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STUDIES ON SEA LICE LARVAE *Lepeophtheirus salmonis* KROYER ON THE WEST COAST OF IRELAND

by

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ABSTRACT

L. salmonis , an ectoparasitic copepod of salmonids, has been associated with a collapse of sea trout (*Salmo trutta* L.) returning to rivers in the mid-west of Ireland was linked with an epizootic of sea lice. This paper reports on the findings of an investigation into the production of *L. salmonis* in selected bays on the West coast of Ireland and examines their distribution and dispersion in these areas and reports on findings regarding settlement of larvae on naive smolts in experimental cages placed close to fish farms and on others close to rivers.

INTRODUCTION

The sea louse *Lepeophtheirus salmonis*, a marine ectoparasitic copepod of salmonids, is an important pathogen in intensive culture of Atlantic salmon (*Salmo salar* L.) and aspects of its biology and life-cycle have been widely investigated (e.g., Johannessen, 1978; Kabata, 1979; Wootten *et al.* 1982; Tully, 1989; Johnson and Albright, 1991 a & b; Boxshall and Defaye, 1993). Although Bron *et al.* (1993) recently published a laboratory-based study on the behaviour of the copepodid, there is little information on the larval densities in the wild or close to salmon farms nor on methods by which this stage locates and attaches to a host in the wild.

In Ireland, references have been made to a possible link between elevated numbers of sea lice (*L. salmonis*) on sea trout (*S. trutta* L.) and distance to the nearest fish farm (Tully and Whelan, 1993; Tully *et al.*, 1993). Tully and Whelan (1993) contend that this infestation of lice on sea trout occurred within the first 2-3 weeks after they had migrated to sea in May-June. The infestation would therefore have occurred within the general area of the river from which the trout had migrated.

This paper investigates the larval densities in and close to a salmon farm in Kilkieran Bay and the levels of infestation in different areas of Killary Harbour. Both bays contain salmonid (*S. salar*) farms and salmonid fisheries. The results are discussed in the light of the possible contribution of lice to the collapse of the sea trout populations.

STUDY AREAS

Kilkieran Bay (Fig. 1) opens to the south west and is a complex area of islands, shallow bays and reefs and deep basins. Two main rivers, the Invermore and Inverbeg, which have been known for their salmonid fisheries empty into the northern part of Kilkieran Bay. Current speeds are highest (ca 2m sec^{-1})in the central part of the bay opposite Kilkieran village (pers. obs.).

Killary Harbour (Fig.2) is a long, fjord-like inlet into which the Erriff and Bundorragha rivers discharge both of which are important salmon and sea trout freshwater fisheries. Surface and bottom tidal currents are strongest in the narrow mouth of the fjord (Keegan and Mercer, 1986). Killary Harbour can be described as a partially mixed fjord. Stratified conditions are mainly due to the large freshwater influence particularly in the inner harbour and a distinct

halocline can be found between 3 and 10m depths during winter and summer (Keegan and Mercer, 1986).

Killary Salmon Farm Ltd. operate a salmonid farm at the mouth of the harbour and were harvesting 1 SW (sea winter) fish, with an average weight of 3kg, continuously during the current study. Stocking numbers of 1 SW fish went from 88,000 in April to 26,000 at the beginning of July.

METHODS

PLANKTON STUDIES

Surface samples were taken with a 150µm plankton net having an internal diameter of 56cm. An estimate of the volume of water sampled was evaluated by multiplying the mouth area of the net by the distance travelled. Samples were taken either by pulling the net across the surface water of a cage by hand or towing it slowly < 1knot behind a boat. The plankton net was washed down with sea water and the residue stored live in plankton jars for analysis on return to the laboratory.

On the 3.8.94 surface tows were taken across the surface of an single cage in Ardmore Bay over a twelve hour period. In addition, surface tows were taken at right angles to the tidal current 10m either side of the cage. There were 25,000 fish in the cage (Emerald Fisheries Ltd., pers.comm.) with an approximate ovigerous lice load of 50,000 (Department of the Marine, Ireland, pers. comm.). Current speeds and direction were recorded every half hour at the surface, 8m and off-bottom (23m).

Dispersion of lice larvae from Ardmore Bay was investigated by taking successive samples on a flooding tide at various distances down stream from the cages on September 15th and 16th, 1994. There were approximately 95,000 one sea-winter salmon with a mean ovigerous lice load of 4.6 per fish (Department of the Marine, Ireland, pers. comm.) in Ardmore Bay at the time of sampling. This gave the number of ovigerous lice in this area of the bay at approximately 437,000 during the transect study. Results from 3.8.94 suggested that larvae were most likely to be found in surface tows during the three hour period before high water on the days after neap tides had occurred. Sampling was therefore designed around this time period.

In order to evaluate the direction of the tidal current, two surface drogues were released at the farm prior to sampling. Surface buoys were placed at 50m, 100m, 300m and 500m along the recorded track of the drogues. On September 15th, surface tows of approximately 100m in length were taken at right angles to the track of the drogues at 10m, 50m, 100m, 300m and 500m from the last down stream cage on the farm every half hour from 12:00hr to 15:00hr.inclusive (predicted high water 14:40hr.). An additional tow was taken 1km from the farm during the 14:30 and 15:00hr. series. This procedure was repeated from 13:00 to 15:00hr. on September 16th. On this occasion, samples were taken hourly and the 1km sample was included in each series of samples.

Surface and oblique tows were taken within a cage in the farm system on the 16.9.94 in order to estimate the number of larvae within the cages. Oblique tows were taken by pulling the plankton net from the inside bottom of the net (12m) on one side of the cage to the surface on the opposite side.

During each of the sampling dates weather conditions were good with slack winds and sunny spells. The sea was calm with very little swell and water temperatures were in the order of 14°C.

In the laboratory, samples were sieved through a 500µm sieve to remove the coarse material and then washed on a 200µm sieve. The fraction retrained on the 200µm sieve was sorted under a dissecting microscope. Larval stages were removed and identified according to Johnson and Albright (1991b) and Schram (1993). Reference was also made to larval stages

(naupliar I and II and copepodids) reared in the laboratory from eggs taken from salmon (*Salmo salar* L.) on the farm.

The relationship between lice larval density and distance from the farm was measured using regression analysis (Sokal and Rohlf, 1981). The dependent data, i.e. lice number, were transformed using the formula

$$Y' = \ln (Y + 1)$$

prior to analysis.

Initial results indicated that the samples taken 10m from the farm were outliers from the rest of the data i.e. they contained a higher number of larvae than expected. This may be explained by the change in hydrographic conditions induced by the proximity of a single cage structure at the 10m sampling point. At this location the cage acts as a baffle reducing water movement and inducing eddies in the lee of the cages. The net effect will result in a concentrating effect of larvae in the lee side of the cage. In addition, the number of larvae in samples taken only 10m from an individual cage will correlate strongly with the number of larvae in that particular cage as lice numbers vary between cages on any one farm. As all the other sampling points were further down stream of the farm and were more representative of the dilution rate of planktonic larvae coming from the farm as a whole, i.e. all the cages in the system, it was decided to remove the 10m data from the analysis.

