Temporal and spatial patterns of sea lice levels on sea trout in western Scotland in relation to fish farm production cycles

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The relationship between aquaculture and infestations of sea lice on wild sea trout (*Salmo trutta*) populations is controversial. Although some authors have concluded that there is a link between aquaculture and lice burdens on wild fish, others have questioned this interpretation. Lice levels have been shown to be generally higher on Atlantic salmon farms during the second years of two-year production cycles. Here we investigate whether this pattern relates to lice burdens on wild fish across broad temporal and spatial axes. Within Loch Shieldaig across five successive farm cycles from 2000 to 2009, the percentage of sea trout with lice, and those above a critical level, were significantly higher in the second year of a two-year production cycle. These patterns were mirrored in 2002–2003 across the Scottish west coast. The results suggest a link between Atlantic salmon farms and sea lice burdens on sea trout in the west of Scotland.

Keywords: *Lepeophtheirus*; *Salmo trutta*; aquaculture

1. INTRODUCTION

The role of aquaculture in the declines of wild salmonid populations is controversial (Revie *et al.* 2009). The question of the contribution of fish farming to levels of sea lice (*Lepeophtheirus salmonis* and *Caligus elongatus*) on wild salmonids in both Europe and North America remains the subject of debate (Revie *et al.* 2009). Of particular concern is the role of sea lice in recent declines in catches of sea trout (Butler 2002) and the question of whether reduction in levels of parasite infection would increase population strength. An important step in addressing these issues is to establish how closely infestation of wild trout relates to farming practices.

Sea trout (anadromous *Salmo trutta*) (hereafter referred to as trout) spend extensive periods of time in near shore waters (Middlemas *et al.* 2009), and are spatially concurrent with coastal fish farms and any parasites they release. In Scotland, Ireland and Norway, the heaviest sea lice infestations of trout have generally been reported in areas in which

salmon are farmed (MacKenzie *et al.* 1998; Gargan *et al.* 2003; Heuch *et al.* 2005). However, MacKenzie *et al.* (1998) and Marshall (2003) found no clear patterns between levels of infestation and proximity to, or levels of lice on, local fish farms.

Lice levels on fish farms are generally higher during the second year of two-year production cycles (Revie *et al.* 2002; Lees *et al.* 2008) and data from two sites over two farm cycles suggest a relationship between levels of lice on farms and on wild trout (Butler 2002; Hatton-Ellis *et al.* 2006). To increase confidence in such findings further data are required across a wider geographic range and over more successive cycles. Here we determine whether lice on wild fish correlate with year of farm cycle, first, within a site across five successive cycles near the salmon farms of Loch Torridon, and second, across the Scottish west coast in 2002–2003.

2. MATERIAL AND METHODS

Trout smolts were collected over five successive fish farm cycles by electrofishing in the lower reaches of the River Shieldaig from 2000 to 2009 (see Hatton-Ellis *et al.* 2006 for details). In 2000 and 2001, presence/absence data were collected, from 2002 onwards each fish was anaesthetized, placed in a white tray and the number of sea lice counted, and classified as attached (chalmus) or mobile (pre-adults/adults). Sampling was also undertaken at 10 sites near salmon farms on the west coast of Scotland during May and June 2002 and 2003 (figure 1). Fish were caught at sites near river mouths with sampling methods constant between years (table 1).

In laboratory studies, Wells *et al.* (2006) found that abrupt changes in a variety of physiological measures occurred at 13 mobile lice per fish (weight range 19–70 g) and suggested that this level be used to indicate the proportion of trout subject to physiological stress and potential death from sea lice infestations. To enable the use of this threshold, only those fish below 198 mm (the equivalent of 70 g) were considered in the analysis. To convert the number of chalmus into an expected number of mobile lice, a survival rate of 0.63 between the stages was used (Bjorn & Finstad 1997). Binomial generalized mixed models were constructed to model the proportion of fish with lice, and those with burdens above the threshold level, with the year of the production cycle (1st/2nd) as a fixed effect and either the production cycle (Shieldaig analysis) or site (west coast analysis) as a random factor (Zuur *et al.* 2009). There was no evidence of overdispersion and the significance of year of the production cycle was examined by comparing the likelihood of models fitted with and without this variable assuming a χ^2 distribution (Zuur *et al.* 2009).

3. RESULTS

Between 2000 and 2009, a total of 326 trout was sampled in the lower reaches of the River Shieldaig (table 2). Lice were observed on a significantly higher percentage of trout (table 2; $\chi^2 = 50.6$, d.f. = 1, $p < 0.001$), and significantly more trout had lice burdens above the threshold level, in the second year of production compared with the first (table 2; $\chi^2 = 39.1$, d.f. = 1, $p < 0.001$).

A total of 784 trout was sampled during 2002 and 2003 (table 1). Although it was not possible to identify attached stages to species, mobile stages were all identified as *L. salmonis*. Overall, lice were noted on 372 (47.5%) of fish sampled, and 90 (11.5%) of fish had lice burdens above the critical threshold level. A clear pattern emerged from the data with a significantly higher percentage of trout observed with lice (figure 2a; $\chi^2 = 84.3$, d.f. = 1, $p < 0.001$), and with lice burdens above the threshold level (figure 2b; $\chi^2 = 15.1$, d.f. = 1, $p < 0.001$), in the second year of production when compared with the first.

