appropriate architecture and assign resources and responsibilities – In parallel to the previous action, map existing or necessary resources across the organisation to create a network of risk experts to establish priorities, develop appropriate framework architecture and agree on an approach.

c) Integrate work on external factors – Integrate work completed on external factors into strategy planning and review how the current strategy of the organisation and its stakeholders addresses risks and opportunities arising from these factors. Update existing (or develop) risk registers to ensure that any changes to objectives are considered and clear ownership is in place.

d) Start integrating elements of risk management into selected organisational processes and governance activities – These may include performance, project or executive management

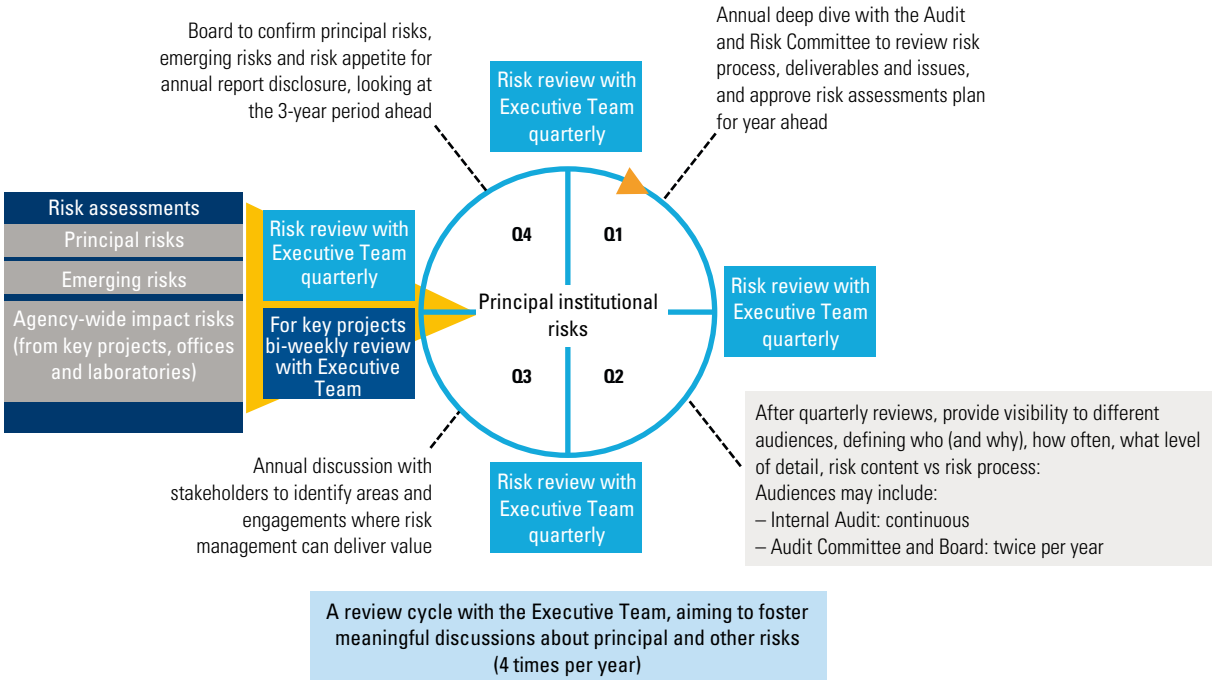

Fig. 4
Risk management cycle integrated into the organisation's performance management cycle

reviews, corporate governance activities, finance activities, funding, information systems, human resources and other functional areas. Ensure that this is done based on perceived benefit and value through consultation and engagement with key stakeholders.

e) Set the foundation for risk management culture – Consider establishing a communication and training plan to ensure that open discussion on risks and mitigations can be initiated and that learning from mistakes is encouraged. Ensure that senior management and its governance bodies set the tone and lead by example.

Organisations often rely on management consulting services initially to help design and introduce a risk management system; management within the organisation subsequently takes ownership of the system and takes responsibility for moving it forward. These services generally promote a specific risk management model that embodies the principles and components described above, but which is adapted to the specific context and needs of the organisation.

Applying risk management to Veterinary Services

It could be argued that this approach to institutional risk management has limited relevance to national Veterinary Services. Veterinary Services are, after all, a public sector agency with a well-defined role and clearly defined technical services to deliver. Their primary management challenges are to provide services as effectively and efficiently as possible to protect and improve health-related productivity within the livestock sector, while remaining prepared to respond quickly and effectively to any disease threat that may emerge. But, if the service is to achieve its mission successfully, it must maintain its preparedness and its ability to adapt to an ever-changing environment and to the ever-changing needs of stakeholders, and this requires continuous reassessment of a range of internal and external factors – some of which are known and many are as yet unknown. The type of risk management framework described in the preceding section is therefore just as relevant to managing Veterinary Services as it is to managing private companies and other organisations.

Table I provides an outline of the types of risk relevant to managers of Veterinary Services, including illustrative examples. The categories cited draw from those that have typically been found to be useful for describing the range of threats to an organisation or business, but also align well with the four Fundamental Components of effective Veterinary Services described in the OIE PVS Tool (3), namely:

a) 'the human, physical and financial resources to effectively plan, coordinate and implement activities within the veterinary domain covering all necessary elements and at all levels, in the national interest'

b) 'the technical authority and capability to address current and new veterinary issues based on scientific principles, including the preparedness, prevention, detection and control of animal diseases, addressing veterinary public health risks including from zoonoses and food safety, and improving animal welfare'

c) 'the sustained interaction with non-government stakeholders in order to harness non-government expertise and support the growth and protection of livestock production and markets in the country based on stakeholders' needs'

d) 'the ability to access markets through harmonising with existing international standards, and by demonstrating overall system integrity and transparency, to inspire confidence in trading partners'.

Using the PVS Fundamental Components as a framework for categorising types of risk can be helpful, as the results of PVS Evaluations provide an external measure that can help Veterinary Services to rank and monitor the corresponding risks, which can be divided into three sets.

The first set relates to the principal resources managed by Veterinary Services to achieve its mission, encompassing its human, financial and physical assets. These revolve around the challenge of securing and protecting an adequate quantity and quality of the resources needed to fulfil the agency's mission. While many aspects of the agency's access to these resources are defined by the bureaucratic structures and political environment within which the agency operates, there are a number of ways the management of Veterinary Services can proactively influence its access or identify other strategies to supplement their resources.

The second set relates to operational, legal and regulatory issues that potentially affect the agency's ability to implement its current activities effectively. If these risks are not effectively managed, trading partners may lose confidence and close their markets to the livestock sector, the very sector the agency is meant to protect.

The third set of risks goes beyond the immediate factors that can affect current operations and takes a longer-term perspective on the continued viability of Veterinary Services, giving attention to reputation and anticipating the future needs of its stakeholders and the role it could play. The approach outlined here for institutional risk assessment provides a framework to help Veterinary Services imagine

Table I
Examples of institutional risks relevant to Veterinary Services

Area	Generic examples of risks relevant to Veterinary Services
Financial	**Operations**
	Disruption in short-term funding affects ability to perform functions
	Unstable or declining public funding in the longer term reduces ability to perform functions and deliver on mandate
	Inability to attract donor project funding to address priority challenges
	Emergency funding
	Insufficient emergency funding available when needed, inhibiting timely response and creating perception of poor performance
	Unable to attract donor funding to address emergencies
People	**Staff**
	Unable to attract and retain staff with the necessary technical skills, limiting ability to perform functions
	Inadequate succession planning, leading to loss of knowledge and key skills
	Inadequate attention to medium and longer-term training and capacity development, leading to limited pool of qualified professionals
	Inadequate investment in continuous professional training means that staff are not up to date with the latest knowledge and are out of touch with current best practices
	Management
	Instability in management team due to changing political environment
	Non-optimal management team quality due to emphasis on political rather than technical and professional selection criteria
	Inadequate investment in continuous professional management training leads to the management team not being up to date with the latest knowledge and being out of touch with current best practices
	Health and safety
	Inappropriate conditions at workplace or lack of appropriate equipment and training for normal or emergency operations impact staff safety and security
Physical assets	**Offices, laboratory, vehicles**
	Insufficient investment and maintenance lead to deterioration and obsolescence of infrastructural capacity, reducing ability to perform functions and respond to emergencies
	Lack of investment to upgrade in new technology limits ability to respond to evolving veterinary threats (e.g. emerging disease) and responsibilities (e.g. food safety)
Operational	**Routine**
	Weak planning and management culture leads to poor performance in delivering services and impact indicators
	Inadequate disease surveillance, control and response leads to disease outbreaks that affect national production and markets, and/or reduces access to external markets
	Weak cyber-security contributes to business disruptions and increases the risk of sensitive data being compromised or lost
	Emergency response
	Lack of planning to ensure business continuity under a range of emergency scenarios limits ability to provide services and respond when critically needed
	Weak preparedness planning, including ensuring appropriate capacity and timely access to emergency resources, limits ability and timeliness in responding to novel disease outbreaks that affect national production and markets, and/or reduces access to external markets
	Animal or zoonotic disease threat emerges that cannot be controlled using conventional technologies and approaches
Effectiveness	**Technical authority**
	Weak technical capacity and inappropriate or ineffective implementation reduces confidence of international trading partners and organisations and reduces compliance among national stakeholders
Legal	An inadequate regulatory framework that fails to anticipate the veterinary interventions that will be needed to control disease outbreaks contributes to confusion and delays, and possibly to legal challenges by stakeholders if Veterinary Services are perceived to be overstepping their mandate Insufficient consultation with other line ministries and agencies leads to misaligned or contradictory policies, creating need for litigation
Regulatory	**Access to markets**
	Inability to establish an appropriate and effective regulatory framework that complies with trade partners' requirements leads to restricted access to external markets for national livestock sector
Strategic	**Maintaining relevance**
	Veterinary Services strategy or structure not fit for purpose Failure to deliver expected value through key strategic transformation initiative Failure to monitor and understand evolving trends affecting the livestock sector means that Veterinary Services fail to make preparations and do not make timely adjustments; they are reactive rather than pro-active, and they have to make rushed, last-minute decisions
	Reputational
	A public scandal about mismanagement or fraud concerning financial or human resources or professional ethics weakens confidence of stakeholders and funders in supporting Veterinary Services Weak compliance with regulatory and disease control measures leads to lower confidence of trading partners in the capacity of Veterinary Services to ensure adequate biosecurity Inappropriate handling of and communication about disease issues or outbreaks leads to weak consumer confidence and scares that impact the livestock sector

possible future scenarios and anticipate their implications. These could include scenarios that are likely to cause little or no impact, e.g. a future in which nothing is expected to change, and scenarios that are likely to have a huge impact, e.g. a dramatic drop in meat consumption (see Grace *et al.* [1]). Having identified any implications, management can consider whether action is merited to adapt accordingly, taking into consideration the range of other risks faced by the agency.

An illustrative example of applying the approach is summarised in Appendix 1, which shows an entry in the risk register of a Veterinary Service facing the challenge of recruiting and retaining the critical staff it needs to effectively carry out its mission. The management team has assessed the failure to attract and retain staff as an important risk, analysed its causes and its impact, ranked it, and identified what is currently being done to address it, what more could be done, and who is responsible for managing the risk.

Final considerations

In many organisations, institutional risk assessment is an internal exercise undertaken by the management team, the results of which are often reviewed within the organisation's governance body. As government departments, Veterinary Services are usually subject to direct bureaucratic oversight and do not have a formal governance structure. Consulting with stakeholders in conducting or reviewing the management team's risk assessment could offer an opportunity to improve communication and transparency for the agency's clients. It could also align well with the continued development of the OIE PVS processes.

There is no simple recipe for adapting the institutional risk framework to the specific context of an organisation. The practice is usually to engage expert consultant services to guide the design of the process and coach the management team through an initial cycle of the process while building capacity internally. The OIE could play a critical role in developing a harmonised approach and support interested Members to adopt and incorporate institutional risk assessment, drawing from and documenting the experiences of national services already applying it. Through this effort, the OIE and its Members would strengthen management capacity of Veterinary Services so that they can improve their current performance and strengthen their ability to evolve and adapt to a changing world.

La gestion du risque institutionnel au sein des Services vétérinaires

G. Solomos & T.F. Randolph

Résumé
L'évaluation et la gestion du risque institutionnel ne sont pas d'un usage systématique dans les Services vétérinaires nationaux, bien qu'elles soient qualifiées de meilleures pratiques par la science de la gestion. Les chefs des Services vétérinaires et leurs équipes sont rarement exposés à ce type d'évaluation du risque institutionnel et n'ont généralement pas été formés pour la mettre eux-mêmes en pratique. Les auteurs décrivent les composantes essentielles de l'évaluation du risque institutionnel ainsi que les applications qui peuvent en être faites dans le contexte des Services vétérinaires.

Mots-clés
Gestion des risques – Risque institutionnel – Services vétérinaires.

Gestión del riesgo institucional para Servicios Veterinarios

G. Solomos & T.F. Randolph

Resumen
En la actualidad no todos los Servicios Veterinarios oficiales aplican sistemáticamente procesos de determinación y gestión del riesgo institucional, pese a que estos gozan de consideración de práctica óptima desde el ámbito de las ciencias de la gestión y la administración. Los Jefes de los Servicios Veterinarios y sus equipos suelen estar poco expuestos a este tipo de procesos o carecer de formación al respecto. Los autores describen los elementos básicos de la determinación del riesgo institucional y la forma en que esta puede ser aplicada en el contexto de los Servicios Veterinarios.

Palabras clave
Gestión de riesgos – Riesgo institucional – Servicios Veterinarios.

References

1. Grace D., Caminiti A., Torres G., Messori S., Bett B.K., Lee H.S., Roesel K. & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item. *In* Proc. 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France. doi:10.20506/TT.2984.

2. MacDiarmid S.C. & Pharo H.J. (2003). – Risk analysis: assessment, management and communication. *Rev. Sci. Tech. Off. Int. Epiz.*, **22** (2), 397–408. doi:10.20506/rst.22.2.1408.

3. World Organisation for Animal Health (OIE) (2019). – OIE Tool for the Evaluation of Performance of Veterinary Services, 7th Ed. OIE, Paris, France. 68 pp. Available at: www.oie.int/fileadmin/Home/eng/Support_to_OIE_Members/docs/pdf/2019_PVS_Tool_FINAL.pdf (accessed on 10 August 2020).

4. International Organization for Standardization (ISO) (2018). – ISO 31000 – Risk management. ISO, Geneva, Switzerland. Available at: www.iso.org/iso-31000-risk-management.html (accessed on 10 August 2020).

5. Dionne, G. (2013). – Risk management: history, definition and critique. *Risk Manag. Insur., Rev.*, **16** (2), 147–166. doi:10.1111/rmir.12016.

6. Committee of Sponsoring Organizations of the Treadway Commission (COSO) (2017). – Enterprise risk management: integrating with strategy and performance. COSO, New York, United States of America. Available at www.coso.org/Pages/erm.aspx (accessed on 10 August 2020).

7. Association of Insurance and Risk Managers (AIRMIC), Alarm & Institute of Risk Management (IRM) (2010). – A structured approach to Enterprise Risk Management (ERM) and the requirements of ISO 31000. AIRMIC, London, UK; Alarm, Weston, UK; IRM, London, UK, 20 pp. Available at: www.ferma.eu/app/uploads/2019/02/a-structured-approach-to-erm.pdf (accessed on 10 Aug 2020).

Appendix 1
An example of a risk register

In this example, the register is being used to record and track the risk of 'failure to attract and retain talent'

No.	12	13
Area / objectives	People	People
Risk / opportunity	Failure to attract talent (example)	Failure to retain talent (example)
Potential causes	Organisation's brand not well known	Unclear priorities
	Unattractive job descriptions	Ineffective talent development and training plan
	Unattractive employee value propositions, including compensation and benefits policies	Poor performance-management system and incentives
		Stress related to high workload
		Poorly managed/negative perception of internal HR processes (transparency, consistency, fairness)
Effect / description	Unable to deliver on strategy	Unable to deliver on strategy
	Overstretched resources leading to staff burn-out	Additional pressure on already overstretched resources
		High turnover and related costs
Actions already undertaken	Organisation's mission made compelling	Organisation's mission communicated
	Compensation package made attractive	Process for objective setting and review revised
	Staff satisfaction benchmarked (exit interviews provide additional input)	Flexible working arrangements and options maintained
		Employee pulse survey recently completed to inform further steps
Further actions to consider or plan	Establish KPIs for recruitment process, e.g. offer rejection rate and number and quality of applicants per vacancy	Analyse turnover rate
		Make use of flexible, short-term contracts or consultancies to have support in peak periods
	Conduct a compensation and benefits review for a more rigorous assessment of the package	Monitor trends in absenteeism
		Improve the performance-management system and automate the process further
		Review employee pulse survey results
Current risk level (low 1–9 high)	9	4
Target risk level (low 1–9 high)	6	4
Ownership	HR Director	HR Director
Status / deadline	31/11/2020	On track

HR: Human resources
KPI: Key performance indicator

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 555-566

Continuing professional development for veterinarians in a changing world

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Summary

The veterinary profession has time and again successfully adapted to new challenges and developments, with considerable evolution of the skills needed. Different contexts, production systems and societal requirements continue to shape the profession, resulting in an increasing demand for specialisation, interdisciplinary collaboration along value chains, and preparedness for the omnipresent risk of emerging diseases.

To keep up with changes, new insights, advances in research and novel ways to address challenges, continuing professional development (CPD) and the adaptation and updating of the veterinary curriculum have been essential to maintain and enhance the quality and performance of Veterinary Services.

This paper reviews actors involved in the provision of Veterinary Services and discusses how vital CPD is in addressing current and future challenges, by focusing on veterinarians and allied veterinary professionals. The authors examine how providers of CPD contribute to the system and how the internal and external factors of a cohort or individual affect the quality and impact of capacity development. The paper further examines the landscape of veterinary CPD in terms of organisational structures, pedagogical approaches, the transition from input- to outcome-based learning, modern delivery tools, and the demands on the different actors involved in the delivery of animal health services.

The authors conclude that CPD is essential if the quality of Veterinary Services is to keep pace with the ever-increasing and evolving demands of the 21st century. A CPD programme should therefore be constructed in a way that is tailored to the needs of veterinary professionals and to the requirements of their workplace, whether they work with animal keepers, livestock value chains, national governments or international regulatory bodies. An optimised and successful veterinary sector requires an evidence-based CPD programme that keeps those professionals who are involved in the delivery of animal health services both competent and relevant in a changing world.

Keywords

Allied veterinary professionals – Continuing professional development – Curriculum – Education – Professional development – Training – Veterinary continuing professional development – Veterinary curriculum – Veterinary para professionals.

Introduction

History shows that the veterinary profession has evolved over time and successfully adapted to new challenges and developments. Transformations in production systems and related value chains, increased regulation linked to the growth in cross-border trade of livestock and their products, evolving societal and ethical values, new diseases and globalisation have all led to the need for specialisation, collaboration across different disciplines and professionalisation of Veterinary Services. Adjustments to veterinary curricula have been necessary to address the need for new knowledge and skills, but often these take time to materialise. Continuing professional development

https://doi.org/10.20506/rst.40.2.3245

(CPD), 'the systematic maintenance, improvement and broadening of knowledge and skills, and the development of personal qualities necessary for execution of professional and technical duties throughout the individual's working life' (1), for veterinarians and allied veterinary professionals (also referred to as para professionals), provides a more rapid route towards updating the knowledge and skills required to address demands for new competencies.