CAGE EXPERIMENTS

The four experimental cages were positioned in Killary Harbour (Fig.2) on 7.5.94 and stocked with approximately 300 salmon smolts in each unit. The capacity of the cages were $45m^3$ (3 x 3 x 5m). The smolts were fed once a week and were not treated with any therapeutants throughout the trial period.

Samples of 30 salmon smolts were removed from each of the experimental cages on 24.5.94 and 7.6.94. On the third sampling date (29.6.94) all remaining fish were removed from the cages. Fish were netted, placed in labelled, individual plastic bags refrigerated for later examination. *L. salmonis* were identified using descriptions by Johnson and Albright (1991b) and Schram (1993). *Caligus elongatus* (Nordmann) from the fourth chalimus stage were differentiated from *L. salmonis* by means of the presence of lunules on the anterior margin of the cephalothorax and on supplementary information obtained from Kabata (1979) and Hogans and Trudeau (1989). In the case of the three earlier chalimus stages, the two species could be differentiated by means of the shape of the cephalothorax, caudal regions and differences in pigmentation. The lice load, the stage of development of the lice and the position on the body were recorded from each of the fish analysed. The chalimus stages of *L. salmonis* were for the most part attached to the fins, while the preadults and adults were found on varying locations on the body surface.

The data were formulated to calculate the mean abundance, mean intensity and percentage prevalence of lice infestation on the fish examined. The terms mean abundance, mean intensity and prevalence follow the definitions of Margolis *et al.* (1982):

- mean abundance can be defined as the mean number of parasites per fish examined,
- mean intensity, the mean number of parasites per infected fish,
- prevalence, the percentage of infected fish.

The term infection level is also used to collectively incorporate the concepts abundance, mean intensity and prevalence (Nagasawa *et al.*, 1993).

Infection levels in the cages were compared using one-way ANOVA and Tukey tests (Sokal and Rohlf, 1981; Zar, 1984). The number of lice on each smolt was treated as a replicate sample from its relevant cage on each of the sampling dates. Prior to analysis, data were transformed using the formula

$$X' = \sqrt{(X + 0.5)}$$

in order that the samples' underlying distributions would be normal (Zar, 1984).

RESULTS

PLANKTON STUDIES

Dispersion from a cage

Larval returns from the samples taken within and either side of the cage on the 3.8.94 are presented in Figure 3. Highest numbers of larvae were consistently recorded within the cage. Densities were not uniform throughout the sampling period in the surface waters of the cage, but increased from 0.1/m^3 just after predicted low water (08:55hr.) to 66.1/m^3 at high water (15:40hr.). Larval densities were considerably lower in each of the samples taken after high water (max. 6.8/m^3). Although there was a slow dispersion of larvae from the cage to the sampling stations either side of the cage while the tide was flowing in their respective directions (Fig.3), relatively low densities of larvae (max. 2.49/m^3) were found in these samples throughout the sampling period. A similar dispersion from the cage was found on the 16.9.94. On this date the maximum density of larvae within the cage was 59.6/m^3 while the maximum density found 10m down stream of the cage was 4.30/m^3 over the sampling period. Fouling on the net by epiphytes and epifauna was relatively heavy on both occasions, reducing water movement through the cage.

Dispersion from the farm system

Results from the tows taken on September 15th and 16th are presented in Figure 4. Most of the cages in the farm had little or no fouling during the sampling period. Highest numbers of larvae down stream of the farm were consistently recovered 10m from the cage (max. 4.8/m^3) with a reduction (max. 2.0/m^3) in tows taken 50m or greater away from it. The mean numbers of larvae recovered at each distance from the farm were similar on both days (Fig. 4) with lower larval numbers recovered with increasing distance from the farm. Although the standard deviations are relatively large, the deviations from the mean are more or less consistent through each transect, i.e. the greatest number of larvae at each of the distances from the farm were found in the samples taken during the same transect series while the least number of larvae in the samples at each distance were taken during another series (see Figure 3).

Regression analysis on the data from each of the sampling dates show a significant relationship ($p = 0.001$) between distance and larval numbers (Fig.5). The analysis indicates that, on September 15th, 98% of the variation within the data set can be explained by the formula

$$\ln(\text{lice number} + 1) = 3.1777 - 0.0015 \text{ distance} \qquad (p = 0.001)$$

while on September 16th, 97.7% of the variation is explained by

$$\ln(\text{lice number} + 1) = 3.3134 - 0.0014 \text{ distance} \qquad (p = 0.001)$$

Although copepodids were picked up in most of the samples, the ratio of copepodids to naupliar stages increases with distance from the farm (Fig. 4). The actual number of copepodids was relatively constant in each of the samples from a series and the maximum number found in a single tow was 0.28/m^3 taken 500m from the farm on the 15.9.94.

SETTLEMENT STUDIES

Smolt Infestation Levels in Relation to Distance from a Farm

The infection levels of *L. salmonis* found on the smolts in the experimental cages are presented in Table 1 (see also Costelloe, J. *et al.*, in press). The cages are numbered in ascending order from the cage positioned nearest to the river to that closest to the fish farm.

Date	Cage Number	Number of fish sampled	Mean(SD) abundance	Mean(SD) intensity	% Prevalence
24.5.94	1	30	1.53(1.59)	2.00(1.55)	77.00
	2	30	0.50(0.68)	1.36(0.45)	37.00
	3	30	0.40(0.81)	1.33(1.00)	30.00
	4	30	0.53(0.65)	1.14(0.36)	47.00
7.6.94	1	30	1.03(1.19)	1.76(1.03)	57.00
	2	30	0.20(0.38)	1.00(0.00)	17.00
	3	30	0.27(0.52)	1.14(0.38)	23.00
	4	30	0.20(0.48)	1.20(0.45)	17.00
29.6.94	1	193	0.06(0.26)	1.10(0.32)	5.00
	2	269	0.18(0.37)	1.10(0.29)	17.00
	3	200	0.19(0.42)	1.10(0.29)	17.00
	4	229	0.56(0.73)	1.40(0.55)	40.00

Table 1. The mean abundance, mean intensity and % prevalence of *L. salmonis* infesting smolts in trial cages in Killary Harbour. (See Figure 1 for location of cages stocked 7.5.94).

On the first sampling date (24.5.94), 17 days after the introduction of fish, cage 1 exhibited the highest levels of infection with a mean (SD) abundance of 1.53 (1.59), a mean (SD) intensity of 2.00 (1.55) and a prevalence of 76.67%. The other three cages had similar levels of infection to each other (See Table 1). There was a reduction in infection levels in all the cages sampled on the 7.6.94. Cage 1 again had the highest levels while the other cages had similar levels of infestation to each other. On the 29.6.94, the final sampling date, the lowest levels of infection were recorded in cage 1 while the highest was found in the cage nearest the fish farm. The two middle cages had similar levels of infection to each other with mean abundances of 0.18 (0.37) and 0.19 (0.42), respectively.

