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Assessment of Consequences of Notifiable Fish Disease Incursions in England and Wales

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ABSTRACT

A consequence assessment framework was developed to evaluate the economic and environmental consequences of an exotic disease in the context of supporting policy level decisions on mitigation strategies. The framework adopted a semi-qualitative analysis of impacts supported by expert judgement. The efficacy of the framework was illustrated via assessment of the notifiable fish disease, *Gyrodactylus salaris*. In this example, the economic cost of an illustrative outbreak of *G. salaris* ranged from £0.22 million to £90 million. The cost of the most likely scenario (regional spread) was estimated to be £7.5 million (minimum to maximum range of £2-22 million), reflecting the uncertainty in the extent of spread of the parasite before detection. The environmental impacts varies by a factor of 35 between incursion scenarios reflecting the number of affected catchments in the scenarios.

Key Words: consequence assessment, *Gyrodactylus salaris,* aquatic fish disease, incursion

INTRODUCTION

During the global trade of live aquatic animals and their commodities, transboundary movement presents significant routes of disease introduction inflicting various economic, environmental and/or socio-economic impacts (Minchin, 2007). There is a range of regulatory and legislative guidance in this area, paramount being the Sanitary and Phytosanitary (SPS) Agreement of the World Trade Organisation (WTO, 1995) providing basic rules for international trade governing food safety, animal and plant health while maintaining a free and safe trade environment among Member states. Key to this agreement is the import risk analysis (IRA) framework determining the level of sanitary measures necessary to provide the safe trade of particular species. Guidelines for its implementation are outlined by the World Organisation for Animal Health (OIE, 2004) and suggest that IRAs assess the consequence of a disease incursion and an estimation of the likelihood of pathogen introduction and establishment. Currently, the UK is free of a number of notifiable diseases listed by the OIE (i.e. those that must be reported by law) that are prevalent in continental European aquaculture (e.g. viral haemorrhagic septicaemia and infectious haematoptic necrosis). Statutory controls are in place to protect the UK's 'disease free' status; for example, live fish can only be imported from areas with the same high health status. The disease control policies used for a particular outbreak (e.g. movement restrictions or culling) are the main predictor of the cost of the process and so consequence assessment plays an important role in evaluating the cost-benefit assessment of intervention to reduce and manage risk.

To date, no example of a structured method for rapidly assessing the consequences of an exotic disease incursion of an aquatic animal pathogen exists. However, consequence assessments have been developed for other risk domains including for natural disasters –

volcanoes and earthquakes (Granot, 1995; Magill and Blong, 2005), mining (Hutchinson *et al.*, 2002) and terrestrial animal disease incursions (Moutou *et al.*, 2001; Australian Department of Agriculture, 2004). As a result, in practice the consequence assessment element of IRA for fish disease often receives minimal attention, sometimes reduced to a few paragraphs of narrative or is excluded completely (Peeler *et al*., 2007a). This may be due to the lack of structured methodology or genuine data deficiency (Edgerton, 2002).

Here, we propose a method for assessing the consequences of exotic notifiable disease incursions for England and Wales (E&W). The method is designed for use by the Centre for Environment, Fisheries and Aquaculture Sciences (Cefas) whose role it is to oversee aquatic animal health and respond to exotic disease outbreaks within E&W.

Background

There is merit in reviewing the decision context, so as to inform the discussion of the proposed approach and case study later in this paper. Decisions about notifiable disease incursions are complex and generally suffer from a paucity of data (Pharo, 2004). Decision-makers (policy and regulatory officials, for example) usually benefit from access to high quality information to inform decisions on intervention strategies to reduce risk. Usually, these decisions require some justification of their benefits in the context of the costs born in the event of a disease outbreak. An evaluation of economic as well as environmental impacts is valuable. The proposed framework presented below operates within the aforementioned regulatory systems and builds upon the SPS agreement's vision of consequence assessment (one currently dominated by economic assessment (Macdiarmid and Pharo, 2003)), by broadening the assessment to include environmental impacts. Consequence metrics are aligned with the fish health legislation in England and Wales (AAHR, 2009), which is largely determined by the European Council Directive 2006/88 on animal health requirements for aquaculture animals, and assesses scale and cost with respect to farmed and wild fin fish species.