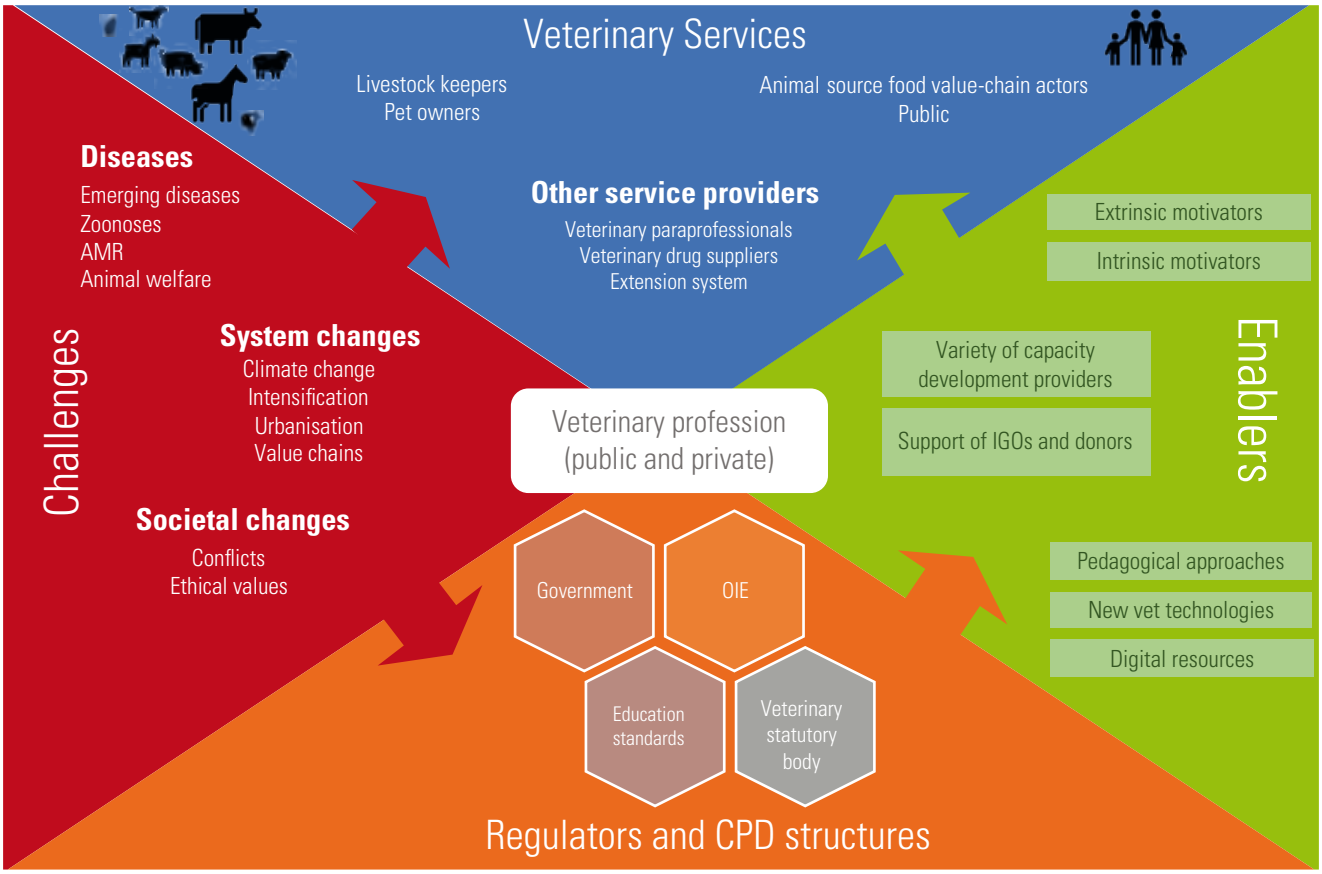
As outlined in Figure 1, the veterinary professional is positioned between the demand from customers for quality veterinary inputs and services, the need to address current and future challenges, regulations that oversee the quality of Veterinary Services, and education providers. Veterinarians and veterinary para professionals are also influenced by intrinsic and extrinsic factors that affect career-long learning. Building on evidence and examples from countries in the Organisation for Economic Co-operation and Development (OECD), as well as low- and middle-income countries (LMICs), the authors discuss possible CPD structures and approaches to address the links presented in Figure 1 and to move from input-based to outcome-based learning.

Actors and skills required for the delivery of Veterinary Services

In accordance with the standards of the World Organisation for Animal Health (OIE), areas considered within the veterinary domain include clinical services; herd-health management; food safety of animal-derived foods and meat inspection; the prevention, control and eradication of infectious diseases; and animal welfare.

Identification, traceability, and the implementation and oversight of animal-health-related regulations linked to livestock production and trade in livestock and livestock products comprise another essential area of the veterinary domain.

Whilst veterinarians from countries in the OECD are largely engaged in the private sector for the purpose of delivering private-good clinical services, veterinarians in LMICs are mostly engaged in the public sector, administering public-



AMR: antimicrobial resistance
IGOs: international government organisations

Fig. 1
Context in which veterinary continuing professional development (CPD) takes place

good services that address a broader mix of areas in the veterinary domain. This diversity is not reflected in the current pool of CPD learning resources. Those resources available are market driven and significantly skewed in favour of the clinical skills required by OECD veterinarians. While the veterinarian plays a central role in providing Veterinary Services, he or she is not the only player and interacts with other service providers in formal or informal ways, with responsibilities that vary from system to system.

This reality is of particular importance in LMICs, where veterinary professionals have team leadership responsibilities that require training skills, so they can cascade their technical knowledge and skills to other livestock value-chain actors. This is essential if an integrated and quality-controlled system of delivering Veterinary Services is to be achieved. Examining livestock-production value chains helps to illustrate the variety of actors involved. These actors play different roles and require specific skills to support the system. The actors and their roles at various nodes in the value chain can be illustrated by the examples of poultry production in Bangladesh and extensive livestock production in Kenya (Table I).

The poultry value chain in Bangladesh is characterised by different levels of complexity, which mainly depend on how many brokers, 'middle-men' and traders are involved (2). Key veterinary challenges in these systems are infectious diseases, biosecurity, and scheduling of vaccinations. Further along the value chain, food safety risks are the main concern.

Veterinary Services are also essential for the extensive systems of livestock production practised in the arid and semi-arid lands of Africa. The multiplicity of environmental constraints, coupled with zoonotic and endemic livestock diseases, causes high levels of morbidity and mortality, particularly in young stock, inhibiting growth rates, creating trade barriers and posing risks to human health. These systems require a combination of sanitary and production-orientated skills, with a focus on the importance of adopting a multidisciplinary interprofessional approach to enhance market access.

Value chains evolve over time and are a reflection of a changing social and economic environment. These changes also require adaptations of veterinary inputs and services along the value chain, with responsibilities shifting between actors or requiring new skills. It is thus important to monitor these changes constantly for the veterinary system of a country to respond and adjust the services and training provided.

Current and future challenges facing veterinary professionals

In the discussion of current and future challenges for the veterinary profession, issues beyond the direct actions of veterinarians or allied veterinary professionals are becoming increasingly important. Through their work, veterinary professionals play an important role in economic development, by contributing to food security, helping livestock keepers to generate their income, and protecting public health through zoonoses control. Besides adapting to changing livestock production systems, which will bring changes to animal health and welfare priorities, veterinary professionals also need to take technological advances on board. All these transitions make a clear case for the importance of veterinary and allied veterinary professionals undertaking CPD.

A Technical Item presented at the 87th OIE General Session in 2019 investigated how external factors, such as climate change, affect Veterinary Services and provided a good indication of future challenges for the profession. The study combined expert opinion and the views of OIE Members, and there was general agreement that the main challenges faced by the veterinary profession are livestock pandemics, antimicrobial resistance, and zoonoses. Also considered important were issues related to intensifying livestock production, food-borne diseases and animal welfare (3). Other areas that need attention are wildlife diseases and aquatic medicine, given the growth of the aquatic sector as a food provider. As seen in OECD countries, with economic development also comes a shift towards more keeping of companion animals, which in turn requires new veterinary skills in emerging economies.

To address these challenges, an increasing level of specialisation, interdisciplinary collaborations along value chains, and climate-smart practices in support of a One Health approach are needed. Continuing professional development and the adaptation and updating of veterinary curricula are key interventions needed to keep pace with these changes, as well as new insights, advances in research and novel ways to address challenges.

Structures of continuing professional development programmes

As outlined above, different contexts, production systems and resources demand different skills of veterinary professionals. The content and organisational framework of

Table I

Simplified livestock-value chains related to animal health, listing the professionals involved and veterinary inputs and services needed, from the point of production to consumption

The two examples given are intensive poultry production in Bangladesh and extensive beef production in Kenya

Value chain	Actors, challenges & skills	Inputs for production	Production/farm	Trading/markets	Processing	Retail
Intensive poultry production, Bangladesh	Actors involved in Veterinary Services provision	Feed providers Veterinary drug sellers Health advisors Researchers	Farmers Private veterinarians Official veterinarians Health advisors Researchers	'Middle-men' and traders at different levels Truck drivers	Slaughterhouse workers Veterinary inspectors	Sales personnel Food safety inspectors
	Veterinary challenges	Veterinary drugs Vaccines Medical feed Knowledge	Neonatal mortality Nutrition Water Husbandry Welfare Epidemics Endemics Zoonoses Metabolic diseases Stock losses Infertility Breeding Biosecurity	Identification and traceability Movement controls Welfare standards Nutrition Water Transport Checkpoints Biosecurity Markets Quarantine Export regulations	Welfare standards **Pre-mortem** Humane slaughter Bleeding carcasses Traceability **Post-mortem** Sanitary standards Carcass quality Primal cuts Labelling Cold storage	Sanitary standards Butchery skills Packaging Labelling Marketing/promotion Cold storage
	Veterinary skills and roles	Oversight of medical feed Oversight of drug quality and drug dispensing Vaccine provision Coordination of surveillance and control programmes	Clinical and herd-health services Surveillance and control programmes Outbreak investigation Diagnostics Animal welfare	Health checks Certification Market inspection Animal welfare	Animal welfare Meat inspection Food safety diagnostics	Management of food safety risks
Extensive beef production, Kenya	Actors involved in Veterinary Services provision	Veterinary drug sellers Community animal health workers Private and public veterinarians Researchers	Disease reporters Private and public veterinarians Researchers	Traders Holding ground and/or quarantine personnel Veterinary inspectors	Slaughterhouse workers Veterinary inspectors	Butchers Sales personnel Food safety inspectors
	Veterinary challenges	Veterinary drugs Vaccines Medical feed Knowledge	Mortality of day-old chicks Nutrition and water Husbandry Bird density Welfare Epidemics Endemics Zoonoses Metabolic diseases Stock losses Infertility Breeding	Mixing multiple species Transport Bird density/heat stress Feed/water Biosecurity Export regulations	Humane slaughter Slaughtering skills Infrastructure Halal slaughter Cold chain Contamination Sanitary standards Carcass quality Post-mortem aging	Hygiene Cold chain Post-mortem aging
	Veterinary skills and roles	Disease diagnosis Treatment Prophylaxis production advice	Clinical and herd-health services Disease prevention Managing zoonotic risks Advanced production practice	Market information Disease recognition Health examination Sanitary certification Animal welfare	Pre- and post-mortem inspection skills Carcass grading	Butchery skills Sanitary/hygiene standards

the CPD undertaken in a given country must reflect this diversity, meaning that there is no 'one size fits all' solution. The obligation of a veterinary professional to undertake CPD, as seen in an increasing number of countries, has developed over time. Initially, it was often simply noted within professional codes of conduct as an expected activity. Nowadays, however, it has evolved into more formalised and mandatory systems in which the quantity and quality of CPD that should be undertaken is a stated requirement, especially for veterinarians although less so for allied veterinary professionals. Monitoring these programmes and assessment mechanisms is, in most cases, administered by a Veterinary Board or Council. Improvements have been shown in some CPD programmes – for example, in a large-scale comparative study in the United Kingdom (UK), in which graduates in the 2000s considered mandatory CPD more effective than did graduates of the 1960s (4). Nonetheless, at a global scale, challenges remain.

An independent review of OIE Performance of Veterinary Services (PVS) assessments found that continuing education training and staff development programmes for all technical staff, including veterinarians, allied veterinary professionals and community-based animal health workers, were almost universally poor, with 84% of the countries assessed scoring levels of 1 or 2 on a scale of 1 to 5 for this critical competency (CC) (5). The review noted that CPD was mandatory in only a few countries and that most of the continuing education provided was through *ad hoc* training from international agencies, non-governmental organisations and donors, who tended to focus on their priorities, not necessarily those of the country or livestock producers. Follow-on PVS assessments showed a marginal improvement in continuing education CC scores, but still fell short of level 4, the ideal level of achievement.

The OIE PVS assessments conducted globally show that different types of CPD programmes have been set up in different countries, with varying degrees of success. A considerable amount of evidence from the health professional sector suggests that commonly used 'input-based' CPD activities are ineffective in improving practitioner performance and health service outcomes (6, 7, 8). Traditional input-based teaching for CPD includes lectures that are episodic and non-reinforcing, with minimal interaction between learners and providers, and with too much emphasis on the acquisition of CPD point targets or certificates. Recent developments in CPD emphasise an outcome-based model of learning and consider novel or improved competencies as favourable outcomes (9). This is increasingly being recognised in newly developed CPD programmes, which use assessments and longer-term study projects to ensure quality, and employ traditional credit points to assess whether sufficient training has been completed. Table II provides some examples of old and newly developed CPD programmes.

Modern CPD programmes, including models from the European Board of Veterinary Specialisation and the UK Certificate in Advanced Veterinary Practice (CertAVP), can serve as examples to produce the veterinary specialists needed by economically important livestock value chains outside OECD countries. Twinning programmes offer an opportunity to share such experiences with LMICs. The OIE Veterinary Education Twinning Programme, established in 2013 (10) within the wider OIE initiative to improve the capacity of Veterinary Services in LMICs, has led to 12 twinning projects between a parent establishment (accredited and established) and a candidate establishment (in a developing country, aspiring to international accreditation), with evident success (11).

A weakness in some of the CPD systems adopted is that the learning programme is not focused on an individual practitioner's personal development needs or desired career path, but is simply a points-gathering exercise from attendance at input-based 'CPD events', such as conferences, which cost money to attend. Likewise, while there are often penalties in place, such as deregistration for non-compliance, there are rarely positive incentives, such as salary increments or preferential selection for further training or promotion based on CPD performance. In addition, in some instances CPD is not a requirement for public-sector veterinary personnel, with consequent impacts on their competencies and readiness to consider and adopt new ideas, whereas in other countries, such as Bangladesh, CPD is only mandatory for government veterinarians.

What counts as CPD varies from country to country, trending towards a more expansive attitude, as evidenced by the latest Royal College of Veterinary Surgeons (RCVS) guidance, which states, 'Anything that is relevant to you, as a veterinary professional, can be counted as CPD so it does not have to be clinically related or formal learning'. Equally variable is the method of undertaking CPD, ranging from face-to-face tuition to remote online e-learning, with the latter very much in the ascendancy for relevance, affordability and convenience. While Internet accessibility and speeds can still be challenging in both OECD Members and LMICs, the majority of users in both types of economy enjoy a rapidly improving online experience. This is opening the door to the increased use of digital tools and platforms for information searches, knowledge transfer, the exchange of ideas and communication in general.

Good CPD practice is embodied in formal CPD frameworks that offer CPD credit hours towards postgraduate certificates and/or diplomas, setting the individual learner on a pathway towards recognition and qualification as a specialist in a chosen area of the veterinary domain. Several countries offer pathways towards specialisation in selected subjects open to veterinarians and these tend to be linked to

Table II
Characteristics of examples of veterinary continuing professional development programmes

Country	Name and role of the regulatory body	Who provides CPD	CPD structure (CPs = credit points)	Targeted service providers
UK	Royal College of Veterinary Surgeons www.rcvs.org.uk/lifelong-learning/continuing-professional-development-cpd/	Universities, digital recording platform (1CPD), certified (AVP) assessment providers	VS – 35 hrs per year VN – 15 hrs per year	Veterinary surgeons (VS) Veterinary nurses (VNs)
South Africa	South African Veterinary Council savc.org.za Accreditation and monitoring of CPD activities	Universities, veterinary professional associations, regulatory bodies and accredited service providers	60 CPs per 3-year cycle, of which 20 points must be structured activities	Veterinarians Veterinary specialists Compulsory veterinary community service animal health technicians Laboratory animal technologists Veterinary nurses Veterinary technologists Veterinary physiotherapists
Bangladesh	Bangladesh Veterinary Council bvc.gov.bd	Bangladesh College of Veterinary Surgeons bcvsbd.org/	Board examinations Public veterinarians: 60 hrs per year	Public-sector veterinarians Board examinations to become a Member and Fellow of the College of Veterinary Surgeons
USA	Association of American Veterinary Medical Colleges www.aavmc.org Continuing education credits as mandated by the state	Universities, veterinary professional associations, regulatory bodies and accredited service providers	Examples: Indiana – 40 hours of CPs per 2 years Idaho – 20 hours of CPs per two years	Veterinarians
Australia	Australian Veterinary Association www.ava.com.au CPD accreditation and monitoring done by individual state veterinary boards	Universities, veterinary professional associations, accredited service providers and Accreditation Program of Australian Veterinarians (APAV)	Example: Queensland – 60 CPs per 3 years At least 15 CPs must be structured activity	Veterinarians
Kenya	Kenya Veterinary Board kenyavetboard.or.ke/cpd/ CPD accreditation and monitoring of CPD activities	Universities, veterinary professional associations, regulatory bodies and accredited service providers	VS – 20 CPs per year VP – minimum of 14 CPs per year Maximum number of CPD hours that can be accredited for 1 day is 8 hours	Veterinary surgeons (VS) Veterinary para professionals (VPs) Formal study for additional qualifications: – short training and organisational activities – professional involvement in professional associations, committees, etc. – publication of scholarly articles in journals and – book chapters – mentorship of students and interns – community service, e.g. extension activities, among others
Namibia	National Veterinary Council	CPD in Namibia mainly organised by the Veterinary Association	VS – 60 CPs per 3 years VP – 30 CPs per 3 years	Structured activities: courses, conferences, preparing and monitoring exams, review articles, giving lectures, developing curricula, promoting theses, online activities with written assessment
Tanzania	Veterinary Council of Tanzania	CPD courses organised by the Tanzania Veterinary Association (TVA) and in association with Zoetis and WSAVA	VS – 30 CPs per 3 years VP – 15 CPs per 3 years	CPD categories include: formal studies, short training and organisational activities, professional involvement, authorship, mentoring, community involvement
Mexico	National Council for Veterinary Medicine Education (CONEVET) No details regarding CPD accreditation and monitoring of CPD activities	CONEVET accredits colleges and certifies professionals (there are 40 veterinary schools)		

AVP: advanced veterinary practice
CE: continuing education
CONEVET: National Council for Veterinary Medicine Education
CPs: credit points
CPD: continuing professional development
UK: United Kingdom
USA: United States of America
VN: veterinary nurse
VP: veterinary para professional
VS: veterinary surgeon
WSAVA: World Small Animal Veterinary Association

professional postgraduate programmes offered by veterinary schools, such as the programmes offered in Nigeria leading to the award of a fellowship of the College of Veterinary Surgeons (www.lasu-info.com/2019/06/cvsn-postgraduate-admission-form.html). Other programmes fulfil the given criteria for recognition as a specialist, such as those listed by the South African Veterinary Council (www.savc.org.za/). Similarly, in Asia, the newly established Bangladesh College of Veterinary Surgeons offers fellowship status through a board examination process (bcvsbd.org).

In addition to the introduction of systems to monitor and assess compliance with CPD requirements, some countries appraise the quality of a given CPD programme, delivered by a CPD provider, to certify that it is current and meets fundamental quality and relevance standards (Table II). This can be the function of a given country's Veterinary Board or Council, as is the case in Kenya, where the Kenya Veterinary Board requires that every continuous professional development provider must be registered with the Board and apply for approval and determination of the worth (in credit points) of the intended activity (kenyavetboard.or.ke/continuous-professional-development-cpd/). Elsewhere, this process is coordinated through an independent regional authority, as is the case with Veterinary Continuous Education in Europe (VETCEE), which runs an accreditation scheme for structured CPD for veterinarians (www.fve.org/vetcee/).

Enablers of continuing professional development

The CPD programmes that focus on the individual learner need to take other factors into consideration that are essential for making a change. Veterinary Services are social acts that take place in highly complex systems, involving different actors, and thus require a team approach to training (12).

When considering CPD for different actors in the value chain, different skills and competencies must be identified. The underlying pedagogical approaches should also reflect these differences. Although all the actors in the value chain can be considered adult learners, the same andragogical (i.e. adult learning) assumptions and principles (13, 14) cannot be applied to all of these students, given the likely differences in their levels of academic development and working perspectives. Some veterinary professionals in the value chain may have an interest in their own development and an ability for self-directed learning (15). They may also be more experienced in learning and assessment. The same cannot be assumed for other actors in the value chain, for example, farmers or community animal health workers. They may have a wealth of 'hands-on' experience and are looking for CPD training appropriate to help solve immediate and practical problems. All actors, however, have the common need to balance the demands of work with CPD. They require bespoke training that is directly related to their individual and employer needs. Designing and delivering effective CPD requires an in-depth understanding of the problems *in situ* and the social and economic barriers facing potential trainees (16, 17). Arguably the most effective form of CPD is through a system of 'learning by doing', in which applied study is undertaken to enhance knowledge and skills in the work being performed or the area of intended specialisation. Ideally, this form of learning should be mentored by an appropriate expert and work assignments assessed and formally reviewed. There is a 'win-win' opportunity for such experts, usually employed by academic and research institutions, to become actively engaged in updating their own knowledge base by mentoring practitioners towards acquiring expertise in their chosen field of study.

Another model for the delivery of CPD to other actors involved in providing Veterinary Services can be built around a system of recognition and support for veterinarians who cascade new skills and knowledge to allied veterinary professionals, who in turn cascade them to community-based personnel. This approach has both practical and cost-efficient benefits, and merits being widely adopted as the CPD method of choice for livestock value chains and extensive livestock production systems. Inherent in this approach is the need for 'training of trainer' skills and an understanding of the pedagogical approaches appropriate for and sensitive to language barriers and illiteracy, adult learning and the environment in which these 'training of trainer' skills are best imparted. This approach can, for example, be integrated into CPD programmes for veterinarians, and practised across various systems of delivery, including face-to-face teaching, online teaching and workplace environments. Peer guidance for 'on-the-job training' and 'learning by doing' has the added value of strengthening interprofessional working relationships, enhancing complementarity, and reducing conflict over roles and responsibilities.

