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Variations in parasitic caligid infestations on farmed salmonids and implications for their management

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In order to evaluate the performance of various sea lice management strategies, data sets from a number of salmon farm sites on the west coast of Ireland were examined. These data sets were collected as part of the ongoing National Sea Lice Monitoring Programme in Ireland. Temporal and geographic variations in infestations of *Lepeophtheirus salmonis* and *Caligus elongatus* are described from two species of farmed salmonids, *Salmo salar* L. and *Oncorhynchus mykiss* Walbaum. Patterns of lice transmission, both within and between fish populations, are discussed and environmental and biotic influences considered. Clear differences in infestation parameters, which persist over a number of seasons, are identified between sites. Where infestation parameters are observed to change over successive seasons, these are linked to changing husbandry practices.

Key words: *Caligus elongatus*, control, husbandry practices, *Lepeophtheirus salmonis*, *Oncorhynchus mykiss*, *Salmo salar*, sea lice.

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Introduction

Monitoring of lice infestation levels on salmonid farms in Ireland was initiated in April/May 1991. This was in response to concerns that lice emanating from farmed salmonids might be the cause of large numbers of sea trout returning to rivers in early summer in an emaciated state and with elevated lice numbers. Monitoring of selected sites continued in 1992 and was increased in intensity and extent in 1993 and again in 1994. Since April 1994 monitoring has been carried out in accordance with the recommendations of the Sea Trout Task Force and its successor body, the Sea Trout Management and Advisory Group. This involves the sampling of each year class of fish at all fish farm sites twice per month during March, April, and May, and monthly for the remainder of the year.

There are three distinct fish farming areas on Ireland's west coast, County Donegal in the north-west, Counties Mayo and Galway in the west, and Counties Cork and Kerry in the south-west. Each of these salmonid farming areas is separated from the next by distances of over 160 km. Fully documented sea trout stock collapses have been recorded in one of these areas, the West (Galway/Mayo) (Anon., 1995). While elevated lice levels on sea trout have been recorded in all three areas, no stock collapses have been recorded in either the north-west or the south-west.

When monitoring commenced in 1991, levels in excess of 20 mobile salmon lice (*Lepeophtheirus salmonis* (*Kroyer*)) per fish were recorded on one-sea-winter salmon at a number of sites and in excess of 100 mobile *L. salmonis* were recorded at two sites on two-sea-winter salmon. Two-sea-winter salmon were found to have significantly higher lice loadings than one-sea-winter salmon (Jackson & Minchin, 1993a). On the basis of the results of the early surveys, a new initiative in salmonid farm management was put in place by the Department of the Marine. This initiative, termed "Single Bay Management", was aimed at introducing new and better husbandry practices on individual farms to give enhanced disease and lice control and co-ordinating the husbandry practices on adjacent farms.

Changes in husbandry practices have centred on reducing lateral and vertical transmission of disease within stocks, including chemical and biological treatment of sea lice. Several new chemical treatments, in both feed and bath, are undergoing trials and the use of cleaner fish as a means of biological control has been investigated (Deady *et al.*, 1995). Most salmon are now produced on a cycle of 14 to 18 months in the sea. Two-sea-winter fish are no longer a feature of the

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industry in Ireland, except in a very limited way and for the early part of the spring. Equally, single-generation sites are fast becoming standard practice with separate sites being used to hold smolts and growers. Single-generation sites not only assist in reducing lice infestation, they show reduced incidence of disease, lower mortality rates and better production figures. Allied to single-generation sites is the practice of fallowing, or leaving the site empty of fish for a period. Annual fallowing of each production site for a minimum period of one month, with adjacent sites being fallowed simultaneously, is the target. This has been achieved in a number of bays and annual fallowing of sites is a feature of the vast majority of production sites in the Irish industry today.

In order to evaluate the performance of these changed husbandry practices, data sets from a number of farms have been examined. These farms differ from each other in terms of distance offshore, degree of exposure, degree of separation from other farms and husbandary practices. The data sets consist of mean lice infestation figures for ovigerous and total mobile lice for two species of lice (*Lepeophtheirus salmonis* (Kroyer) and *Caligus elongatus* Nordmann), compiled as part of the National Sea Lice Monitoring Programme. During the course of the programme, both salmonid species commercially farmed in Ireland, (the Atlantic salmon (*Salmo salar*, L.) and rainbow trout (*Oncorhynchus mykiss*) (Walbaum)), were monitored. Unless otherwise stated results presented are for Atlantic salmon.

