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A model of the emergence of infectious pancreatic necrosis virus in Scottish salmon farms 1996–2003

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ARTICLE INFO

Article history:
Received 8 June 2005
Received in revised form
30 May 2006
Accepted 16 June 2006
Published on line 30 August 2006

Keywords:
Epidemiological models
Farmed salmon
IPNV
Scotland

ABSTRACT

Infectious pancreatic necrosis virus (IPNV) is an increasingly common pathogen in farmed Scottish Atlantic salmon; over 80% of marine sites are now infected, although most do not suffer clinical disease. The increasing prevalence of this pathogen in farms over the period 1996–2003 is modelled using a simple susceptible–infected (SI) epidemic model. Because salmon production approximately doubled over this period, population-dependent and -independent transmission models are compared. The model generates mean R_0 (increase ratio) of 1.41 in fresh and 1.45 in marine water farms at the national level; higher values apply with time under population-dependent transmission (1.58, freshwater, 1.80 marine by 2003). Regional differences in R_0 are mostly moderate, indicating similar regional processes in spite of substantial difference in prevalence. Prevalence of IPNV for marine sites was further increased by the use of smolts (young salmon) from multiple freshwater sources. The model suggests that prevalence is entering dynamic equilibrium and will stabilise or only increase slowly as population increases. Cutting freshwater transmission is the most effective single strategy at reducing IPNV prevalence, but a combination of strategies (including reducing the number of sources of smolts) is better and indeed is required for eradication. Eradication would require cuts in transmission of at least 30–45% and this is unlikely to be practicable.

1. Introduction

In recent decades several pathogens have increased in prevalence or range, these emerging diseases affect humans (Krause, 1998) and other animals (Daszak et al., 2000). Environmental and social changes have led to the development of environments which facilitate this process (Daszak et al., 2000), for example aquaculture has increased the density and mixing of fish populations (Murray and Peeler, 2005). Diseases affecting aquaculture are economically important in themselves, and can provide a relatively well-documented environment for the study of disease emergence processes.

Infectious pancreatic necrosis (IPN) is an example of a disease which is emerging under aquaculture. This disease was first reported from trout hatcheries in North America in the 1950s (Wood et al., 1955), but has since spread to most countries with salmonid production, it also affects several farmed non-salmonid fish species (OIE, 2003). IPN was first reported in the UK in 1971 from a trout hatchery in freshwater Loch Awe (Ball et al., 1971) and from wild and escaped fish in the loch (Munro et al., 1976). The disease later spread to marine salmon farms (Smail et al., 1992). It is now considered the most damaging viral disease for farmed salmon production in the EU (Ariel and Olesen, 2002).

In Great Britain IPN virus (IPNV) in salmon farms was controlled by movement restrictions and controls on vertical transmission (Anonymous, 2003). Controls have recently been relaxed in accordance with international trade regulations. To support the control policy there was extensive official monitoring of the virus (Anonymous, 2003). This monitoring

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0304-3800/$ – see front matter
doi:10.1016/j.ecolmodel.2006.06.010

has allowed reconstruction of a time series of the emergence of this virus from low prevalence, to near ubiquity in marine salmon (*Salmo salar*) farms over the period 1996–2001 (Murray et al., 2003); these time series are extended here to 2003. The data describe prevalence of infection, clinical disease, while increasing, remains less common (Bruno, 2004).

Modelling has been extensively applied to the understanding of epidemic spread for diseases of humans (Anderson and May, 1991) farmed animals (Kao, 2002) and wildlife (Smith and Cheeseman, 2002). Epidemic modelling of fish diseases has been used to describe general issues behind disease spread (Reno, 1998) and for specific diseases such as pilchard herpesvirus (Murray et al., 2001). Revie et al. (2005) have modelled development of sea lice infestation within Scottish salmon farms, using data from many such farms. The spread of IPNV within a single trout population has been modelled using experimental data (Smith et al., 2000). Risk factors for IPN outbreaks, including those behind spread of IPNV to farms, have been determined using the classical epidemiological methods of case control analysis (Jarp et al., 1994; Raynard et al., 2005). However, modelling disease spread between populations, which has been a major focus in agriculture (e.g. Kao, 2002; Durand et al., 2004), has not much been applied to aquaculture. Here I use time series of observed IPNV prevalence for 1996–2003 to fit a simple epidemiological model of spread of IPNV at the regional and national level; this allows us to obtain insight into the processes behind IPNV's emergence, potential for control and likely future spread in Scotland.

2. Material and methods

2.1. *Materials—the data used*

Scottish salmon farms have been sampled regularly for IPNV by Fish Health Inspectors (FHI) of the Fisheries Research Services (FRS) (Anonymous, 2003). Freshwater farms were sampled at least annually, and marine farms at least once every 2 years; in practice sampling was often more frequent (Anonymous, 2003). The time series analysed have been extended to cover the period 1996–2003. During this period 1376 samples were taken from 218 freshwater sites, and 1663 samples were taken from 384 marine sites (not all sites were active over the entire period). These samples have been analysed by region and year (Table 1).

These data have been used to estimate prevalence, the proportions of farms infected, for marine and freshwater environments at a national and regional level and to create time series of regional emergence (Murray et al., 2003). Prevalence within farms was not estimated, any sample containing at least one positive pool was treated as a positive sample (Murray, 2006) and hence came from an infected farm. Most samples (67%) consisted of 30 fish, but this was field surveillance data and sample size did vary from 1 to 150 fishes.

Regions that have been used for this analysis are: Shetland, Orkney, the Western Isles, northern mainland and southern mainland; the north and south being separated by the Ordnance Survey's 800 km north line (Fig. 1).

The modelling which follows describes the spread of IPNV in salmon as they follow production cycle from fry to harvestable salmon. In freshwaters some sites are broodstock sites which receive adult salmon from seawater; IPNV in these is therefore not part of the model. Freshwater sites were found to have an overall mean prevalence of 13%, but 24% of samples from sites that had received broodstock were positive. I have therefore removed these inappropriate sites from the analysis of freshwater sites, leaving 1185 freshwater samples, although this only marginally reduced mean prevalence (to 12%). Prevalence has been recalculated and some further minor corrections made. The effects of these corrections on estimated prevalence are minimal, except where very small numbers of positive samples were obtained and so relative

Table 1 – Annual numbers of IPNV samples taken from salmon farms by region and across all Scotland

	Shetland	Orkney	Western Isles	Northern mainland	Southern mainland	Scotland
Freshwater						
1996	9	5	36	44	40	134
1997	10	6	42	47	41	146
1998	8	2	33	41	25	109
1999	6	4	36	52	34	132
2000	13	7	51	76	48	195
2001	14	3	39	57	41	154
2002	13	9	49	59	44	174
2003	13	3	37	48	40	141
Marine						
1996	58	16	31	39	40	184
1997	60	7	33	42	26	168
1998	47	15	31	26	42	161
1999	69	12	40	50	35	206
2000	99	49	33	40	61	282
2001	97	20	42	43	57	259
2002	73	20	35	36	36	200
2003	71	23	34	29	46	203

Freshwater samples exclude those taken from sites that were used to hold broodstock.