Institution: University of Stirling

Unit of Assessment: B11 Computer Science and Informatics

Title of case study: Models of the control of Koi Herpes Virus

1. Summary of the impact

Koi Herpes Virus is a notifiable disease in the UK which can cause serious economic losses in coarse and ornamental carp. It is a viral disease which is highly contagious and can cause 100% mortality in infected fish. In 2010, the Department for the Environment Food and Rural Affairs (DEFRA) made a policy decision, based on our mathematical modelling and computational work, that they would not attempt to eradicate the disease because it would not be cost effective. They used the model predictions to carry out an economic analysis which took into account the cost of the predicted number of outbreaks and the cost of surveillance. They concluded that the benefit of an eradication programme, over a time period of 20 years, would range between a net cost of £213m and a net benefit of £8.36m with their best estimate being a net cost of £5.48m (Section 5, reference 1, paragraph 1.6).

2. Underpinning research

Koi herpes virus (KHV) can cause serious disease in carp *Cyprinus carpio* populations globally. Populations of carp exposed to the virus are already widespread across England and Wales, and there is a need to determine whether and how to control its spread. In an attempt to answer these questions, a theoretical study on KHV spread was carried out between 2007 and 2009 for DEFRA in a collaboration between Prof Norman at Stirling and colleagues at the Centre for Environment, Fisheries and Aquaculture Science (Cefas). Prof Norman provided expertise on mathematical modelling and the computational aspects of the research. She developed key elements of the model which enabled the model output to be related to the available data. Norman and Taylor, together with other colleagues at Cefas, worked on parameterisation and analysis of the model and the interpretation of the results. A report was submitted to DEFRA (September 2009) who used the results of the model as the inputs to an economic analysis which was used to make their policy decision (See reference 1 in section 5). The work was subsequently published in the Journal of Applied Ecology [1]. The modelling approach was employed as it was the only rigorous way to answer the questions asked by DEFRA due to the inherent lack of data available in the case of this emerging disease. Although Cefas had conducted as much field and laboratory work as was feasible since the introduction of KHV, computational and mathematical modelling was the only way to tie this together and address the data gaps.

The study by Taylor, Norman, Way and Peeler [1] uses mathematical models to evaluate potential management options and provides recommendations applicable to many infected countries. The influences of the main drivers of the KHV epidemic, such as contacts between fisheries through the movement of live fish and external infection pressure due to fish importations, were investigated using a family of compartment-based, coupled non-linear ordinary differential equation models. Computer-based numerical solution of these models predicted the time course of the spread of infection under different driving conditions. These computational solutions enabled the effectiveness of several potential control options to be evaluated. To ensure the robustness of the model outcomes, the average results produced by the ordinary differential equation models were checked against extensive computer simulations of stochastic versions of the ordinary differential equations, in which factors (such as the transfer of fish between sites) were assumed to occur at random times rather than at a continuous rate. These stochastic models were used to explore the likely variation in the solutions predicted by the ordinary differential equation models. The models were parameterized using recorded fish movement, field and experimental data.

Experimental studies suggested the risk of transmitting the virus between waters on angling equipment was low. Data from previous studies suggested live fish movements between fisheries, and the introduction of imported ornamental fish to be the most likely routes by which a fishery could be infected.

The models suggest that fish movements between fisheries alone could not have led to the number of exposed sites known to exist in 2007. An additional external infection pressure such as the introduction of imported ornamental fish would have been required, and this is likely to have been the main driver of the epidemic in its early stages. Predictions of future scenarios suggest that fish movements between fisheries have taken over as the main driver of the epidemic, and consequently restricting imports to reduce the external infection pressure is unlikely to have much impact on its own. Due to the small proportion of infected waters currently detected, increasing the duration of movement restrictions placed on infected sites from four years to permanent was predicted to have little effect on the epidemic. The study concluded that, given the current stage of the koi herpes virus epidemic, reducing the spread of the virus between fisheries was likely to be challenging, but may be possible by conducting an active surveillance programme and placing permanent movement restrictions on exposed sites. However, this would only be effective if the external infection pressure can also be reduced, possibly through restrictions on the import of fish from koi herpes virus infected countries.

3. References to the research

1. Nick Taylor, **Rachel Norman**, Keith Way and Edmund J Peeler (2011) "Modelling the koi herpesvirus (KHV) epidemic highlights the importance of active surveillance within a national control policy" *Journal of Applied Ecology*, 48(2) pp. 348-355, DOI: 10.1111/j.1365-2664.2010.01926.x

4. Details of the impact

According to a 2004 environmental agency report (6), angling tourism in England and Wales is growing, bringing new income into rural areas. A survey in 2001 showed that the total capital value of coarse fisheries was £2.3 billion with annual expenditure by coarse anglers almost £2billion on tackle, travel, accommodation and meals in rural economies. Approximately 50% of these coarse fisheries contain carp.