Materials and methods

Estimations of lice infestation levels were obtained from all licensed fish farms by regular sampling of the production fish on site by Marine Institute staff. Sampling was carried out bi-monthly for the months of March to May inclusive and monthly for the remainder of the year, with the exception of the December–January period, when only one sample was taken. Generally, two cages of fish were sampled for each population of fish on site; a standard cage, which was sampled at each inspection, and another cage selected at random at each inspection. Different year classes of fish were considered as different populations, as were different species (i.e. *Salmo salar*, *Oncorhynchus mykiss*).

Lice counts presented in this paper are based on arithmetic means obtained according to the following protocol:

(1) A sample of approximately 30 fish was taken from a single cage.
(2) The fish were anaesthetized and all mobile lice were removed and preserved in alcohol as described by Jackson and Minchin (1993a).
(3) All lice remaining in the anaesthetic after the sample was processed were retained and included in the sample.
(4) All lice were identified and development stages determined.
(5) For each sample, a mean number of lice in each category was obtained by dividing the number of lice recorded by the number of fish examined.
(6) Unless otherwise stated, where more than one cage of a population on site was examined the means of the samples were averaged to give a mean for the population on site.

Results

Over the period from 1991 to 1995, there has been a downward trend in lice infestation levels on farmed fish in all three farming regions (Fig. 1). This has accompanied the implementation of new husbandry practices and improved lice treatment strategies.

1. Farm A. An offshore site with no chemical lice treatments utilized; distant from other farms

Two generations of salmon were monitored from stocking to harvest at this farm. No chemical or biological lice control treatments were used and there was incomplete separation of generations. Smolts were stocked into a separate site but during the course of the study they were transferred to the production site before the previous generation was harvested out. The 1994 generation salmon (i.e. salmon stocked in sea cages as smolt in 1994) maintained a low level of lice until harvesting commenced in August 1995 (Fig. 2) and lice numbers steadily increased on the remaining fish until the main harvest was completed in November 1995. A small number of 1994 generation fish were held to satisfy contractual arrangements to supply fish over the period from December 1995 to March 1996. The 1995 generation salmon maintained low lice levels until after their transfer to the production site, which was still holding fish of the 1994 generation in November. Lice levels on the 1995 generation increased until harvesting of the 1994 generation salmon adjacent to them was completed in the following March. Lice numbers then fell back to previous levels without any therapeutic treatment. The steep rise in lice numbers on the 1994 fish during periods of harvest was due to an increase in adult and ovigerous lice recorded in the monthly sampling and not a build-up of juveniles. This is presumed to be a result of lateral transfer of lice from fish being harvested.