Currently there is no formal framework used by UK Government to assess the consequences of exotic disease incursions. Instead, outbreak scenarios have been employed to assess the likelihood of outbreaks of varying geographic scale (*personal communication* EJ Peeler, Cefas); a method also used by the Australian Department of Agriculture, Fisheries and Forestry (2004). The framework presented below was developed fit-for-purpose and intended to provide a structured and transparent approach for 'high-level' assessment of fish disease, thus providing strategy and policy makers a standardised perspective of consequence. Due to a lack of fish disease examples in the UK, supporting data is minimal and therefore the framework relies upon expert judgement. .The intention is to provide a framework that improves organisational capacity for comparing the consequences of different exotic diseases, enabling improved decision making. We believe this to be the first example of a framework for rapidly assessing the impact of an aquatic notifiable disease incursion in an industrial/commercial context and illustrate the efficacy of the framework using an example outbreak of *Gyrodactylus salaries*, a freshwater parasite of salmonids.

METHODS

Rationale for approach and treatment of consequences

The literature on fish disease consequence assessment is not extensive and methods for describing the impacts of aquatic disease were linked to the wider body of risk literature, most notably those applied to characterising environmental harm (Pollard *et al*., Willis *et al.*, 2004). A key consideration for the successful development and implementation of the framework was the alignment of consequence attributes with organisational objectives and the need for a pragmatic comprise between usability and depth of description (Willis *et al.*, 2004; HCN, 1996). Environmental and economic consequences used to assess the impact of a disease incursion were developed through an elicitation process with experts from Cefas. Experts were chosen based on their familiarity with the subject material and capacity for providing a 'high-level' assessment of the issue such that the methodology developed would have broad utility across a range of exotic diseases.

The main economic driver identified was the impact on aquaculture trade. However, costs are also incurred during disease eradication. Disease control regulations can, for example, instruct the destruction of infected stock (AAHR, 2009) leading to short term production losses and subsequent reduction in future production due to loss of juveniles. These consequences are readily quantifiable based on market values, as are the impacts of mitigation activities (*e.g.* disinfection, site clean-up) and lost productivity (Macdiarmid and Pharo, 2003). An economically-focused viewpoint of consequences (Table 1) provides easily comparable values between different types of disease incursions. However, such an approach is limited in providing a broader overview of the wider range of impacts associated with an incursion. Below we address economic and environmental consequences in turn.

{Table 1 about here please}

Key economic aspects of aquaculture were disaggregated to provide close detail about consequence. A key differentiator is "fish utility" (farmed and wild species), the rationale for which is the differences in disease management activities between the two types of utility. Moreover, some diseases do not affect farmed and wild species equally (Peeler *et al*., 2007b) and decision-makers require further detail to provide an accurate representation of disease consequence. Further disaggregation enables the assessor to make a distinction between economic impacts to infected water bodies (inf) and those suspected of infection (susp) as each will initiate a different regulatory response (AAHR, 2009). A farm may fall under suspicion if it has an epidemiological link with an infected farm (e.g. within the same river catchment or received movements of fish). Finally, differentiation is given to farms producing fish for consumption (table) versus those that produce fish for restocking of river or still-water fisheries (resto). This distinction accounts for economic differences of particular mitigation strategies, dependent upon a farm's status (Table 2) as well as the end value of the fish.

{Table 2 about here please}

Environmental consequences are less tangible and difficult to quantify, though remain vital for ensuring a well informed decision. Capture of environmental information relies upon a qualitative assessment and expert judgement. Here, we determined that the environmental consequences needed to be further fragmented to consider environmental and ecological attributes that emphasised the impact on the wider community of aquatic species. Whilst these were by no means inclusive of all possible environmental consequences, the process of considering such broad consequences as ‘knock-on ecological effects’ will provide much greater value to decision makers than a simple statement of expected monetised stock at risk.

Populating the framework

The framework was populated by extrapolating economic information from market prices and outbreak scenarios, as well as the opinion of experts within Cefas. Experts were asked to determine the extent of economic harm arising from an outbreak. Where available, stochastic distributions were used to represent the variability in cost estimates and take into account the size of a potential outbreak, the size of aquaculture farms and cost variability. These distributions were gathered from in house Cefas data and from expert extrapolation of predicted outcomes. To account for an incursion that affects more than one farm or catchment, stochastic values were multiplied by the number of farms or catchments affected in line with the outputs of the outbreak scenarios. Aggregating all economic values provided an overall assessment of economic consequence.