It is well established that reflection is an important component in learning for personal and professional development (18, 19, 20). In addition, it is sometimes necessary to 'unlearn' some behaviours and beliefs in order to develop and improve (21). Reflections by the student on their own assumptions and practice are therefore essential in CPD. Developing reflective practitioners is the central philosophy of the new approach proposed for CPD by the RCVS in the UK. This new programme, which builds on the four-stage model of self-assessment, career exploration, decision-making and implementation planning, is used in training medical graduates (22). Under this framework, the way in which CPD compliance for veterinarians

and veterinary nurses is assessed has changed, with the introduction of a new outcome-based learning model. This outcome-based approach comprises four elements – 'plan, do, record and reflect' – with a focus on the quality, impact and relevance of the CPD being undertaken (23). Setting out a CPD plan and providing a written or oral reflection on the learning impact once it has been completed are key innovations introduced by the new assessment model. The reflective element on the learning impact seeks information on:

– how well the CPD related to the learning needs and CPD plan

– what key things were learned

– what impact the CPD has had, in terms of professional development or work performed.

Evidence from other health professionals also provides support for this approach (24).

Novel CPD structures also allow different modes of delivery, such as face-to-face workshops, online courses (25), Webinars combined with discussions, recorded lectures, podcasts, audio-based radio programmes, and blended learning approaches based on face-to-face workshops and hands-on training. Mobile phones or Web-based platforms offer new opportunities to avoid heavy bureaucracy in monitoring the progress of registered veterinarians in their CPD. Such an example is the '1CPD' recording platform in the UK (www.rcvs.org.uk/lifelong-learning/continuing-professional-development-cpd/access-1cpd/).

Successful models using participatory approaches have also been described from the health sector (16, 26). Continuing professional development for the veterinary sector is designed and delivered by private corporations, universities, international organisations and relevant government departments (see Table II for examples). The trainers who develop CPD for field veterinarians are often university-based educators and researchers, and they sometimes lack the same in-depth understanding of *in situ* issues. These trainers are, however, well placed to develop the confidence and skills in field veterinarians to construct their own knowledge, which then influences their practice (27).

A cost-efficient method for face-to-face workshops was found in Bangladesh, in the form of a conference, which brought together hundreds of veterinarians with different job descriptions (28). The conference consisted of plenary sessions and specialised lectures on relevant topics for the evolving veterinary sector in the country. Although interactive, face-to-face workshops, based on hands-on practice, are considered more effective in CPD delivery, distance learning has been evaluated as a satisfactory method of learning for health professions (29), offering the opportunity to access training materials from different countries and allowing more flexibility. The benefits of veterinary CPD distance learning have been recognised at both the personal and societal level (30). There is a wealth of information available to support self-study, accessed by online search engines. These channels depend on the speed, distribution and affordability of Internet services available, which can be variable and challenging in both OECD countries and LMICs (though, as noted above, less and less so as the technology driving these services continues to rapidly improve). The Commonwealth Veterinary Association provides a comprehensive list of online self-learning sites (www.commonwealthvetassoc.com/links/). Other CPD opportunities are provided by more than 60 OIE Collaborating Centres, which offer scientific expertise and training opportunities, either within countries or globally, on a variety of topics relevant to the veterinary sector (www.oie.int/en/what-we-offer/expertise-network/collaborating-centres/).

When planning and running CPD programmes, it is important to understand the motivation of trainees to participate in the programme. These factors can be classified as extrinsic and intrinsic motivators (4, 31). Intrinsic motivators relate to self-motivation for professional development and wanting to improve one's skills and knowledge. Programmes that allow individual preferences to be addressed have a positive impact on the trainee's motivation. Recent advances in veterinary curricula focus on fostering skills related to lifelong learning, with the aim of strengthening the individual's motivation to seek CPD, and not having to rely on external motivating factors.

External motivators include penalties or deregistration if CPD targets are not met. Positive external factors could include the prospect of promotion, increased respect and recognition from clients, or receiving payments for participating in and concluding training programmes. Specialisation diplomas and certification are routes by which veterinary professionals can focus their CPD towards gaining specialist status and furthering their careers.

Perceived barriers to participating in CPD include the timing and relevance of events, travelling distance, money, workload, stage of career, family demands, lack of information about available courses, and poor previous experiences (32, 33, 34).

It is also important to note the efforts of the OIE in supporting CPD for veterinarians and veterinary para professionals, by providing guidelines and recommending competencies to prioritise. This has also helped to focus investment from funders to strengthen such systems in LMICs.

Conclusions

An optimised and successful veterinary sector requires an evidence-based programme of CPD that fulfils the needs of all the actors involved, and society at large. The CPD being undertaken should update, strengthen and be highly relevant to the knowledge and skills required by veterinary professionals and para professionals engaged in the delivery of private- and/or public-good services. Market forces should drive the motivation to use CPD to improve the supply of services to the private sector while incentives, by way of promotion, salary increases and further training, are needed to motivate improvement in supplying services to the public sector.

While it is valuable to employ CPD to achieve set professional and allied professional standards of competency in the workplace, practitioners should be actively encouraged to build on these basic competencies to move into given fields of specialisation, as dictated by market needs, or to face emerging challenges. All actors in livestock value chains must be trained, and identifying and monitoring this training is part of the responsibility of veterinary service providers. Advances in digital tools offer opportunities to access high-quality training, even in remote areas, both in OECD countries and LMICs, but such training will need to undergo regular reappraisal to ensure that it is up to date and relevant for a given setting or country, and that it continues to address the specific needs of a changing world.

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La formation professionnelle continue des vétérinaires dans un monde en mutation

B. Wieland, C. Daborn, N. Debnath & A. Silva-Fletcher

Résumé

La profession vétérinaire s'est adaptée à maintes reprises et avec succès à de nouveaux défis et évolutions qui ont nécessité la mobilisation d'un grand nombre de compétences nouvelles. La diversité des contextes, des systèmes de production et des exigences sociétales impose à la profession vétérinaire des transformations continues, avec pour conséquences une demande croissante de spécialisation et de collaborations interdisciplinaires le long des chaînes de valeur et la nécessité de mieux se préparer au risque omniprésent de maladies émergentes. Face aux changements intervenus, aux nouvelles connaissances, aux progrès de la recherche et aux nouvelles manières de relever les défis, la formation professionnelle continue (FPC) et l'adaptation et actualisation des cursus d'enseignement vétérinaire ont joué un rôle déterminant pour maintenir et améliorer la qualité et les performances des Services vétérinaires.

Les auteurs font le point sur les divers prestataires de services vétérinaires et examinent le rôle essentiel de la FPC pour relever les défis actuels et futurs, en mettant l'accent sur les vétérinaires et les professions connexes travaillant en lien avec les vétérinaires. Ils analysent la contribution des fournisseurs de FPC au système de santé animale, ainsi que l'influence sur la qualité et l'impact du renforcement des capacités d'un certain nombre de facteurs internes et externes à l'échelle des cohortes ou des individus. Les auteurs décrivent également le paysage de la FPC dans le domaine vétérinaire et plus particulièrement les structures organisationnelles, les approches pédagogiques, la transition d'un apprentissage axé sur les contenus à un apprentissage axé sur les résultats, les outils modernes de formation et les exigences imposées aux différents prestataires de services de santé animale dans un monde en constante évolution.

En conclusion, les auteurs insistent sur l'importance cruciale de mettre en place des dispositifs de formation professionnelle continue destinés au secteur vétérinaire, afin que la qualité des services fournis soit à la hauteur des exigences croissantes et en constante évolution du 21e siècle. Les programmes de FPC doivent donc être conçus en veillant à s'adapter aux besoins des vétérinaires et des professionnels

des domaines connexes concernant les compétences spécifiques qu'ils doivent déployer en fonction des exigences de leur activité, qu'ils travaillent auprès des gardiens d'animaux, des professionnels des filières issues de l'élevage, des gouvernements nationaux ou des organismes internationaux chargés de l'élaboration de normes. Un secteur vétérinaire optimisé et performant nécessite un programme de FPC fondé sur des données concrètes afin que les vétérinaires et les autres prestataires de services de santé animale puissent maintenir leur niveau de compétences ainsi que la pertinence de leurs interventions au regard des exigences évolutives d'un monde en pleine transformation.

Mots-clés
Enseignement – Formation professionnelle continue des vétérinaires – Paraprofessionnels vétérinaires – Professionnels des secteurs travaillant en lien avec les vétérinaires.

Perfeccionamiento profesional continuo veterinario en un mundo en plena evolución

B. Wieland, C. Daborn, N. Debnath & A. Silva-Fletcher

Resumen
La profesión veterinaria siempre ha sabido adaptarse con éxito a las novedades y nuevos problemas que han ido surgiendo, y que requieren la adquisición de nuevos conocimientos y aptitudes. Los diferentes contextos, sistemas productivos y necesidades sociales siguen configurando la profesión veterinaria y generando una creciente demanda de especialización, de colaboración interdisciplinar en todos los eslabones de las cadenas de valor y de preparación ante el omnipresente riesgo que plantean las enfermedades emergentes. El perfeccionamiento profesional continuo (PPC) y la adaptación y actualización de los planes de estudios veterinarios han sido factores esenciales para seguir el ritmo de las transformaciones, las nuevas ideas, los avances científicos y las novedosas respuestas a los problemas y, gracias a ello, mantener y mejorar la calidad y el desempeño de los Servicios Veterinarios.
Los autores pasan revista a cuantos agentes intervienen en la prestación de servicios veterinarios y, centrándose en los veterinarios y cuerpos profesionales conexos, exponen la función crucial que cumple el PPC para hacer frente a los problemas de hoy y de mañana. También explican cómo contribuyen al sistema los proveedores de PPC y cómo los factores internos y externos de una cohorte o un individuo afectan a la calidad y la repercusión del desarrollo de capacidades. Además, describen el panorama que ofrece el PPC en veterinaria desde el punto de vista de las estructuras organizativas, los planteamientos pedagógicos, la transición del aprendizaje de asimilación al aprendizaje por resultados, las modernas herramientas de trabajo y las exigencias que deben satisfacer los distintos agentes que intervienen en la prestación de servicios zoosanitarios en un mundo en plena evolución.
Los autores concluyen que es de la máxima importancia ocuparse del PPC para que los servicios veterinarios dispensados sigan siendo de calidad y respondiendo a las crecientes y mudables exigencias que trae consigo el siglo XXI. Hay que establecer pues un programa de PPC especialmente adaptado a las necesidades de los veterinarios y cuerpos profesionales conexos, pensando en dotarlos de las competencias necesarias para satisfacer los requisitos propios de su lugar

de trabajo, ya obren al servicio de la producción animal, de cadenas de valor ganaderas, de administraciones nacionales o de organismos internacionales de reglamentación. Un sector veterinario optimizado y eficaz requiere un programa de PPC científicamente fundamentado, que sirva a los veterinarios y demás agentes de la prestación de servicios zoosanitarios para seguir siendo a la vez competentes y útiles ante las cambiantes exigencias que les plantea un mundo en plena evolución.

Palabras clave
Enseñanza – Perfeccionamiento profesional continuo veterinario – Profesionales paraveterinarios – Profesionales relacionados con la veterinaria.

References

1. Friedman A., Davis K., Durkin C. & Phillips M. (2000). – Continuing professional development in the UK: policies and programmes. Professional Associations Research Network, Bristol, United Kingdom, 243 pp.

2. Høg E., Fournié G., Hoque M.A., Mahmud R., Pfeiffer D.U. & Barnett T. (2018). – Competing biosecurity and risk rationalities in the Chittagong poultry commodity chain, Bangladesh. *BioSocieties,* **14**, 368–392. doi:10.1057/s41292-018-0131-2.

3. Grace D., Caminiti A., Torres G., Messori S., Bett B., Lee H.S., Roesel K. & Smith J. (2019). – How external factors (e.g. climate change, conflicts, socio-economics, trading patterns) will impact Veterinary Services and the adaptations required. Technical Item. *In* Proc. 87th General Session of the World Organisation for Animal Health (OIE), 26–31 May, Paris, France. OIE, Paris, France. doi:10.20506/TT.2984.

4. Dale V.H.M., Pierce S.E. & May S.A. (2010). – The importance of cultivating a preference for complexity in veterinarians for effective lifelong learning. *J. Vet. Med. Educ.*, **37** (2), 165–171. doi:10.3138/jvme.37.2.165.

5. World Organisation for Animal Health (OIE) (2019). – Independent review of PVS Pathway reports from African Member Countries: final report. Weaver Consulting International, Hong Kong, Special Administrative Region of the People's Republic of China; Intiga Consulting, Upper Hutt, New Zealand; & Colibri Consulting, Leuven, Belgium, 121 pp. Available at: rr-africa.oie.int/wp-content/uploads/2020/01/oie_pvs_africa_evaluation-report_final_revised.pdf (accessed on 15 September 2020).

6. Cantillon P. & Jones R. (1999). – Does continuing medical education in general practice make a difference? *Br. Med. J.*, **318** (7193), 1276–1279. doi:10.1136/bmj.318.7193.1276.

7. Fox R. & Bennett N. (1998). – Learning and change: implications for continuing medical education. *Br. Med. J.*, **316** (7129), 466–468. doi:10.1136/bmj.316.7129.466.

8. Wallace S. & May S.A. (2016). – Assessing and enhancing quality through outcomes-based continuing professional development (CPD): a review of current practice. *Vet. Rec.*, **179** (20), 515–520. doi:10.1136/vr.103862.

9. Moore D.A., Klingborg D.J., Brenner J.S. & Gotz A.A. (2000). – Motivations for and barriers to engaging in continuing veterinary medical education. *JAVMA*, **217** (7), 1001–1006. doi:10.2460/javma.2000.217.1001.

10. World Organisation for Animal Health (OIE) (2013). – A guide to veterinary education twinning projects. OIE, Paris, France, 40 pp. Available at: www.oie.int/app/uploads/2021/03/veterinary-education-twinning-guide.pdf (accessed on 15 September 2020).

11. Sherman D.M. & Dehove A. (2020). – Perspective on the OIE Veterinary Education Establishment Twinning Programme. *J. Vet. Med. Educ.*, **47** (Suppl. 1), 3–7. doi:10.3138/jvme.2019-0122.

12. Olson C.A. & Tooman T.R. (2012). – Didactic CME and practice change: don't throw that baby out quite yet. *Adv. Hlth Sci. Educ. Theory Pract.*, **17** (3), 441–451. doi:10.1007/s10459-011-9330-3.

13. Knowles M. (1984). – The adult learner: a neglected species, 3rd Ed. Gulf Publishing, Houston, United States of America, 292 pp.

14. Merriam S.B. (2002). – Andragogy and self-directed learning: pillars of adult learning theory. *New Dir. Adult Cont. Educ.*, **2001** (89), 3–14. doi:10.1002/ace.3.

15. Grow G.O. (1991). – Teaching learners to be self-directed. *Adult Educ. Q.*, **41** (3), 125–149. doi:10.1177/0001848191041003001.

16. De Villiers M., Bresick G. & Mash B. (2003). – The value of small group learning: an evaluation of an innovative CPD programme for primary care medical practitioners. *Med. Educ.*, **37** (9), 815–821. doi:10.1046/j.1365-2923.2003.01595.x.

17. Kirschner P.A., Sweller J. & Clark R.E. (2006). – Why minimal guidance during instruction does not work: an analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educ. Psychol.*, **41** (2), 75–86. doi:10.1207/s15326985ep4102_1.

18. Schön D.A. (1983). – The reflective practitioner: how professionals think in action. Basic Books, New York, United States of America, 374 pp.

19. Brookfield S. (1995). – Becoming a critically reflective teacher. Jossey-Bass, San Francisco, United States of America, 296 pp.

20. Sandars J. (2009). – The use of reflection in medical education. AMEE Guide No. **44**. *Med. Teach.*, **31** (8), 685–695. doi:10.1080/01421590903050374.

21. Macdonald G. (2002). – Transformative unlearning: safety, discernment and communities of learning. *Nurs. Inq.*, **9** (3), 170–178. doi:10.1046/j.1440-1800.2002.00150.x.

22. Elton C. & Borges N.J. (2014). – Career progression and support. *In* Understanding medical education: evidence, theory and practice, 2nd Ed. (T. Swanwick, ed.). John Wiley & Sons, Oxford, United Kingdom, 421–431.

23. Royal College of Veterinary Surgeons (RCVS) (United Kingdom) (2021). – Continuing professional development (CPD): overview of changes. RCVS, Westminster, London, United Kingdom. Available at: www.rcvs.org.uk/lifelong-learning/continuing-professional-development-cpd/ (accessed on 2 July 2021).

24. Jayatilleke N. & Mackie A. (2013). – Reflection as part of continuous professional development for public health professionals: a literature review. *J. Public Hlth*, **35** (2), 308–312. doi:10.1093/pubmed/fds083.

25. Short N., Maddison J., Mantis P. & Salmon G. (2007). – Veterinary e-CPD: a new model for providing online continuing professional development for the veterinary profession. *J. Vet. Med. Educ.*, **34** (5), 689–694. doi:10.3138/jvme.34.5.689.

26. Kalupahana R. & Silva-Fletcher A. (2016). – A participant-led programme for field veterinary training to identify bacteriological quality of milk from the farmer to the retail outlet. *Food Control*, **63**, 128–134. doi:10.1016/j.foodcont.2015.11.012.

27. Scales P., Pickering J., Senior L., Headley K., Garner P. & Boulton H. (2011). – CPD in the lifelong learning sector. *In* Continuing professional development in the lifelong learning sector, 1st Ed. Open University Press, Maidenhead, United Kingdom, 176 pp.

28. Holm D. & Debnath N. (eds) (2019). – *Council on International Veterinary Medical Education (CIVME) Newsletter*, **3** (4). Available at: conta.cc/2Qb4bJr (accessed on 15 September 2020).

29. Berndt A., Murray C.M., Kennedy K., Stanley M.J. & Gilbert-Hunt S. (2017). – Effectiveness of distance learning strategies for continuing professional development (CPD) for rural allied health practitioners: a systematic review. *BMC Med. Educ.*, **17**, 117. doi:10.1186/s12909-017-0949-5.

30. Kinnison T., Thuranira-McKeever C., Kalupahana R. & Silva-Fletcher A. (2020). – Multi-level impact of continuing professional development on Sri Lanka's veterinary sector. *Open Learn., J. Online, Distance, e-Learn.* doi:10.1080/02680513.2020.1758650.

31. Friedman A. & Woodhead S. (2008). – Approaches to CPD measurement. Professional Associations Research Network, Bristol, United Kingdom, 157 pp. Available at: www.iaesb.org/system/files/meetings/files/3629.pdf (accessed on 15 September 2020).

32. Moore D.E., Green J.S. & Gallis H.A. (2009). – Achieving desired results and improved outcomes: integrating planning and assessment throughout learning activities. *J. Contin. Educ. Hlth Prof.*, **29** (1), 1–15. doi:10.1002/chp.20001.

33. Karp N.V. (1992). – Physical therapy continuing education part I: perceived barriers and preferences. *J. Contin. Educ. Hlth Prof.*, **12** (2), 111–120. doi:10.1002/chp.4750120210.

34. Delver H.A. (2008). – Continuing veterinary medical education needs and delivery preferences of Alberta veterinarians. *J. Vet. Med. Educ.,* **35** (1), 129–137. doi:10.3138/jvme.35.1.129.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 567-584

Global Burden of Animal Diseases: a novel approach to understanding and managing disease in livestock and aquaculture

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Summary

Investments in animal health and Veterinary Services can have a measurable impact on the health of people and the environment. These investments require a baseline metric that describes the burden of animal health and welfare in order to justify and prioritise resource allocation and from which to measure the impact of interventions. This paper is part of a process of scientific enquiry in which problems are identified and solutions sought in an inclusive way. It poses the broad question: what should a system to measure the animal disease burden on society look like and what value would it add? Moreover, it aims to do this in such a way as to be accessible by a wide audience, who are encouraged to engage in this debate. Given that farmed animals, including those raised by poor smallholders, are an economic entity, this system should be based on economic

https://doi.org/10.20506/rst.40.2.3246

principles. These poor farmers are negatively impacted by disparities in animal health technology, which can be addressed through a mixture of supply-led and demand-driven interventions, reinforcing the relevance of targeted financial support from government and non-governmental organisations. The Global Burden of Animal Diseases (GBADs) Programme will glean existing data to measure animal health losses within carefully characterised production systems. Consistent and transparent attribution of animal health losses will enable meaningful comparisons of the animal disease burden to be made between diseases, production systems and countries, and will show how it is apportioned by people's socio-economic status and gender. The GBADs Programme will produce a cloud-based knowledge engine and data portal, through which users will access burden metrics and associated visualisations, support for decision-making in the form of future animal health scenarios, and the outputs of wider economic modelling. The vision of GBADs – strengthening the food system for the benefit of society and the environment – is an example of One Health thinking in action.

Keywords
Agriculture – Aquaculture – Baseline – Burden – Economics – Gender – Global Burden of Animal Diseases Programme – Investment – Livestock – One Health – Poverty – Women farmers.