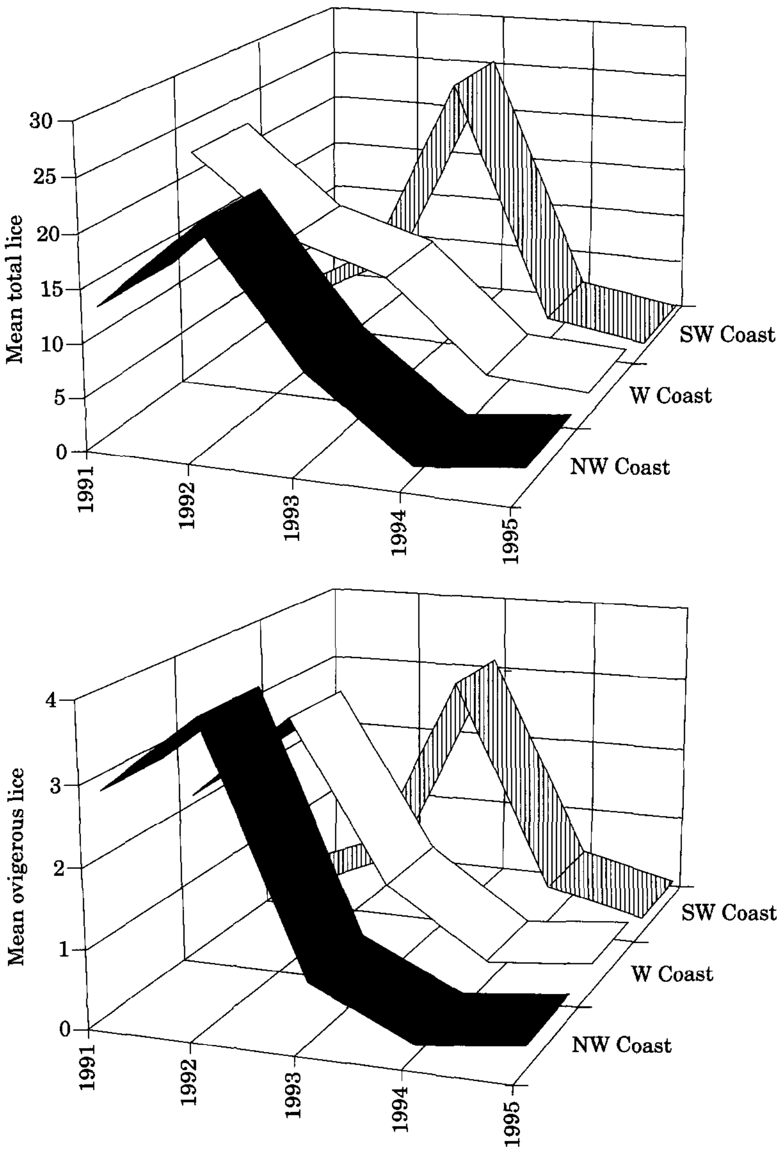

Figure 1. Lice infestation trends on farmed salmon sampled in the Spring during the period 1991–1995 for the three fish-farming regions in Ireland.

2. Farm B. An inshore site, distant from other farms; lice control strategies include chemical and biological treatments and separation of generations

Two generations of salmon were monitored from stocking to harvest at this site (Fig. 3). The 1994 and 1995 generations were stocked into a site 0.5 km distant from the production site, which still held stock of the previous generation. Lice levels on both generations of fish were low in the winters of 1994/1995 and 1995/1996, with negligible levels of ovigerous lice. In 1995 and 1996, an early settlement of juveniles was detected which was out of proportion to the development of ovigerous females on site. This is illustrated graphically for the standard cage in 1996 in Figure 4. Later settlements of juveniles are associated with previous peaks in ovigerous females and can be seen to be the result of re-infection by farm-produced infective stages.

3. Farm C. An exposed inshore site, adjacent to other farms; lice control strategies include chemical lice treatments and partial separation of generations

Two generations of salmon were monitored at this site (Fig. 5). Smolts were held at an offshore site and

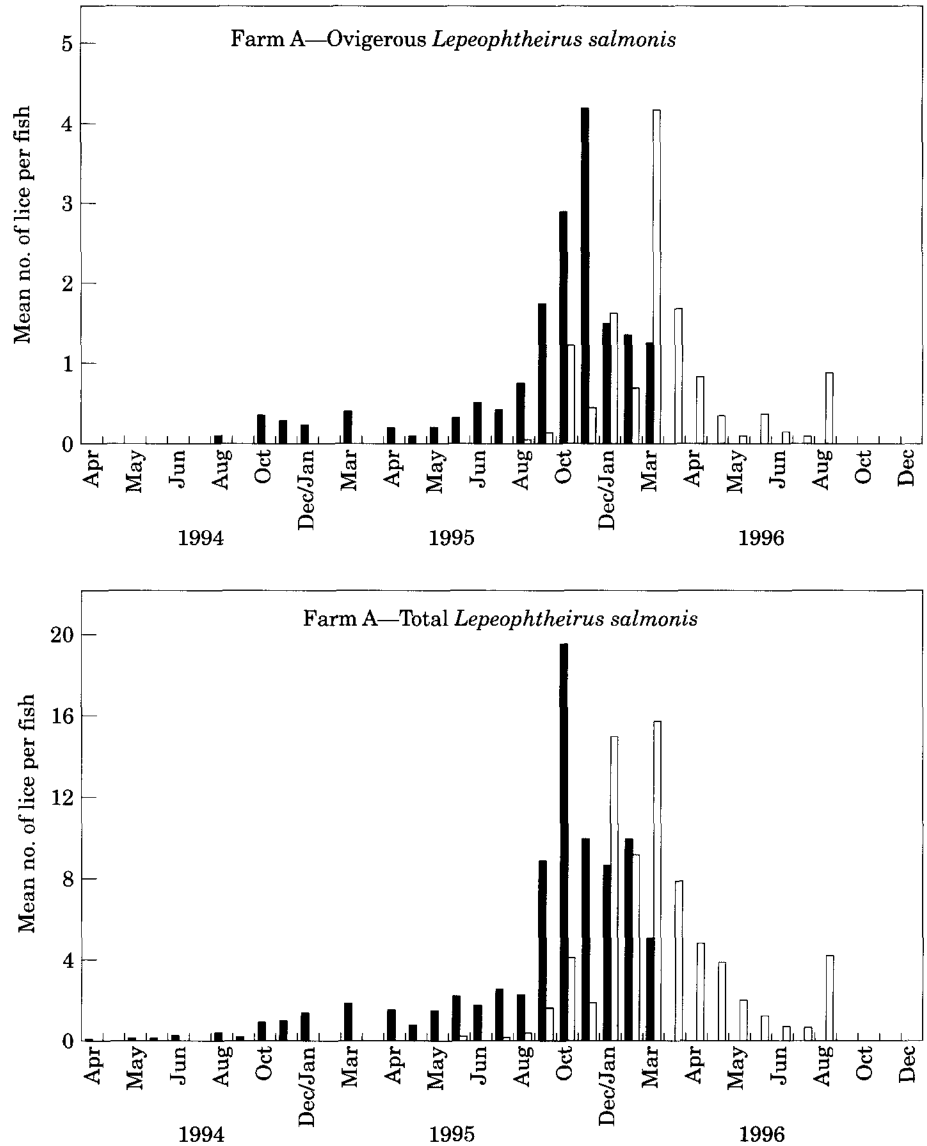

Figure 2. *Farm A.* Mean lice infestation levels per fish from the time of stocking at sea to harvest. Information is presented for ovigerous lice and total lice numbers for two successive generations of Atlantic salmon. 1994 fish (■); 1995 fish (□).

