

Zoonoplasticity as an intuitive risk protocol for pet-linked zoonoses

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Summary

Zoonoses are diseases transmissible between non-human and human animals. Over 200 zoonoses are known, of which at least 60 are associated with (especially exotic) pet animals. Current risk-impact assessment approaches for zoonoses are largely cumbersome and, to be meaningful, may require extensive detailed information. A literature search and review were conducted for current risk-assessment protocols for common zoonoses, with subsequent development of two novel rapid scoring methods for evaluating potential risk associated with pet-linked zoonoses. Accordingly, a novel, two-tier methodological concept – ‘zoonoplasticity’ – was prepared using an intuitive risk approach. The first tier considers risk principles for pets and husbandry practices, and pre-weights animals by class or species. The second tier considers established pathogen- or disease-based questions and assigns a degree of risk. Thus, the zoonoplasticity concept enables pathogens or their resultant zoonoses to be scored and provides a clear points-based protocol offering guidance concerning potential threat, in particular where more quantifiable risk assessment is unavailable because of information deficits. The zoonoplasticity concept was tested with 15 animal species and 22 known zoonoses against European Centre for Disease Prevention and Control (ECDC) operational guidance as a comparative system. Risk categorisation was 100% consistent for 21 of the 22 specific zoonoses, while requiring minimal information input,

and the overall comparison rate was 98.85%. Zoonoplasticity is not intended to provide an absolute measure of risk or to replace existing methodologies, rather it is an attempt to standardise a practical judgement protocol that accounts for various relevant issues, and to offer a potentially helpful indicator of concern. The zoonoplasticity concept will be relevant to remits for medical professionals, veterinary medical professionals, public health professionals, government administrators, biomedical researchers and others.

Keywords

Companion animal – Intuitive risk – Pet – Zoonoplasticity – Zoonoses.

Introduction

Zoonoses are diseases transmissible between non-human and human animals, and relevant pathogens include parasites, bacteria, viruses, fungi and prions (1, 2, 3). Across human diseases 61% are believed to be of potentially zoonotic origin (4) and 75% of global emerging human diseases have a wild animal link (5). Over 200 zoonoses are known (3, 6), of which at least 60 are associated with pet animals (3). It is estimated that in the United Kingdom 13 million households (45%) collectively keep 51 million pets, which include 17 million domesticated dogs and cats, and 34 million semi-domesticated and exotic animals (using the lower published estimate of 30 million indoor aquaria and outdoor fishes) (7). Over 13,000 species across all animal classes (invertebrates, fishes, amphibians, reptiles, birds, mammals) are involved in pet trading and keeping (8), meaning that >99% of kept animals are exotic, or types other than dogs and cats.

Whilst humans and domesticated animals may have closer associations and more regular contact, exotic pet zoonoses are considered a disproportionate risk due to these animals harbouring locally atypical pathogens (3, 9). In addition, familiarity of veterinarians with exotic zoonoses and with normal and abnormal animal health states across diverse species is highly limited, as is the availability of advice to the public (3, 10, 11). Accordingly, the zoonotic reservoir is large and diverse, with close proximity to regular human lifestyles (12) – leading

to pet trading and keeping being described as a ‘Trojan horse’ because wild animals in particular are invited into households that are unaware of relevant risks (13, 14). Despite many targeted governmental and non-governmental attempts at public health education regarding pet-linked zoonoses (3, 15), emergent diseases, for example reptile-related salmonellosis, are not abating (16). For some zoonoses much is known regarding pathogens and resultant diseases and therapies, as well as related epidemiology, prevalence and incidence, whereas for others little is known beyond occurrence, thus the importance of the threat remains under-ascertained (1, 15). For this report, zoonoses and risk issues are associated with animals kept as pets in the home or at any of the variety of hubs at which supply, storage and trading of animals occurs. In such situations, proximity and therefore direct or indirect contact with animals is common. Although this report focuses on exotic pets, some semi-domesticated and domesticated animals are also included, in particular for comparative purposes.

This investigation resulted in the development of a novel, two-tier methodological concept – ‘zoonoplasticity’ – which uses an intuitive risk approach for evaluating potential risk associated with pet-linked zoonoses. The first tier considers risk principles for pets and husbandry practices, and pre-weights animals by class or species. The second tier considers established pathogen- or disease-based questions and assigns a degree of risk. Thus, the zoonoplasticity concept enables pathogens or their resultant zoonoses to be scored and provides a clear points-based protocol offering guidance concerning potential threat, in particular where more quantifiable risk is unavailable because of information deficits. It is intended that the zoonoplasticity concept will be relevant to remits for medical and public health professionals, government administrators, impact assessors, researchers and others.

