Institution: University of Liverpool

Unit of Assessment: 10 – Mathematical Sciences

Title of case study: Control of epidemics in the aquaculture industry of England and Wales

1. Summary of the impact (indicative maximum 100 words)

In July 2011, a fish disease simulator developed in the Department of Mathematical Sciences at the University of Liverpool was installed on computers at the Centre for Environment, Fisheries & Aquaculture Science (Cefas), an executive agency of the UK government Department for Environment, Food and Rural Affairs (Defra).

Since this date, the simulator has significantly improved the capability available to Cefas for understanding the likely spread of infectious diseases in the aquaculture industry of England and Wales, and enabled the optimisation of methods for the prevention and control of outbreaks. Specifically, a user-friendly interface enables Cefas to focus on particular diseases of concern, understand their specific pattern of spread and optimise methods for their control. The simulator is currently being used to develop contingency planning for outbreaks.

2. Underpinning research (indicative maximum 500 words)

In 1998, it was estimated (Giorgetti, 1998) that the single notifiable aquatic disease Viral Haemorrhagic Septicaemia Virus (VHS) costs the Western European aquaculture industry US$ 60 million annually. Iversen et al 2005 assessed the general cost of disease to the Norwegian fish farming industry to be US$150 million annually. The UK has so far been lucky in excluding major infectious diseases such as VHS, *Gyrodactylus salaries* (GS) and Infectious Haematopoietic Necrosis (IHN) virus among others. Our collaborators at Cefas state that the economic impact of one of these diseases becoming endemic in the UK *“could easily amount to millions of pounds per year with significant impact on the economic viability of large sections of the aquaculture industry.”*

The underpinning research carried out at the University of Liverpool was conducted between April 2004 and August 2010 in collaboration with Cefas. This work was partly funded by Defra grant FC1153 with Prof Kenton Morgan, of the Veterinary school at the University of Liverpool, as PI. The core mathematical modelling research was initiated by Prof Roger Bowers of the Department of Mathematical Sciences at the University of Liverpool and by Dr Kieran Sharkey (at this time a post-doc in this department, April 2004-September 2007). The work was continued by Dr Sharkey when he returned to the submitting unit as a lecturer, between September 2009 and publication of the results in September 2010. Dr Sharkey was primarily responsible for design of the model and for coordinating the project across all project partners. Dr Sharkey and Dr Jonkers (the latter time-split between the University of Liverpool and the University of Munster, Germany) collaborated on producing the computer simulator.

The research generated the first detailed stochastic simulation model of the British aquaculture system, integrating detailed transportation and river networks in addition to control measures [3.2]. It involved a particularly detailed assessment of the issues surrounding water-borne spread of pathogens, incorporating information about river speeds and fish farm locations. The transportation networks were built up using confidential data collected by Cefas via recorded “live fish movements”—i.e. commercial transportation of live fish. By law, each live fish movement must be recorded and this represents the most serious route of contamination. This enabled them to obtain a network structure for disease spread with unprecedented detail in terms of epidemic modelling. During the development of the work, regular meetings were held with Cefas in addition to communication by telephone and email to ensure that the research was directly relevant to them.

The potential control measures depend on the type of infection, particularly because many aquatic diseases can be asymptomatic for long periods, requiring a shift towards more preventative rather than reactive strategies. Hybrid strategies combining preventative measures and reactive measures were therefore considered. General quantitative guidelines for preventing and controlling future infection outbreaks were published [3.2] based on the simulation model.

The research enabled a unified modelling of several mechanisms of transmission, generating a complex system with emergent properties which could not be investigated by looking at each mode of transmission separately. Methods of control anticipating these complex interactions could also be implemented for the first time.

The stochastic simulation model was designed with a user-friendly interface and incorporates sufficient tuneable parameters to be adaptable to many specific infectious diseases which threaten the aquaculture industry of England and Wales. This model is currently installed on computers at Cefas.

References:
Giorgetti, The cost of disease, FAO EastFish Mag., 1 (1998), pp. 40–41
Iversen et al. Stress responses in Atlantic salmon (*Salmo salar* L.) smolts during commercial well boat transports, and effects on survival after transfer to sea Aquaculture, 243 (1–4) (2005), pp. 373–382

3. References to the research (indicative maximum of six references)

[3.1] Sharkey KJ, Fernandez C, Morgan KL, Peeler E, Thrush M, Turnbull JF, Bowers RG, Pair-level approximations to the spatio-temporal dynamics of epidemics on asymmetric contact networks J Math Biol vol 53 pp 61-85 (2006) doi:10.1007/s00285-006-0377-3 (peer reviewed journal, impact factor 2.4).