KHV causes a highly virulent disease affecting carp, and poses a serious socio-economic threat to the UK carp industry. Given the right environmental conditions it can cause 100% mortality in infected fish. It was first reported in Israel in 1998 and was recorded in the UK for the first time in 2003 in angling waters experiencing large mortalities in carp, although there is some evidence that it has been here for longer than that. In 2006, 23 sites had outbreaks and the disease became notifiable in the UK in 2007. It is also listed under Council Directive 2006/88/EC as a disease subject to European Community controls. In 2010, a paper was published (7) in which it was found that 37% of fisheries sampled and 50% of imported fish tested positive for the virus. The total number of carp fisheries in the UK is unknown but, given the data we have on fish movements, there are in excess of 5000.

English fisheries which experienced an outbreak in 2008 had to follow a four year KHV monitoring and test programme. Each of the fisheries was placed under movement controls in the form of a confirmed designation notice for the control of KHV disease following an initial outbreak in 2008. The ones which did not have any further clinical outbreaks and tested negative for the presence of KHV had this designation lifted in January 2013 (8). In addition, it was estimated in Germany that costs of an outbreak in a farm producing 20 tonnes of fish will range from €150,000 to €250,000, this includes disinfection, removal of cadavers, cleaning and partly restocking (9).

In July 2008, it was reported in the popular press that DEFRA was about to announce a policy of eradication of KHV (10). However, following the modelling exercise carried out by Taylor, Norman et al, DEFRA carried out an economic analysis of the costs and benefits of attempting to eradicate KHV. For this analysis DEFRA compared the Taylor and Norman model outputs (referred to as the "Cefas outputs" in the following quote) with different detection rates against a static model. According to the DEFRA report on this work (ref 1, Conclusions 12.1 & 12.2, pg 18), "In putting together the impact assessment, three different models have been included in producing the cost benefit analysis, each with a varying degree of future spread of clinical outbreaks cases and the likely affect an eradication programme would have on the future number of clinical outbreak cases. The three models are i) the static model, ii) the model based on Cefas outputs with 0.6% detection rate and iii) a model based on Cefas outputs with a 50% detection rate. We believe that the second of these, the model based on Cefas outputs with a 0.6% detection rate, is the best and most suitable model to use in calculating the net benefit of an eradication programme. The model is based on the best possible available scientific outputs at our disposal and the current detection rate of 0.6% is far more likely than a 50% detection rate, which is what would be required to prevent further spread". In summary, DEFRA used the predictions from the model by Taylor, Norman et al, about levels of infection and how much effort would have to be put into surveillance to detect them and did a cost benefit analysis which they used to make this major policy decision.

Therefore, in July 2010 it was reported in the popular press that DEFRA had announced (3) that "Following a lengthy consultation exercise and evaluation of the possible benefits and likelihood of success, it has been concluded an eradication programme will not be undertaken for KHV disease in England and Wales. This means that Category V (infected) status will be assumed immediately for England and Wales. Passive surveillance would continue, the disease would remain notifiable and existing control arrangements will stay in place when an outbreak is confirmed. Imports of susceptible species from countries outside the European Union and movements from other Member States would continue in line with the rules that currently applied. However, movements of susceptible species would not be possible from GB to areas of a higher health status in other Member States. The exception being those movements from compartments in GB (eg individual farms) which have gained KHV disease free status (category I). This decision clearly had economic impact for individual fisheries but this was determined to be less than if an eradication programme was attempted."

5. Sources to corroborate the impact

1. Impact Assessment of declaring an aquatic animal health status for Koi herpesvirus (KHV) disease in England and Wales, DEFRA report, March 2010 (PDF available from HEI)
2. http://webarchive.nationalarchives.gov.uk/20110201180000/http://www.efishbusiness.co.uk/news/khv-impact-assessment.pdf
3. http://www.anglingtradesassociation.com/module/news/display/newsdisplay.aspx?news=209 (note: original DEFRA announcement now unavailable due to changes to their website)
4. http://www.gofishing.co.uk/Angling-Times/Section/News--Catches/General-News/July-2010/Many-carp-will-die-as-Defra-decides-not-to-tackle-KHV-/
5. http://webarchive.nationalarchives.gov.uk/20110201180000/http://www.efishbusiness.co.uk/news/khv-health-status-england-wales.asp
6. www.environment-agency.gov.uk/static/documents/Leisure/fisheries_eng_765655.pdf
7. N G H Taylor, P F Dixon, K R Jeffery, E J Peeler, K L Denham and K Way "Koi herpesvirus: distribution and prospects for control in England and Wales" *Journal of Fish Diseases* 2010, 33, 221–230
8. http://www.defra.gov.uk/aahm/2013/01/29/khv-withdrawn-notification-2013/.
9. Brauer, G, Herms, J and Schlotfeld, H-J. (2004) Severe losses of common carp in Germany due to KHV. *Bull Eur Assoc Fish Pathol* 26 97-104.
10. http://www.gofishing.co.uk/Angling-Times/Section/News--Catches/General-News/July-2008/Defra-poised-to-rid-UK-of-deadly-KHV-carp-disease/