transferred inshore to the production site in the autumn. In both years of the study, 1995 and 1996, there was an overlap of generations at the production site. Lice infestations were characterized by the maintenance of good control up to the period immediately preceding the harvesting of the production generation.

4. Farm D. An inshore site; lice control strategies include chemical treatments and partial separation of generations

One cage of one-sea-winter salmon was monitored through a season (Fig. 6a) and at an adjacent site a cage of smolts was similarly monitored through (Fig. 6b). Succession of lice generations can be seen in the smolts but is less discernible in the one-sea-winter fish. The large settlement of juvenile lice on the one-sea-winter fish in mid-May is not associated with a previous peak in ovigerous females. The asterisks, indicating lice treatment dates, graphically demonstrate the re-infestation pressure at this site.

5. Comparison of infestation characteristics of rainbow trout (*Oncorhynchus mykiss*) and salmon (*Salmo salar* L.) cultured in adjacent cages

Adjacent populations of salmon and rainbow trout were monitored through a season, until harvesting of the

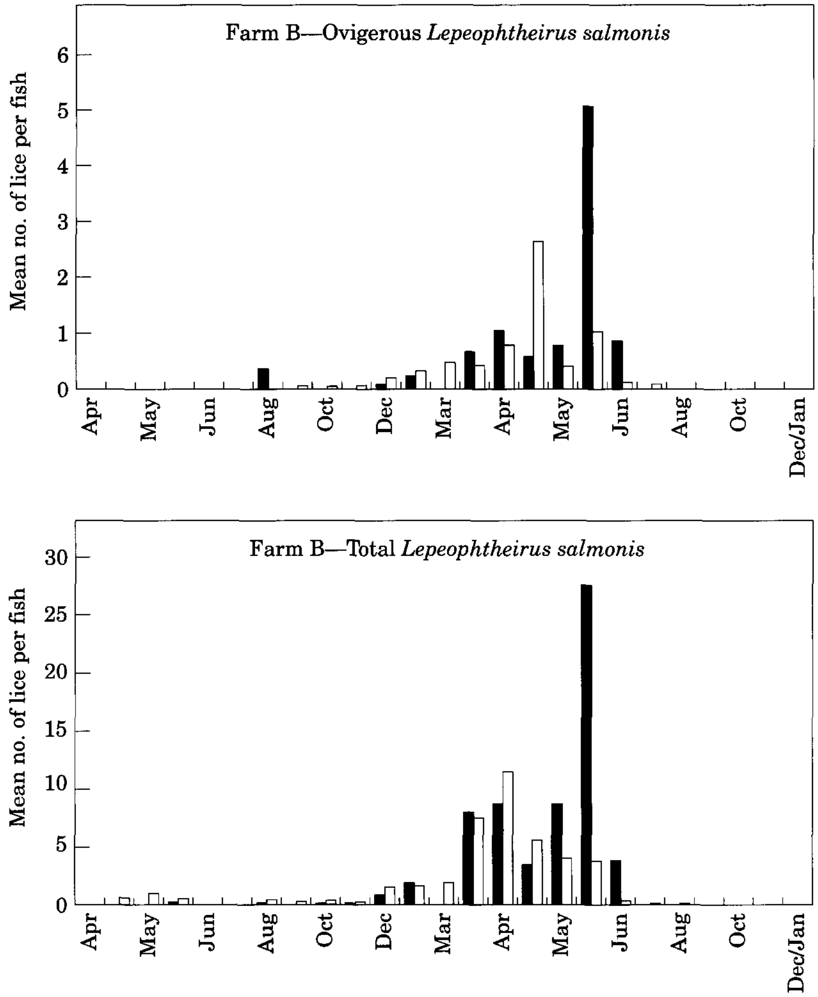

Figure 3. *Farm B.* Mean lice infestation levels per fish from the time of stocking at sea to harvest. Information is presented for ovigerous lice and total lice numbers for two successive generations of Atlantic salmon. 1994 fish (■); 1995 fish (□).