Terminology

In this report, the following terms have these particular meanings:

- ‘Zoonoplasticity’ = generalisation of pathogenic potential in a population accounting for diverse biological and management factors that can increase public health risk, including microbial

pathogenicity, microbial reservoir, disease prevalence, transmissibility and opportunities for transmission.

- ‘Intuitive risk’ = an approach associated with either situation- or evidence-specific decision-making that involves recognising cues or patterns (17). Intuitive risk utilises both subjective and objective information (18, 19, 20, 21).
- ‘Exotic pet’ = any animal produced or kept for pleasure or companionship that is non-native to a region or non-domesticated (8).
- ‘Low’, ‘Moderate’, ‘High’ and ‘Very High’ are indications of potential risk that broadly correspond to categorisations in general use. Each zoonoplasticity risk category is divided into points, for example Low (1–10), therefore this category effectively includes very low risk where scores are at or close to 1 and borderline moderate risk where scores are at or close to 10, and this principle continues across all categories.
- ‘Risk assessment’ = use of Figure 1 and Tables I to III to evaluate potential threat.

Intuitive risk in epidemiology and public health

At its most essential, applying intuitive risk to zoonoses is commonly practised. For example, it may be correctly presumed that rabies (a rhabdovirus) manifests extremely high pathogenicity and mortality whilst having a minimal reservoir, and being rare in western global regions (22), whereas giardiasis (*Giardia* spp.) manifests low pathogenicity and mortality despite having common reservoirs and occurring in eastern and western global regions (23). Beyond such examples, prioritising risk elements can be highly speculative, and user-friendly systematisation is probably beneficial. Wisdom and experience offer helpful guidance in public health. However, individual experience can also bias decision-making (24), i.e. ‘negative medical salience’, although this complication may be reduced or avoided by reference to

essential tabulated prompts (24), which the zoonoplasticity concept may augment.

Accordingly, intuitive risk-based assessment, whether resulting from unconscious experiential prompts or from external algorithms, is integral to medical and epidemiological decision-making. Zoonoplasticity potentially offers an alternative provisional assessment criterion to protracted analytical deliberative evaluations.

Current zoonoses assessment methods

Several general zoonotic risk assessment methods are available to prioritise risk, for example multidisciplinary evidence- and expert-based assessment and opinion (25), questionnaire-based evaluation of public perception (26), study of local community and human practices (27) and evaluation of global disease hotspots and human occupation of regional habitats (28). These and other approaches inform and refine the evaluation of zoonoses in various contexts, although their application to exotic pet trading and keeping is limited, in particular because this sector has certain uniquely combined and cumulatively relevant characteristics including complex animal sources and routes, animals of uncertain origin and health states, rapid global movement of animals, largely unregulated and widely criticised husbandry and hygiene practices, negligible quarantine procedures and a high frequency of exposure in the home (3, 12).

Methods

Literature search and review

A literature search and review were conducted by the author for current common zoonoses risk-assessment protocols using online resources, Google Scholar, Embase and PubMed, since the year 2000, using the following key terms: ‘zoono’, + ‘disease’, + ‘animal’, + ‘human’, + ‘risk assessment’, + ‘evaluation’. Sixty-seven publications were identified to which inclusion–exclusion criteria were applied in respect of sufficient relevance on the basis of: *a*) appearing in a peer-reviewed source; *b*) relevance to multiple rather than specific zoonoses and

c) containing risk assessment discussion or protocols. Twelve publications met all inclusion criteria. Of the twelve selected publications, five included protocol-based zoonoses assessment methodologies and thus were considered of further particular relevance. The twelve selected publications and their essential messages were:

- Brown (5) provides an assessment of risk factors associated with emerging zoonoses
- Karesh *et al.* (4) provide an assessment of risk factors associated with emerging zoonoses
- Chomel *et al.* (1) provide an assessment of risk factors associated with emerging zoonoses
- the European Centre for Disease Prevention and Control (ECDC) (25) provides a risk-assessment protocol for zoonoses
- Ng & Sargeant (26) provide a method for prioritisation of zoonotic diseases
- Smith *et al.* (14) provide background to vulnerable groups and risk factors concerning exotic pets
- Stull *et al.* (15) provide background to public attitudes to zoonoses and relevant risk factors
- Warwick *et al.* (3) provide a general review of over 60 exotic pet zoonoses, related pathogens, risk factors and guidance on prevention and control
- Ashley *et al.* (12) provide an explanation of exotic pet trade dynamics and veterinary and human medical health consequences
- Warwick *et al.* (29) provide a general evaluation of both zoonotic risk factors and animal welfare concerns related to exotic and domesticated and non-domesticated – ‘wild’ – pet animals

- Whitfield & Smith (2) provide a review of pets and zoonoses, and offer recommendations for improvement interventions
- Allen *et al.* (28) provide a review of global hotspots of zoonotic disease.

The five publications that included protocol-based zoonoses assessment methodologies were: ECDC (25), Ng & Sargeant (26), Warwick *et al.* (3), Warwick *et al.* (29) and Allen *et al.* (28).

Development of zoonoplasticity protocol

The zoonoplasticity concept borrows its design from a pet suitability algorithm called 'EMODE', which categorises pet animal species as 'Easy', 'Moderate', 'Difficult' or 'Extreme' based on both pre-weighted scores and secondary refined questionnaire evaluation (29). The pre-weighted scores were arrived at on the basis of criteria determined by the EMODE system for each animal category. Two complementary methods (Tiers 1 and 2) were developed for the zoonoplasticity protocol. Certain relevant background considerations on zoonoses that inform the two complementary methods are summarised in Table I. Figure 1 converts information from Table I into a longitudinal bar chart depicting 'at a glance' broad risk for animal 'type' – e.g. fish, amphibian, reptile, bird, mammal or mammal primate.

Tier 1 assessment (Table II) is derived from established risk principles for pets and husbandry practices (3), including:

- a) whether or not local relevant veterinary and other expert advice is regularly available (familiarity with a particular animal class, species-specific health states and potential common zoonoses associated with such animals)
- b) degree of ease or difficulty associated with husbandry demands (greater husbandry challenges imply increased specific contact with animals)
- c) commonness of zoonotic association (regular reported infection indicates certain risk)

d) likelihood of following strong preventative measures.

Animals are pre-weighted by class or species, providing a Foundation score (a more precise numerical score of 5–15 derived from data in Figure 1) to which Refinement scores procured from specific management questions are added. The final cumulative score is numerically (1–35+) tracked along a colour-coded bar indicating zoonoplasticity intuitive risk level.

Tier 2 assessment (Table III) considers pathogen- or disease-based questions and assigns a degree of risk, accumulating an independent score level (1–50+). Given that this zoonoplasticity approach involves novelty of design, it was tested for comparative consistency against an existing assessment method, the ECDC operational guidance on rapid risk assessment (25), using the same input information. Consistency was assessed based on percentage of similarity between the zoonoplasticity scores and the comparison system risk assessment method, to rate zoonotic risk as ‘Low’, ‘Moderate’, ‘High’ or ‘Very High’ (Table IV). To avoid selectivity bias, the list of sample zoonoses was compiled using all 22 zoonoses that were common to two major reviews (3, 26) and that are known to be associated with exotic pets; because only known zoonoses were considered, a ‘no risk’ criterion was redundant.

Given that assessments using zoonoplasticity are intuition-based, the scoring method is intended to accommodate wide judgement margins, and this is implied in the four risk categories. Essentially, the objective of zoonoplasticity scoring is broadly to place a zoonosis within one of the four risk categories with reasonable consistency. Although alternative questions could reasonably have been used for Tables II and III, it is proposed that those included are adequate to enable assessment using the intuitive risk principle.

The method and questions for Table II criteria 1–9 and Table III criteria 1–6 were developed according to the following approaches. Table II criterion 1 uses as a guide the Warwick *et al.* (29) system for broadly determining potential physical risk of injury to humans from different animals, and implied infection risk. Criterion 2 uses as a guide

the Warwick *et al.* (29) system in which animals with potential lifespans of ≥ 10 years are regarded as relatively long-lived and thus involve greater overall exposure time to their keepers. Criterion 3 uses as a guide Brown (5), Karesh *et al.* (4), Chomel *et al.* (1) and Ashley *et al.* (12) regarding a high proportionate presence of human pathogens in wildlife. Criterion 4 assumes greater pathogen contamination in fresh versus processed animal feed. Criterion 5 uses as a guide Allen *et al.* (28) regarding global zoonoses hotspot regions. Criterion 6 applies general quarantine principles inherent in regular legislation and local monitoring. Criterion 7 applies general notifiable disease principles inherent in regular legislation and local monitoring. Criterion 8 uses as a guide Smith *et al.* (30), who identify particular vulnerable groups in relation to exotic pet keeping. Finally, criterion 9 provides for arbitrary accommodation of speculative risk factors.