Results from one-way ANOVA indicate that there was a significant difference ($p < 0.001$) between the infection levels within the cages on each of the sampling dates. A multiple comparison of the means (Tukey test) of infection levels in the cages reveals those cages which had significantly different infection levels from the other cages on each occasion (Table 2).

Date	Cages			
24.5.94	1^{a***}	2^{b}	3^{b}	4^{b}
07.6.94	1^{a***}	2^{b}	3^{b}	4^{b}
29.6.94	1^{a***}	2^{b}	3^{b}	4^{c***}

Table 2. Relationship between infection levels within the cages positioned in Killary Harbour. Cages sharing the same superscript letter on each date were not significantly different as determined by Tukey tests. * indicates significant level of difference between cages: * = $p \leq 0.05$, *** = $p \leq 0.001$.

On 24.5.94, cage 1 was highly significantly different ($p \leq 0.001$) from the other three cages which in turn showed no significant difference between each other. This situation was again repeated on 7.6.94. On the final sampling date (29.6.94), cage 4 was highly significantly different ($p \leq 0.001$) from the other three cages; cage 1 was significantly different ($p \leq 0.05$) from cages 2 and 3 which showed no significant difference from each other.

At Killary Salmon Farm Ltd., a cage stocked with farm smolts was selected as a background for infection levels. The smolts in this cage were stocked approximately 1 month prior to the experimental cages and had not been treated with any therapeutants. These fish were sampled on two occasions during the trial period (7.6.94 and 29.6.94). The level of infection was the same on both dates (mean abundance 0.13 (0.35), mean intensity 1.00 (0.00) and prevalence 13.33%). These figures of infection are significantly lower ($p \leq 0.001$) than those recorded in the experimental smolt cage near the farm (Table 1) even though the farm smolts were in the water a month before the experimental fish.

Lice Population Structure

The population structure of the lice recovered from the smolts from each cage are given in the form of pie charts in Figure 7. The charts represent the cumulative percentage of the stages of the lice found on the total fish sampled from each cage on different dates.

Although the population structures of the lice from the smolts in each of the cages are quite different at the start of the programme, a similar population composition developed over the study. This was evident in the final samples (29.6.94) where most of the lice stages were represented in all the cages. The pattern of the initial infestation would appear to have been different.

On the 24.5.94, the lice on the smolts in cage 1 consisted predominantly of chalimus stage I, cage 2 were predominantly chalimus IV, whereas cages 3 and 4 had a mixed population of lice with no single stage dominating.

Cage 1 had been relocated on 18.5.94, 6 days prior to the first sample being taken. Given that the development time between chalimus I and chalimus II at 10°C is approximately 3 days (Johnson and Albright, 1991a), and the predominant stage on the fish were chalimus I, it is apparent that a second major pulse of lice had settled on the fish in this cage after it was moved. The structure of the lice population from the second and third samples suggests that further infestation was minimal after this pulse and that lice mortality was high between 7.6.94 and 29.6.94.

DISCUSSION

Plankton Studies

The dispersion and distribution of the copepodids and nauplii derived from the lice populations on the farms is very much dependent in the first instance on the release of the larvae from the cages and then on the hydrography of that particular bay. Results from the study showed a high retention of larvae within the cage sampled. This was due to a reduction of water movement inside the cage caused by the physical barrier of the net which was heavily fouled during the sampling period.

Dispersion of the larvae which are washed out of the cages on a farm will depend primarily on the current patterns within that area and to a lesser extent on larval behaviour i.e. vertical migration. Løland (1993) contends that neutrally buoyant contaminants originating from a cage will stay concentrated in the wake of a cage over large distances, mixing slowly with the surrounding water unless there are waves or large-scale turbulences involved. Aspects of the data presented here indicate that *L. salmonis* larvae have the ability to migrate vertically through the water column and are found at or near the surface in the three to four hour period prior to high water. Heuch *et al.* (in press) suggest that light intensity is of major importance for the vertical distribution of *L. salmonis* copepodids. As the studies are carried out during flooding tides on relatively bright days, it is assumed that the number of larval recovered from surface samples taken at various distances from the farm in its tidal wake will represent the density of lice at those distances. Although some of these may have originated from lice on wild fish, it is probable that the vast majority were derived from the farm.

In Ardmore Bay, samples were taken on two occasions in order to determine the number of farm-produced larvae present in the water body relative to the distance from the farm. There was a 90% reduction in larval densities in tows taken 1km from the farm (max. 0.4/m^3) compared to those taken at 10m (max. 4.8/m^3) from the last cage on the farm during any one series of samples. These reductions in densities are due to dilution, vertical mixing, natural mortality and to local hydrographic conditions in Ardmore which cause a percentage of the larvae to be retained within the farm system.

Regression analysis indicated a highly significant relationship ($p = 0.001$) between distance from the farm and the number of larvae picked up in the tows. The models produced by the analysis predicted that few larvae would have been found in surface tows taken greater than 2km from the last cage on the farm on the sampling dates. Results from this study would therefore suggest that the farms located in Ardmore Bay have little effect on the lice infestations outside its immediate environs.

Although low numbers of copepodids were found in most samples (max. 0.28/m^3, 500m from the farm), the ratio of copepodids to nauplii increased with distance from the farm. Given the above dispersion patterns and also that the number of nauplii are constantly being reduced due both to development to the copepodid stage and natural mortality, it is not surprising that the ratio of copepodids increased with increasing distance from the farm. It must be remembered that the actual numbers of copepodids (max. 0.28/m^3) were relatively low and the density did not increase with increasing distance. It has been suggested that copepodids, which have only previously been recorded from bottom samples in the wild, have an epibenthic existence (Jackson *et. al.*, 1994). The findings from this study suggest that, at least during part of its life history, it has a pelagic phase. In all, 134 copepodids were found in the surface waters from samples taken on September 15th and 16th, 1994.Correlations between production of the infective stages of *Lepeophtheirus salmonis* and subsequent infestations of hosts will exist only along limited geographic scales defined by the dispersion and distribution of the host and parasite populations (Tully and Whelan, 1993).

SETTLEMENT STUDIES

Temperature and salinity have strong influences on the development time and survival of *L. salmonis* larvae (Johannessen, 1978; Wooten et al., 1982; Johnson and Albright, 1991a). Comparisons of development times from different studies is difficult due to the various experimental procedures followed. However, in general, higher temperatures reduce development time while survival is seen to be enhanced at salinities less than that of full strength sea water (Johnson and Albright, 1991a). The ambient temperature and salinity in Killary Harbour during the study was approximately 10°C and 32S, respectively. Johnson and Albright (1991a) found the cumulative development time from naupliar I to copepodid was 3.6 days at 10°C with survival times of copepodids at 30S of 5.5 days . These results suggest that *L. salmonis* larvae would survive approximately 9 days from hatching under the temperature and salinity conditions found during the study. However, it must be assumed that the infectious copepodids will settle on the first suitable host encountered and that its ability to infect a host diminishes as it expends energy.

