The application of GBADs methodology to aquatic animal production

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Summary

The Global Burden of Animal Diseases (GBADs) programme's key objective to provide a systematic approach to determine the burden of animal disease is as relevant to aquatic as terrestrial animal production systems. However, to date GBADs methods have mainly been applied to terrestrial animal production systems. The key objectives. The challenges to applying GBADS methods, notably the animal health loss envelope (AHLE), varies considerably with production systems. We demonstrate how the AHLE can be calculated for rainbow trout (RBT) production in England and Wales, and acknowledge that its application to other systems (e.g. hatchery production, polyculture and no-feed mollusc production) is more complex and raises questions around how sub-optimal nutrition constrains production. Recirculating aquaculture systems (RAS) have

inherent high levels of biosecurity and disease control and thus low levels of disease. Removing the capital and running costs associated with biosecurity fundamentally changes the system and invalidates the AHLE calculation. Lack of data from many systems, notably small-scale tropical finfish farming, will mean that expert opinion will be needed to support the application of GBADs methods. Whilst calculation of the AHLE was the focus of this paper, it should be noted that attribution to causes and value chain modelling are needed to generate data on the wider societal impact of aquatic animal diseases (and possible interventions), needed by governments to support decision about resource allocation.

Keywords

Animal health – Aquaculture – Disease burden – Economics – Shrimp – Trout.

Introduction

Aquaculture has been practised for many centuries, but it was only in the 19th century that intensive breeding and production started with brown trout (*Salmo trutta*), initially to supplement wild populations diminished by pollution and obstructions to migration. In the 1950s, the development of artificial pelleted feed allowed for the rapid expansion of freshwater rainbow trout (RBT) (*Oncorhynchus mykiss*) production for human consumption. In the 1970s, the development of inexpensive, light, robust floating cages led to Atlantic salmon *(Salmo salar*) production in the marine environment, which grew rapidly in Europe (Norway and Scotland) and Chile. Technological developments resulted in the similarly rapid expansion of penaeid shrimp farming, predominantly in Asia, from the 1980s. Aquaculture now contributes more to the global food supply than wild capture fisheries [1].

The expansion and intensification of aquaculture, accompanied by the emergence and spread of diseases that caused serious economic impacts to the industry and environmental impacts (e.g. biodiversity loss) [2,3], stimulated the application of epidemiology to aquatic production. Epidemiological approaches developed in the human and terrestrial animal fields were first applied to aquatic animal diseases in the late 1980s (reviewed by Peeler and Taylor [4]). There now exists an extensive body of published epidemiological studies of aquatic animal diseases, however, most research has focused on commercial salmonid and shrimp production, with few studies investigating production and disease in smaller scale, subsistence aquaculture. Similarly, information on the cost of aquatic animal diseases is available mainly for disease outbreaks in salmonid and shrimp production. Very few studies have examined costs of disease at a production systems or national level. Moreover, there is a lack of information about expenditure on disease prevention and control, which should be examined alongside losses to achieve a holistic view of the burden [5]. Control of internationally listed transboundary and epidemic diseases has, arguably, driven decision-making and resource allocation to aquatic animal health (AAH) by government, at the expense of control of endemic diseases [6]. Similar observations have been made regarding funding of epidemic and endemic human disease [7]. The lack of information on the true cost of endemic aquatic animal disease may partly be to blame for its neglect.

The Global Burden of Animal Diseases (GBADs) programme seeks to address the deficiency in information on the losses attributable to animal disease and health expenditure. The programme includes aquatic animals in its scope, and it has become incorporated as a pillar in the FAO progressive management pathway for aquatic biosecurity (PMP/AB) (citation). Under the auspices of FAO, a Technical Working Group (TWG) was convened in April 2021, to support developing a framework for understanding the burden of diseases of farmed aquatic organisms [8]. The TWG identified the key considerations when applying the GBADs framework to aquaculture (summarised in Box 1). This led to short-scoping projects in Vietnam and Ghana to better understand the aquatic animal data ecosystem and how political landscape impacts AAH decision-making. The extent to which GBADs methods have been applied to aquatic animal production, is, therefore, limited. In this paper, we *i)* assess the challenges of applying GBADs methods across a number of diverse aquatic animal production systems (grow-out, hatchery, mollusc and recirculation systems), *ii)* use GBADs methods to calculate the burden of disease in a typical rainbow trout farm in England and *iii)* consider how analyses using GBADs methods may address shortcomings in the current literature.

Application of GBADs methods to aquatic animal production

The GBADs programme provides data-driven evidence that policy-makers can use to evaluate options, inform decisions, and measure the success of animal health and welfare interventions. The 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.