Table III criterion 1 applies general notifiable disease principles inherent in regular legislation and local monitoring, as well as using a presumption of epidemiological prevalence of $\geq 5\%$ of all sources of a relevant pathogen in a population as an indicator of a significant public health hazard (for example, salmonellosis associated with pet reptiles has $\geq 5\%$ prevalence [31] and is considered a significant disease risk). Criterion 2 applies general notifiable disease principles inherent in regular legislation and local monitoring. Criteria 3 and 4 apply general disease transmission principles inherent in regular medical training. Criterion 5 considers whether relevant regional governmental public health advice is widely available. Finally, criterion 6 provides for arbitrary accommodation of speculative risk factors.

Low	Moderate	High	Very High
	Fishes		
	Amphibians		
	Reptiles		
	Birds (unusual, exotic)		
	Mammals (unusual, exotic)		
	Primates		
	Domesticated/semi-domesticated other than dogs and cats (e.g. rats, rabbits, ferrets, chickens, pot-bellied pigs, horses)		
	Dogs and cats		

Fig. 1

Zoonoplasticity intuitive risk assessment tool for pet-linked zoonoses. Broad risk associated with animal class and species

Darker shaded areas indicate zones of null relevance (i.e. for Fishes the relevant categorisation area commences at the mid-point of 'Low' and extends to the full range of 'Very High', and for Dogs and Cats the relevant categorisation area commences at the mid-point of 'Low' and extends only to the full range of 'High', but no further); lighter shaded areas indicate risk relevance

Table I**Zoonoses considerations by animal class**

Based on reports (1, 2, 3, 7)

Animal class	Zoonoses associated (at least)	Representation in home	Degree of handling/contact	Husbandry demands	Available impartial expert biological, veterinary and medical advice
Fishes	10	Very common	Rare	Low	Low
Amphibians	40	Uncommon	Infrequent	Moderate–extreme	Low
Reptiles	40	Common	Frequent	Moderate–extreme	Low
Birds (semi-domesticated, unusual, exotic)	34	Common	Occasional	Moderate–extreme	Low
Mammals (semi-domesticated, unusual, exotic)	30	Common	Frequent	Moderate–extreme	Low–moderate
Primates	15	Rare	Frequent	Extreme	Low
Dogs and cats*	16	Very common	Frequent	Low	Very high

*Note: Dogs and cats can be categorised as relatively easy to keep compared with exotic or non-domesticated wild animals. Reasons for this difference include the facts that dogs and cats are: naturally affiliative, domesticated, typically able to freely roam a household, able to have regular access to outside environments, well understood by the public in terms of their welfare needs and well supported by easily accessible local veterinary services. In comparison, exotic, non-domesticated or wild animals typically do not have the same listed advantages, and are instead usually caged, thus requiring regular human maintenance of enclosed environments.

Table II (Tier 1)

Zoonoplasticity intuitive risk assessment tool for pet-linked zoonoses. Biological (animal)- and management-based questionnaire evaluation

Foundation score	
	Pre-weighted points
Fishes e.g. eels, rays, goldfish	5
Amphibians e.g. frogs, toads, newts, salamanders	10
Reptiles e.g. crocodiles, turtles, tortoises, lizards, snakes	10
Birds e.g. parrots, cockatiels, cockatoos	10
Mammals (unusual, exotic) e.g. bats, foxes, meerkats, kinkajous, sloths	10
Primates e.g. monkeys, apes, prosimians	15
Domesticated/semi-domesticated e.g. rats, rabbits, ferrets, chickens, pot-bellied pigs, horses	5
Dogs and cats	5

Refinement scores

Select relevant Foundation score (pre-weighted points), then add Refinement scores (accumulator points) below.

Answer one (most relevant) question from each criterion (1–9) then add all accumulator points

Criteria/questions are divided into:

biological (e.g. about an animal, its habits and background) and

management (e.g. about environment, formal controls, household)

			Foundation score =
Criterion/question	Rationale	Answer yes or no Points	Accumulator points

Biological questions

If answer is 'yes' add points indicated. If answer is 'no' move to next question.