The dispersion and distribution of the copepodids and nauplii derived from lice on salmon in farm and wild fishery populations is very much dependent on the hydrography of the particular bay in which they are dispersed. Drogues released at various points in Killary Harbour indicate that current speeds differ between the outer and inner areas. Relatively uniform current speeds and directions flow throughout its outer western half due to the relatively even depth and shape. This pattern changes in inner Killary, i.e. inside the "elbow", due to shallow depths, a back-up of tidal water and a stronger influence of freshwater runoff. Booth (in Keegan and Mercer, 1986) estimated that the ratio of net inflow over net outflow in the main body of water near the mouth of Killary Harbour was 2.37. To satisfy the conservation of mass in the harbour, a surface layer with a net outflow is considered, i.e. an estuarine circulation (Keegan and Mercer, 1986). The boundary separating the surface layer from the

main body of water is defined as the surface over which the net horizontal movement of water is zero (Tully, 1958). These factors have a major influence on the distribution of plankton within these areas. Roden *et al.* (1987) found that only phytoplankton species which had high growth rates were concentrated in the inner harbour as the seaward current removed plankton rapidly from this shallow area. The species composition of the subsurface phytoplankton in the outer harbour was typical of coastal rather than estuarine water due to transport of these species by the landward-moving bottom current in this relatively deep area (Roden *et al.*, 1987). Ryan *et al.* (1986) also found that the zooplankton of Killary Harbour could be divided into two broad groups depending on their salinity preferences. Recent studies have shown that *L. salmonis* copepodids are found distributed within the top 6m of the water body and that they migrate to the top 2m during daylight (Heuch *et al.*, in press). As the larvae are carried in and out on the flooding and ebbing tide, respectively, the net movement of larvae would be seawards as they would be carried in the seaward-moving surface layer. Larvae that sink below the seaward surface current in the outer harbour would make little progress either way over one full tidal cycle while larvae in the inner harbour could maintain their position in this area if they only migrate to the surface layer on a flooding tide as suggested by (pers. obs.). Given that the salmonid farm was approximately 6km west of the experimental cages positioned near the Bundorragha river and 12km from the cage close to the Erriff, it would seem improbable that appreciable numbers of farm produced lice could have an impact on the inner areas of the harbour, particularly in the area near the inner cage where the piston effect associated with the fjord and the seaward-moving surface current are at their greatest. In addition to the distance lice originating from the fish on the salmon farm would have to travel to reach the upper reaches of the harbour, other factors such as natural mortality, retention at the farm and dispersal and dilution of larvae would be major considerations in the transfer of lice. Costelloe, M. *et al.* (in press) found that from densities of *L. salmonis* larvae of $4.8m^{-3}$ 10m downstream from a salmon farm, few farm-produced larvae would have been recovered at distances greater than 2km downstream from the farm due to these factors.

Infestation levels on the smolts which were placed at various distances between the Erriff river and Killary Salmon Farm Ltd. also suggest that the lice on the farm contribute little to densities of larvae in the inner harbour areas. Given the hydrography, it is doubtful if farm-produced larvae can make any significant progress towards the head of the harbour. However, if there was a net inward movement into the harbour, they would encounter the middle two cages at the 'elbow' of the harbour in the first instance. These two cages would therefore have had the highest rates of infection of the four cages positioned in the harbour. This was not the case. Results from the first sampling show that the cage nearest the river had the highest rates of infection. This was again the case in the samples taken on the 7.6.94 although mean abundances were lower in all four cages, probably due to natural mortality of lice on the fish without further infection. On the final sampling date (29.6.94), the fish nearest the farm (cage 4) suffered a new settlement of lice between sampling dates which increased the mean abundance of lice on the fish to a similar level as was found on the 24.5.94. However, the number of lice on the fish in the two middle cages did not increase but had slightly lower levels of infection compared to previous levels on these fish. There was a major mortality or fall-off of lice on the smolts nearest the Erriff, probably caused by reduced salinities due to freshwater run-off after a period of heavy rainfall prior to the last sampling date.

The population structure of the lice on the smolts in the cages suggested that the larvae settled in pulses rather than by a continuous settlement over the trial period. The development of a single cohort from chalimus I through to the preadult stage could be followed over time, particularly in cage 1 which had been relocated on the 18.5.94, 6 days prior to the first sample being taken. Given that the development time between chalimus I and chalimus II at 10°C is approximately 3 days (Johnson and Albright, 1991[a]), and the predominant stage on the fish were chalimus I, it is apparent that a pulse of lice had settled on the fish in this cage after it was moved. The structure of the lice population from the second and third samples suggests that further infestation was minimal after this pulse. The population structures of the other cages were also dominated by one or two cohorts although at a different stage of development compared to cage 1. Continuous settlement did not occur in the cages as this would have

resulted in mixed population structures with a number of cohorts contributing equally to the overall population. Tully (1989) also found chalimus peaks which could be followed over time when he looked at infestation of salmon smolts between July 1987 to January 1988. These pulses of larvae must be associated with some sort of synchronised hatching of the eggs. In ectoparasites, the timing of egg hatching and the release of free-living stages plays a major role in successfully locating a host during their short life-span. In some species of parasitic copepods, it has been suggested that environmental cues trigger egg hatching (Poulin *et al.*, 1990). Roth (1988) reported that egg hatching in *Haemobaphes intermedius*, a copepod gill parasite of intertidal fish, may be under the influences of tides and other environmental stresses. *H. intermedius* may use these cues to hatch at times when several hosts are concentrated in a small volume of water (i.e. tidal pools), thus facilitating the transmission of the parasite. Hatching in a variety of other crustaceans, including non-parasitic copepods, is regulated by environmental factors such as illumination, tides and temperature (De Coursey, 1983; Sastry, 1983).

It must be pointed out that sea lice and host relationships have evolved and adapted over millions of years. Fish farming has imposed a relatively new dimension to the ecological equation. Ecological and behavioural characteristics of both the host and parasite in natural habitats play major roles in determining the probability of them coming into contact with each other. Lice infections on fish will depend on the number of infectious copepodids within a particular location, the time spent by the fish within this area during periods of available copepodids and the susceptibility of the fish to infection at that particular time. In the context of the area studied during the present work it would seem probable that settlement of lice on the smolts are potentially derived from more than one source.

Salmonid farms normally occur in the outer areas of embayments. In the initial stages of fish production, lice infestations occur from the natural background levels derived from wild fish. After these events, the farm becomes self-infesting with the generation times of the lice being dependant on the prevailing water temperature. The effect that this source of lice has on the water body in which it is located is predominantly related to topography and hydrography. Infection levels of lice on the smolts in Killary Harbour and the current patterns within the bay suggest that the impact of lice from Killary Salmon Farm is mainly confined to the outer harbour areas. A further likely source of lice production occurs in the inner harbour, particularly in the areas close to the river mouths. Recent studies on farmed fish indicate that adult lice are smaller and the numbers of eggs carried by ovigerous females are less than those on wild fish (Tully and Whelan, 1993). On their migration from salt to freshwater systems, wild salmonids remain in the inner estuarine areas until conditions are suitable to move into the rivers and thereby provide a lice population in this area. Additionally, the potential is there for ovigerous female sea lice and egg strings from these females to drop off wild fish when they actually migrate into the freshwater (McLean *et al.*, 1990). It is well known that truncated egg strings will hatch and produce viable larvae (Johnson and Albright, 1991a; Gresty *et al.* 1993; Pike *et al.*, 1993). Johnson and Albright (1991a) and recent studies in University College Cork (Fitzgerald, pers. comm.) have shown that newly moulted copepodids have maximum survival at 10°C and 25S. In Killary Harbour, wild salmon are caught by netting from mid-March to mid-July. Although the greatest number of fish are caught around June (720 salmon from one boat over a 10 day period), a significant number of salmon are caught in the early part of the season (Ryan, pers.comm.). These salmon provide a viable source of infective larvae.