Environmental consequences are difficult to quantify and therefore a semi-quantitative approach was adopted using scalar values linked to qualitative descriptors (Table 3). This allowed aggregation of all environmental consequences into a single semi-quantitative output, thus enabling a relative comparison between two or more disease agents (Granot, 1995; Australian Department of Agriculture, 2004). Attribute weighting was introduced to assign an importance to each environmental descriptor – often due to regulation (e.g. protected species). Weights ranged from 1 (low importance) to 5 (high importance) and were assigned by Cefas experts informed by AAHR guidelines (AAHR, 2009). Ranges were assigned using expert consultation and with reference to existing outbreak scenarios. To illustrate the efficacy of the framework an assessment of the consequences of an incursion of *Gyrodactylus salaris* was performed.

{Table 3 about here please}

RESULTS

Case study - an illustrative assessment for *Gyrodactylus salaris*

An assessment of the likely impact of *Gyrodactylus salaris*, a freshwater parasite of salmonids, was used to explore the efficacy and appropriateness of the framework. *G. salaris* is a freshwater parasite not found in the UK. The limited available data (Mackenzie, 1993) indicates that Atlantic salmon populations in the UK are highly susceptible to *G. salaris* and thus, if infected, are likely to experience population declines similar to those observed in Norway following introduction of the parasite from Sweden (Johnsen and Jensen, 1991). In consultation with experts at Cefas, four outbreak scenarios for *G. salaris* were developed and likelihoods ascribed (Table 2). The economic consequence of an outbreak of *G. salaris* for the defined attributes is presented in Table 3. The outbreak scenarios and economic consequences were then combined to provide a total economic cost (minimum, maximum and most likely) for each outbreak scenario (Table 4).

{Table 4 about here please}

Elicitation sessions of experts from within Cefas were used to develop a general weighting for each environmental consequence. Weightings were considered fixed for all disease outbreaks. Experts assigned scores for all environmental attributes of an incursion of *G. salaris* (Table 5). The magnitude of the environmental consequence was a product of the weighting and ranking score, the sum of which gives an overall environmental consequence score for *G. salaris* (OCS) of 50. This was then scaled by the number of affected catchments to give a consequence score for each scenario (Table 6). Five economic attributes (Table 2) were considered by experts as being 'cost independent of pathogen', meaning the stochastic distributions did not significantly vary with the pathogen of concern. The main cost for surveillance and supervision was manpower, which is unlikely to vary substantially between pathogens (diagnostic costs may vary but comprise a relatively small proportion of the total costs) and therefore the cost to the competent authority does not change. The cost of disinfection, loss of stock, restocking and loss of trade for the farm also do not vary between pathogens. As an example, farms carry out the same disinfection process no matter what type of pathogen has infected stocks. Similarly, the cost of destroying an entire stock is also unlikely to be affected by different pathogens.

{Table 5 about here please}

{Table 6 about here please}

The economic attributes dependent on a particular pathogen included 'economic impact of a decrease in wild population levels', 'national market reaction' and 'loss of international trade'. These attributes required re-estimation by experts for different pathogens because of the need to account for changes in market values associated with different species. Re-estimation may be necessary for diseases that affect only farmed and not wild species (or vice versa) and this is to take account for effects on recreational fishing and tourism.

DISCUSSION

The method assesses economic and environmental consequences of a disease incursion in the context of UK/EU regulation. Consequences to human health are excluded from the assessment as there are no clear links to human health implications of finfish disease (OIE, 2009). Broader social consequences are captured from an economic perspective when assessing the attribute 'economic impact of a decrease in wild population levels', which assesses the economic loss due to a decrease on recreational fishing and tourism caused by a decline in wild population levels. However, the attributes considered here do not consider the social impact on the farming population or perception of the industry after an event.

From a pragmatic perspective the method assesses economic and environmental consequences separately, which has the advantage of enabling extraction of specific information dependent upon a user's data requirements. This avoids the contentious topic of combining quantitative and qualitative data (Granot, 1995). Our rationale was to provide decision makers with a transparent presentation of data rather than a reductionist single score of consequence. However, decision makers may wish to have economic and environmental consequences combined, possibly by using a matrix, as a single value to more easily compare the impact of different diseases. This is possible only where economic and environmental consequences are commensurable and can be achieved by monetisation of non-marketed goods (i.e. environmental). Stated preference methods, such as contingent valuation method (CVM) or choice experiments generate data that describe a respondent's preferences and determines society's valuation of environmental attributes (Green *et al.*, 1998; Veisten, 2007). Monetising environmental consequences is challenging due to the small size of the freshwater fisheries sector, which limits the volume of non-biased data one can obtain. Also, economic valuation techniques may fail to capture broader values (Fischhoff, 2005) and there is a trend in economic valuation to acknowledge the impossibility of monetising certain environmental services (TEEB, 2010). Therefore, we prefer a rapid evaluation of environmental consequences (as presented) providing a depth of information that better informs decision processes.