1.	Animal capable of inflicting injurious bites or scratches?	Many zoonoses are transferred via bites and scratches.	+1
2.	Animal has potentially long lifespan (e.g. ≥ 10 years)?	Longer-lived animals may accumulate greater pathogen loads and increased opportunities for transmission.	+1
3.	Wild-caught?	High uncertainty of origin and health state. Wild-caught animals more likely to harbour certain pathogens and shed = elevated concern.	+2
	or		
	Captive-bred?	Reduced uncertainty of origin and health state. Captive-bred animals less likely to harbour certain pathogens and shed = reduced concern.	+1
		Note: If unsure presume wild-caught.	
4.	Food sources include fresh animal protein, live food, plant matter, frozen?	Carnivorous and herbivorous species more likely to harbour potential pathogens than animals fed processed feed.	+2
	or		
	Dried/processed?		+1

Management questions

If answer is 'yes' add points indicated. If answer is 'no' move to next question.

5.	Animal from a global zoonoses hotspot?	Animal sourced from global zoonoses hotspots may harbour inherent significant or raised risk levels.	+3
6.	Animal subject to quarantine?	Endothermic ('warm-blooded') animals (i.e. mammal, bird) normally quarantined = reduced risk.	0
	or Animal not subject to quarantine?	Ectothermic ('cold-blooded') animals (i.e. invertebrate, fish, amphibian, reptile) not normally quarantined = increased risk.	+1
7.	Is animal strongly associated with a regionally notifiable disease?	Indicates pathogen or disease already at significant or raised risk level.	+2
8.	Home includes vulnerable group?	Vulnerable groups (e.g. under 5 years, immunocompromised, pregnant, undergoing chemotherapy, post-surgical, sick) are significantly more susceptible to many zoonoses.	+5
9.	Other question(s)	Provides optional additional scores according to novel factors.	+1 (per novel point)

Total points =

Zoonoplasticity intuitive risk level

Low	Moderate	High	Very High
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27 28 29 30	31 32 33 34 35 +

Table III (Tier 2)**Zoonoplasticity intuitive risk assessment tool for pet-linked zoonoses. Pathogen- or disease-based questionnaire evaluation**

Answer one (most relevant) question from each criterion (1–6) then add all accumulator points

If answer is 'yes' add points indicated. If answer is 'no' move to next question.

Criterion/question	Rationale	Answer yes or no	Accumulator points
		Points	
1. Zoonosis absent?	Regional absence of a zoonosis negates requirement to assess risk. However, theoretical risk can still be calculated on presumption of presence (see footnote).	1	
or			
Zoonosis rare (e.g. <1% of all sources of a relevant pathogen in a population)?		1	
or			
Zoonosis uncommon (e.g. $\geq 1\%$ of all sources of a relevant pathogen in a population)?	Incidence, prevalence and opportunities for transmission are implied.	2	
or			
Zoonosis common (e.g. $\geq 5\%$ of all sources of a relevant pathogen in a population)?		3	
or			
Zoonosis very common (e.g. $\geq 10\%$ of all sources of a relevant pathogen in a population)?		6	

2.	Zoonosis is an emergent disease (i.e. recently rising)?	Particular concerns re. incidence rate.	6-0
3.	Person to person communicability low?		1
	or		
	Person to person communicability moderate?	Potential virulence implied.	2
	or		
	Person to person communicability high?		3
	or		
	Person to person communicability very high?		6
4.	Symptomatically typically mild and self-limiting?		1
	or		
	Symptomatically typically moderate and requiring minor treatment?	Indicates management challenges and treatment burden.	3
	or		
	Symptomatically typically serious and requiring major treatment?		10
	or		
	Symptomatically typically severe or fatal, requiring critical treatment?		20
5.	Public awareness of risk and self-directed precautions?	Public awareness, regularity of vaccination, commitment to effective hygiene, risk avoidance (assign one score: i.e. poor = 6; low = 3; good = 1).	6-1

6.	What if?	Addresses other scenarios (e.g. mutation, public habit [fad], infrastructure competency, antimicrobial resistance, low opportunities for control).	0–20
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Total points =

Zoonoplasticity intuitive risk level																																																		
Low															Moderate															High										Very High										
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	+

Note: A ‘1’ score total (e.g. a disease being regionally absent) is included as the minimum score because zero-risk for any pathogen or disease is theoretically improbable owing to invasive or smuggled species or other unforeseen factors. Accordingly, the risk score scale commences at ‘1’.