Drivers

The key driver for developing the GBADs programme is the lack of a systematic process to determine the burden of animal disease. The programme seeks to address the lack of systematic collection of data for *i)* production losses, *ii)* expenditure on disease control and *iii)* the wider economic impact of disease, and thus support decision making and ultimately to improve societal outcomes from animal production. These objectives are equally relevant to aquatic as terrestrial animal production. The methods can be applied at the production system, country, and global levels.

The range of aquaculture production systems

Today, over 500 aquatic species are being cultivated across the globe, finfish, molluscs, crustaceans, and aquatic plants in diverse habitats. Countries engaged in aquaculture vary from low-income to high-income nations. The scale of production ranges from different levels of intensification and extensification, and access to and utilisation of technology, in addition to data recording and accessibility, further contribute to the large diversity within aquaculture production. All the above mentioned creates challenges to applying GBADs methods. The challenges to applying GBADs methods vary greatly between production systems, which can be classified using a number of factors [8,9]:

a) inputs (intensity) (feed, disease control, energy, stocking density, capital)
b) species (finfish, molluscs, crustaceans)
c) scale (large, medium, small)
d) feed (fed *versus* non-fed, pasteurised *versus* unpasteurised)
e) production input (hatchery, wild stock)
f) environment (freshwater, brackish, marine; land-based *versus* water-based)
g) polyculture *versus* monoculture
h) integrated (e.g. livestock-fish) *versus* unintegrated
i) commercialisation/ownership (production for subsistence, local or national markets, or export).

From a GBADs perspective, and notably the calculation of the animal health loss envelope (AHLE), classifying aquaculture production systems by inputs is informative. In Table I, selected aquatic animal production systems are assessed by level and type of input. Local definitions of production system classification may be necessary when assessing the construction of local datasets. Therefore, a flexible system that respects both local understanding and aggregation to generate burdens at national and global levels is needed.

Approach to data collection

The GBADs approach aims to make use of existing production data through systematic literature reviews. Data gaps are addressed through expert elicitation. Production data will be most readily available for commercial salmonid production systems (salmonid and shrimp), and largely lacking from small-scale subsistence aquaculture (notably tropical freshwater cyprinid farming). Farmers' data may be considered commercially important or otherwise sensitive (e.g. mortality rates), which may present challenges around confidentiality and publication.

Calculation of the animal health loss envelope (AHLE)

The GBADs programme is described in other papers in this edition. Fundamental to the GBADs approach is the description of populations under study, their value, the resources they consume, and the products generated. Modelling the efficiency of the relationship between input and output for both current conditions and an 'ideal health' scenario (absence of disease), generates an 'envelope' of total disease burden which contains the sum of lost production due to disease and total additional resources used to mitigate disease and achieve current production in the presence of disease (e.g. expenditure on treatments, vaccinations, etc.) [10].

Gilbert *et al.* [11] calculated the AHLE at the national level for a representative broiler chicken sector. Under 'ideal' conditions, veterinary costs, post-harvest rejection and mortality rates are set to zero. The food conversion ratio (FCR) and length of the production cycle are adjusted to a level that would be expected in the absence of disease (resulting in lower feed costs for the same production). For example, in the analysis of poultry production, FCR decreased from 1.6 to 1.41 for large broilers [11]. The input of purchased one-day-old chicks is reduced under ideal, compared with current, production, to keep output (chicken meat), and final stocking density unchanged between current and ideal conditions. The large majority (68%) of the AHLE is attributed to reduced feed costs.

The main sources for key production parameters (industry, government, published data, and expert opinion) required for the AHLE calculation are summarised by the production system in Table II. Not all parameters are relevant for all systems, for example, molluscan systems have no feed costs. In some countries, industry is required to report mortality to the Competent Government Authority and these data may be available from official sources. Similarly, costs of water abstraction (freshwater) and seabed leasing are generally in the public domain. It is clear from Table II that expert opinion is required for most of the production parameters for subsistence cyprinid and small-scale shrimp production. If available, farm data from commercial aquaculture sectors can be used to determine between farm variation in production parameters, e.g. FCR and production cycle length. These analyses can inform estimates of production parameters achievable under 'ideal conditions'.

Applying the AHLE to hatchery production

Many aquaculture systems are based on a relatively small number of hatcheries producing juvenile animals supplied to a considerably larger number of 'ongrowing' farms. The application of the AHLE to hatchery production is more complex and subject to greater uncertainty compared with 'ongrowing' farms, as the population is comprised of both breeding stock and juveniles destined for sale. Outputs from the farm include live fish for ongrowing and culled breeding stock for consumption. FCR and survival rates of broodstock and juveniles are required, as well as the impact of disease on reproduction. Populations simulation modelling will be required to apply GBADs methods to breeding populations.