rainbow trout was completed (Fig. 7). The infestation characteristics of the rainbow trout were very different from those of the salmon, particularly for *Lepeophtheirus salmonis.* Infestation levels of *L. salmonis* were significantly higher on the salmon, both for ovigerous females and total mobile stages (t-tests; $p<=0.001$). Levels for *Caligus elongatus*, however, were not significantly different. The significantly higher *L. salmonis* infestations on the salmon were all the more remarkable as the salmon were being treated to reduce lice infestations and the rainbow trout were not. In other sites investigated (Fig. 8), infestation levels of *L. salmonis* on rainbow trout were lower than on adjacent salmon stocks. In all these cases too, the salmon were being treated for lice infestation and the rainbow trout were not. In many cases, however, this difference was not statistically significant, especially where lice numbers on salmon were low.

Discussion

Results from the offshore site, Farm A, show clearly that in some circumstances transmission rates within a site were very low and that low lice levels can be maintained naturally in the absence of any active intervention on the part of the farmer. This farm has been under study since 1991 by one of the authors and has exhibited a similar lice infestation pattern over the years (Jackson and Minchin, 1993a). However, this situation is exceptional, and at most sites, even those offshore, lice treatments are required to maintain low infestation levels.

In inshore areas, good lice control can generally be maintained at those sites with separation of generations by application of an appropriate lice control strategy involving treatments or a combination of treatments and biological control. The results at Farm B exemplify the level of control which can be maintained in these

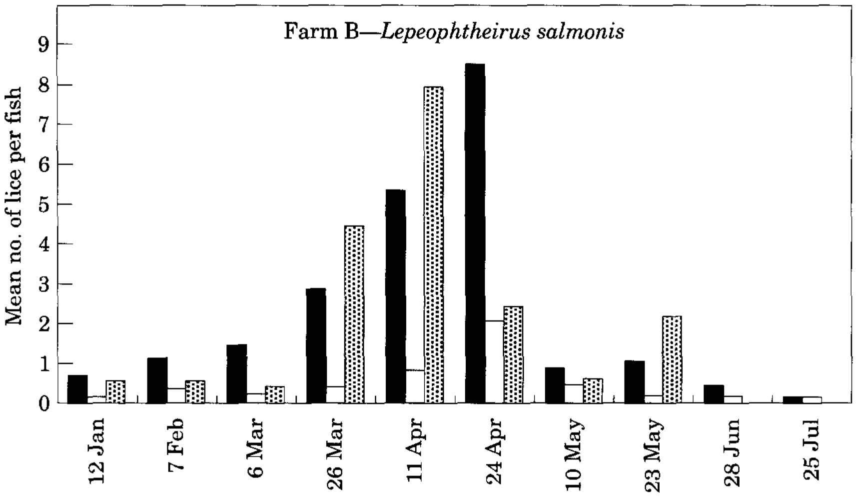

Figure 4. *Farm B.* Mean lice infestation levels per fish (1-sea-winter Atlantic salmon) in the standard cage during 1996. Information is presented for ovigerous lice, total adult lice, and juvenile lice. adult (■); ovigerous (□); juvenile (▩).