Results

Table I provides an essential summary of relevant background factors that assist in informing the subsequent approaches, and Figure 1 translates this into an ‘at a glance’ risk evaluation. Tables II and III present the zoonoplasticity concept and the Tier 1 and Tier 2 assessment questionnaires. Table IV provides results of a comparative consistency test for the zoonoplasticity pathogen- or disease-based assessment questionnaire presented in Table III, where categorisation was 100% consistent for 21 of the 22 specific zoonoses and the overall comparison rate was 98.85%. Appendix 1 provides worked examples for the Tier 1 questionnaire presented in Table II, regarding animal-related risk. Appendix 2 provides worked examples for the Tier 2 questionnaire presented in Table III, regarding pathogen- or disease-related risk.

Table IV**Comparative assessment for consistency of zoonoplasticity concept**

Zoonoses list derived from reports (3, 26)

Zoonosis	Zoonoplasticity	ECDC operational guidance (2011)	Consistency (%)
Zoonoses risk score			
(Low, Moderate, High, Very High)			
Avian influenza	Low	Very low	100
Bartonellosis	Low	Low	100
Baylisascariasis	Low	Low	100
Brucellosis	Low	Low	100
Campylobacteriosis	Moderate	Moderate	100
Chlamydiosis/psittacosis	Low	Very low	100
Coccidioidomycosis	Low	Very low	100
Cryptosporidiosis	Moderate	Moderate	100
<i>Escherichia coli</i> infection	Moderate	Moderate	100
Giardiasis	Low	Very low	100
Hepatitis A	Low	Very low	100
Larva migrans	Low	Very low	100
Leptospirosis	Low	Low	100
Lyme disease	Moderate	High	75
Marburg haemorrhagic fever	Low	Very low	100
Monkeypox	Low	Very low	100
Q fever	Moderate	Moderate	100
Rabies (non-endemic)	Low	Very low	100
Rabies (endemic)	High	High	100
Salmonellosis	Moderate	Moderate	100
Toxocariasis	Low	Very low	100
West Nile virus	Low	Low	100
Overall consistency			98.85%

Note: Zoonoplasticity categories include only Low, Moderate, High and Very High. Within each category there are 15 scores, the lowest of which (1) effectively implies negligible, through very low, low and lower than moderate (15). Accordingly, comparative test scores of Very Low and Low are addressed by the zoonoplasticity Low score (see Appendix 1 for worked examples).

ECDC: European Centre for Disease Prevention and Control

Discussion

Objective assessment of zoonoses is a desirable priority and is practised where feasible based on available information. Intuitive systems are by their nature somewhat subjective, requiring individualised input that may harbour experiential drivers, although such compromise arguably infiltrates all decision-making aids. However, the use of closed questions in the zoonoplasticity protocols is aimed at reducing subjectivism where data limitation and individual experience are relevant.

Current methods

Current impact-assessment methods are typically extensive, may run to many pages and may include complex algorithms and flow diagrams – each of which demands information that is frequently incomplete or absent and confounding assessments. Considerations such as travel to exotic locations, bushmeat importation or consumption, farming and wildlife migration are commonly applied to zoonoses risk assessments. However, these issues are commonly transient and unusual and have limited value for determining risk where pet-linked zoonoses are involved, because animals in the domestic environment represent continuous potential threats. Exotic pet trading and keeping is essentially a specific issue with particular considerations infrequently factored-in to zoonosis assessment models.

General considerations

The number of zoonoses with which animals are associated indicates possible infectivity; representation of animals in the home indicates a potential microbial reservoir; degree of human contact such as handling indicates possible direct or indirect contact episodes, dispersal of microbes and opportunities for transmission. Furthermore, demanding husbandry indicates the extent and frequency of close contact required to manage animals, which may result in dispersal of microbes and opportunities for transmission, and availability of impartial expert advice indicates the level of support or lack thereof for the prevention and management of disease. In addition, many zoonoses superficially

resemble regular diseases, making their under-ascertainment by keepers and healthcare professionals more likely and leading to under-reporting.