The score for the environmental impact of an exotic disease incursion can be used to rank the importance of exotic diseases, once the framework has been applied to the most prevalent and/or severe exotic diseases. Such ranking may aid decision-makers in the allocation of resources between competing activities; for example, in the selection of exotic pathogens for targeted surveillance. A robust ranking of the diseases based on their likely environmental impact (and information on the economic consequences and likelihood of introduction) is generally sufficient for this purpose. Approximate monetisation of environmental impacts would not significantly improve the evidence base for decision making.

Expert opinion is a useful for eliciting reliable risk data and has been shown to provide valuable information regarding climatic impacts to aquatic species (McDaniels *et al.*, 2010). Similar to climatic impact, the consequences of new disease outbreaks in England and Wales are generally unknown and therefore suffer from a paucity of data. In this context, expert judgement is often the only source of reliable, informed data and previous research has demonstrated the efficacy of multi-disciplinary Delphi panels (including fish health specialists, economists and ecologists) that are useful for collating information and generating consensus (Peeler *et al.*, 2006). However, given the small size of the sector and the demand for rapid assessment, access to a range of experts is not frequently feasible. Under this constraint, a small panel of experts on finfish disease and IRA was used to complete the assessment for *G. Salaries*, with their main role being to provide expert synthesis and extrapolation of disease data taken from countries where the disease is present. An obvious limitation is the potential for poor translation of environmental impacts between regions or the introduction of bias. Though access to numerous experts is advantageous, pragmatic compromise suggests that assessment be completed using the resources available.

Overall, the framework provides a relative, rather than absolute, assessment of consequence based upon best available data and expertise. Decision makers must be careful to consider all available information because, like all risk tools, this framework will not provide a definitive answer to the questions they raise. The case of a *G. salaris* disease outbreak served to illustrate the efficacy of the consequence assessment framework. The economic cost of an outbreak of *G. salaris* may range from £0.22 million to £90 million. The cost of the most likely scenario (regional spread) was £7.5 million (minimum to maximum range of £2-22 million). The range of costs reflects primarily the uncertainty about the extent of spread of the parasite before detection. Similarly, the environmental impact varies by a factor of 35 which reflects the number of affected catchments in the scenarios. The environmental consequences provide a non-monetary value and therefore, to provide usable comparison to other diseases this method needs to be consistently applied to all the major notifiable fish pathogens. In general, this case study demonstrates the ease in which a formal, structured and transparent consequence assessment may be generated and when applied to a variety of diseases will provide equitable evidence for decision makers.

CONCLUSION

The need to assess the consequence and risk of a fish disease incursion is well recognized. This paper presents a standardised approach for assessing consequence, suggesting suggested framework comprised of two components (economic and environmental). Challenged by a severe lack of data, the assessment was informed by experts from Cefas who provided technical and regulatory expertise. The methodology developed in this paper may be used for assessment and relative comparison of consequences for exotic aquatic animal disease incursions and thus, will is a useful tool for aquatic animal health management.

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Attributes affecting economic consequence magnitude	Definition	Who bears the cost
Farm level		
Surveillance by competent authority	Cost of sampling and diagnostics carried out by the government on infected farms and farms under suspicion of being infected to control the presence of a pathogen	Government
Disinfection of a farm	Cost of eradicating a pathogen in a farm, including killing, disposal of fish, drainage of ponds and disinfection	Farm
Supervision by competent authority	Supervision of killing and disposal of fish, drainage of ponds and disinfection of a farm	Government
Loss of stock	Economic losses due to the loss of saleable stock	Farm
Restocking	Cost of restocking the farm	Farm
Loss of trade	Loss of income due to fallowing and movement restrictions	Farm
Catchment level		
Surveillance by competent authority	Cost of sampling and diagnostics (electrofishing wild populations) carried out by the government in affected catchments to control the presence of a pathogen and the two years of sampling to re-establish disease-free status in infected catchments (EC 2006/88)	Government
Decrease in wild fish population	Decrease of recreational fishing and tourism caused by a decrease in wild population levels	Local economy
National level		
National market reaction	Loss due to a decreased demand for farmed fish within UK	Industry
Loss of international trade	Loss of overseas market due to a decreased demand for product and eggs	Industry
Attributes affecting environmental consequence magnitude	**Definition**	**Who bears the cost**
Number of species affected	Total number of species affected by the assessed pathogen	Public
Number of threatened species affected	Number of threatened species affected by the assessed pathogen	Public
Likely level of population decline (in affected rivers)	Decline of population due to a disease incursion (taking into account the age of affected fish)	Public
Duration of population decline	Temporal scale of the decline on population levels	Public
Knock-on ecological effects	Secondary or indirect effects of a disease incursion on the ecology	Public