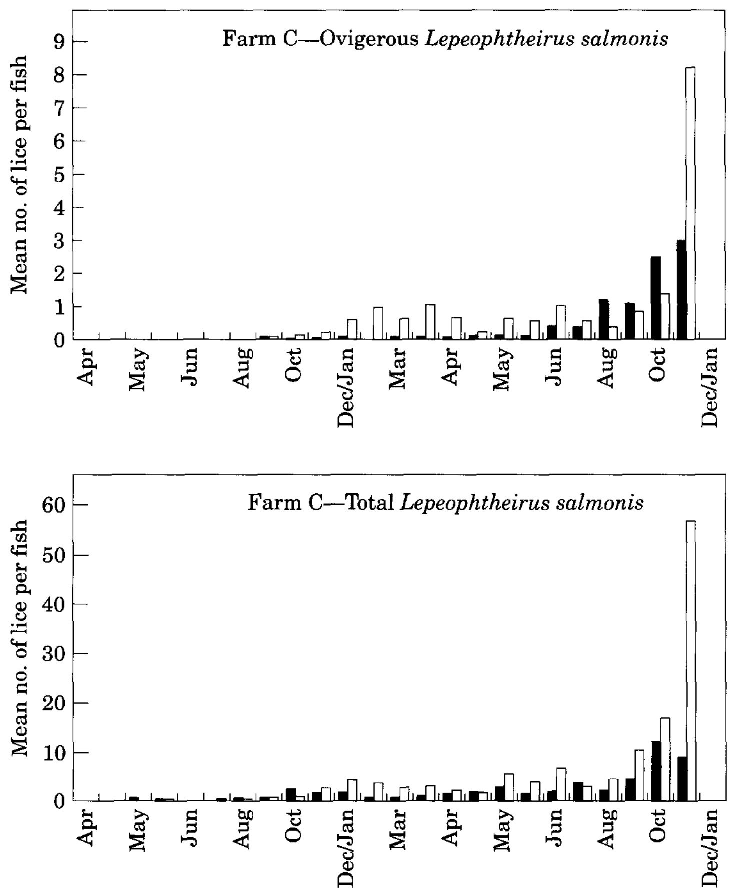

Figure 5. *Farm C.* Mean lice infestation levels per fish from the time of stocking at sea to harvest. Information is presented for ovigerous lice and total lice numbers for two successive generations of Atlantic salmon. 1994 fish (■); 1995 fish (□).

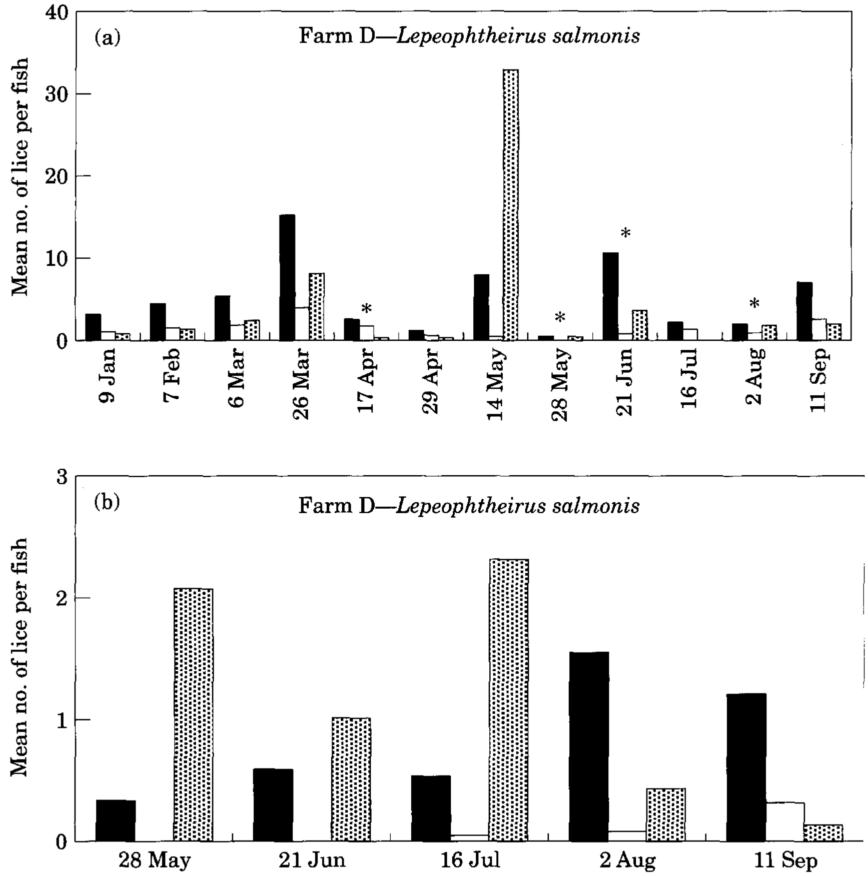

Figure 6. *Farm D.* Mean lice infestation levels per fish. (a) One-sea-winter salmon. (b) Smolts. Information is presented for ovigerous lice, total adult lice, and juvenile lice. Dates on which treatments took place are indicated by asterisks. adult (■); ovigerous (□); juvenile (■).