Target users and application

Target users of the zoonoplasticity tool include medical professionals, veterinary medical professionals, public health professionals, government administrators, biomedical researchers and others. The zoonoplasticity tool is designed to require minimal data input to complete Tables II and III, therefore users should be able to access relevant information via a basic internet or other literature search. Application of the tool is potentially relevant to development of positive or negative lists of species for inclusion or exclusion from trading and keeping as pets by governmental or non-governmental agencies, occupational health assessors, inspectors of legal or illegal animal importations, quarantine facility managers and others.

The two zoonoplasticity approaches (Tiers 1 and 2) set out in Tables II and III can be used independently or in concert to crosscheck assessments. Tier 1 primarily assesses animals in trade and keeping and secondarily assesses traditional epidemiological issues and allows for assessment of risk, whether or not a particular pathogen exists in a region or disease in a population. Tier 2 primarily assesses traditional epidemiological issues and secondarily assesses animals in trade and keeping, and thus relevant risk is significantly based on presence of a pathogen in a region or disease in a population.

Accordingly, the zoonoplasticity concept non-competitively presents a possible opportunity to ameliorate some pivotal factors common to pet-linked and other zoonoses. By intentionally limiting the range of questions for the zoonoplasticity concept, less overall information is necessarily targeted for accumulation than for other methods. However, much of that same background information, although ideally included, is unavailable for most zoonoses.

Conclusions

Zoonotic significance and our responses to it depend on many factors, and one such factor is individual or collective judgement. Ideally, risk assessments for zoonoses should benefit from detailed information across all relevant factors, which are diverse and numerous. Current risk-impact assessment approaches for zoonoses are largely cumbersome, and to be meaningful they may require extensive detailed information input. Zoonoplasticity is not intended to provide an absolute measure of risk, or to replace existing methodologies, rather it is an attempt to provide a practical judgement protocol that accounts for various relevant issues, and to offer a potentially helpful indicator of concern.

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Appendix 1

Worked examples (questions and answers) for scores used in

Table II that primarily assess animals in trade and keeping.

Assessment represents zoonoses mostly associated with the United Kingdom and Europe. In these examples there is low or no regional endemic involvement; thus, worked examples and scores may change significantly for relevant highly endemic and global hotspot regions

Animal	Worked example (Q = questions from Table II)	Total points/score (vg = score with vulnerable group)	Category
Goldfish (<i>Carassius</i> sp.)	5+ Q1 = 0; Q2 = 1; Q3 = 1; Q4 = 1; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	9 to (14 vg)	Low to Moderate (vg)
Clownfish (<i>Amphiprioninae</i> sp.)	5+ Q1 = 0; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	11 to (16 vg)	Moderate
African clawed frog (<i>Xenopus</i> sp.)	10+ Q1 = 0; Q2 = 1; Q3 = 1; Q4 = 2; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	15 to (20 vg)	Moderate
Marine toad (<i>Rhinella</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	17 to (22vg)	Moderate to High (vg)
Bearded dragon (<i>Pogona</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 2; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	16 to (21 vg)	Moderate to High (vg)
Nile monitor lizard (<i>Varanus</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	20 to (25 vg)	High
Corn snake (<i>Pantherophis</i> sp.)	10+ Q1 = 0; Q2 = 1; Q3 = 1; Q4 = 2; Q5 = 0; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	15 to (20 vg)	Moderate
Burmese python (<i>Python</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 1; Q7 = 0; Q8 = 0(5); Q9 = 0	20 to (25 vg)	Moderate to High (vg)
Budgerigar (<i>Melopsittacus</i> sp.)	10+ Q1 = 0; Q2 = 1; Q3 = 1; Q4 = 1; Q5 = 0; Q6 = 0; Q7 = 0; Q8 = 0(5); Q9 = 0	13 to (18 vg)	Moderate
African grey parrot (<i>Psittacus</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 0; Q7 = 0; Q8 = 0(5); Q9 = 0	19 to (24vg)	Moderate to High (vg)
Fruit bat (<i>Megachiroptera</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 0; Q7 = 2; Q8 = 0(5); Q9 = 0	21 to (26 vg)	High
Meerkat (<i>Suricata</i> sp.)	10+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 0; Q7 = 0; Q8 = 0(5); Q9 = 0	19 to (24 vg)	Moderate to High (vg)
Spider monkey (<i>Ateles</i> sp.)	15+ Q1 = 1; Q2 = 1; Q3 = 2; Q4 = 2; Q5 = 3; Q6 = 0; Q7 = 2; Q8 = 0(5); Q9 = 0	26 to (31 vg)	High to Very high (vg)
Rabbit (<i>Oryctolagus</i> sp.)	5+ Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 1; Q5 = 0; Q6 = 0; Q7 = 0; Q8 = 0(5); Q9 = 0	9 to (14 vg)	Low to Moderate (vg)
Domestic dog (<i>Canis</i> sp.)	5+ Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 1; Q5 = 0; Q6 = 0; Q7 = 0; Q8 = 0(5); Q9 = 0	9 to (14 vg)	Low to Moderate (vg)