Introduction

Years of investment in the development of frameworks (1, 2) for data capture and analysis have allowed estimations of investment in human health, so that today it is possible to find that, in 2017, global human health spending was US$ 7.8 trillion, equivalent to 10% of the global gross domestic product (GDP) or US$ 1,080 per capita (ranging from US$ 41 in low-income countries to US$ 2,937 in high-income countries) (3). In contrast, while data and information on expenditure for animal health are collected, they are as yet disaggregated, often unavailable or uncertain, and unlikely to be easily accessible. There are estimates that the animal health products market was valued at US$ 24 billion in 2015, about 2.5% of the global human health market (4), yet this figure provides little information on the cost of services, or investments into education, coordination and research. Given that animal health is integral to the well-being of society, understanding animal health investments is critical to support decision-making and achieve the One Health vision.

In assessing changes in human health, the concept of using health-adjusted life year (HALY) metrics is well established. A number of such metrics have since been developed and used, most notably the quality-adjusted life year (QALY), which was introduced in the 1970s and describes the health benefit in terms of mortality and morbidity for a medical intervention (5, 6). Since the 1990s, the Global Burden of Disease (GBD) Study has used the disability-adjusted life year (DALY) to measure health loss in humans, in terms of premature death and changes in the level of disability during the acute, chronic and recovery phases of a disease or health problem (7). This has become a standard used to describe the disease burden in a human population and, although not a monetary metric, is used as an outcome measure for interventions. The GBD Study generates longitudinal estimates that have the power to look at specific targeted actions to change human health, as well as to measure the impacts of policy and investment changes on human health in a more general sense. Through the provision of objective, standardised and therefore comparable information, the human health sector (and in particular the GBD) has redefined the way in which the global community assesses resource mobilisation and allocation to human disease priorities.

There is, as yet, no equivalent, consistently applied, systematic process in animal health, as DALYs do not map so cleanly into measures for animals in a market-based, anthropocentric society. Therefore, both components of the burden of animal health and welfare – losses due to disease and health problems, and expenditure on preventative and reactive measures (hereafter referred to as the burden of animal disease) – are currently inaccessible at the sector, national or global level. This information is required to increase society's understanding of the misallocation of resources across animal production systems, and also within responses to individual animal health issues. The Global Burden of Animal Diseases (GBADs) Programme intends to correct this deficiency through the creation of a standardised international system, which over time will generate the information required to make such estimations.

Land, water and air resources have significant public good attributes and are used by small- and large-scale producers alike. Livestock (which, throughout this paper, unless qualified, means both terrestrial and aquatic farmed animals) have become dominant on the planet. Research on terrestrial farming has estimated that two-thirds of agricultural land is dedicated to livestock (8); agriculture takes between 70% and 90% of the Earth's fresh water (9) and a third of this is used on livestock (10); and livestock are a major source of methane (and, indirectly, carbon dioxide) emissions and local pollution (11). The allocation of resources to healthy, productively efficient animals kept in good welfare conditions is culturally appropriate. Yet, so that this resource allocation does not place an unacceptable opportunity cost on others, due to inefficient or unsustainable resource use, a thorough understanding of this societal issue is needed (12).

Importance of livestock to the smallholder farmer

The challenges that small- and large-scale farmers face in the global context can, on the one hand, be remarkably similar (for example, the consumption of environmental resources), yet also differ starkly (access to animal health services and technologies). There is disparity in the distribution of animal health systems and infrastructure. A great proportion of livestock are kept in large farms under controlled and intensive conditions (13). These farms are major users of pharmaceutical products. Yet the majority of livestock keepers across the world are small-scale producers. These people are poor and, in many situations, have little access to veterinary services and technologies.

This poor access can be attributed to the lack of funding in many resource-constrained countries. However, in many cases, this is an outcome of market failure that requires societal intervention. For example, lower-income countries have a smaller market and low willingness to pay for products. This means that the high overheads faced by producers of pharmaceutical veterinary products are better met by targeting their development and supply towards the predominant animal health issues in high-income countries, where there is a larger market and increased willingness to pay (14). Availability of these products in low-income countries is not in itself a solution; last-mile distribution network initiatives seek to address the high transaction costs that prevent access to animal health technologies. Sustainable solutions for smallholders must take into account the nuanced socio-economic roles that livestock play in low- and middle-income countries (15).

Box 1
The context for the smallholder farmer

The final report of the World Health Organization (WHO) Commission on Social Determinants of Health states, 'Inequity in the conditions of daily lives is shaped by deeper social structures and processes; the inequity is systematic, produced by policies that tolerate or actually enforce unfair distribution of and access to power, wealth, and other necessary social resources' (16). This narrative was continued in a report marking the starting point for the Lancet–University of Oslo Commission on Global Governance for Health, which described power asymmetry as the root cause of inequity (17). Considering that those with power determine animal health systems, the risk of an asymmetry of power translating into an asymmetry of information means that market failures, such as those described above, are inevitable. It is, therefore, of moral significance that asymmetry of information is challenged in order to redistribute power and address inequity in animal health systems.

Explaining the importance of foot and mouth disease (FMD) control to Juanita Perez and her family, who are sheep farmers high in the Bolivian Andes, could certainly leave one questioning whether or not resources are invested wisely. Juanita trades her sheep and their wool at the local markets. What relevance do the Bolivian FMD control strategy and implications for international trade hold for her? It becomes clear that enabling access to and providing advice on nutrition, genetics and parasite control has the potential to have a tangible impact on the productivity of Juanita's flock and the wealth and well-being of her family. It is not wholly surprising that mismatches such as this exist – where well-intentioned policies imposed at the national level, perhaps reflecting a country's ambitions on the regional or global stage, provide little or no support to the daily problems encountered by farmers producing for their own consumption and the local market.

Women like Juanita, and the families and flocks they support, play crucial roles in human nutrition and health and in society as a whole, providing income, food, clothing, building materials, fertiliser, fuel and draught power. Across the world, 1.3 billion people are directly dependent on food animals for their livelihoods, of whom 600 million, such as Juanita, are smallholder farmers in some of the world's poorest countries (18). The health of their animals is under constant pressure from communicable and non-communicable animal diseases; inadequate access to feed, forage and clean water; injuries; and predation. For these vulnerable people, poor animal health leads directly to poverty and malnutrition, exposure to zoonotic disease risk, poor health and reduced welfare. Aside from the animal keepers, unhealthy animals themselves suffer. At the global level, the lower productivity of diseased animals contributes to climate change and environmental degradation, as more resources are required to produce a unit of output.

Understanding the context for smallholder farmers and others on the margins of society re-emphasises the moral need to address the information asymmetry in animal health systems. A standardised process to understand the burden across the whole of society, which is applied in a consistent and transparent way, is an essential part of the solution.

This paper poses the question: what should a system to measure the burden of animal disease look like and what value will it add to Veterinary Services? It is, after all, their role to mitigate the health and welfare issues of animals that provide food, fibre, manure, draught power and a source of investment. As well as supplying important social and cultural benefits, the livestock sector is fundamentally an economic activity; hence this paper presents livestock production as an economic process. The paper will summarise the use of economics in animal health, drawing on important theories from the literature. It will provide an explanation of how economics can be used to understand and address private (farm-level) and public (societal-level) costs. This information will be gathered to detail the steps needed to integrate physical science with economic theory, in order to ask important questions for the animal health sector at the societal level.

The framework presented is applicable across all levels, from the individual farmer and his or her household to the agri-food sector, as well as at the national level and globally. Once institutionalised, the longitudinal estimates generated will help to guide the allocation of resources to major problems and allow the evaluation of animal health programmes. The urgency of such work has never been greater, with the rise in the proportion of human diseases coming from animals (19), the greater frequency of disease outbreaks (20), the potential scale of the impact of an emerging zoonotic disease that becomes transmissible among humans (e.g. COVID-19) and the role of livestock in climate change.

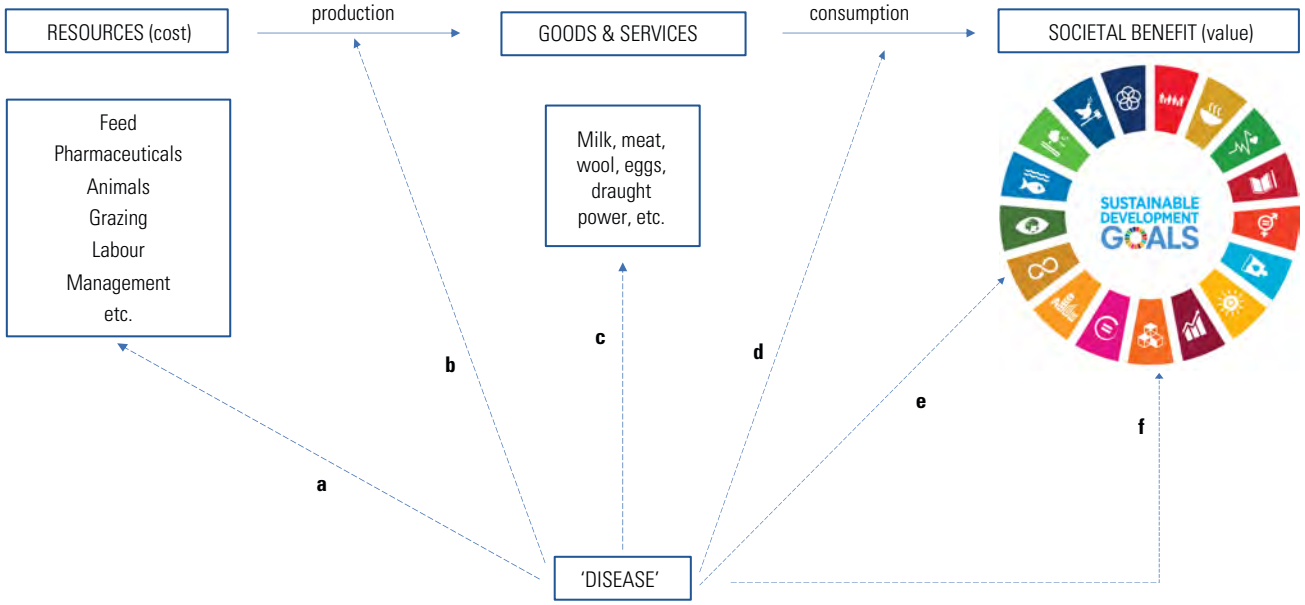
The system proposed will accurately describe the role of animals in society and the importance of managing animal health and welfare. Moreover, it will improve our ability to explain how activity in the animal health system can support the achievement of economic, social, public health, food security and environmental goals. It is based on an understanding of the need to make the best use of the available data; to describe gaps that need to be filled, and to use logical frameworks to systematically generate credible and useful information. The system must create clarity for decision-making in a complex world.

The use of economics in animal health

Farmers use formal and informal budgeting methods to allocate their scarce resources. Historically, these have been the basis of the emergence of farm-level micro-economics (21). Important lessons are also drawn from present-day, small- and large-scale farmers who routinely use well-tested farm-budgeting methods and multi-criteria decision tools to evaluate their enterprises and plan for the future. By investing resources in veterinary care and management advice, farmers demonstrate an understanding that providing for their animals' health and welfare will underpin the success of their business. However, rarely is the evidence available to understand the relative contributions of interventions to control different diseases, as compared to, for instance, resources spent on improving the quality of the animals' housing, feed or water.

A collaboration between colleagues J. McInerney and K. Howe in the 1980s led to early work on the use of economic principles for animal health (22, 23). A framework emerged (24), and McInerney presented a seminal paper on the economics of animal health to the Society of Agricultural Economics in 1996 (25). McInerney described the multi-faceted effects of animal disease on the food system (Fig. 1); modelled input/output relationships in the presence and absence of disease, explaining disease losses as a 'genuinely economic variable'; and extended this framework to describe a disease loss–expenditure frontier, explaining that 'optimal management is concerned with reducing to its lowest level the cost incurred due to disease' (Fig. 2a). He proposed areas for development: notably, improving information on disease losses, particularly as they extend downstream in the food chain, and their impacts on trade and disease control, particularly in regard to expenditure on veterinary medicines and services in the pursuit of disease treatment, prevention or eradication. Thus, an economic assessment of the burden of animal diseases must extend to the investigation of private and public costs throughout the food system.

Tisdell (26) extended McInerney's theory by exploring models for optimising disease control for more than one disease, and relaxing McInerney's example of strict concavity of the benefit function from controlling disease (Fig. 2a). Tisdell introduced curves that mirror those of McInerney by comparing benefits – as opposed to costs – against expenditure, and describing a break-even point for the benefits realised from expenditure on disease control (Fig. 2b). In some cases, these S-shaped curves predict no benefit from expenditure before exceeding a threshold level. The curve that Tisdell describes is analogous to those used to explain the poverty trap (Fig. 2c), a concept that was originally championed by Sachs and retold by Banerjee and Duflo (27, 28), based on ideas described in a series of texts from the mid-20th century (29, 30, 31, 32, 33). A poverty trap exists when income today is insufficient for a person or family to afford, for example, education, healthcare or animal health technologies, resulting in a future in which their income is even lower. The S-shaped curve describes how this situation will result in impoverished people in the poverty trap zone becoming poorer over time. These people will not move out of this zone without outside support.



Disease is a particular class of negative influences in the value-creating process that uses livestock as economic resources. Its negative effects are most widely recognised in the production sector of livestock farming and arise because it:

a) destroys the basic resources (mortality of breeding or productive animals)

b) lowers the efficiency of the production process and the productivity of resources used (reduced rates of growth or feed conversion)

c) reduces the realised physical output of the production process or its unit value (lowered milk yield or quality).

A broader view of the food system recognises that animal disease can also:

d) lower the suitability of livestock products for processing, or generate additional costs in the distribution chain (drug residues, meat inspection)

e) affect human well-being directly (through zoonoses such as *Salmonella* and brucellosis).

Finally, there are:

f) an array of more diffuse negative economic effects which reduce the total value that a society gains from livestock. These range from constraints on trade in animal products to the reduction in consumption benefits, or even outright negative benefit, that people experience when the awareness of a disease (e.g. bovine spongiform encephalopathy) changes their image of a food product. Added to this are the utility reductions (i.e. reduced satisfaction from consumption) felt by people who associate animal disease with poor animal welfare.

Fig. 1
Livestock production is an economic process and is subject to the negative influences of disease
Adapted from McInerney (25)

The question of whether disease and sub-optimal productivity of livestock contribute to a poverty trap for poor smallholder farmers is an important one. If this is the case, and if a threshold expenditure on animal health – which is more than poor people can afford – is needed to see sustained and meaningful income from livestock, continued government and non-governmental organisation (NGO) support in the form of grants or loans will be essential to achieve societal benefits from livestock farmed by poor people. However, if this poverty trap is not real, and other socio-economic factors are not limiting, a demand-driven, more equitable, private supply of animal health services and technologies can support these small-scale producers to improve the health and productivity of their animals, thus contributing to their own wealth and well-being.

This threshold expenditure is a combination of the cost of establishing an available service and the cost of the service at the point of delivery. Ahuja (34) explains that, while evidence exists that poor farmers are willing to pay market price for assured and good-quality veterinary services, market failures exist, and it is the role of the state to address these. Recognising the role of local NGOs in channelling government funds and generating demand for veterinary services, Ahuja states that: 'government has the additional responsibility of nurturing the development process in a way that empowers the farmers to demand quality services'. In a technical paper presented to the 84th General Session of the World Organisation for Animal Health (OIE), Rushton and Gilbert (35) explain how animal health policy can become a mix of demand-driven responses and, where market failure exists, supply-led responses to address poor resource allocation. They conclude that the evidence base for policy decisions needs to be improved.

In considering the need to supplement poor, small-scale farmers' expenditure on animal disease control with outside financial support (from the state or otherwise), this debate

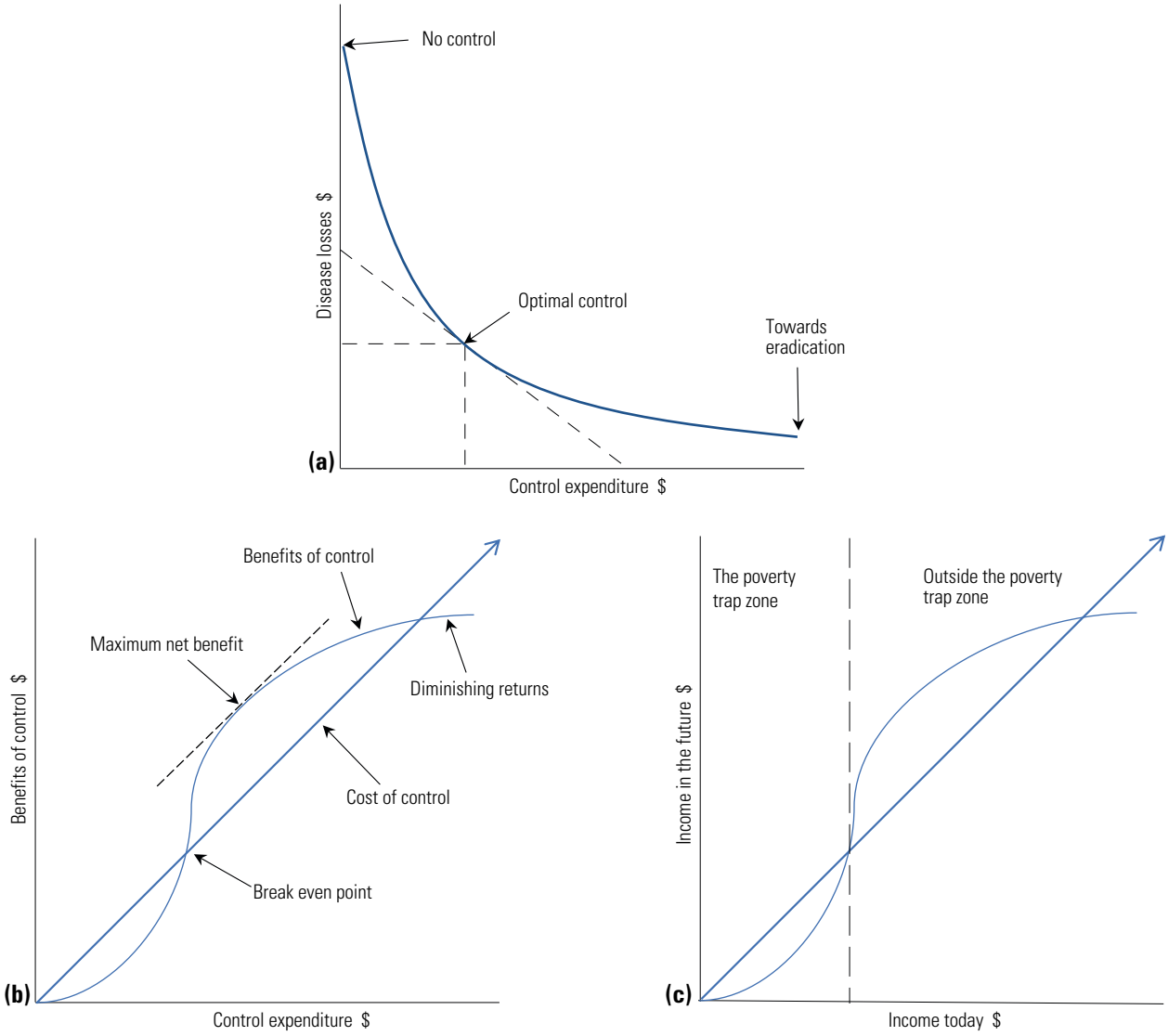


Fig. 2
The Disease Loss–Expenditure Frontier (a), relaxing strict concavity of the benefit function from controlling disease (b), and drawing parallels with the Poverty Trap (c) to highlight the requirement for supply-led as well as demand-driven responses in equitable provision of animal health services
Adapted from McInerney (a) (25), Tisdell (b) (26) and Banerjee and Duflo (c) (27)

takes place within the wider scope of the policy arena. Not only will individual animal diseases be vying for a proportion of the animal health spend but, more crucially, the total animal health spend will be determined alongside the state's spend on infrastructure, human health, education and defence, to name but a few examples.

A large and valuable volume of work has been produced by a community of economists and epidemiologists who have, over time, become comfortable working hand in hand, providing practical support for farming operations of all scales and advice to governments on policy. This community is well represented by the International Society for Veterinary Epidemiology and Economics (ISVEE), the International Society for Economics and Social Sciences of Animal Health and, in the United Kingdom, the Society for Veterinary Epidemiology and Preventive Medicine. The OIE has commissioned two editions of the *Scientific and Technical Review* on the economics of animal health, edited by Perry in 1999 (36) and Rushton in 2017 (37). The wider agricultural economics literature is also fertile ground, particularly for studies examining the wider economic (public) costs of animal diseases.

These important bodies of work have tackled the issue of suitable approaches for private and public costs of animal disease control (38), provided useful, practical overviews of analytical methods (39), and challenged the heuristic nature of the decision-making process at the national policy level (35). This last aspect is arguably the most important, when considering the change in paradigm that is required to take an objective societal view on animal disease control.