Applying the AHLE to small-scale tropical finfish production

A range of production systems are used in small-scale freshwater pond finfish production systems in Asia. Polyculture is widely practised based primarily on indigenous and exotic species of fish. For example in Bangladesh, the major indigenous cultured species are catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*) and kalbaush (*Labeo calbasu*), which may be co-cultured with exotic species: silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), pangas (*Pangasius sutchi*), Thai silver barb (*Barbodes gonionotus*), tilapia (*Oreochromis* spp.) and hybrid magur (native *Clarias batrachus* x African catfish *Clarias garipinus*) [12]. In some system shrimp may also be introduced. Integration of fish with duck or chicken farming is also common. The AHLE would need to be separately modelled for each farmed species, and then combined at farm level. It is possible that a significant element of the AHLE in small scale backyard systems is attributable to sub-optimal nutrition.

Applying the AHLE to mollusc production

In ongrowing aquaculture system reduced feed costs are highly likely to account for a large element of the AHLE (due to improved FCR and reduced mortality). However, molluscan production has no feed input. Under ideal condition (i.e. optimal concentrations of microalgae and other food sources), molluscs may grow faster but no studies exist to inform expert opinion on the time to harvest under current and ideal conditions. Optimal growth can be estimated based growth rate data: the fastest observed growth could be used as an estimate of growth rate under ideal conditions. The AHLE would comprise *i)* increased production from reduced time to harvest and *ii)* reduced cost of purchased animals from reduced mortality (all other variable costs would remain constant). Whilst it is useful to know what proportion of the AHLE can be attributed to suboptimal nutrition, as the system has zero feed inputs it is not amenable to intervention. The costs of mollusc production in many countries depend on water quality. Production in water little impacted by anthropogenic activities (agricultural runoff, sewage discharges) (e.g. class A waters under EU classification) can be marketed directly. By contrast, production where microbiological quality is poor (as measured by coliform counts) incurs additional costs from legally mandated interventions, notably depuration, before sale. If it is assumed that the burden of disease includes costs associated with product safety/market ready, then under ideal conditions costs of depuration should be omitted.

Applying the AHLE to recirculation aquaculture systems (RAS)

The AHLE may provide new insight into the differences between RAS with traditional aquaculture systems. Shrimp are produced in a range of systems including small-scale and extensive pond production, and increasingly in RAS. RAS are epidemiologically isolated and, therefore, compared with open water systems, inherently more biosecure. The environmental conditions (water quality) can be tightly controlled. Whilst RAS are not disease free, they generally operate with lower levels of mortality and morbidity compared with production of the same species in pond systems. In addition, the high level of biosecurity in RAS results in low levels of disease control costs. Thus, compared with pond systems the AHLE will be smaller compared with pond production. The biosecurity costs derive from the high capital start up and energy costs which are inherent to the system. Removing these costs under ideal conditions effectively changes the system and thus invalidates calculation of the AHLE.

Case study: AHLE calculations for RBT production in England and Wales

A key component of the salmonid aquaculture sector in England and Wales (E&W) is the production of rainbow trout (RBT) for human consumption by farms that purchase juvenile fish and grow them on to harvest weight. An existing dataset, collected through expert elicitation and systematic literature reviews, was used to model the relationship between inputs and outputs of a site producing 350 metric tonnes of RBT for human consumption per annum and generate an AHLE estimate. Data were collected using the typical farm approach [13] (summarised in Table III). The total number of fish harvested was estimated using the known number of fish stocked and mortality estimates. Revenue was calculated as the product of number of fish harvested, the mean average individual fish harvest weight, and the farmgate price per kilogram (kg). Feed cost was based on the FCR, feed cost per kg, and total biomass produced (fish harvested and mortalities). Under 'ideal conditions' mortality, veterinary costs, and annual costs associated with mortality removal were set to zero, and the number of fish stocked was reduced to achieve the same production under 'ideal' and current conditions (it was assumed that stocking density at the point of harvest under current conditions was optimal). Other costs were unchanged between ideal and current conditions. The British Trout Association (BTA) estimates that FCR for farmed RBT in E&W ranges between 0.8–1.1 [14]. The FCR was reduced from 1.1 to 0.8 under ideal conditions (harvest size was unchanged). The AHLE was estimated to be £203,849 (compared with a revenue of £873,180) (Table IV), a 25% reduction in expenditure under ideal compared with current production. The majority (79%) of the AHLE was attributed to reduced feed costs, which decreased by 32%. The other key saving was reduced stocking costs as fewer fingerlings were purchased (as mortality was zero under ideal conditions). The analysis was at farm level and prices were assumed to remain constant. Scaling the analysis to national should ideally involve modelling potential changes to farmgate price.