Appendix 2

Worked examples (questions and answers) for scores used in Table III that primarily assess traditional epidemiological issues. Assessment represents zoonoses mostly associated with the United Kingdom and Europe. In these examples there is low or no regional endemic involvement; thus, worked examples and scores may change significantly for relevant highly endemic and global hotspot regions

Zoonosis	Worked example (Q = questions from Table III)	Total points/score	Category
Avian influenza (United Kingdom/non-endemic region)	Q1 = 1; Q2 = 0; Q3 = 0; Q4 = 0; Q5 = 0; Q6 = 0	1	Low
Avian influenza (less developed endemic region)	Q1 = 3; Q2 = 3; Q3 = 6; Q4 = 10; Q5 = 2; Q6 = 10	34	High
Bartonellosis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 0	11	Low
Baylisascariasis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 0	11	Low
Brucellosis	Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 2; Q5 = 6; Q6 = 0	11	Low
Campylobacteriosis	Q1 = 6; Q2 = 3; Q3 = 1; Q4 = 1; Q5 = 6; Q6 = 0	17	Moderate
Chlamydiosis/psittacosis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 0	11	Low
Coccidioidomycosis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 0	11	Low
Cryptosporidiosis	Q1 = 6; Q2 = 5; Q3 = 2; Q4 = 3; Q5 = 6; Q6 = 5	27	Moderate
Escherichia coli infection	Q1 = 1; Q2 = 2; Q3 = 2; Q4 = 10; Q5 = 3; Q6 = 5	23	Moderate
Giardiasis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 1; Q5 = 6; Q6 = 3	12	Low
Hepatitis A	Q1 = 2; Q2 = 0; Q3 = 1; Q4 = 1; Q5 = 5; Q6 = 0	9	Low
Larva migrans	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 0	11	Low
Leptospirosis	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 10; Q5 = 3; Q6 = 0	15	Low
Lyme disease	Q1 = 6; Q2 = 4; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 5	25	Moderate
Marburg haemorrhagic fever (United Kingdom/non-endemic region)	Q1 = 1; Q2 = 0; Q3 = 0; Q4 = 0; Q5 = 0; Q6 = 0	1	Low
Marburg haemorrhagic fever (less developed endemic region)	Q1 = 1; Q2 = 0; Q3 = 6; Q4 = 15; Q5 = 6; Q6 = 10	38	High
Monkeypox (United Kingdom/non-endemic region)	Q1 = 1; Q2 = 0; Q3 = 0; Q4 = 0; Q5 = 0; Q6 = 0	1	Low
Monkeypox (less developed endemic region)	Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 10; Q5 = 6; Q6 = 5	24	Moderate
Q fever	Q1 = 1; Q2 = 1; Q3 = 1; Q4 = 3; Q5 = 6; Q6 = 4	16	Moderate
Rabies (United Kingdom/non-endemic region)	Q1 = 1; Q2 = 0; Q3 = 0; Q4 = 0; Q5 = 0; Q6 = 0	1	Negligible/Low
Rabies (non-endemic region – theoretical)	Q1 = 1; Q2 = 0; Q3 = 1; Q4 = 20; Q5 = 1; Q6 = 0	23	Moderate
Rabies (endemic region – disease)	Q1 = 6; Q2 = 0; Q3 = 1; Q4 = 20; Q5 = 1; Q6 = 10	38	High
Salmonellosis	Q1 = 2; Q2 = 3; Q3 = 1; Q4 = 1; Q5 = 5; Q6 = 5	17	Moderate
Toxocariasis	Q1 = 1; Q2 = 1; Q3 = 3; Q4 = 3; Q5 = 3; Q6 = 0	11	Low
West Nile virus	Q1 = 1; Q2 = 0; Q3 = 0; Q4 = 1; Q5 = 6; Q6 = 0	8	Low