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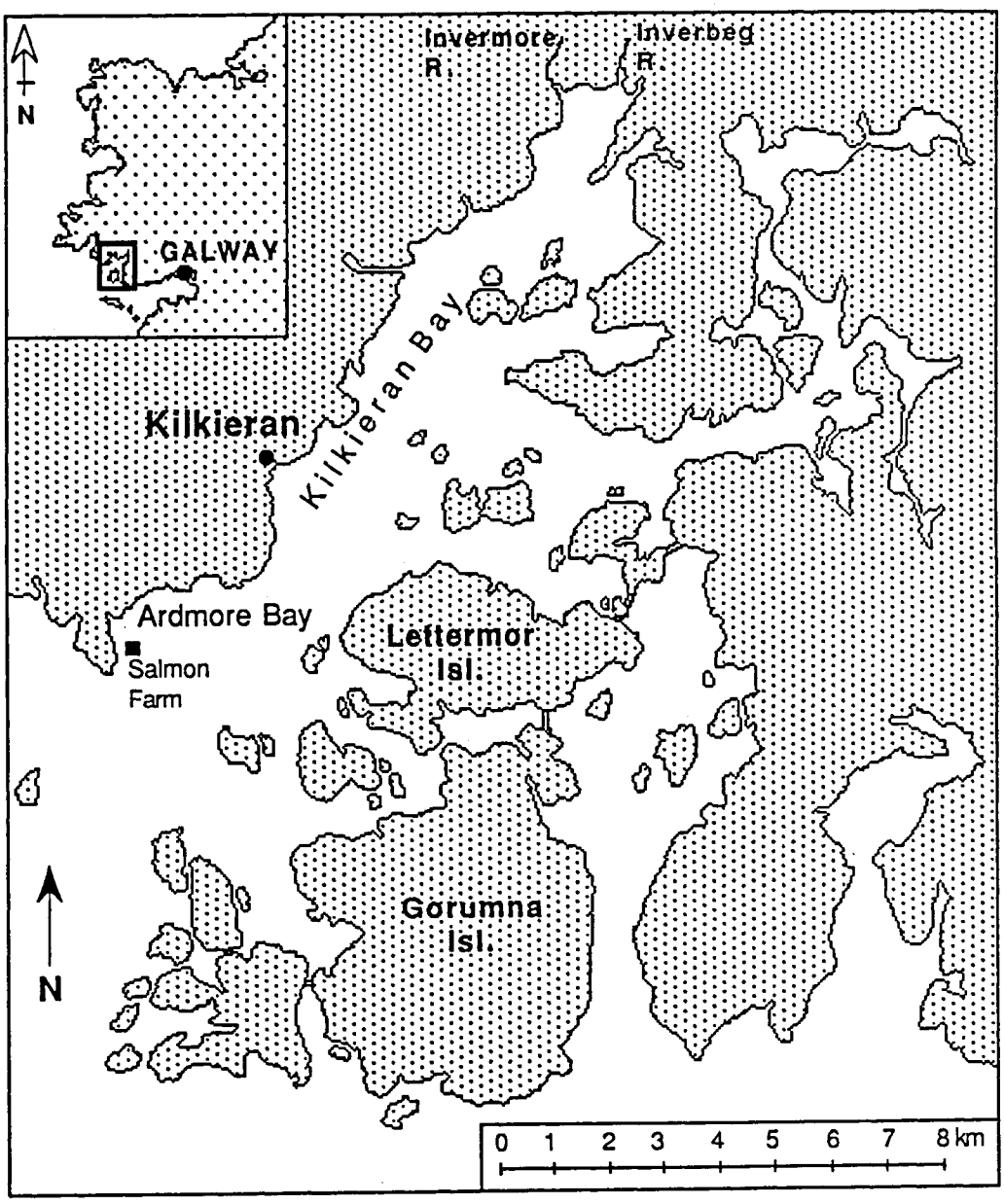

Figure 1. Location of the salmon farm at Ardmore, Kilkieran Bay, where plankton studies were carried out.