Economics in animal health has traditionally been used as an adjunct to advocacy for reducing or eliminating a specific pathogen in a population (Fig. 3) (40). Partial budget analyses, cost–benefit analyses of specific issues, crisis response ('fire-fighting') and heuristics (rules of thumb to simplify and speed up decision making) have driven the investment agenda. Instead, the authors favour an approach that searches for optimal solutions in resource allocation, driving evidence-based decision-making and improving productivity and human well-being (Fig. 3).

Turning theory into practice at the policy level – building blocks

In his 1996 presentation to the Society of Agricultural Economics, McInerney stated:

> 'The complexity we can add to the core (economic) model does not obscure its fundamental validity as a representation of the real world – indeed, it is the complexity that illuminates it.' (25)

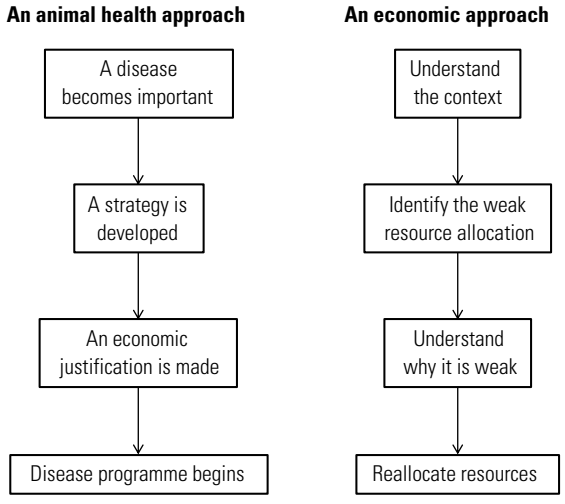


Fig. 3
An economic versus animal health approach
Adapted from Rushton (40)

The application of the economic approach relies on a crucial first step: understanding the context. A multidisciplinary approach is required to carefully and successfully disentangle the apparent complexity of the food system into bite-sized portions. Future publications are planned which will elaborate on research methods and provide examples of early outputs for critique.

Populations and production systems, biomass and value

The baseline data needed to characterise livestock and production systems (including their productivity levels) in different parts of the world have seldom been available at the level of disaggregation necessary to make informed decisions on disease prioritisation, the upscaling potential of key interventions, and their impacts on productivity and household nutrition, income and the empowerment of women. The role of women in these systems is often emphasised but the value of their work is rarely adequately quantified. By describing the value of their work in economic terms, the GBADs Programme will lay the foundation for generating information on animal health problems that affect women, as well as indicating where women have ownership and control over livestock.

Isolated examples relying on painstaking manual data collation do exist (41), and more recent studies have benefited from access to new data sources (42, 43). As a result, some coherent building blocks are emerging (44, 45). In some specific areas, detailed pieces of work are starting to provide information on the potential for productivity increases in the small-scale producer setting (46, 47).

Outputs of these exercises include (at the production-system level) an appreciation of population numbers, including age and sex structure, weights and prices (live animals for breeding and further production, and finished animals). Rothman-Ostrow *et al*. (48) explore alternatives to the use of the tropical livestock unit for biomass measurement, and provide refined estimates of cattle biomass that take into account data on breed, live weight and herd structures. Updated, accurate biomass estimates, based on a sound understanding of livestock population dynamics, are essential to ensure that greenhouse gas (GHG) emissions estimates are a true representation (49, 50).

Further investment in the collation of accurate baseline data, allowing us to refine our understanding of biomass and capital investments in livestock, will provide an important starting point to: create business cases for investment in animal health, determine the (re-)allocation of resources, and improve estimations of GHG emissions from the livestock sector.

Measuring animal health loss

The pros and cons of applying a HALY approach to losses caused by disease in animals are discussed in Shaw *et al.* (51) and Torgerson *et al.* (52). The DALY metric was founded on general concepts presented by Murray (7). These ideas point towards a moral conviction that all human lives are of equal value and notably include the choice to restrict the characteristics of an individual affected by a health outcome to age and sex only. Ultimately, as livestock are an economic entity, a monetary measure is most appropriate. However, adjustments may be needed to reflect local, per-capita gross national product (GNP), and thus to measure the actual impact of animal diseases on livestock owners (52). There are further important lessons that can be derived from the successful GBD Study, notably the first general concept proposed by Murray: 'To the extent possible, any health outcome that represents a loss of welfare should be included in an indicator of health status' (7).

This extends the concept of human health problems beyond disease impacts to include other causes of poor health from nutrition, mental health, and accidents and injuries – indeed any that society will use resources to avert. In this way, the HALY approach does translate to GBADs and shapes two important ground rules:

1. All possible causes of the animal disease burden should be considered – not only notifiable/transboundary diseases or those historically viewed as 'important', but also including (and not limited to) endemic and non-communicable diseases, nutritional issues, injuries and accidents, as well as the impacts of poor animal husbandry practices.

2. To capture the burden of animal disease, an appreciation of the enterprise budget is required. Livestock output encapsulates all entries and exits of animals, while enterprise costs reflect other productivity indices, such as feed conversion and veterinary expenditure, as well as spending on infrastructure, including biosecurity measures. Using the enterprise budget as a basis will ensure that all losses associated with animal health (or disease) can be considered while, at the same time, preventing overstatement of the effects of individual diseases.

By collating data on input and output relationships, the animal health losses for specified production systems can be modelled as a function of the current enterprise budget, compared with a defined, transparent, and consistently applied utopian situation, which need not necessarily be based on empirical data. This is analogous to the GBD, where the human disease burden is estimated as a loss of healthy life expectancy, compared to an idealised healthy life expectancy with no loss due to disease or injury (53). But with animals, rather than using life expectancy, it is necessary to use an idealised system where there are no losses due to disease, injury or inadequate nutrition. It is important to appreciate that, while this idealised situation may seem unachievable to the producer, its primary purpose is to facilitate the methodological framework, creating a total boundary on losses that cannot be exceeded at the attribution stage.

Animal health ontology and attribution

The GBADs Programme relies on a massive volume of data from multiple data sources, including scientific articles published in journals, national animal censuses, electronic farm and agribusiness records, and agriculture statistics curated by the World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO) and the OIE. These data sets display considerable heterogeneity in their methodological design and descriptors (54), creating a challenging environment in which to use this information to make meaningful comparisons – for example, between diseases in various production systems and different countries – in a consistent and transparent way.

Ontology for flexible classification

Ontologies are frameworks comprising concepts and their relationships that are interpretable by both humans and computers, within a structured vocabulary. Ontologies play an important role in knowledge and data standardisation to support data integration, sharing, reproducibility and analysis. Components of the ontology tool for GBADs will incorporate: animal demography, specific disease aetiologies or syndromes, measure(s) of severity, and associated effects on production. Ontologies can incorporate existing resources but require agreed classification standards as a basis for true integration and interoperability (55). In this context, the ontology will be integrated with the OIE's codification of animal health electronic data, resulting in interoperability with other existing international health terminologies and information systems.

Establishing ontologies, vocabularies, and an associated knowledge graph will enable complex reasoning about the data being provided by all participants and will supply modellers with information about the quality of their data. The model's representation of the real-world situation can be improved by integrating feedback from end users, leveraging a dynamic process to enhance relevance and reliability.

Attribution

In his paper, 'The application of economics in animal health programmes: a practical guide', which appeared in volume 18 (2) of the *Scientific and Technical Review,* Morris explained:

> 'Economic analysis is not a form of financial accounting; the main concern in economics is to rank alternative disease control measures in order of the merit of each alternative, hence to make the best decision, and not to calculate the exact monetary value. Thus, although imperfect data is often used in many analyses, this does not necessarily reduce the value of the results.' (39)

The task of prioritising animal health intervention strategies must be informed by quantitative assessments of the burden of disease from specific causes. Thus, the first methodological step in estimating animal health loss by cause is to determine the 'envelope' that contains losses and expenditure due to individual diseases, health issues and injuries. Adapting methodology developed for the GBD (53, 56), the animal health loss envelope is then divided into specific causes (such as specific pathogens, syndromes or accidents), with components of the animal disease burden, such as production loss, expenditure on disease mitigation and market effects, attributed to their causes and identifying their associated risk factors.

In extensive livestock systems, where data may be sparse or unvalidated (57), we can harness the principles of ontology, adopt them to make the best use of diverse untapped data sources, and accept (as Morris explains in the quote above [39]) that analyses based on imperfect data can still be of great value for decision-makers, for whom information on the relative importance of a specific disease or intervention is often as important as the absolute. In other words, sometimes the ranking order, not the impeccability of the data, is the important thing. Through a process of structured discovery, data strengths and weaknesses can be systematically described and the marginal benefits of closing specific data gaps evaluated.

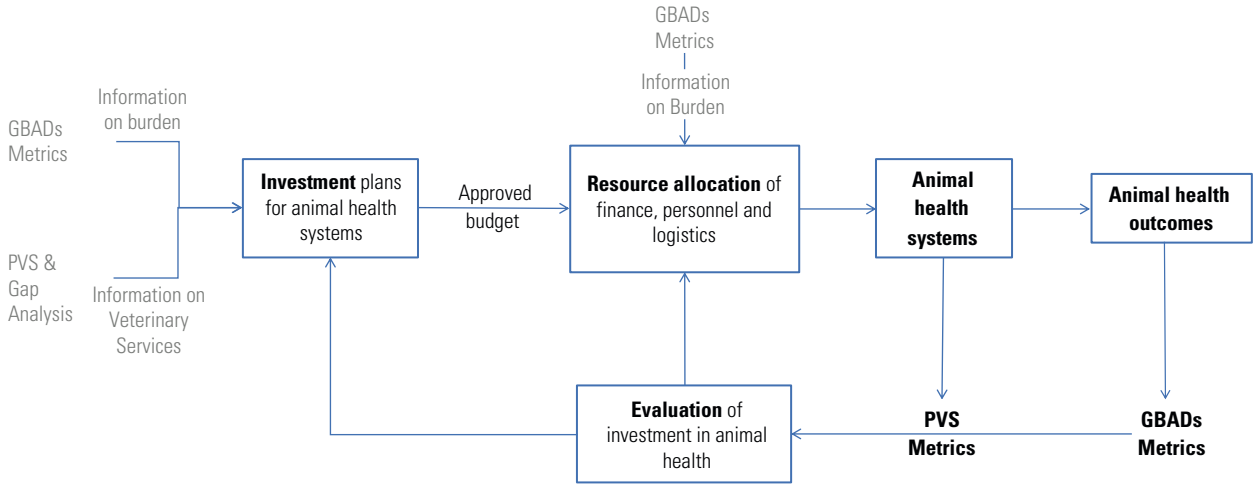
Using economic analyses to guide equitable investment prioritisation

Economic analysis of the impact of disease on domestic and international markets can produce rich – and valuable – decision-making criteria for the individual household up to the policy-maker. The information that methods such as cost–benefit analysis and cost-effectiveness analysis produce creates a powerful resource for decision-makers, but it is important that this power is part of the solution not the problem. A systematically applied framework producing widely (and freely) available information has the advantage of reducing asymmetries in information and hence decision-making power.

The classical animal health approach (Fig. 3) is driven by structures that place decision-making power in the hands of veterinarians who provide expert opinion on the importance of disease and the subsequent control strategy. Conversely, the economic approach (Fig. 3) can be a vehicle for a more equitable distribution of power. For this approach to be successful, it must be based on a thorough understanding of the drivers of disease outcomes and the production systems in which they act. It requires that economic approaches be developed with input from a wide range of participants throughout the value chain. A range of alternative interventions should be identified, across which changes in benefits and the costs of the disease burden can be measured (58). Considering the impact on all economic agents throughout the value chain, including the consumer, is a requirement of any complete, objective, economic evaluation of a food system. This is key to identifying the net benefits that stakeholders, governments, and society receive, and the costs incurred, from the disease burden, interventions, and policies or regulations. A range of models (partial equilibrium, input–output, budgeting) have been used to understand the impact of disease – in its simplest form, an output supply constraint – on the agriculture sector, regional non-agricultural sector and government spending (59). Models can be extended to include a temporal aspect, tracking changes in producer and consumer welfare over time.

By providing this information, the GBADs Programme will support evidence-based investment plans for animal health systems, and improve our understanding of the marginal gains to society that can be made from investments in animal health. Figure 4 describes how GBADs will be a natural adjunct to the OIE's Performance of Veterinary Services (PVS) Pathway, including the Gap Analysis component. Information that disaggregates the burden of animal diseases by the type of farmers and consumers affected, and also addresses the gender balance of the burden, will allow the allocation of resources to key social, economic and environmental problems, strengthening PVS outcomes. The GBADs Programme and PVS metrics will work in conjunction to support high-quality evaluations of existing animal health investments and, in doing so, will demonstrate the value of animal health systems.

A strength of the GBADs Programme is in the foundations that have been built both through the evolving work described above, and specifically by the development of a theoretical – and practical – framework during a thorough development phase (2018–2020) (60). The steps described above will provide the necessary contextual information on the animal disease burden to identify weak resource allocations in specific production systems and describe how this impacts the wider economy. This baseline information will provide the ground work for the systematic application of analytical methods to support decisions.



GBADs: Global Burden of Animal Diseases
PVS: Performance of Veterinary Services

Fig. 4
The Global Burden of Animal Diseases: supporting the investment cycle

Joining the blocks together

Engagement

For the GBADs Programme to function, the building blocks described above must be linked together so that data can be acquired, analysed and interacted with. For GBADs to add value, this process must be relevant, credible and useful. 'Hitting the mark' in these aspects will be crucial to the GBADs Programme's long-term success and must be founded on thoughtful engagement with the public and private sectors, intermediary beneficiaries (e.g. policy-makers) and end users (e.g. farmers) to understand their values and needs. Those who value GBADs will more readily supply the data to feed the analyses and respond to close gaps in data availability, accessibility or quality. A survey conducted in 2019 of more than 150 key animal health decision-makers across governments, NGOs and the private sector provided evidence that an operational GBADs system would create an increased willingness to share animal health data; and over 90% of respondents said they would use GBADs analysis to support decision-making (61). Further work is planned to understand the values of the end users that drive their decisions, with a particular emphasis on the role and empowerment of women at the individual farm level.

Informatics

Modern technology provides the potential to readily harness the wealth of data that exists in the animal health and production domains. Learning from the best current examples, while acknowledging emerging trends and technologies, will ensure that GBADs meets the needs of its users now and into the future. The vision for the user interface of GBADs is a cloud-based knowledge engine composed of:

– diverse data sources

– open application programming interfaces (APIs), which specify the interactions that are possible with a software component, such as a database, program or web application

– dynamic, open-source models applying GBADs methods for analyses

– tools that enhance the findability, accessibility, interoperability and re-use of data on animal diseases and their burdens.

A modern knowledge engine and data portal must also take into account issues such as data provenance and the ethical impact of the use of data on diverse communities (not just the GBADs community). In particular, as technological methods allow for data ingestion from mobile devices, indigenous communities around the globe may take part in local data gathering (and even data analysis and modelling). To ensure that the appropriate ethical guidelines are followed, the GBADs Programme will take a number of standards into consideration, such as:

– guidelines for accurate and transparent health estimates reporting (GATHER), to disclose how human health estimates are developed (62)

– meeting principles of findability, accessibility, interoperability and reusability (FAIR), and extending this to include security (D. Stacey, K. Wulff, N. Chikhalia & T.M. Bernardo, unpublished data)

– the CARE principles (collective benefit, authority to control, responsibility, ethics) for indigenous data governance (63).

This knowledge engine will maximise the use of existing data from a variety of sources, both public and private, at the global, national, sector and project levels, providing new insights and improved functionality, and enabling collaborators to find meaning in and formulate evidence from these data.

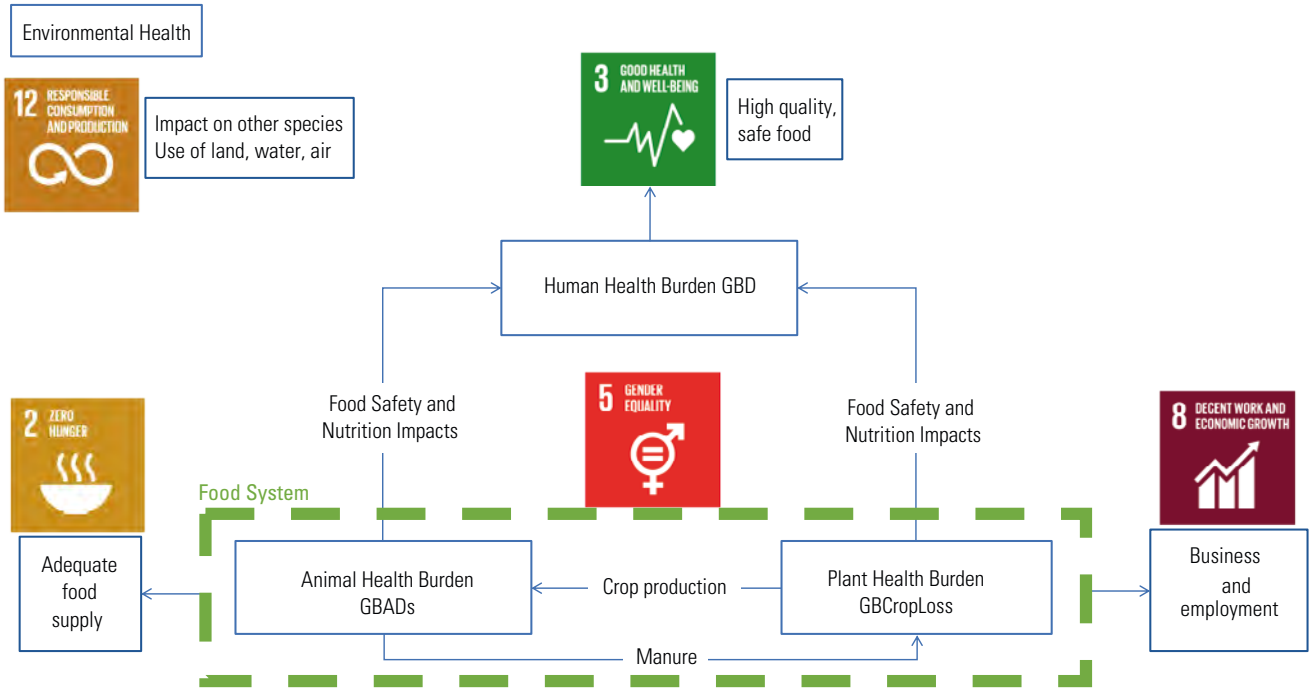
Global Burden of Animal Diseases and human health

The GBD and WHO Global Burden of Foodborne Disease estimates (64) describe human health outcomes associated with zoonotic and foodborne diseases. Furthermore, they include information on animal population demographics in modelling processes that recognise animal factors as covariates for human health outcomes. For those zoonotic and foodborne disease estimates that are already included in these global initiatives, GBADs will provide an opportunity to supplement the existing models with additional data and updated evidence. For those foodborne and zoonotic diseases that are conspicuous in their absence as human health outcomes, the GBADs data collation process will support their future inclusion in global human health work. Over all, the GBADs Programme will provide a mechanism to understand the potential for zoonotic diseases to emerge from livestock, thereby supporting the development of surveillance and prevention actions to manage and limit the risks of disease emergence.

The food system – an example of One Health in action

Through the complementary use of resources (e.g. feed, manure) and services (draught power), animal and plant health are part of a linked economic process. Together they are part of a food system that supports society and contributes to the attainment of the United Nations' Sustainable Development Goals (Fig. 5) (65). In this context, GBADs supports the development of the framework for the Global Burden of Crop Loss (66).

Future activities will support decision-making from the One Health perspective in areas of antimicrobial use and resistance, and human nutrition. Important associations are yet to be fully explored between antimicrobial use in humans and animals and antimicrobial resistance patterns in these populations, and also the environment. Detailed data from food systems – data sets which not only identify production constraints and access to alternative food sources but also collate information on micronutrient availability



GBADs: Global Burden of Animal Diseases
GBCropLoss: Global Burden of Crop Loss
GBD: Global Burden of Disease

Fig. 5
The Global Burden of Animal Diseases as part of a One Health approach that addresses the United Nations Sustainable Development Goals (67)

from different meat sources and carcass components – will enhance already established food production and consumption models.

Conclusions

The GBADs Programme will provide essential baseline information on the social, economic and environmental burden of animal diseases. It will address the needs of keepers of livestock and aquatic animals, consumers and the environment by supporting investment plans, which ensure that there are adequate animal health systems; the allocation of resources to problems that most affect animal health and well-being; and evaluations of animal health investments to ensure that they are delivering good societal outcomes.

Food safety, nutritional impacts, and existing and emerging zoonotic pathogens in farmed animals all present challenges and opportunities. Both must be addressed to provide high-quality, safe food to alleviate the human health burden. In this context, GBADs will partner with global initiatives in human health (GBD, WHO) and plant health (Global Burden of Crop Loss). All those involved in the food system must be aware of the impact it has, both in terms of the welfare and diversity of farmed species it relies on, and the wildlife on which it undoubtedly has direct and indirect effects (67). The food system is a major consumer of land and water resources; it produces, and can capture, environmental pollutants. Therefore, as society strives for means to ensure a responsible and sustainable impact on the globe's natural resources, a food system supported by evidence-based decision-making is more important now than ever.