Discussion

Government decision-making and resource allocation to aquatic animal health are often focused on diseases which have garnered political attention through the listing by WOAH [6]. WOAH listed diseases have global significance and are generally highly infectious epidemic diseases which can spread through trade in animals and their product. As a consequence, the control of endemic diseases is often neglected. Information on the true of cost endemic disease can help redress this imbalance. GBADs methods offer a sound basis for both data collection and analysis to generate information on the burden of disease in aquaculture systems. In this paper we have demonstrated that GBADs methods can successfully be applied to aquaculture, specifically, the RBT case study illustrates an AHLE calculation at farm level, which can be scaled for a sectoral analysis. A more accurate AHLE estimate requires better data on the occurrence of mortality over the production cycle and on variation in FCR within the industry. Nevertheless, the calculation presented here indicates the maximum possible benefit achievable through improved AAH intervention and is in line with a similar analysis of Norwegian farmed Atlantic salmon and RBT at the national level which indicated cost reduction of 31–38% under ideal compared to current production [15]. Whilst achieving zero mortality and no expenditure on disease control is not a realistic goal, establishing the AHLE as an objectively defined standard, representing the maximum benefit that can be achieved by eliminating the disease burden, overcomes many of the problems inherent in comparing different production systems [11]. It is an important first step in attributing burden to different causes.

All modelling involves simplification of complex biological systems. For example, we are not able to model the relationship between mortality and stocking density in the calculation of the AHLE. Furthermore, we acknowledge that for hatcheries and polyculture, the calculations are more complex. Further work is required to fully explore the application of the methods to zero feed molluscan production.

In many systems, notably small-scale tropical finfish production, a lack of published data will be a key constraint. Estimates of disease burden can only be achieved across production systems and at national level if efficient, consistent data collation and integration techniques are developed and adopted by aquaculture producers. In Atlantic salmon production, an approach to data collection on the cause of mortality, based on a logical hierarchy has been proposed [16], which could be applied to other systems. Government can support better data collection by requiring as a condition of farm authorisation, that mortality (and potentially other parameters) is recorded, with information that allows for attribution to cause. Importantly, farmers need to be benefit from data analyses to incentivise data collection and sharing. Beyond attribution, value chain modelling is needed to determine societal impacts of disease burden. It was noted by Rojas *et al.* [8] that the link between aquatic production to post-production systems (e.g. value creation in different product distribution models) is unclear. Thus, the impacts aquatic diseases on supply chain stakeholders (e.g. processors, wholesalers) are difficult to address. Addressing these gaps is needed to determine the societal, economic, human nutritional and health and gender impact of aquatic diseases and investments in disease control. Work by Countryman and Shakil, overseen by Marsh and Pendell as part of the GBADs Ethiopian case study (papers currently in review) has elaborated how the AHLE can serve as an input to scenarios in wider economy models, generating estimates of changes in GDP, producer and consumer surplus due to the burden of animal diseases.

Conclusions

This review demonstrates how GBADs methods, and notably the AHLE, can applied to aquaculture production systems. Data availability is a key limitation in the calculation of the AHLE. Ideally production under ideal conditions would be informed by experiment results but in reality is based on models, meta-analysis of peer-reviewed data or expert opinion. Government has an important role to play in facilitating data collection and analysis that supports decision-making by both governments and industry. The GBADs programme is an important first step to generate evidence on the cost of disease at the production system and national level to support decision-making about investment in AAH. Additional assessments are required to support government decision-making. Analyses of the costs and benefits of animal health interventions, such as vaccination, will allow prioritisation of mitigation measures. The environmental impact, both negative and positive, and how the societal benefits of aquaculture are distributed, will support the development of national aquaculture strategies.

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Box 1

Challenges and considerations when applying the GBADs framework to aquaculture

Source: adapted from Rojas *et al.* [8]

- Both public and private decision-makers rely on economic evaluation to make strategic, operational and contingency decisions related to aquaculture.
- The management of water is central to the structure and operation of aquaculture systems, the epidemiology of diseases, prevention and control measures, and therefore investment, losses and costs of diseases.
- Aquaculture systems are highly diverse, with small producers being very important for most farmed species. Sufficient variables to classify aquaculture production systems are: species, production phase, type of production (one or two variables), intensification and size.
- The structure of disease losses is similar to terrestrial animals. Co-infection of diseases makes it difficult to establish the impact of a specific disease. Water connectivity makes it is more difficult at the aggregate level for many systems, (compared with terrestrial production) to establish epidemiological boundaries between production units.
- A complexity of many aquaculture systems is the difficulty of monitoring individuals due to populations size, poor accessibility and visibility increasing under-reporting or misclassification of disease.
- The expenses of diseases derive from prevention and control and escalate significantly in emergency situations. Expense categories are similar to those established in terrestrial animals.
- In aquaculture, environmental emergencies can have important impacts on production which can impose costs from both prevention and response, similar to infectious diseases.