Table 1. Definition of economic and environmental consequences

		Outbreak scenarios			
		1.No spread	2.Local spread	3.Regional spread	4.National spread
Infected farm	**Table farms**	1	1	5	38
	Restocking farms	0	1	4	25
Farms under suspicion	**Table farms**	5	11	43	91
	Restocking farms	3	7	29	61
Affected catchments		1	1	9	35
Likelihood (%)		8	7	80	5

Table 2. Outbreak scenario for *G. salaris*: (number of affected farms, catchments and likelihoods)

Attributes affecting economic magnitude		Farmed stock stochastic magnitude distributions (£)			Wild populations stochastic magnitude distributions (£)		
		min	max	most likely value	min	max	most likely value
Farm level					**Catchment level**		
1. Surveillance by competent authority*		1000	10 000	2000	Sampling immediately post outbreak		
					3000	60 000	30 000
					Status re-establishment		
					8000	100 000	30 000
2. Disinfection of a farm*	Inf/table	5000	30 000	10 000	n/a		
	Inf/resto	5000	30 000	10 000			
	Susp/table	5 000	30 000	10 000			
	Susp/resto	5 000	30 000	10 000			
3. Supervision by competent authority*		1000	5000	1500	n/a		
4. Loss of stock*	Inf/table	50 000	180 000	90 000	n/a		
	Inf/resto	50 000	180 000	90 000			
	Susp/table	0	0	0			
	Susp/resto	0	0	0			
5. Restocking*	Inf/table	50 000	180 000	90 000	n/a		
	Inf/resto	50 000	250 000	140 000			
	Susp/table	0	0	0			
	Susp/resto	0	0	0			
6. Loss of trade	Inf/table	50 000	300 000	100 000	n/a		
	Inf/resto	50 000	300 000	150 000			
	Susp/table	0	0	0			
	Susp/resto	0	200 000	75 000			
7. Economic impact of a decrease in wild population levels		n/a			10 000	500 000	75 000
National level							
8. National market reaction		0	50 000	10 000	n/a		
9. Loss of international trade		0	50 000	10 000	n/a		

Table 3. Economic consequence assessment framework for an outbreak of *G. salaris*. Inf – farms that are infected; Susp – farms under suspicion of infection (i.e. situated in the same catchment as or have received live fish from infected farms); Table – farms producing fish for human consumption; Resto – farms producing live fish for restocking purposes; n/a – no available information (i.e. no relevance to wild or farm stock).

*costs are independent of pathogen

Outbreak scenarios	Minimum	Maximum	Most likely
1.No spread	0.23	2.39	0.77
2.Local spread	0.42	4.43	1.63
3.Regional spread	1.95	21.60	7.52
4.National spread	11.00	89.40	33.40

Table 4. Overall stochastic summation of economic consequences (£ million) for each outbreak scenario

Environmental consequences of *G. salaris*	Weighting (W)	Ranking criteria Scalar:Value	Ranking scores (S)	Magnitude (W*S)
1. Number of species affected	1	**1**: 1 **2**: 2-4 **3**: 5-7 **4**: >7	1	1
2. Number of threatened species affected	3	**0:** 0 **1**: 1 **2**: 2 **3**: 3 **4**: >4	1	3
3. Likely level of population decline in the affected rivers (%)	4	**1**: <5 **2**: 5-40 **3**: 41-70 **4**: >70	4	16
4. Duration of population decline (years)	5	**1**: <1 **2**: 1-10 **3**: 11-20 **4**: >20	4	20
5. Knock-on ecological effects	5	**1**: Negligible **2**: Minor **3**: Moderate **4**: Severe	2	10
Overall consequence score (OCS): (∑ W*S)				50

Table 5. Environmental consequence assessment framework for an outbreak of *G. salaris*. Linear weighting (1 – least significant; 5 – most significant) was determined by Cefas experts. Experts provided ranking scores which were then multiplied by the categorical weight.

Outbreak scenarios	Number of affected catchments (IC)	Outbreak scenario score (IC * OCS)
1. No spread	1	50
2.Local spread	1	50
3.Regional spread	9	450
4.National spread	35	1750

Table 6. Overall scores of environmental consequences for an outbreak of *G. salaris* scaled by number of catchments affected for each outbreak scenario