Acknowledgements

The authors would like to acknowledge the valuable contributions of David Adamson, João Afonso, Peter Ballantyne, Camille Bellet, David Brodbelt, Paula Caceres-Soto, Hannah Davies, Nicoline de Haan, Alexis Delabouglise, Matthew Ferrari, Simon Firestone, Jane Gibbens, Marius Gilbert, Barbara Häsler, Robert Jakob, Olga Jonas, Vivek Kapur, Joe Lane, Timos Lanitis, Tim Leyland, David McIver, Dianne Mayberry, Sumiko Mekaru, Shannon Mesenhowski, Anna Okello, Walter Okello, Brian Perry, Marisa Peyre, Julio Pinto, Didier Raboisson, Tom Randolph, Karl Rich, Timothy Robinson, Jaime Romero, Peregrine Rothman-Ostrow, Jeremy Salt, Emily Tagliaro, Peter Tozer, Mark Van Wijk, William Wint, Paul Wood and Panagiotis Zervas.

The Global Burden of Diseases programme has received funding from the Bill & Melinda Gates Foundation; the Foreign, Commonwealth and Development Office of the United Kingdom; and the Australian Centre for International Agricultural Research.

L'impact mondial des maladies animales : une nouvelle approche pour mieux comprendre et gérer les maladies affectant le bétail et l'aquaculture

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Résumé

Les investissements réalisés en santé animale et dans les Services vétérinaires ont un impact mesurable sur la santé des personnes et de l'environnement. Le système de mesure appliqué à ces investissements doit reposer sur un référentiel de base décrivant l'impact de la santé et du bien-être animal de manière à justifier et classer par priorités les ressources allouées et à mesurer les effets des interventions. Les auteurs présentent une étude conduite dans le cadre d'une enquête scientifique destinée à identifier les problèmes et à rechercher des solutions de manière inclusive. L'étude pose la question de savoir à quoi devrait ressembler un système conçu pour mesurer l'impact sur

la société des maladies animales, et quelle serait sa valeur ajoutée. En outre, l'étude est conduite de manière à être accessible à une large audience afin d'encourager cette dernière à participer aux discussions. Étant donné que les animaux d'élevage constituent une entité économique, y compris les animaux appartenant à des éleveurs pauvres, le système de mesure doit reposer sur des principes économiques. Les exploitants pratiquant une agriculture de subsistance subissent les effets négatifs des disparités entre les différentes technologies applicables à la santé animale, disparités auxquelles il est possible de remédier par le biais d'interventions associant des mesures dictées par l'offre et par la demande et en renforçant l'efficacité du soutien financier ciblé apporté par les organisations gouvernementales et non gouvernementales. Le Programme « L'impact mondial des maladies animales » (GBADs) aura pour tâche de glaner les données existantes afin de mesurer les pertes associées à la santé animale au sein de systèmes de production qui auront été soigneusement caractérisés au préalable. Grâce à l'élucidation cohérente et transparente des pertes imputables à chaque problème de santé animale, des comparaisons pertinentes pourront être effectuées concernant l'impact des maladies animales par maladies, par systèmes de production et par pays, et la répartition de cet impact dans les populations concernées suivant le statut socio-économique et le genre des intéressés sera mieux comprise. Le Programme GBADs entend créer un moteur de recherche et un portail de données qui seront disponibles sur le Cloud et donneront aux utilisateurs l'accès à des outils de mesure de l'impact des maladies et à d'autres informations présentées sous forme graphique, ainsi qu'à des outils d'aide à la décision sous forme de scénarios prospectifs sur la santé animale et aux résultats d'études plus larges de modélisation économique. La vision du GBADs – renforcer le système de production de denrées alimentaires au profit de la société et de l'environnement – est un exemple de mise en œuvre du concept Une seule santé.

Mots-clés
Agricultrices – Agriculture – Aquaculture – Bétail – Économie – Genre – Impact – Investissement – Pauvreté – Programme « L'impact mondial des maladies animales » – Référentiel de base – Une seule santé.

El impacto global de las enfermedades animales, como nuevo planteamiento para aprehender y manejar las enfermedades en la ganadería y la acuicultura

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Resumen
Las inversiones en sanidad animal y en los Servicios Veterinarios pueden tener un efecto mensurable en la salud de las personas y el medio ambiente. Para efectuar estas inversiones se precisan parámetros que describan y cuantifiquen la situación de partida y el impacto de los problemas de sanidad y bienestar animales, a fin de poder, a partir de ahí, justificar y jerarquizar la asignación de recursos y medir los efectos de las intervenciones. Este artículo, inscrito en un

proceso de indagación científica encaminado a detectar problemas y buscar soluciones de forma incluyente, plantea la cuestión general de cómo debería ser y qué valor añadido aportaría un sistema destinado a medir el impacto que imponen a la sociedad las enfermedades animales. Los autores, además, tratan de exponer la cuestión de manera que sea accesible a un público amplio, al que se alienta a participar en este debate. Dado que los animales de granja (incluidos los de pequeñas explotaciones) constituyen una entidad económica, tal sistema debería estar basado en principios económicos. Los productores que trabajan en régimen de subsistencia se ven negativamente afectados por las disparidades existentes en materia de tecnología zoosanitaria, disparidad que cabe corregir con una combinación de intervenciones marcadas por la oferta y otras marcadas por la demanda, dirigiendo así más selectivamente el apoyo económico de entidades gubernamentales y organizaciones no gubernamentales. El programa GBADs (El impacto global de las enfermedades animales) servirá para compilar datos ya existentes con el fin de medir las pérdidas zoosanitarias dentro de sistemas productivos cuidadosamente caracterizados. La atribución coherente y transparente de estas pérdidas zoosanitarias permitirá efectuar comparaciones significativas del impacto que representan las enfermedades animales en el caso de diferentes dolencias, sistemas productivos o países y pondrá de relieve cómo se distribuye este impacto en función del género y la condición socioeconómica de las personas. Por medio del programa GBADs se creará un motor de conocimiento y portal de datos ubicado en la nube que permita al usuario acceder a mediciones del impacto de enfermedades y representaciones gráficas conexas, a herramientas de apoyo a la adopción de decisiones, en forma de hipotéticas situaciones zoosanitarias futuras, y a los resultados de modelizaciones económicas más generales. La aspiración del programa GBADs – reforzar el sistema alimentario en beneficio de la sociedad y el medio ambiente – constituye un ejemplo de aplicación en la práctica del pensamiento en clave de Una sola salud.

Palabras clave
Acuicultura – Agricultoras-productoras – Agricultura – Economía – Ganado – Género – Impacto – Inversión – Pobreza – Programa «El impacto global de las enfermedades animales» – Situación de partida – Una sola salud.

References

1. Organisation for Economic Co-operation and Development (OECD) (2000). – A system of health accounts. OECD Publishing, Paris, France, 208 pp. doi:10.1787/9789264181809-en.

2. Organisation for Economic Co-operation and Development (OECD), Eurostat & World Health Organization (WHO) (2017). – A system of health accounts 2011: revised edition. OECD Publishing, Paris, France, 520 pp. doi:10.1787/9789264270985-en.

3. World Health Organization (WHO) (2019). – Global spending on health: a world in transition. WHO/HIS/HGF/HFWorkingPaper/19.4. WHO, Geneva, Switzerland, 68 pp. Available at: www.who.int/health_financing/documents/health-expenditure-report-2019.pdf?ua=1 (accessed on 30 January 2021).

4. HealthforAnimals (2015). – Global benchmarking survey 2015: benchmarking the competitiveness of the global animal health industry. HealthforAnimals, Brussels, Belgium, 36 pp. Available at: healthforanimals.org/150-global-benchmarking-survey-2015-report.html (accessed on 30 January 2021).

5. Fanshel S. & Bush J.W. (1970). – A health-status index and its application to health-services outcomes. *Oper. Res.*, **18** (6), 1021–1066. doi:10.1287/opre.18.6.1021.

6. Bush J.W., Fanshel S. & Chen M.M. (1972). – Analysis of a tuberculin testing program using a health status index. *Socioecon. Plann. Sci.*, **6** (1), 49–68. doi:10.1016/0038-0121(72)90006-7.

7. Murray C.J.L. (1994). – Quantifying the burden of disease: the technical basis for disability-adjusted life years. *Bull. WHO*, **72** (3), 429–445. Available at: apps.who.int/iris/handle/10665/264057 (accessed on 6 August 2021).

8. Wirsenius S., Azar C. & Berndes G. (2010). – How much land is needed for global food production under scenarios of dietary changes and livestock productivity increases in 2030? *Agric. Syst.*, **103** (9), 621–638. doi:10.1016/j.agsy.2010.07.005.

9. Molden D. (ed.) (2007). – Water for food, water for life: a comprehensive assessment of water management in agriculture. Earthscan, London, United Kingdom; & International Water Management Institute, Colombo, Sri Lanka, 640 pp. Available at: hdl.handle.net/10568/36463 (accessed on 30 January 2021).

10. Gerbens-Leenes P.W., Mekonnen M.M. & Hoekstra A.Y. (2013). – The water footprint of poultry, pork and beef: a comparative study in different countries and production systems. *Water Resour. Indust.,* **1–2**, 25–36. doi:10.1016/j.wri.2013.03.001.

11. Steinfeld H., Gerber P.J., Wassenaar T., Castel V., Rosales M. & de Haan C. (2006). – Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome, Italy, 416 pp. Available at: www.fao.org/3/a0701e/a0701e.pdf (accessed on 30 January 2021).

12. Ostrom E. (1990). – Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge, United Kingdom. doi:10.1017/CBO9780511807763.

13. Herrero M., Thornton P.K. […] & Havlík P. (2017). – Farming and the geography of nutrient production for human use: a transdisciplinary analysis. *Lancet Planet. Hlth*, **1** (1), e33–e42. doi:10.1016/S2542-5196(17)30007-4.

14. Tisdell C.A. & Adamson D. (2017). – The importance of fixed costs in animal health systems. *In* The economics of animal health (J. Rushton, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 49–56. doi:10.20506/rst.36.1.2608.

15. Herrero M., Grace D., Njuki J., Johnson N., Enahoro D., Silvestri S. & Rufino M.C. (2013). – The roles of livestock in developing countries. *Animal*, **7** (Suppl. 1), 3–18. doi:10.1017/S1751731112001954.

16. World Health Organization (WHO) Commission on Social Determinants of Health (2008). – Closing the gap in a generation: health equity through action on the social determinants of health: final report of the Commission on Social Determinants of Health. WHO, Geneva, Switzerland, 246 pp. Available at: apps.who.int/iris/bitstream/handle/10665/43943/9789241563703_eng.pdf?sequence=1&isAllowed=y (accessed on 31 May 2021).

17. Ottersen O.P., Dasgupta J. [...] & Scheel I.B. (2014). – The political origins of health inequity: prospects for change. *Lancet*, **383** (9917), 630–667. doi:10.1016/S0140-6736(13)62407-1.

18. Thornton P.K., Jones P.G. [...] & Kulkar U. (2006). – Mapping climate vulnerability and poverty in Africa. International Livestock Research Institute, Nairobi, Kenya, 200 pp. Available at: hdl.handle.net/10568/2307 (accessed on 30 January 2021).

19. Cleaveland S., Laurenson M.K. & Taylor L.H. (2001). – Diseases of humans and their domestic mammals: pathogen characteristics, host range and the risk of emergence. *Philos. Trans. Roy. Soc. Lond. B, Biol. Sci.*, **356** (1411), 991–999. doi:10.1098/rstb.2001.0889.

20. Patterson G.T., Thomas L.F., Coyne L.A. & Rushton J. (2020). – Moving health to the heart of agri-food policies; mitigating risk from our food systems. *Glob. Food Secur.*, **26**, 100424. doi:10.1016/j.gfs.2020.100424.

21. Backhouse R.E. (2004). – The ordinary business of life: a history of economics from the ancient world to the twenty-first century. Princeton University Press, Princeton, United States of America, 384 pp. Available at: press.princeton.edu/books/paperback/9780691116297/the-ordinary-business-of-life (accessed on 3 September 2020).

22. Howe K.S. (1985). – An economist's view of animal disease. *In* Proc. Society for Veterinary Epidemiology and Preventive Medicine (M.V. Thrusfield, ed.), 27–30 March, Reading, United Kingdom. Society for Veterinary Epidemiology and Preventive Medicine, 122–129.

23. McInerney J.P. (1987). – An economist's approach to estimating disease losses. *In* Diseases in farm livestock: economics and policy (agriculture) (K.S. Howe & J.S. McInerney, eds). Commission of the European Communities, Brussels, Belgium, 25–60.

24. McInerney J.P., Howe K.S. & Schepers J.A. (1992). – A framework for the economic analysis of disease in farm livestock. *Prev. Vet. Med.*, **13** (2), 137–154. doi:10.1016/0167-5877(92)90098-Z.

25. Mclnerney J. (1996). – Old economics for new problems – livestock disease: presidential address. *J. Agric. Econ.*, **47** (1–4), 295–314. doi:10.1111/j.1477-9552.1996.tb00695.x.

26. Tisdell C. (1995). – Assessing the approach to cost–benefit analysis of controlling livestock diseases of McInerney and others. Working Paper No. **3**. Research papers and reports in animal health economics: an ACIAR Thai–Australian project. University of Queensland, Brisbane, Australia, 19 pp. doi:10.22004/ag.econ.164425.

27. Banerjee A.V. & Duflo E. (2011). – Poor economics: rethinking poverty and the ways to end it. Penguin Random House India, Gurugram, India, 320 pp.

28. Sachs J. (2005). – The end of poverty: economic possibilities for our time. Penguin Books, New York, United States of America, 416 pp.

29. Rosenstein-Rodan P.N. (1943). – Problems of industrialisation of Eastern and South-Eastern Europe. *Econ. J.*, **53** (210–211), 202–211. doi:10.2307/2226317.

30. Nurkse R. (1952). – Some international aspects of the problem of economic development. *Am. Econ. Rev.*, **42** (2), 571–583.

31. Scitovsky T. (1954). – Two concepts of external economies. *J. Polit. Econ.*, **62** (2), 143–151. doi:10.1086/257498.

32. Leibenstein, H. (1957). – Economic backwardness and economic growth: studies in the theory of economic development. John Wiley & Sons, New York, United States of America, 319 pp.

33. Hirschman A.O. (1958). – The strategy of economic development. Yale University Press, New Haven, United States of America, 230 pp.

34. Ahuja V. (2004). – The economic rationale of public and private sector roles in the provision of animal health services. *In* Veterinary institutions in the developing world: current status and future needs (C. de Haan, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **23** (1), 33–45. doi:10.20506/rst.23.1.1464.

35. Rushton J. & Gilbert W. (2016). – The economics of animal health: direct and indirect costs of animal disease outbreaks. *In* Proc. 84th General Session of the World Organisation for Animal Health (OIE), 22–27 May, Paris, France. OIE, Paris, France. doi:10.20506/TT.2551.

36. Perry B.D. (ed.) (1999). – The economics of animal disease control. *Rev. Sci. Tech. Off. Int. Epiz.*, **18** (2), 561 pp.

37. Rushton J. (ed.) (2017). – The economics of animal health. *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 384 pp.

38. Pritchett J., Thilmany D. & Johnson K. (2005). – Animal disease economic impacts: a survey of literature and typology of research approaches. *Int. Food Agribus. Manag. Rev.*, **8** (1), 1–23.

39. Morris R.S. (1999). – The application of economics in animal health programmes: a practical guide. *Rev. Sci. Tech. Off. Int. Epiz.*, **18** (2), 305–314. doi:10.20506/rst.18.2.1173.

40. Rushton J. (2017). – Improving the use of economics in animal health – challenges in research, policy and education. *Prev. Vet. Med.*, **137** (Pt B), 130–139. doi:10.1016/j.prevetmed.2016.11.020.

41. Rushton J. & Viscarra R. (2004). – Livestock production systems in South America: analysis and trends. Report for a study on livestock production systems in South America for FAO. Food and Agriculture Organization of the United Nations, Rome, Italy, 33 pp.

42. Henderson B., Godde C., Medina-Hidalgo D., van Wijk M., Silvestri S., Douxchamps S., Stephenson E., Power B., Rigolot C., Cacho O. & Herrero M. (2016). – Closing system-wide yield gaps to increase food production and mitigate GHGs among mixed crop–livestock smallholders in sub-Saharan Africa. *Agric. Syst.*, **143**, 106–113. doi:10.1016/j.agsy.2015.12.006.

43. Herrero M., Havlík P., Valin H., Notenbaert A., Rufino M., Thornton P., Blümmel M., Weiss F., Grace D. & Obersteiner M. (2013). – Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proc. Natl. Acad. Sci. U.S.A.*, **110** (52), 20888–20893. doi:10.1073/pnas.1308149110.

44. Gilbert M., Nicolas G., Cinardi G., Van Boeckel T.P., Vanwambeke S.O., Wint G.R.W. & Robinson T.P. (2018). – Global distribution data for cattle, buffaloes, horses, sheep, goats, pigs, chickens and ducks in 2010. *Sci. Data*, **5**, 180227. doi:10.1038/sdata.2018.227.

45. van Wijk M., Hammond J. […] & Yameogo V. (2020). – The rural household multiple indicator survey, data from 13,310 farm households in 21 countries. *Sci. Data*, **7**, 46. doi:10.1038/s41597-020-0388-8.

46. Mayberry D., Ash A., Prestwidge D., Godde C.M., Henderson B., Duncan A., Blummel M., Ramana Reddy Y. & Herrero M. (2017). – Yield gap analyses to estimate attainable bovine milk yields and evaluate options to increase production in Ethiopia and India. *Agric. Syst.*, **155**, 43–51. doi:10.1016/j.agsy.2017.04.007.

47. Mayberry D., Ash A., Prestwidge D. & Herrero M. (2018). – Closing yield gaps in smallholder goat production systems in Ethiopia and India. *Livest. Sci.*, **214**, 238–244. doi:10.1016/j.livsci.2018.06.015.

48. Rothman-Ostrow P., Gilbert W. & Rushton J. (2020). – Tropical livestock units: re-evaluating a methodology. *Front. Vet. Sci.*, **7**, 556788. doi:10.3389/fvets.2020.556788.

49. Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A. & Tempio G. (2013). – Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy, 139 pp. Available at: www.fao.org/3/i3437e/i3437e.pdf (accessed on 30 January 2021).

50. Mayberry D., Bartlett H., Moss J., Davison T. & Herrero M. (2019). – Pathways to carbon-neutrality for the Australian red meat sector. *Agric. Syst.*, **175** (44), 13–21. doi:10.1016/j.agsy.2019.05.009.

51. Shaw A.P.M., Rushton J., Roth F. & Torgerson P.R. (2017). – DALYs, dollars and dogs: how best to analyse the economics of controlling zoonoses. *In* The economics of animal health (J. Rushton, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 147–161. doi:10.20506/rst.36.1.2618.

52. Torgerson P.R., Rüegg S., Devleesschauwer B., Abela-Ridder B., Havelaar A.H., Shaw A.P.M., Rushton J. & Speybroeck N. (2018). – zDALY: an adjusted indicator to estimate the burden of zoonotic diseases. *One Hlth*, **5**, 40–45. doi:10.1016/j.onehlt.2017.11.003.

53. GBD 2017 Risk Factor Collaborators (2018). – Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet*, **392** (10159), 1923–1945. doi:10.1016/S0140-6736(18)32225-6.

54. Afonso J.S., Bruce M., Keating P., Raboisson D., Clough H., Oikonomou G. & Rushton J. (2020). – Profiling detection and classification of lameness methods in British dairy cattle research: a systematic review and meta-analysis. *Front. Vet. Sci.*, **7**, 542. doi:10.3389/fvets.2020.00542.

55. Dórea F.C. & Vial F. (2016). – Animal health syndromic surveillance: a systematic literature review of the progress in the last 5 years (2011–2016). *Vet. Med. (Auckl.)*, **7**, 157–170. doi:10.2147/VMRR.S90182.

56. Mathers C.D., Lopez A.D. & Murray C.J.L. (2006). – The burden of disease and mortality by condition: data, methods, and results for 2001. *In* Global burden of disease and risk factors (A.D. Lopez, C.D. Mathers, M. Ezzati, D.T. Jamison & C.J. Murray, eds). World Bank, Washington, DC, United States of America. Available at: www.ncbi.nlm.nih.gov/books/NBK11808/ (accessed on 26 November 2020).

57. Rushton J. (2009). – The economics of animal health and production. CABI, Wallingford, United Kingdom. doi:10.1079/9781845931940.0000.

58. Marsh T.L., Pendell D. & Knippenberg R. (2017). – Animal health economics: an aid to decision-making on animal health interventions – case studies in the United States of America. *In* The economics of animal health (J. Rushton, ed.). *Rev. Sci. Tech. Off. Int. Epiz.*, **36** (1), 137–145. doi:10.20506/rst.36.1.2617.

59. Pendell D.L., Marsh T.L., Coble K.H., Lusk J.L. & Szmania S.C. (2015). – Economic assessment of FMDv releases from the National Bio and Agro Defense Facility. *PLoS One*, **10** (6), e0129134. doi:10.1371/journal.pone.0129134.