Large companies and governments of developed countries hold most of the data.
Elsewhere (e.g. small-scale production in developing countries) data are more limited.

GBADs: Global Burden of Animal Diseases

Table I

Aquaculture production systems classified by the intensity of inputs

Input	**Aquatic animal production system**							
	Salmonid		Cyprinid		Molluscs		Crustacean	
	Marine netpen (Atlantic salmon)	Freshwater pond (rainbow trout)	Subsistence – tropical (small scale)	Commercial (large scale)	Marine rope culture (mussel)	Bottom culture (bottom)	Land-based recirculation (shrimp)	Pond (shrimp)
Feed	VH	H	L	M	Z	Z	L	M
Disease control (vaccination)	H	H	L	M	VL	VL	L	L
Biosecurity	H	H	L	M	VL	VL	H	M
Stocking density	H	H	L	M	L	L	VH	M
Energy	M	M	L	L	VL	VL	VH	M
Labour	L	M	H	L	L	L	M	M
Capital	M	M	L	L	L	L	H	M
Overall intensity of input	**H**	**H**	**L**	**ML**	**VL**	**VL**	**H**	**M**

H: high
L: low
M: medium
ML: medium low
VH: very high
VL: very low
Z: zero (no inputs)

Table II

Availability for production parameters by aquaculture production system – current production

Production cost	**Aquatic animal production system**					
	Salmonid	Cyprinid		Molluscs	Crustacean	
	Atlantic salmon/rainbow trout	Subsistence – tropical (small scale)	Commercial (large scale)	Mussel/oyster	Recirculation (shrimp)	Pond (shrimp)
			Production costs			
Labour costs	ID and PD	**EE**	ID and PD	ID	ID	**EE**
Infrastructure	ID	**EE**	ID	ID	ID	**EE**
Water*	OS	NR	OS	OS	OS	OS
Veterinary costs	ID	**EE**	ID	NR	ID	**EE**
Energy costs	ID	**EE**	ID	ID	ID	**EE**
			Production parameters			
FCR	ID and PD	**EE**	ID and PD	NR	ID and PD	**EE**
Mortality rate (by stage of production)	ID and OS IS	**EE**	ID and OS	**EE**	ID	**EE**
Harvest rejection	OS	NR	OS	NR	OS	OS
Carcass downgrading	OS	NR	OS	NR	OS	OS
Harvest weight	ID and OS	**EE**	ID and OS	ID and OS	ID and OS	ID and OS

EE: expert opinion required
FCR: food conversion ratio
ID: industry data
NR: not relevant
OS: official statistics
PD: published data
* for example, abstraction/seabed lease costs
** feed costs based on FCR

Table III

Rainbow trout (RBT) typical farm model production parameters, prices and costs

Costs derived from the typical farm model

Production parameter	
Fingerling weight at stocking (g)	5
Fish stocked per annum	1.1 million
Fingerling mortality (%)	20
Ongrowing fish mortality (%)	10
Fingerling average weight at death (g)	37
Ongrowing fish average weight at death (g)	217
Average harvest weight (g)	450
Food conversion ratio	1.1
Price data (£GBP)	
Cost of feed per kg	1.16
Farm gate price per kg	2.45
Purchase of fish (100)	10.45
Annual operating costs (£GBP) (% total)	
Feed	489,389 (60)
Fish purchase	115,000 (14)
Veterinarian	9,000 (1)
Electricity	13,500 (2)
Oxygen and ice	24,000 (3)
Mortality removal	2,000 (>1)
Other variable	3,000 (>1)
Total fixed costs	89,000 (11)
Labour costs	65,000 (8)

Table IV

Typical rainbow trout farm AHLE, expenditure, output under current with disease and ideal without disease

	Current	**Ideal**	**Net**
Ordinary input cost	£800,889	£606,039	£194,849
Disease control input cost	£9,000	£0	£9,000
Total output value	£873,180	£873,180	£0
Biomass valuation	£0	£0	£0
		AHLE	£203,849

AHLE: Animal Health Loss Envelope