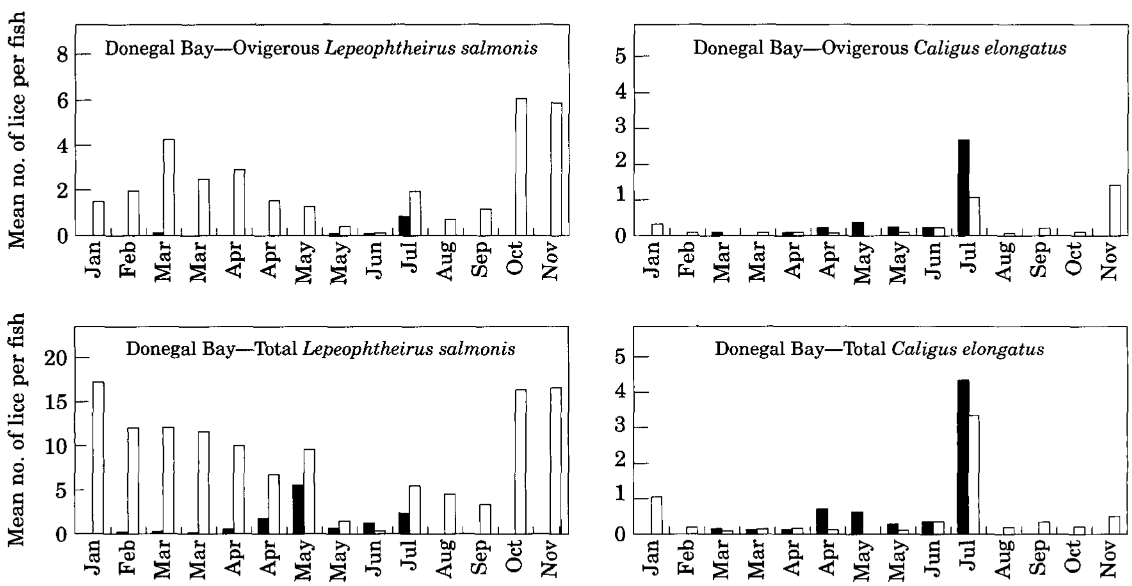

Figure 7. Mean lice infestation levels per fish on rainbow trout and Atlantic salmon reared in adjacent cages in Donegal Bay during 1996. rainbow trout (■); Atlantic salmon (□).

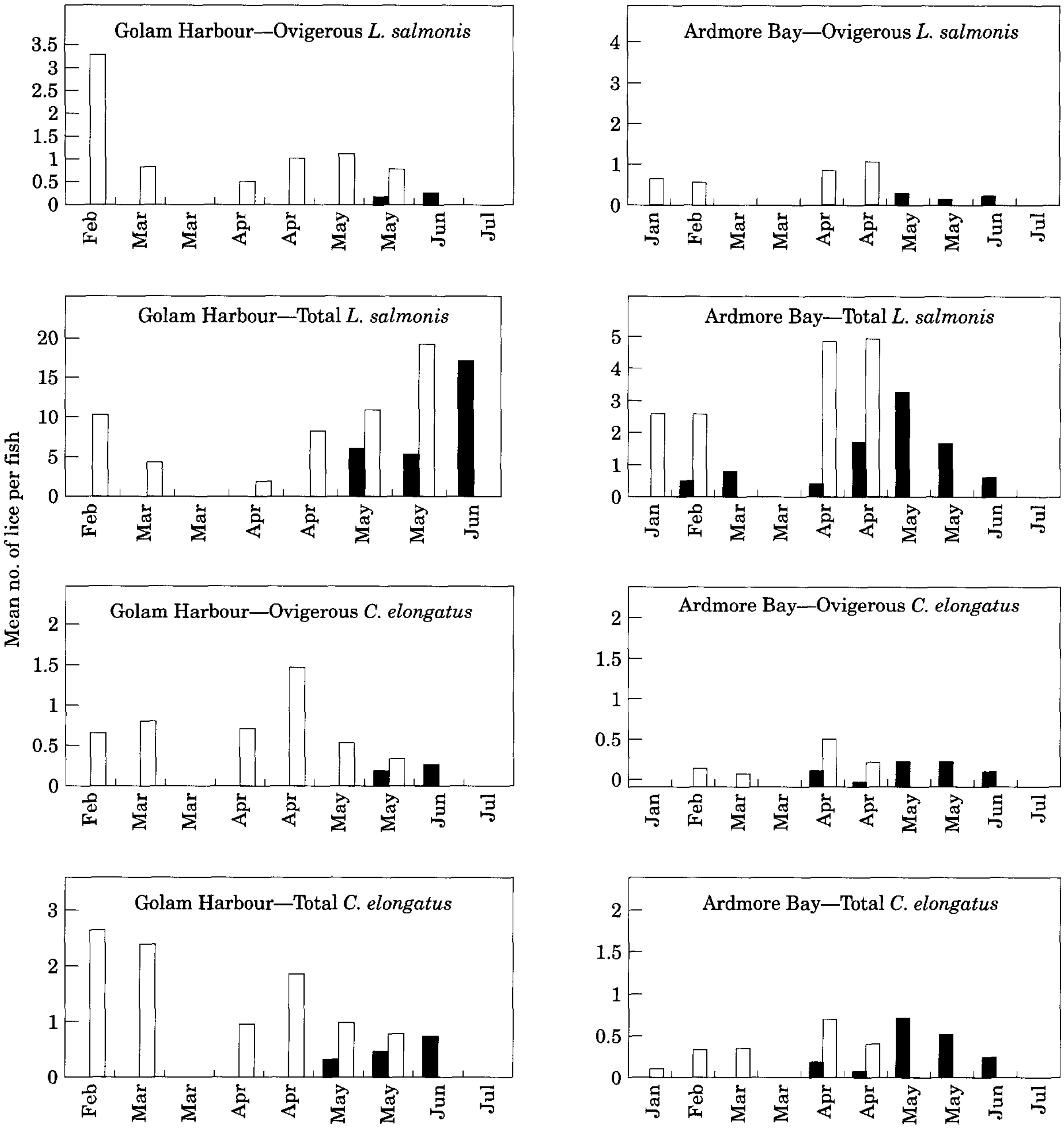

Figure 8. Mean lice infestation levels per fish on rainbow trout and Atlantic salmon reared in adjacent cages at two sites in 1994. (■) rainbow trout; (□) Atlantic salmon.