60. Rushton J., Bruce M., Bellet C., Torgerson P., Shaw A., Marsh T., Pigott D., Stone M., Pinto J., Mesenhowski S. & Wood P. (2018). – Initiation of Global Burden of Animal Diseases Programme. *Lancet*, **392** (10147), 538–540. doi:10.1016/S0140-6736(18)31472-7.

61. Watkins K.L., Rutten-Ramos S. & Huntington B. (2020). – Modeling broiler industry loss to estimate the value potential of tracking the global burden of animal diseases [abstract 88]. *In* Poultry Science Association (PSA) 109th Annual Meeting: Abstracts, 20–22 July, Champaign, United States of America, 45 pp. Available at: poultryscience.org/files/galleries/2020-PSA-Abstracts.pdf (accessed on 29 September 2020).

62. Stevens G.A., Alkema L. […] & the GATHER Working Group (2016). – Guidelines for accurate and transparent health estimates reporting: the GATHER statement. *PLoS Med.*, **13** (6), e1002056. doi:10.1371/journal.pmed.1002056.

63. Research Data Alliance International Indigenous Data Sovereignty Interest Group (2019). – CARE principles for indigenous data governance. Global Indigenous Data Alliance. Available at: www.gida-global.org/care (accessed on 30 January 2021).

64. Havelaar A.H., Kirk M.D. [...] & Devleesschauwer B. (2015). – World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med.*, **12** (12), e1001923. doi:10.1371/journal.pmed.1001923.

65. United Nations (UN) (2015). – Transforming our world: the 2030 Agenda for Sustainable Development. UN, New York, United States of America, 41 pp. Available at: sustainabledevelopment.un.org/post2015/transformingourworld/publication (accessed on 29 September 2020).

66. Finegold C., Ried J., Denby K. & Gurr S. (2019). – Global burden of crop loss [poster] [version 1; not peer reviewed]. *Gates Open Res.*, **3**, 1599. doi:10.21955/gatesopenres.1116448.1.

67. Osofsky S.A. (2019). – The global burden of (how we manage) animal disease: learning lessons from southern Africa. *J. Wildl. Dis.*, **55** (4), 755–757. doi:10.7589/2019-01-024.

Rev. Sci. Tech. Off. Int. Epiz., 2021, **40** (2), 585-595

Sustainable Development Goals and livestock systems

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Summary

Within the framework of the Sustainable Development Goals (SDGs) of the United Nations, particularly those that livestock impact most significantly (SDGs 1, 2, 3, 5, 8, 12, 13, 15 and 17), this paper provides an overview of the livestock sector's impact on food system sustainability and opportunities for building solutions through sustainable livestock options that are supported by robust animal health services.

The discourse is shaped by the experiences of the Global Agenda for Sustainable Livestock, a multi-stakeholder partnership which facilitates policy dialogue and action among diverse stakeholders to make livestock systems more sustainable. The Global Agenda for Sustainable Livestock adopted the aforementioned SDGs as the reference framework for its actions, which are organised under four domains (food and nutrition security, animal health and welfare, livelihoods and economic growth, and climate and natural resources). These domains are used to highlight the complexity and diversity of the livestock sector, its positive and negative relationships to development, the integral roles of animal health systems and the opportunities for livestock sector contributions towards a sustainable future.

Keywords

Animal health – Animal health system – Climate – Economic growth – Food and nutrition security – Global Agenda for Sustainable Livestock – Human health – Livelihoods – Livestock system – Natural resource use – SDGs – Sustainable Development Goal.

Introduction

The livestock sector plays multiple, predominantly positive roles in all Sustainable Development Goals (SDGs), with multiple and diverse interactions and trade-offs. The Global Agenda for Sustainable Livestock (GASL) defines sustainable livestock as follows: 'To be sustainable, livestock sector growth needs to simultaneously address key environmental, social, and economic challenges [which include] growing natural resources scarcity, climate change, widespread poverty, food insecurity and global threats to animal and human health and animal welfare' (1). Shaping sustainable livestock solutions is influenced by two key factors – the demand for livestock commodities and the sector's diversity. Livestock are produced in multiple different ways across the world: on large-scale industrial farms (sometimes referred to as 'capital-intensive' production), on one of the half a billion small-scale, mixed crop–livestock farms (sometimes referred to as 'labour-intensive' production) and on extensive pastoral lands, which make up over a quarter of the Earth's land area. In some parts of the world, 'livestock' means a piece of packaged meat or a bottle of milk on the supermarket shelf, whereas, in others, 'livestock' means animals that are an integral part of managing household economy and risk. This diversity means that to enhance the positive, and mitigate the negative, impacts of livestock on development, and thereby improve sustainability for the sector, different actions are needed depending on the production system, the commodity, and the agro-climatic and socio-economic context.

The demand for livestock products will increase by more than 70% between 2005 and 2030 (2). While this demand is growing only modestly in high-income countries (HICs), it is growing rapidly in lower- and middle-income countries

https://doi.org/10.20506/rst.40.2.3247

(LMICs). In some LMICs, such as those in some parts of Asia (3), this growth is due mostly to rising incomes, whereas, in much of Africa, the increasing demand is due to population growth (4). The growth in meat consumption is expected to continue in the coming decades, and livestock systems are raising production to meet this demand. At the same time, they are adapting to satisfy the changing preferences of an increasingly affluent and urbanised population in a globalised economy. Such rapid, uneven growth in production and trade varies by region and production system and presents multiple risks as well as opportunities for sustainable development (4).

There are multiple ways to meet the demand for livestock products, and these will undoubtedly change over time. In LMICs, where demand is rising the most, growth will be met, at least in the short term, by sustainably intensifying the small- and medium-scale farms that produce the bulk of meat and milk today. In HICs, the challenge for large-scale, capital-intensive production will be to determine how to adapt to tapering demand. Such transitions need to consider multiple development outcomes and trade-offs. It will be important to foster balanced growth and environmentally friendly intensification to allow sustainable development, and it is essential to learn lessons from the already intensive agriculture systems in many HICs – both their pros and their cons.

The ongoing COVID-19 pandemic illustrates the fact that the global food system is fully interconnected and at the same time fragile. We do not yet know the full impact of the pandemic, but what we do know is that a sustainable livestock sector is needed that simultaneously responds to the demand for food, contributes to development opportunities and mitigates harm. In this context, well-functioning, fully integrated animal health services are key. In the context of this paper, animal health services are also referred to as 'animal health systems', indicating the link to the One Health approach. They are defined as public and private agencies that preserve and develop animal resources, improve rural livelihoods (thereby reducing poverty and hunger) and support global health security (5). They do this both by combating food safety crises and antimicrobial resistance and by addressing 'risk at source' for emerging pandemic threats.

Cross-sectoral integration and prioritisation of Sustainable Development Goals

While livestock systems are relevant to all SDGs, the Global Agenda for Sustainable Livestock (GASL) recognises nine SDGs that are of particular relevance to the livestock sector; they include SDG 17 – the goal that underpins every other goal – and eight goals that livestock contribute to directly (see Fig. 1).

Fig. 1
The nine Sustainable Development Goals (SDGs) with strong links to the livestock sector, as identified by the Global Agenda for Sustainable Livestock (GASL)
These include the eight goals to which livestock contribute to directly, plus SDG 17, which underpins every other goal. GASL is enhancing livestock stakeholders' commitment and investments in support of all 17 of the SDGs contained in the United Nations' Agenda 2030

In its current 2019–2021 Action Plan (6) and in its theory of change developed in 2020 (7), GASL concentrates on four sustainability domains: a) food and nutrition security, b) livelihoods and economic growth, c) animal health and welfare, and d) climate and natural resource use. These domains were adopted by the 2018 Global Forum for Food and Agriculture in Berlin (8) to better focus its actions in support of achieving the SDGs. Noting their relationship to the three pillars of sustainable development (societal well-being, environmental protection and economic growth) and the central role of animal health services, the authors use these domains to frame the present overview of ways in which to improve livestock and its contributions to the SDGs (see Fig. 2).

Food and nutrition security

The livestock sector has a critical role to play in this domain, which is related particularly to SDGs 2 and 3. Beyond providing 18% of the total calories and 40% of the

Fig. 2
Relationship between Sustainable Development Goals and sustainability domains
Goals outlined in black fall under more than one domain. Darker colours indicate the goals with strong links to the livestock sector

protein in people's diets at the global level (3), livestock-derived foods provide essential micronutrients, such as vitamin A, vitamin B12, riboflavin, calcium, iron, and zinc. These nutrients are difficult to obtain in adequate quantities from plant sources alone (9), especially for the world's most vulnerable groups, such as children, pregnant women, and the elderly (10). Milk, meat, and eggs can help combat micronutrient deficiencies, or 'hidden hunger', by providing people with essential vitamins and minerals. They can help reduce mortality and stunting among children. In contrast, excess consumption of livestock-derived foods is often associated with non-communicable diseases caused by obesity. Many emerging economies are now facing a 'double burden' of malnutrition, with some segments of the population undernourished, and other, wealthier, segments increasingly overweight and obese (in 2016, 39% of the world's population aged 18 years or older were overweight and 13% were obese [11]). Consequently, for some people, having a balanced, healthy diet will mean consuming less milk, meat, and eggs, whereas, for others, it will mean consuming more.

In addition to providing much-needed nutrients in many parts of the world, especially areas where mixed crop–livestock farms are ubiquitous, as is the case in many LMICs, livestock are integral to food security because of the intimate connection between raising animals and growing crops. Income from livestock, manure, and provision of traction and transport (within the farm and between farms and markets) contributes to crop production to such an extent that over half the developing world's staple cereals can only be produced because livestock are integral to the system. Such integrated production means that livestock can transform materials such as grass, straw, and agro-industrial and household wastes – none of which are edible by humans – into high-quality protein (12). However, especially in capital-intensive systems, animal feed may be based on cereals that people do eat, and/or are grown on land that could be used to produce food crops for humans. To enhance livestock's contribution to ending hunger, ways must be found to avoid such feed–food competition. These will include improving the use of crop by-products (13) and improving feed conversion efficiency through genetic improvement (14). Responsible consumption and production (SDG 12) will also reduce feed–food competition.

Animal health services are indispensable to maximising livestock's contributions to food and nutrition security. Healthy, well-cared-for animals can meet increasing food demands thanks to their higher productivity. They also require less land and feed per unit of product, and they support healthy, balanced diets.

In short, sustainable livestock systems support healthy, balanced diets.

Animal health and animal welfare

This domain relates to all three pillars of sustainable development, but especially to the pillar of societal well-being, as there is a strong connection between human health and well-being and animal health and welfare. It concerns mainly SDGs 2 and 3, because it addresses the crucial interface of animal health and human health, where issues of zoonoses, foodborne diseases and antimicrobial resistance are major challenges to sustainability and must be addressed. The present COVID-19 pandemic has both highlighted and exacerbated such challenges and drawn the world's attention to the interdependence of animals, people, and the environment, raising again the need for a One Health approach to tackle such complex problems. The Tripartite Alliance between the Food and Agriculture Organization of the United Nations (FAO), World Organisation for Animal Health (OIE) and World Health Organization (WHO) (15) calls for a stronger focus on the One Health approach, emphasising that it is the optimal approach for preventing and responding to zoonotic disease outbreaks and pandemics. The One Health approach, as well as the One Welfare approach (16), goes far beyond the boundaries of infectious disease control and is essential to achieving the SDGs. A recent assessment of opportunities to mitigate future pandemics (17) also highlighted One Health as a key solution. Adopting a One Health approach, which unites medical, veterinary, and environmental expertise, will help governments, businesses and civil society to achieve enduring health for people, animals, and environments alike. One of the key challenges that requires a One Health approach is that of antimicrobial resistance (AMR), which is a rapidly emerging threat to human health. As major consumers of antibiotics, livestock are important contributors to global AMR, so avoiding or banning the use of antibiotics as growth promotors and focusing on better animal care and welfare will be vital if we are to reduce the threat of AMR. It will be important when addressing this challenge to adapt the One Health approach to the many diverse production systems (18).

Systems that ensure animals are healthy are a vital component of the solutions to these multiple challenges and require greater investment, especially in LMICs. Stronger and better-resourced animal health systems will ensure that animal diseases are diagnosed and that their impact is mitigated, which can prevent them from becoming zoonoses. Furthermore, good animal husbandry, good animal welfare and access to relevant vaccines can limit the unrestrained use of antimicrobials in animal production. Healthy animals are also inherently associated with reduced foodborne diseases. Veterinary personnel on the ground (both private and public) need to be able to work with public and environmental health officers in a seamless way to prevent future pandemics. Continuous access to professional advice is key for all livestock farmers and needs to be made available by both public and private animal health services (19).

In short, sustainable livestock systems support healthy, well-cared-for animals that provide safe food and ensure healthy people and ecosystems.

Livelihoods and economic growth

This domain relates to the pillars on economic development and societal well-being and to SDGs 1, 8 and 12. At the beginning of 2020, about 10% of the world's population was estimated to be living on less than US$ 1.90/day, 60 million more people than in 2014. The COVID-19 crisis may push another 120 million people into poverty in a very short time (15). About half of the world's poor people depend directly on livestock for their livelihoods. Even for many not-so-poor people, livestock are essential for their livelihoods (although it may look very different in different parts of the world). In multiple ways, farm animals are a major asset – providing capital and a source of (often regular) income, supporting resilience and insuring against risks. In addition, if the income from livestock production is enough to allow farmers to save, they can use the additional money to move out of the sector, e.g. by starting a small business; thus, for the poor, raising livestock can often be a stepping stone to prosperous alternative livelihoods (20).

On average, globally, livestock production contributes 40% of agricultural gross domestic product (GDP). Livestock production and merchandising in industrialised countries account for 53% of agricultural GDP (21), and across the developing world they account for between 15% and 85% of agricultural GDP. Economically, livestock production is one of the fastest-growing sectors in developing countries (2.5% per year over the last two decades) (22). Capturing the economic benefits of the expanding livestock market can help to sustain overall economic growth. Increasing the currently limited productivity of labour in the livestock sector through training, technological upgrading and innovation can produce substantial and sustained value creation in developing country livestock supply chains. Employment returns on investment in the livestock sector are higher than average, because of its high growth rate and labour intensity. This is true not only in rural livestock

production, but also in urban processing and marketing. The development of national livestock master plans to support effective investment planning is key to optimising livestock's contribution to national economic growth. Good examples of such plans are those of Ethiopia (23), Bihar in India (24), and the African Union Inter-African Bureau for Animal Resources (25).

In LMICs, the livestock sector has particularly important roles for women, who often provide much of the labour for animal care. Women's access to land, finance, information, and markets is, however, very uneven, particularly in extensive and labour-intensive systems (26, 27). There are also instances where, as labour-intensive systems transition to become more capital-intensive systems, and livestock activities become more lucrative or formalised, women's roles can become marginalised and their access to income benefits can be reduced (28). To help achieve gender equality in agricultural populations, gender concerns need to be integral to every solution, and so they must be taken into account when planning access to animal health systems. In LMICs in particular, partly because of cultural sensitivities, female veterinarians and female animal health workers are needed to support women involved in livestock production (29).

Livestock contributions to livelihoods and economic growth at every level – from farm to nation – can only be fully realised if the animals are healthy and productive, and animal health services are key in this regard. The role of farm animals in mitigating risk for the poor will be negated if animals are lost to disease. According to FAO, 21% of the world's livestock are lost to disease (30), and, at present, animal health services – public and private – are limited in LMICs (31).

In short, sustainable livestock systems support men, women, and young people worldwide to benefit from economic opportunities, to mitigate livelihood risks and contribute to national economies.

Climate and natural resource use

The relationship between livestock, climate and natural resource use is key for all three pillars of sustainable development and relates directly to SDGs 12, 13 and 15. This relationship has also given rise to debate on the consumption of animal-source food: a growing number of studies (32, 33) argue that reducing the share of animal-source food in diets could bring important environmental and health benefits, while others emphasise the fact that there is scientific evidence that animal-source food is essential for infants up to 1,000 days of age (34).

The livestock sector contributes significantly to climate change: globally, it is reported to be responsible for 14.5% of human-induced greenhouse gas (GHG) emissions (although estimates vary depending on the life-cycle analysis used) (35). Like all agricultural sectors, it faces the challenge of improving efficiency and, more specifically, of reducing morbidity and mortality through improved animal health systems. Climate change mitigation options can lead to large environmental benefits, with some technical interventions potentially reducing livestock's impact by between 14% and 41% (36, 37). Such interventions usually include improving resource-use efficiency, which simultaneously lessens the GHG emissions per unit of output. These interventions also make a substantial contribution to food security.

Addressing animal health challenges through robust animal health services is one of the key ways of improving animal production efficiency, and healthier animals emit fewer greenhouse gases (38). Improving animal health services will have the biggest impact in places where productivity is currently low, e.g. across the small- and medium-sized farms of Africa and Asia. Here, implementation requires a transfer of technology and knowledge, together with the right incentives and a conducive regulatory framework. In addition, implementation requires participatory and context-specific solutions that integrate traditional knowledge and practices and build upon local, integrated livestock production systems.

Almost one-third of all food produced in the world is lost or wasted between farm and fork, with the livestock sector showing considerable variation in terms of the part of the value chain where the greatest losses occur. In the capital-intensive systems of HICs, most losses occur at the consumer and retail parts of the chain. In LMICs, losses predominantly occur at production (39) stages, often because of poor animal health, which again points to the essential role of animal health systems. Limiting waste and losses along the supply chain can contribute to improved efficiency and sustainability and thus reduce the environmental impacts per unit of livestock commodity (40). To combat food waste, multi-stakeholder action spanning large and small industries and involving every actor (producers, traders, retailers, and consumers) will be key. Livestock also have the potential to play a greater role in waste reduction through their contributions to a 'circular bioeconomy' (i.e. an economy centred on bio-based products, organic waste streams, resource-efficient value chains, organic recycling, and nutrient cycling) (41). Circular bioeconomies are common (but not necessarily the most efficient) in the ubiquitous, mixed crop–livestock farms across LMICs, but far less so in the developed world.

In addition to contributing to climate change, the livestock sector is impacted by climate change: it affects animal performance, feed availability, access to water, animal

health and welfare (42), and biodiversity, particularly in rangelands, which make up 26% of the Earth's land area. Livestock keepers in LMICs, particularly pastoralists, are among the most vulnerable to climate change. Resilience to climate change in livestock production can be enhanced through water and grazing management, breeding of both animals and forage crops for drought and heat resistance, and, more broadly, incorporating animal health and welfare into national and regional disaster response planning (Livestock Emergency Guidelines and Standards) (43). For many pastoral communities, climate-smart interventions include options for income diversification, insurance, and early warning systems. Providing animal health services to these communities, who are often remote and mobile, is challenging but vital, and new business models may help here. For example, Sidai, a company in Kenya that supplies livestock, crop inputs and training, operates a unique 'last-mile' service delivery model that reaches farmers and pastoralists in remote and under-served locations (www.sidai.com).

Pastoral systems can play an important role in environmental stewardship if their risks are mitigated and if animals are managed in ways that contribute to carbon sequestration and biodiversity conservation. For example, improving grazing management can contribute to grassland restoration and carbon sequestration in soils, and, in addition, it can reduce deforestation. Finely balanced approaches that integrate animals, trees, and vegetation, such as agro-silvo-pastoralism, can prevent soil erosion, facilitate water infiltration, and decrease damage to production from extreme weather (44).

Agricultural biodiversity and well-adapted livestock are essential, particularly in harsh environments where crop farming is difficult or impossible. Genetically diverse livestock populations are a precious resource that will help to address future challenges and should be conserved (45) and, mainly in LMIC countries, the close link between livestock breeding services and animal health services should not be overlooked. Through the engagement of animal health services, the impact of livestock on climate change can be reduced through improved health and welfare. The veterinary profession can also be a leading force for sustainability, and there are organisations that are championing a holistic, sustainable approach to the provision of animal health services (www.vetsustain.org). Finally, animal health professionals play a role in reducing the impact of climate change on animals through contributing to disaster response planning and supporting adaptation measures.

In short, sustainable livestock systems mitigate the detrimental impacts of the livestock sector on the environment and climate and support improved production efficiency and resilience outcomes.

Multi-stakeholder partnerships to address complexity and diversity

Given the complexity and diversity of the livestock sector, there is no single solution to the problems that arise and no single way of ensuring that potential sector harms are mitigated, its potential to contribute to development ambitions is realised, and the rising demand for livestock commodities is addressed. Solutions vary depending on the production system, the stakeholders involved, and the economic context of the region concerned. Finding solutions that fit each context requires partnerships between the public and private sectors, governments, non-governmental organisations, civil society, community-based organisations, research, academia, and intergovernmental organisations, with animal health services represented in each stakeholder group. The Global Agenda for Sustainable Livestock provides one such inclusive partnership, at all levels, from local to global. Built upon a shared vision, it is based on agreed goals and principles that hold people and the planet as central (46), while also recognising the diversity of routes towards improving sustainability (47). This multi-stakeholder partnership mobilises and shares knowledge, provides robust evidence, develops cutting-edge tools, and promotes an integrated approach to enhance policy coherence for sustainable livestock production.