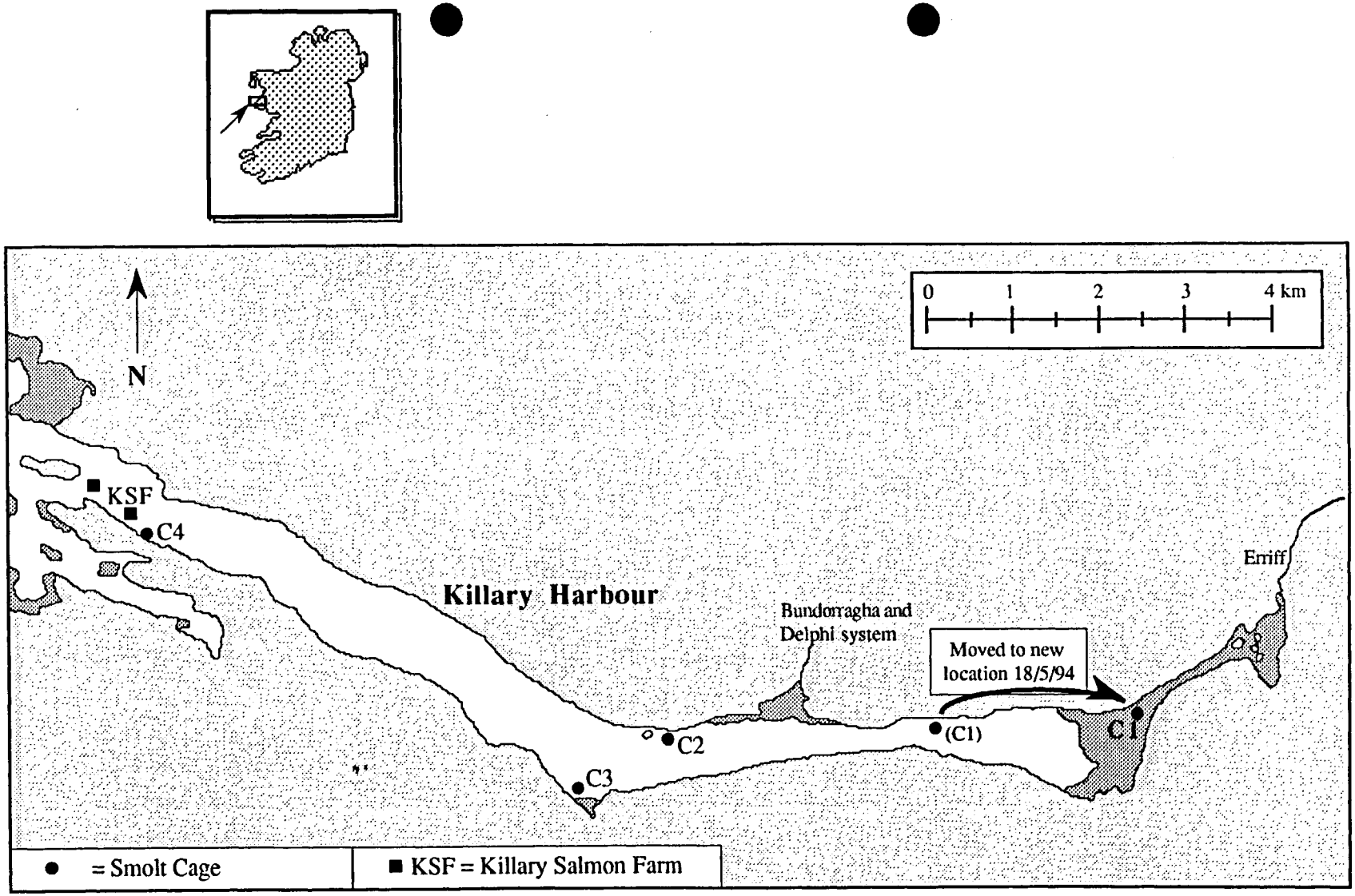

Figure 2. Location of smolt cages in Killary Harbour, May-June, 1994 (All cages stocked 7.5.94).

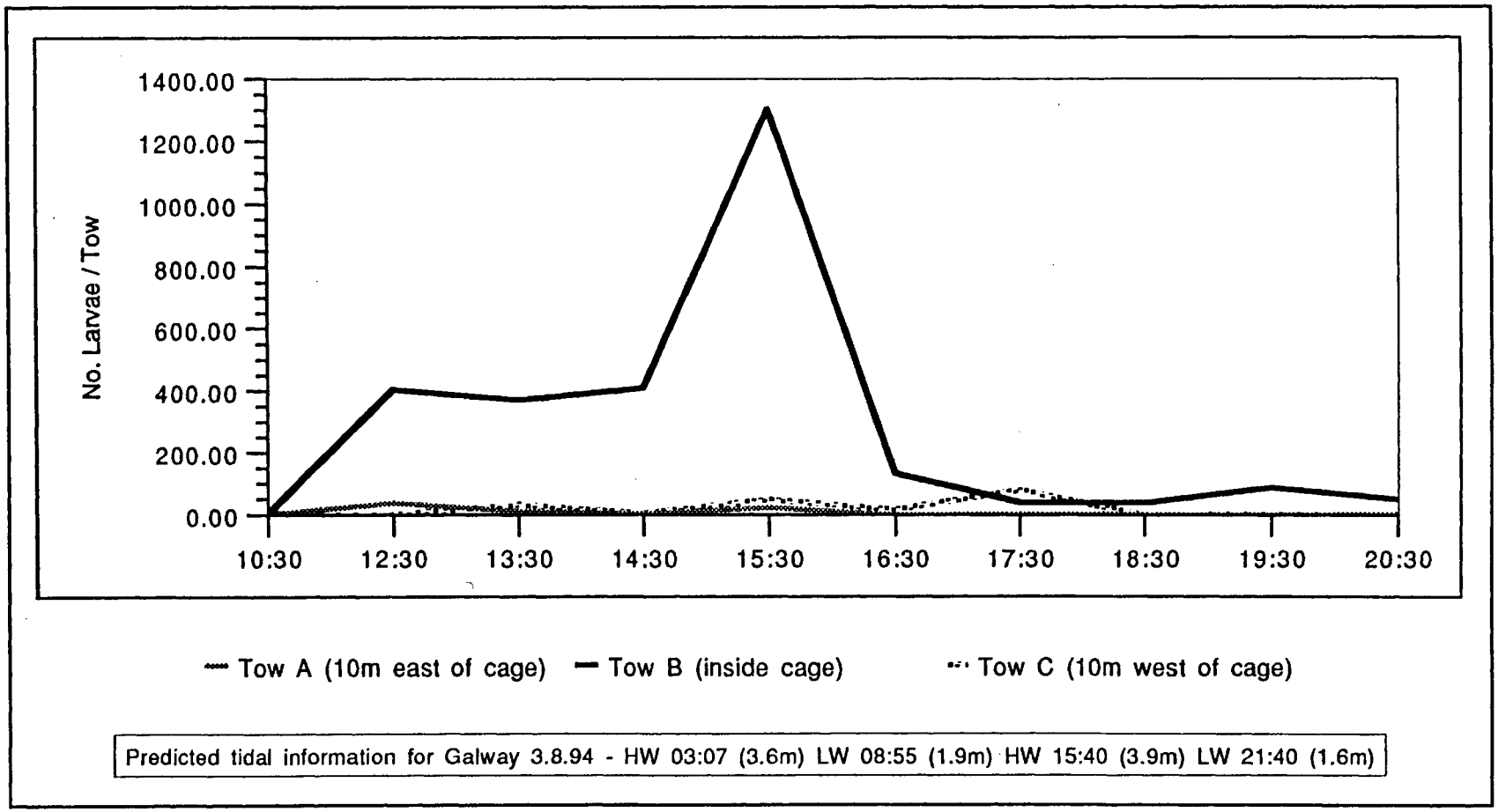

Figure 3. Number of *L.salmonis* larvae collected in surface tows inside and on either side of a salmon cage over a tidal cycle at Ardmore, Kilkieran Bay, August, 1994.