circumstances. The 1996 generation at this site was stocked into a smolt site 2 km distant from the production site, thus enhancing the separation of generations. However, overlapping generations, while not preventing lice control, clearly add an additional burden in terms of transmission of infestation within the site. This makes control of lice infestations more problematic and can lead to higher levels of infestation. This is clearly the case at Farm D. Mixing of generations on site does not appear to be the sole cause of high infestation pressures. At Farm B, as at Farm D, settlement of juveniles which are not consistent with the previous levels of ovigerous females was observed. Both Farm B and Farm D are located in bays with a significant run of wild salmonids. Costelloe *et al.* (1995) have shown that in certain estuaries there is a potential for relatively high concentrations of lice larvae, originating from wild salmonids, to be present at specific times of the year. It appears likely that at certain times of the year, January/February at Farm B and May at Farm D, a significant proportion of the lice on the farmed fish may have originated from wild sources.

The effects of fallowing and separation of generations have been reported previously from both Ireland (Jackson and Minchin, 1993a) and Scotland (Grant and Treasurer, 1993). Grant and Treasurer (1993) indicated that smolts became rapidly infested at multigeneration sites and estimated that a fallow period of 30 d was necessary to break the cycle of infestation by *L. salmonis*. Data collected in Ireland over the 7 years of the National Sea Lice Monitoring Programme have shown that fallow periods of 14 d have been effective in breaking the cycle of infestation (Anon., 1995). At sites where one-sea-winter fish (12 months at sea) have been harvested in February, smolts stocked 14 d later have not exhibited any signs of infestation pressure. A minimum fallowing period of one month is normally the target set by farms participating in Single Bay Management agreements in Ireland, as this is in excess of the predicted maximum residence time of infective larvae in the absence of hosts (Grant and Treasurer, 1993).

The infestation characteristics of farmed rainbow trout in Ireland differ from those of farmed salmon. Prior to the early 1990s the available information was anecdotal and differences in infestation between the two species had not been quantified. A study carried out on rainbow trout and salmon in 1992 and 1993 (Jackson and Minchin, 1993b) showed that in all cases rainbow trout had a significantly lower level of infestation with *L. salmonis* than salmon. While similarly significant results were recorded in 1996 in Donegal Bay, at many locations the lower infestations found on rainbow trout were not significantly different from those found on adjacent salmon. This appears to be largely due to the reductions achieved in lice infestation levels on farmed salmon in recent years (Fig. 1) rather than any change in infestation parameters in rainbow trout. The fact that untreated rainbow trout can consistently maintain lower lice levels than salmon, even those under treatment for lice, is clear evidence of a lower susceptibility to lice infestation in rainbow trout. As this phenomenon has been observed over a 5-year period (Jackson and Minchin, 1993b) and over a wide range of site types and husbandry regimes (this study), it seems likely that it is due to some intrinsic host response to infestation with *L. salmonis*.

The implementation of improved and co-ordinated husbandry practices such as annual site fallowing, separation of generations, the virtual elimination of two-sea-winter fish and improved treatment regimes has led to a progressive reduction in lice levels, both nationally, as represented diagrammatically in Figure 1, and on individual farms. At certain sites, such as Farm A, lice levels have now reached the practical minima which are obtainable in a situation where re-infestation from wild sources is a constant reality. The challenge for the future is to achieve similar results across the fin fish farming industry and maintain low lice levels despite ever-changing commercial imperatives and other challenges such as disease or adverse environmental conditions. To achieve this, a robust and reactive management framework is required. Smith (1995), discussing conflict and consensus in fisheries management, concluded that a "management scheme is measured not by its internal consistency and modelled predictive success but by the extent to which people comply with it. And a willingness to comply is usually a general acceptance, grounded in perception that it 'makes sense'." This conclusion applies equally well to any proposed scheme for the rational management of fin fish farming. The Single Bay Management process being implemented in Ireland has many of the characteristics required to ensure acceptance. It allows for flexibility, is locally based, and encourages dialogue between interested parties which frequently are also competing interests. To achieve success the output from this process will have to be seen to "make sense" to all concerned in terms of the sustainable development of the salmonid farming industry, the conservation of wild salmonid stocks and the protection of the environment.

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