The central role of animal health services in supporting the contributions of livestock to the Sustainable Development Goals

The present COVID-19 pandemic emphasises the essential role of animal health services. The discourse above has also emphasised how robust and focused animal health services are integral to achieving positive development outcomes through improving sustainable livestock solutions in every sustainability domain. The multiple roles of animal health services need to be prioritised based on scientific evidence. These services must be supported by comprehensive capacity development across all stakeholders in order to enable them to recognise the importance of good animal health and engage with the animal health sector in developing and implementing solutions. Use of the One Health approach and the provision of science-based information to stakeholders, particularly consumers, will further give animal health services the attention and investment needed to help prevent the next pandemic and to

contribute to improving the role of livestock in sustainable development (48). In GASL's multi-stakeholder approach, the role of its action networks is crucial. These networks, which include the Animal Welfare Action Network and the Livestock Antimicrobial Partnership, ensure that GASL's multi-stakeholder dialogue assigns due importance to measures related to veterinary and animal welfare issues so as to ensure sustainability in the livestock sector (6).

Conclusions

This brief overview of the opportunities and challenges that must be addressed for the livestock sector to improve its role in sustainable development has emphasised that, because of the sector's diversity, the actions towards sustainable development vary by production system, national economy, and changing demand context. A complex mixture of trade-offs and the positive and negative impacts of policies and practices concerning livestock management, production and consumption all need to be factored in. The solutions differ, even if they are all supporting progress towards common goals. Despite such immense variation, several common elements have also been highlighted. These include the essential roles of animal health and veterinary services and the need for multi-stakeholder approaches (GASL and others). The importance of the latter was emphasised in the 2018 report of the High Level Panel of Experts on Food Security and Nutrition, which highlighted the importance of multi-stakeholder partnerships for the livestock sector's ongoing efforts to respond to the increasing demand for livestock commodities (49). The COVID-19 pandemic has further emphasised that unilateral approaches will not solve the present pandemic catastrophe, or prevent others in the future, and that the One Health approach, supported by other multi-stakeholder approaches, is key (18). In spite of the fact that livestock, animal health and animal welfare are rarely mentioned explicitly in the SDGs of the United Nations Agenda 2030, they provide a globally accepted reference framework to guide us towards more sustainability in general and in the livestock sector specifically.

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Les objectifs de développement durable et les systèmes de production animale

F. Schneider & S. Tarawali

Résumé

Se plaçant dans la perspective des objectifs de développement durable (ODD) des Nations unies et plus particulièrement ceux sur lesquels l'élevage exerce le plus grand impact (ODD 1, 2, 3, 5, 8, 12, 13, 15 et 17), les auteurs font un tour d'horizon de l'impact du secteur de l'élevage sur la durabilité des systèmes d'approvisionnement alimentaire et font ressortir les solutions qui peuvent être envisagées en mettant en place des pratiques d'élevage durables soutenues par des services de santé animale robustes.

L'exposé est structuré par les expériences acquises dans le cadre du Programme mondial pour un élevage durable, un partenariat multipartite qui facilite le dialogue politique entre diverses parties prenantes ainsi que les mesures visant à rendre les systèmes d'élevage plus durables. Le Programme mondial a intégré les ODD susmentionnés en tant que cadre de référence de ses interventions, qui se répartissent en quatre domaines (alimentation et sécurité nutritionnelle, santé et bien-être des animaux, moyens de subsistance et croissance économique, climat et ressources naturelles). Ces domaines permettent de souligner la complexité et la diversité du secteur de l'élevage, ses liens positifs et négatifs au regard du développement, le rôle prépondérant des systèmes de santé animale et les perspectives offertes au secteur de l'élevage pour contribuer à un futur durable.

Mots-clés

Climat – Croissance économique – Moyens de subsistance – Objectif de développement durable – ODD – Programme mondial pour un élevage durable – Santé animale – Santé humaine – Sécurité alimentaire et nutritionnelle – Système d'élevage – Système de santé animale – Utilisation des ressources naturelles.

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Objetivos de Desarrollo Sostenible y sistemas ganaderos

F. Schneider & S. Tarawali

Resumen

Situándose en el perspectiva de los Objetivos de Desarrollo Sostenible (ODS) de las Naciones Unidas, en especial de aquellos en los que más influye la ganadería (ODS 1, 2, 3, 5, 8, 12, 13, 15 y 17), los autores exponen a grandes líneas el impacto del sector ganadero en la sostenibilidad del sistema alimentario y las oportunidades que existen para elaborar soluciones que pasen por actuar sobre el sector ganadero con el apoyo de robustos servicios zoosanitarios.

La reflexión se fundamenta en la experiencia del Programa mundial para una ganadería sostenible, alianza multipartita que facilita la acción conjunta y el diálogo sobre políticas de diversas partes interesadas con objeto de hacer más sostenibles los sistemas ganaderos. El Programa mundial adoptó los mencionados ODS como marco de referencia de sus actividades, que están organizadas en cuatro ámbitos: seguridad alimentaria y de la nutrición; sanidad y bienestar animales; medios de sustento y crecimiento económico; y clima y recursos naturales. Estos ámbitos sirven para poner de relieve la complejidad y diversidad del sector ganadero, sus nexos positivos y negativos con el desarrollo, las funciones integrales que cumplen los sistemas de sanidad animal y las posibilidades existentes para que el sector ganadero contribuya a forjar un futuro sostenible.

Palabras clave

Clima – Crecimiento económico – Medios de sustento – Objetivo de Desarrollo Sostenible – ODS – Programa mundial para una ganadería sostenible – Salud humana – Sanidad animal – Seguridad alimentaria y de la nutrición – Sistema ganadero – Sistema zoosanitario – Uso de los recursos naturales.

References

1. Global Agenda for Sustainable Livestock (2021). – About the agenda. Available at: www.livestockdialogue.org/about-agenda/about-the-agenda/en/ (accessed on 28 June 2021).

2. Tilman D. & Clark M. (2014). – Global diets link environmental sustainability and human health. *Nature*, **515** (7528), 518–522. doi:10.1038/nature13959.

3. International Livestock Research Institute (2019). – Options for the livestock sector in developing and emerging economies to 2030 and beyond. Meat: the Future Series. World Economic Forum, Geneva, Switzerland, 28 pp. Available at: hdl.handle.net/10568/99006 (accessed on 11 August 2020).

4. Tarawali S.A. (2020). – Til the cows come home: a well-worn path or a new trajectory? Exploring why livestock matter in sustainable development [PowerPoint presentation]. Presented at the Global Academy of Agriculture and Food Security, Edinburgh, Scotland, 19 February 2020. International Livestock Research Institute, Nairobi, Kenya. Available at: hdl.handle.net/10568/107181 (accessed on 10 March 2021).

5. Eloit M. (2019). – Strengthening Veterinary Services through the OIE PVS Pathway [Preface]. *In* Strengthening Veterinary Services through the OIE PVS Pathway: the case for engagement and investment. World Organisation for Animal Health, Paris, France, 3. Available at: www.oie.int/fileadmin/Home/eng/Media_Center/docs/pdf/SG2018/PVS_BUSINESS_CASE_FINAL.pdf (accessed on 10 March 2021).

6. Global Agenda for Sustainable Livestock (GASL) (2019). – GASL Action Plan 2019–2021. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/About_Agenda/GASL_AP_2019-2021-web.pdf (accessed on 11 August 2020).

7. Global Agenda for Sustainable Livestock (GASL) (2020). – GASL Theory of Change. Visual, narrative, and monitoring and evaluation recommendations. Unpublished. GASL & Wageningen University, Wageningen the Netherlands.

8. Food and Agriculture Organization of the United Nations (FAO) (2018). – Shaping the future of livestock: sustainably, responsibly, efficiently. FAO, Rome, Italy, 20 pp. Available at: www.fao.org/publications/card/en/c/I8384EN/ (accessed on 11 August 2020).

9. Randolph T.F., Schelling E., Grace D., Nicholson C.F., Leroy J.L., Cole D.C., Demment M.W., Omore A., Zinsstag J. & Ruel M. (2007). – Invited review: role of livestock in human nutrition and health for poverty reduction in developing countries. *J. Anim. Sci.*, **85** (11), 2788–2800. doi:10.2527/jas.2007-0467.

10. Grace D., Dominguez-Salas P., Alonso S., Lannerstad M., Muunda E., Ngwili N., Omar A., Khan M. & Otobo E. (2018). – The influence of livestock-derived foods on nutrition during the first 1,000 days of life. ILRI Policy Brief 25. International Livestock Research Institute (ILRI), Nairobi, Kenya, 4 pp. Available at: hdl.handle.net/10568/93116 (accessed on 10 March 2021).

11. World Health Organization (WHO) (2020). – Global Health Observatory (GHO) data repository. WHO, Geneva, Switzerland. Available at: www.who.int/data/gho/ (accessed on 10 March 2021).

12. Teenstra E., Andeweg K. & Vellinga T. (2016). – Manure helps feed the world: integrated manure management demonstrates manure is a valuable resource. Practice Brief. Global Alliance for Climate Smart Agriculture, Rome, Italy, 8 pp. Available at: www.fao.org/3/a-bl516e.pdf (accessed on 10 March 2021).

13. Blümmel M., Tevmouri F., Moore J., Nielson C., Videto J., Kodukula P., Pothu S. Devulapalli R. & Varijakshapanicker P. (2018). – Ammonia fiber expansion (AFEX) as spin off technology from 2nd generation biofuel for upgrading cereal straws and stovers for livestock feed. *Anim. Feed Sci. Tech.*, **236**, 178–186. doi:10.1016/j.anifeedsci.2017.12.016.

14. Tolkamp B., Wall E., Roehe R., Newbold J. & Zaralis K. (2010). – Review of nutrient efficiency in different breeds of farm livestock. SAC Consulting, Penicuik, Scotland, 105 pp. Available at: sciencesearch.defra.gov.uk/Document.aspx?Document=FinalReportIF0183.doc (accessed on 10 March 2021).

15. Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development, United Nations Children's Education Fund, United Nations World Food Programme & World Health Organization (2020). – The state of food and nutrition security in the world 2020: transforming food systems for affordable healthy diets. FAO, Rome, Italy, 320 pp. doi:10.4060/ca9692en.

16. García Pinillos R., Appelby M.C., Manteca X., Scott-Park F., Smith C. & Velarde A. (2016). – One Welfare: a platform for improving human and animal welfare. *Vet. Rec.*, **179** (16), 412–413. doi:10.1136/vr.i 5470.

17. United Nations Environment Programme (UNEP) (2020). – Preventing the next pandemic: zoonotic diseases and how to break the chain of transmission. UNEP, Nairobi, Kenya, 82 pp. Available at: wedocs.unep.org/handle/20.500.11822/32316 (accessed on 11 August 2020).

18. Berntman E. (2020). – Fighting infection: animal welfare and antimicrobial resistance. Federated Hermes, London, United Kingdom. Available at: www.hermes-investment.com/eos-insight/eos/fighting-infection-animal-welfare-and-antimicrobial-resistance/ (accessed on 11 August 2020).

19. World Organisation for Animal Health (OIE) (2019). – The OIE PPP Handbook: guidelines for public–private partnerships in the veterinary domain. OIE, Paris, France, 64 pp. Available at: www.oie.int/fileadmin/Home/eng/Media_Center/docs/pdf/PPP/oie_ppp_handbook-20190419_ENint_BD.pdf (accessed on 13 January 2021).

20. Tarawali S., Amanor Boadu V., Baltenweck I., de Haan N. & Kohler-Rollefson I. (2019). – Innovation for sustainable livestock: livelihoods and economic growth. Background paper for the 9th annual multi-stakeholder partnership meeting of the Global Agenda for Sustainable Livestock, 9–12 September 2019, Manhattan, KS, United States of America. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2019_Sept_Kansas/2_Livelihoods_and_Economic_Growth_-_Online_consultation.pdf (accessed on 10 March 2021).

21. World Bank (2020). – PovcalNet: an online analysis tool for global poverty monitoring. World Bank, Washington, DC, United States of America. Available at: iresearch.worldbank.org/PovcalNet/home.aspx (accessed on 10 March 2021).

22. Food and Agriculture Organization of the United Nations (FAO) (2018). – World livestock: transforming the livestock sector through the Sustainable Development Goals. FAO, Rome, Italy, 228 pp. Available at: www.fao.org/3/CA1201EN/ca1201en.pdf (accessed on 11 August 2020).

23. Shapiro B.I., Gebru G., Desta S., Negassa A., Negussie K., Aboset G. & Mechal H. (2015). – Ethiopia livestock master plan: roadmaps for growth and transformation. International Livestock Research Institute, Nairobi, Kenya. Available at: hdl.handle.net/10568/68037 (accessed on 11 August 2020).

24. Shapiro B.I., Singh J.P. […] & Baltenweck I. (2018). – Bihar livestock master plan 2018–19 – 2022–23. Government of Bihar, Bihar, India, 147 pp. Available at: hdl.handle.net/10568/100538 (accessed on 11 August 2020).

25. African Union– Inter-African Bureau for Animal Resources (AU–IBAR) (2015). – The livestock development strategy for Africa (LiDeSA) 2015–2035. AU–IBAR, Nairobi, Kenya, 158 pp. Available at: www.celep.info/wp-content/uploads/2017/10/2015-LiDeSA.pdf (accessed on 10 March 2021).

26. Njuki J. & Sanginga P.C. (eds) (2013). – Women, livestock ownership and markets: bridging the gender gap in Eastern and Southern Africa. Routledge, Abingdon, United Kingdom & International Development Research Centre, Ottawa, Canada. Available at: www.idrc.ca/en/book/women-livestock-ownership-and-markets-bridging-gender-gap-eastern-and-southern-africa (accessed on 10 March 2021).

27. The Brooke (2013). – Voices from women (India): women's views on the contributions of working donkeys, horses and mules to their lives. Brook Hospital for Animals, Ghaziabad, India, 5 pp. Available at: www.thebrooke.org/sites/default/files/Advocacy-and-policy/India-voices-from-women.pdf (accessed on 28 June 2021).

28. Galiè A., Teufel N., Korir L., Baltenweck I., Girard A.W., Domínguez-Salas P. & Yount K.M. (2018). – The Women's Empowerment in Livestock Index. *Soc. Indic. Res.*, **142** (2), 799–825. doi:10.1007/s11205-018-1934-z.

29. International Livestock Research Institute (ILRI) (2020). – How the other half works: making a living with livestock. International Livestock Research Institute 2019 annual report. ILRI, Nairobi, Kenya. Available at: www.ilri.org/research/annual-report/2019 (accessed on 11 August 2020).

30. Food and Agriculture Organization of the United Nations (FAO) (2016). – Economic analysis of animal diseases. FAO Animal Production and Health Guidelines No. **18**. FAO, Rome, Italy. Available at: www.fao.org/publications/card/en/c/c5d37847-9a62-4ed0-931e-8d65773e7b6f/ (accessed on 26 June 2021)

31. Tarawali S., Dolapo E. & Pfeifer C. (2018). – Food of animal origin: demand and diversity [PowerPoint presentation]. Presented at the Expert Panel: Food of Animal Origin 2030 – Solutions to Consumption Driven Challenges. *In* Proc. Global Forum for Food and Agriculture, 18 January 2018, Berlin, Germany. International Livestock Research Institute, Nairobi, Kenya, 30 pp. Available at: hdl.handle.net/10568/90542 (accessed on 10 March 2021).

32. Food and Agriculture Organization of the United Nations (FAO) (2009). – The state of food and agriculture: livestock in the balance. FAO, Rome, Italy, 180 pp. Available at: www.fao.org/3/a-i0680e.pdf (accessed on 11 August 2020).

33. Willett W., Rockström J. […] & Murray C.J.L. (2019). – Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food. *Lancet*, **393** (10170), 447–492. doi:10.1016/S0140-6736(18)31788-4.

34. Giyose B., Kraemer K., Iannotti L., Stewart M., Dar O. & Alonso S. (2018). – Livestock-derived foods and the first 1000 days: the essential role of livestock-derived foods in the nutrition of mothers and infants [PowerPoint presentation]. Presented at the 45th session of the United Nations Committee on World Food Security, 15–19 October, Rome, Italy. International Livestock Research Institute, Nairobi, Kenya, 35 pp. Available at: hdl.handle.net/10568/97922 (accessed on 10 March 2021).

35. Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A. & Tempio G. (2013). – Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations, Rome, Italy, 139 pp. Available at: www.fao.org/3/i3437e/i3437e.pdf (accessed on 10 March 2021).

36. Mottet A., Henderson B., Opio C., Falcucci A., Tempio G., Silvestri S., Chesterman S. & Gerber P.J. (2016). – Climate change mitigation and productivity gains in livestock supply chains: insights from regional case studies. *Reg. Environ. Change*, **17**, 129–149. doi:10.1007/s10113-016-0986-3

37. Arango J., Ruden A. […] & Chirinda N. (2020). – Ambition meets reality: achieving GHG emission reduction targets in the livestock sector of Latin America. *Front. Sustain. Food Syst.*, **4**, 65. doi:10.3389/fsufs.2020.00065.

38. Skuce P.J., Bartley D.J., Zadoks R.N. & MacLeod M. (2016). – Livestock health and greenhouse gas emissions. Moredun Research Institute, Edinburgh, Scotland, 74 pp. Available at: www.climatexchange.org.uk/media/2031/livestock_health_and_ghg.pdf (accessed on 10 March 2021).

39. Grace D., Nguyen-Viet H., Mehta P., Lindahl J. & Kakkar M. (2014). – Policy and practice: developing countries and livestock drug use. Paper presented at the 3rd International Conference on Responsible Use of Antibiotics in Animals, 29 September to 1 October, Amsterdam, the Netherlands. Available at: hdl.handle.net/10568/52325.

40. Food and Agriculture Organization of the United Nations (FAO) (2011). – Global food losses and food waste: extent, causes and prevention. FAO, Rome, Italy, 37 pp. Available at: www.fao.org/3/a-i2697e.pdf (accessed on 11 August 2020).

41. Carus M. & Dammer L. (2018). – The 'circular bioeconomy' – concepts, opportunities and limitations. Nova Institut, Hürth, Germany, 9 pp. Available at: renewable-carbon.eu/publications/ (accessed on 10 March 2021).

42. Food and Agriculture Organization of the United Nations (FAO) (2016). – Synthesis: livestock and the sustainable development goals. FAO, Rome, Italy, 12 pp. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/2016/Panama/FAO-AGAL_synthesis_Panama_Livestock_and_SDGs.pdf (accessed on 11 August 2020).

43. Livestock Emergency Guidelines and Standards Project (2014). – Livestock Emergency Guidelines and Standards (LEGS), 2nd Ed. Practical Action Publishing, Rugby, United Kingdom, 314 pp. Available at: www.livestock-emergency.net/wp-content/uploads/2012/01/LEGS-Handbook-2nd-edition-web-version-1.pdf (accessed on 10 March 2021).

44. Chara J., Reyes E., Peri P., Otte J., Arce E. & Schneider F. (2018). – Silvopastoral systems and their contribution to improved resource use and sustainable development goals: evidence from Latin America. Food and Agriculture Organization of the United Nations, Rome, Italy, 62 pp.

45. Food and Agriculture Organization of the United Nations (FAO) (2007). – The state of the world's animal genetic resources for food and agriculture (B. Rischkowsky & D. Pilling, eds). FAO, Rome, Italy, 524 pp. Available at: www.fao.org/3/a1250e/a1250e.pdf (accessed on 10 March 2021).

46. United Nations (UN) (2020). – Goal 17: Revitalize the global partnership for sustainable development. UN, New York, United States of America. Available at: www.un.org/sustainabledevelopment/globalpartnerships/ (accessed on 11 August 2020).

47. Global Agenda for Sustainable Livestock (GASL) (2011). – Agenda consensus. Available at: www.livestockdialogue.org/fileadmin/templates/res_livestock/docs/About_Agenda/Consensus_Document_digital.docx (accessed on 11 August 2020).

48. Action for Animal Health (2020). – A call to action for animal health. The Brook, London, United Kingdom. Available at: www.actionforanimalhealth.org/wp-content/uploads/2021/05/AFAH-Call-to-Action.pdf (accessed on 11 August 2021).

49. High Level Panel of Experts on Food Security and Nutrition (HLPE) (2018). – Multi-stakeholder partnerships to finance and improve food security and nutrition in the framework of the 2030 Agenda. Report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. HLPE, Rome, Italy, 144 pp. Available at: www.fao.org/3/CA0156EN/CA0156en.pdf (accessed on 10 March 2021).

Acknowledgements/Remerciements/Agradecimientos

Veterinary Services in a changing world: climate change and other external factors

Scientific and Technical Review,
Vol. **40** (2), 2021

Les Services vétérinaires dans un monde en mutation : le changement climatique et autres facteurs externes

Revue scientifique et technique,
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Los Servicios Veterinarios en un mundo en transformación: el cambio climático y otros factores externos

Revista científica y técnica,
Vol. **40** (2), 2021

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