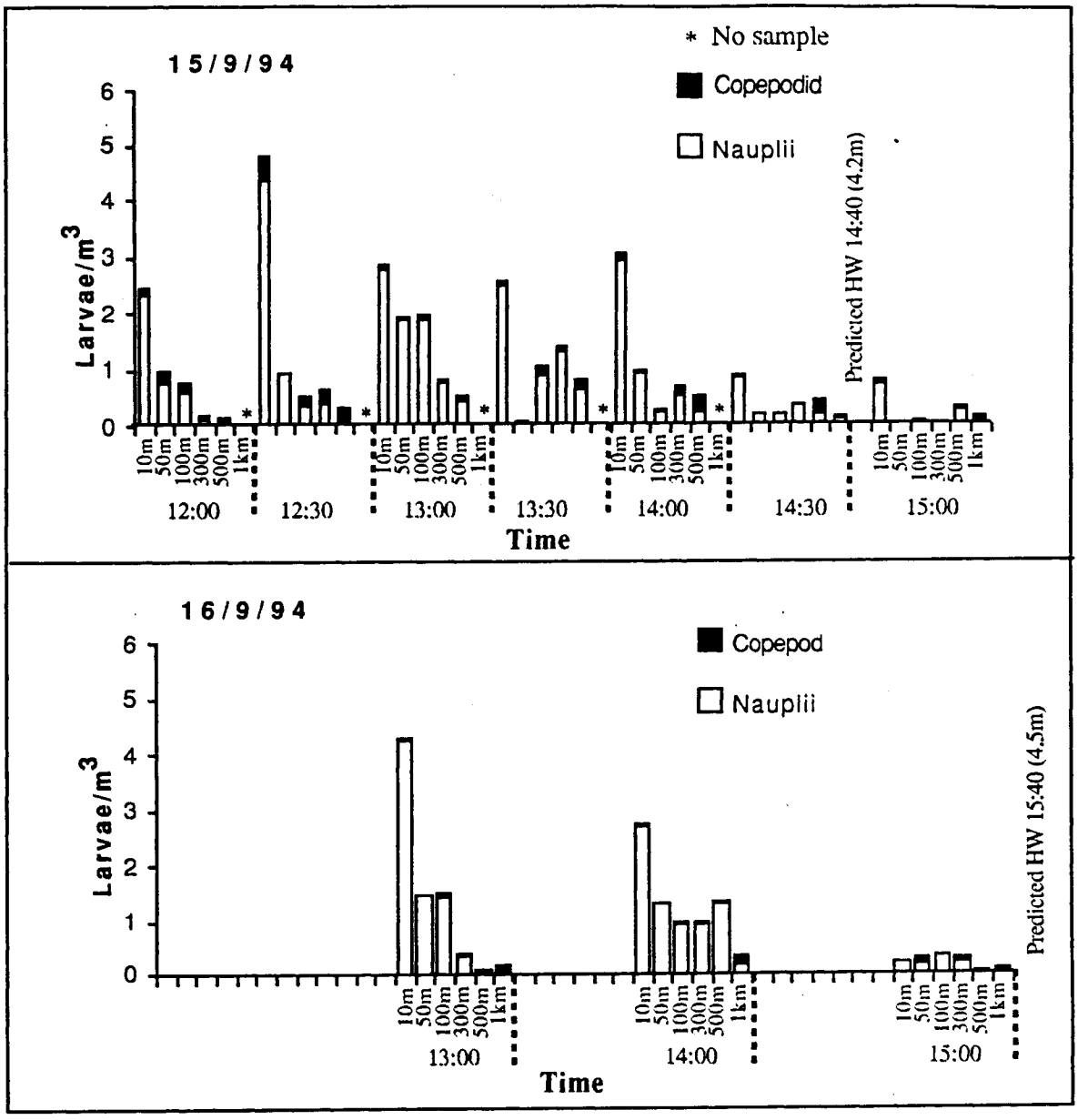

Figure 4. Larval densities recorded at varying distances from a fish farm at Ardmore, Kilkieran Bay, September 1994.

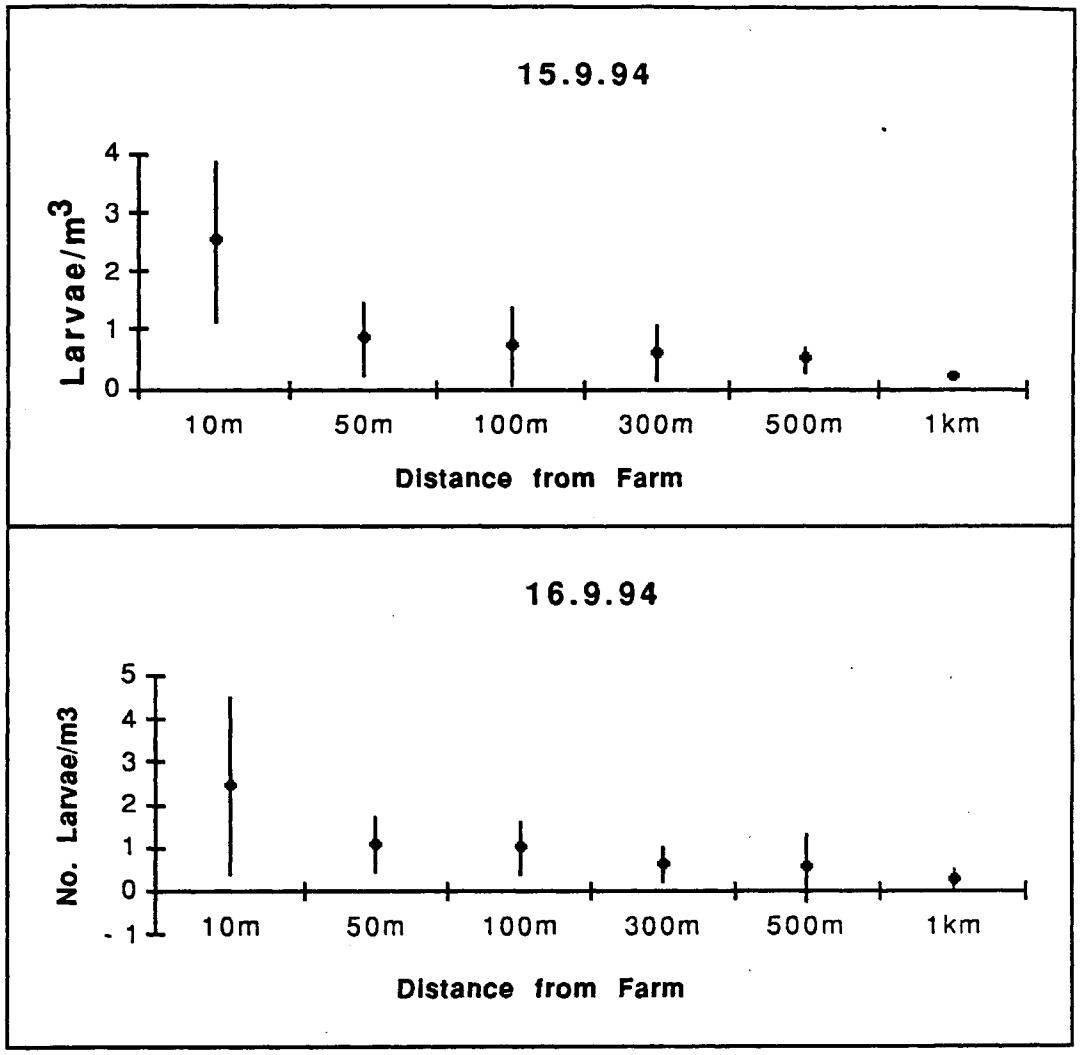

Figure 5. Means and standard deviations of larval *L.salmonis* collected at varying distances from the salmon farm at Ardmore, Kilkieran Bay, September 1994.