Figure 1. Map of the trout sampling sites on the Scottish west coast used in the study.

Table 1. Number of trout sampled from sites on the west coast of Scotland in 2002 and 2003. Method of capture, samples sizes and the year of production cycle of the local farms are provided.

river	sampling method	2002		2003	
		production year	fish sampled	production year	fish sampled
Dundonnell	fyke net	1st	6	2nd	14
Dunstaffnage	seine net	1st	68	2nd	98
Glen Mor	fyke net	2nd	25	1st	29
Kinlocheil	seine net	1st	31	2nd	43
Loch Fyne	seine net	1st	70	2nd	32
Loch Linnhe	seine net	1st	32	2nd	66
Laxdale	seine net	1st	126	2nd	23
Laxford	seine net	1st	31	2nd	18
Shieldaig	electrofishing	1st	31	2nd	44

4. DISCUSSION

The patterns identified in this study indicate a link between local salmon farm production cycles and infestations of wild trout smolts, consistent with high levels of infestation during years when lice levels on farms are high (Revie *et al.* 2002; Lees *et al.* 2008) and with previous small-scale studies (Butler 2002; Hatton-Ellis *et al.* 2006). The significant relationship across years at the intensively studied Shieldaig site was mirrored through 2002–2003 across sites throughout the west coast. Because the year of production cycle coincided in 9 of the 10 sites in the spatial analysis, the possibility that, in these data, infestation was

associated with variation in calendar year rather than farm cycle cannot be ruled out. During 2002–2003, salmon farms in their second year of production were known to have higher levels of lice than those in their first year, irrespective of calendar year (Lees *et al.* 2008). Insufficient data were available to factor in possible effects of inter-annual variation in other environmental parameters, such as salinity. In the current analysis, significant relationships were evident between year of production and incidence of fish with parasite burdens exceeding a threshold level considered by Wells *et al.* (2006) to ‘provide a clear indication of the proportion of sea trout within a

Figure 2. The percentage of trout sampled in the different areas with (a) lice and (b) lice numbers above the threshold level. Open bars are those in the first year of production, filled are in the second year.

Table 2. The percentage of trout sampled in the lower reaches of the River Shieldaig found with lice and with lice burdens above the threshold level in first and second years of production. The italic figures show the production year with the highest percentage in each cycle.

production cycle	number of trout sampled		percentage with lice (1st/2nd years)	
	1st year	2nd year	all	above threshold
2000/2001	15	87	13/31	a
2002/2003	31	44	6/20	3/14
2004/2005	15	26	0/0	0/0
2006/2007	39	30	8/87	5/70
2008/2009	14	21	0/33	0/19
combined	114	208	6/33	3/26

^aData not collected.

population that are subject to physiological stress and potential death from sea lice infestations’.

A strength of the study is that by comparing years of production within sites it is possible to control for spatial variation in a wide variety of environmental factors that are known to affect sea lice levels. Sea lice tend to be lost from hosts in brackish water, thus introducing variation among lice levels on fish caught under different salinity conditions, irrespective of initial rates of infestation (Revie *et al.* 2009). Furthermore,

because sea lice dispersal is thought to be mainly driven by wind, the physical geography and juxtaposition of the farm and sampling sites are likely to influence lice levels and distribution in the environment, and in turn on trout (Amundrud & Murray 2009). These among-sites variables are controlled for in studies comparing within-site and between-year of farm production cycle but not in direct comparisons among sites (MacKenzie *et al.* 1998), where they would introduce noise and reduce power to detect an effect.

Although the results suggest a general relationship between lice burdens and fish farm production cycles, there were exceptions to this pattern (figure 2; table 2). Such exceptions may reflect local between-year variations inconsistent with the typical incidence of lice during the farm cycle. For example, lice on farms may be lowest in the second year of the cycle because of treatment of fish (Lees *et al.* 2008). Indeed, the apparently anomalous 2004–2005 Shieldaig trout data coincided with unusual patterns of lice numbers on local farms and in the water column (Penston & Davies 2009). Furthermore, spatial concurrence of fish and parasite may vary among years, for example, owing to wind direction affecting dispersal of lice (Amundrud & Murray 2009).

The data presented in this study add to the evidence from a number of countries that, in general, the sea lice burdens of wild sea trout are related to the occurrence of salmon farming (Gargan *et al.* 2003;

Heuch *et al.* 2005). However, although lice burdens can be used to estimate likelihood of individuals surviving (Bjørn & Finstad 1997; Wells *et al.* 2006), it is not currently possible to use such data to predict the effect of sea lice infestations on the source populations (Revie *et al.* 2009). This is because sampling may be biased with respect to lice infestation level and also would not provide information regarding those fish that had already died. However, the data presented here suggest that there is a link between Atlantic salmon farms and lice burdens of wild trout in the west of Scotland.

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