[3.2] Jonkers ART, Sharkey KJ, Thrush MA, Turnbull JF, Morgan KL, Epidemics and control strategies for diseases of farmed salmonids: a parameter study, Epidemics vol. 2 pp 195-206 (2010). doi:10.1016/j.epidem.2010.08.001 (peer reviewed journal, impact factor 2.3).

Research grants:

Part of this work was supported by a grant awarded to. Prof. Kenton Morgan (PI): Stochastic spatially explicit models of the likely spread of IHN, VHS and G. salaris in farmed and wild UK fish populations; DEFRA (grant code: FC1153); £205,741

1. **Details of the impact** (indicative maximum 750 words)

Since July 2011, our stochastic infectious disease simulator has been installed on computers at Cefas, with a user-friendly interface. Since then, Cefas have used this simulator to model potential epidemics in the aquaculture industry of England and Wales, and develop contingency planning to control them.

By using simulations of infectious disease outbreaks, Cefas have gained a much better understanding of the dynamics of such diseases in the aquaculture system and are able to determine the efficacy of potential control strategies. This very detailed quantitative analysis was not previously available to them and has had an impact on their practice by significantly increasing their analytic capacity and capability. Our collaborators at Cefas state[5.1]: *"This research has enabled us to better understand the potential impact of exotic disease introduction to the salmonid aquaculture industry in England and Wales." and: "The information obtained provides support for our methods of control and, in conjunction with other qualitative and quantitative inputs, provides evidence to underpin contingency plans for combatting infectious diseases in the UK. The simulator is currently being used in further development of contingency planning contributing to the drafting of disease-specific annexes which inform government policy on the control of infectious diseases in the aquaculture industry."*

Indeed, a primary extension of analytic capacity available to Cefas provided by the simulator lies in its ability to study specific infectious diseases. Cefas say that *"This (the simulator) has significantly impacted on our capacity to tailor our analysis towards specific diseases as opposed to more generic measures of control. Our use of the simulator has so far focused on the infectious diseases that are likely to cause the most damaging outbreaks in the UK including IHN, VHS and Gs."*

Another key advantage brought by the simulator is a much greater degree of confidence in understanding the dynamics of the system than can be gained from a qualitative analysis alone. Cefas say that *"By unifying all of the major routes of transmission into a single assimilated model, we have a better understanding of the scenarios we would face given an outbreak. The level of detail incorporated within the model has also increased our confidence in measures to control infectious diseases in the aquaculture industry. "*

Combining the complexities of several modes of transmission together with the impact of interventions was not previously possible in a quantitative way. Increased understanding of the pattern of spread is also vital, as well as highlighting the most important generic aspects for targeting which are found to be time to detection, laboratory testing capacity during an outbreak, delays in implementing control measures on infected sites and the time until fish-farm restocking should be allowed.

Another major impact is the increase in capability for Cefas to investigate different control strategies including proactive and reactive strategies. This is particularly important as many fish diseases can spread without obvious symptoms, complicating control efforts.

The cost of an outbreak of a notifiable infectious disease becoming endemic is potentially millions of pounds per year (see section 2, first paragraph), and so the impact of any percentage increase in the chance of successfully controlling outbreaks can measured on this scale. Reducing the impact of these notifiable diseases is central to the viability of many aquaculture businesses in a global market environment, with some diseases inevitably leading to unsustainable losses for fish farmers. Additionally it should be noted that the export market to any country which does not have these notifiable diseases will immediately disappear until the infectious disease is demonstrably no longer present.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Group Manager, Aquatic Pests and Pathogens (Cefas) has provided a letter of support to corroborate the critical impact of our fish disease simulator upon the capacity of CEFAS to analyse and control fish disease.

[5.2] Pages from the Cefas website showing the role of our modelling within Cefas statutory remit.

[5.3] DEFRA Policy planning document. Page 3 indicates the role of the modelling work in informing UK "development of contingency plans for disease outbreaks and biosecurity" Aquatic Animal Health Evidence Plan. Policy portfolio: Animal Health: Global trade and aquaculture health. Policy area within portfolio: Aquaculture Health. (DEFRA 2013)