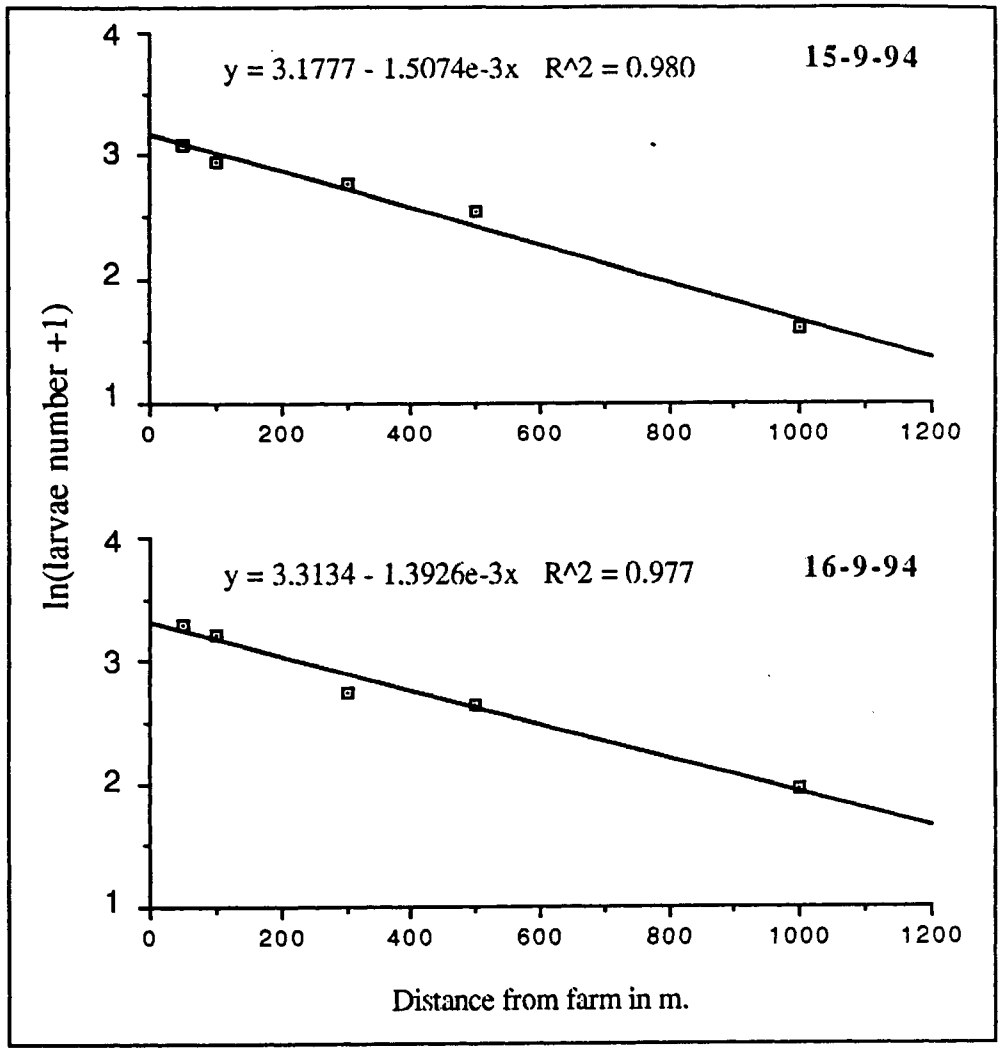

Figure 6. Regression analysis of mean larval *L. salmonis* data collected at varing distances from a salmon farm at Ardmore, Kilkieran Bay, September 1994.

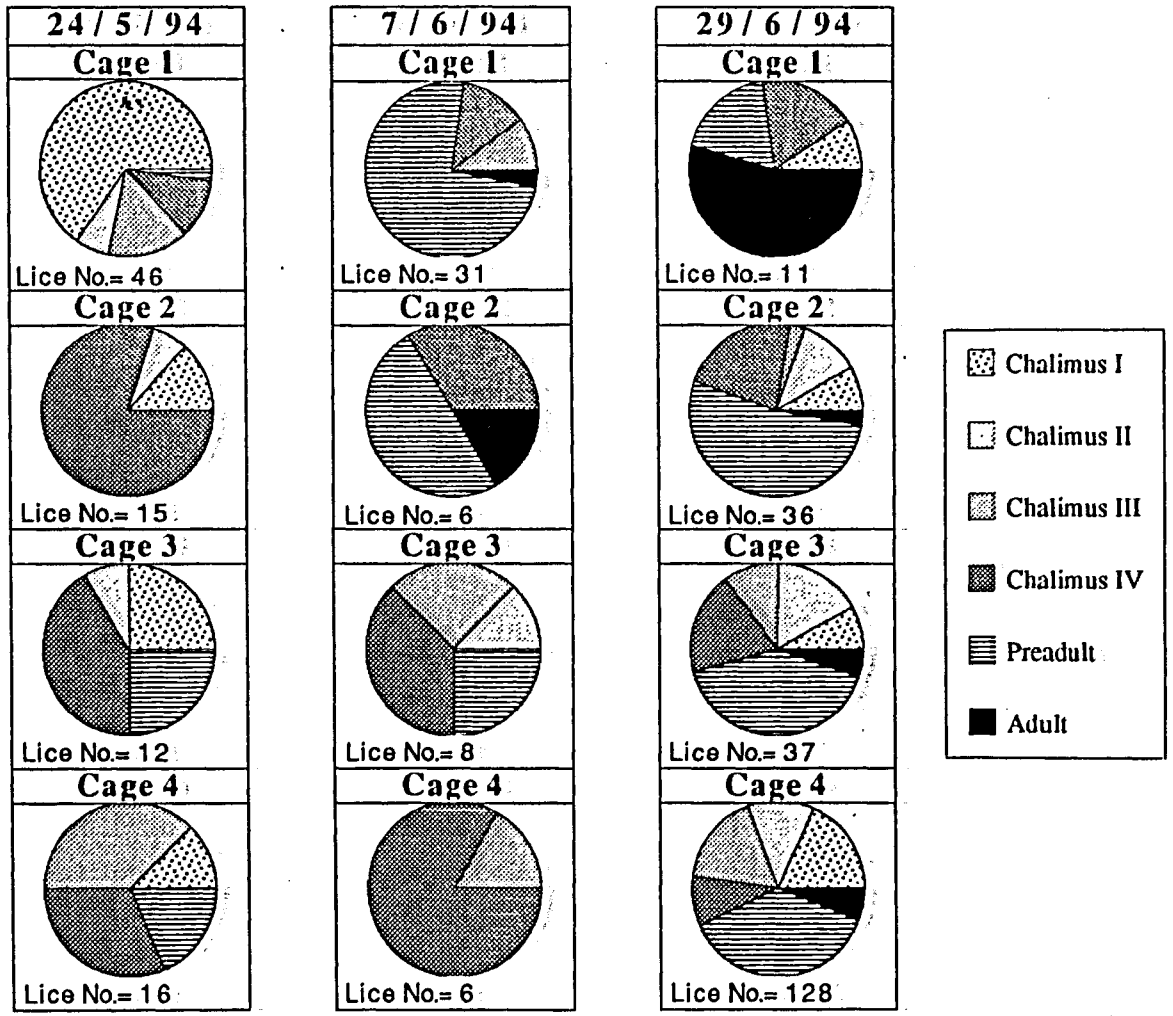

Figure 7. Population structure of *L. salmonis* on salmon smolts held in experimental cages in Killary Harbour (cages stocked 7.5.94).