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ICHTHYOPLANKTON STUDIES ON THE LOWER WAIKATO RIVER

III. Downstream variation in distributions

by

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Report to Electricity Corporation of New Zealand Ltd

(Information in this report should not be used without prior consent of ECNZ)

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SUMMARY

Quantitative ichthyoplankton sampling was carried out on the lower Waikato River at Huntly, Clune Road and Tuakau Bridge between October 1985 and May 1987. The sampling regime allowed diel, spatial and seasonal distribution patterns of the ichthyoplankton migrations to be compared between sites, and downstream recruitment to be estimated. To help determine the origin of larval fish migrations, tributaries were also sampled at irregular intervals during 1986 and 1987.

The major taxa recorded, in decreasing order of abundance were smelt (*Retropinna retropinna*), bullies (*Gobiomorphus* spp.), cyprinidae (carps) (includes Koi carp, *Cyprinus carpio*; goldfish, *Carassius auratus* and rudd, *Scardinius erythropthalmus*), and kokopu/koaro species (*Galaxias* spp. excluding *G. maculatus*). The overall composition of the ichthyoplankton catch did not change appreciably along the length of the river except for decreased numbers of eggs and post-larvae of all taxa at downstream sites.

All the major ichthyoplankton groups showed regulated rather than passive migration. Although most ichthyoplankton drift at night, there were local variations. At Huntly, larval smelt and bullies were most abundant after dusk, and densities decreased throughout the night. This pattern was less distinct at Clune Road, and at Tuakau only a day/night difference was apparent. These variations were probably the result of local differences in the distribution of spawning and hatching sites, and the accumulated drift of larvae downstream.

All groups of larval fishes were regularly recorded from all zones of the river but distinct distribution patterns were still evident at all sites. Generally, patterns became less distinct downstream as cumulative recruitment obscured localised recruitment patterns. The river middle was an important corridor for all larval species, while the margins were important zones for bully larvae at Huntly and Tuakau, and for cyprinid larvae at Huntly. The right channel was of secondary importance for most species, and the left channel was of least importance. Most larvae were captured in the bottom waters of all zones at all three sites. Lowest densities were recorded in the river channels at the surface.

Seasonal migration patterns were similar at all three sites, with greatest abundances in spring (bullies and cyprinidae) and autumn/early winter (smelt and bullies). The onset of annual larval migrations was the same at all sites.

The daily maxima and total cumulative annual migrations of smelt and bully larvae increased downriver, with numbers doubling between sites. It is estimated that 5.5 billion smelt larvae and 0.9 billion bully larvae passed Tuakau during 1986. Cyprinid larvae did not increase uniformly down river, and catches reflected localised rather than cumulative drift patterns. Greatest drift of cyprinid larvae was at Clune Road where a total migration of 0.85 billion was estimated.

Tributary inflows contributed significant numbers of bully larvae in autumn, and significant numbers of bully larvae, cyprinid larvae and shrimp zoea in spring. Few smelt larvae were caught from tributaries. Larval bullies were especially abundant in tributary outflows.

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1. INTRODUCTION

The majority of New Zealand's freshwater fish species and the shrimp, *Paratya curvirostris*, are migratory and spend at least part of their lifecycle in the estuary or at sea (McDowall 1978, Chapman and Lewis 1976). The Waikato River is a pathway between the sea and the Waikato basin.

In river systems thermal power stations can have significant effects on the passage of larval fish and eggs. Larvae which drift passively downstream, are susceptible to thermal, chemical and mechanical shock, when entrained with cooling water and/or thermal discharges. This impact can be minimised by appropriately designed intake and outfall structures.

At the time of the studies, there were two thermal power stations operating on the Waikato River - Huntly and Meremere. Impacts on ichthyoplankton have been assessed at Huntly Power Station (Meredith *et al.* 1987). A third power station may be developed at Clune Road (Fig. 1). This report provides information for the consents and the design process.

This report compares the distribution, abundance and migration patterns of larval fishes at Huntly, Clune Road and Tuakau Bridge. The importance of tributary inflows is also considered.

The main aims of the study were:

- to investigate migratory pathways and larval distributions downriver from Huntly;
- to estimate the level of recruitment or production of larvae downstream of Huntly;
- to investigate the likely impact of the proposed Clune Road Power Station on ichthyoplankton.

The investigation was part of a suite of studies instituted by ECNZ Ltd (formerly Electricity Division, Ministry of Energy) to determine the biological and fisheries resources of the lower Waikato River. It is the third in a series of reports on the biology of larval fishes in the lower Waikato River system.

2. STUDY AREAS

The lower reaches of the Waikato River flow through low lying areas. The river has been extensively channelised between Huntly and Tuakau for flood protection and land reclamation (Strachan 1979). Water is abstracted for rural and domestic water supplies, industrial processes and cooling at thermal power stations.

Three sites were sampled. Huntly is at the upstream end of the channelised reach, Tuakau is close to the downstream end of channelisation, and Clune Road is in the middle. There are existing or proposed thermal power stations at Huntly, Meremere and Clune Road (Fig. 1).

2.1 Huntly

The Huntly site was 100 m upstream of Huntly Thermal Power Station. This power station is 80 km from the sea, and draws and discharges water on the left bank.

The Waipa River enters the Waikato on the left bank, fifteen kilometres upstream of Huntly at Ngaruawahia. The other major tributaries in this reach are the Mangawara Stream, 8 km upstream of Huntly on the right bank, and Waahi Stream, 200 m upstream of the sampling site on the left bank. Waahi Stream is the outlet of Lake Waahi, a small shallow eutrophic lake with an abundant fish community (Stephens 1982, Wells 1984).

Upstream of the Waipa confluence, the Waikato is confined to a deep channel until interrupted by the first hydroelectric dam at Karapiro. Physical descriptions of the river profile and hydrology at Huntly over the sampling period are given in Meredith *et al.* (1989).

2.2 Clune Road

The site of the proposed power station at Clune Road is on the right bank of the river, 45 km from the sea (Fig. 1). Extensive river retraining has occurred in the reach such that river width and profile vary greatly. River sediments are destabilised, and emergent sandbars and islands are dominant features during low flows.

Between Huntly and Clune Road, the main tributaries are the Whangape and Opuatia streams which join the Waikato on the left bank 11 and 8.5 km upstream of Clune Road respectively. Whangape Stream drains Lake Whangape, while Opuatia Stream drains an extensive area of wetland.

From November 1985 to February 1986 sampling was undertaken at a site 500 m downstream of the proposed power station site near the entry of Pungapunga Stream. This site had been used as a transect for other related fisheries investigations (Boubee *et al.* 1986). During 1986, river retraining works caused the formation of extensive emergent sandbars over much of the sampling area, especially on the right side of the river. The surrounding area was similarly affected by shadowing from developing islands and dunes.

From February 1986, sampling was shifted 2 km downstream to a site 1 km upstream from Meremere Power Station. This site also contained uncompacted drifting sand but no emergent islands or sandbars. No major tributaries entered the river between the two transect points.

2.3 Tuakau Bridge

Tuakau Bridge is at a narrow point in the river (180 m river width) at the entrance to the estuary. Downstream the river spreads out into an extensive delta. The site is 30 km from the river mouth. Although tidal rises of 0.4 m to 0.6 m are experienced, there is no saline influence. Sand dredging occurs both above and below the bridge but there is little disruption from river retraining structures.

Between Clune Road and Tuakau, the Whangamarino and Mangatawhiri rivers enter the Waikato River on the right bank. The transect was established opposite the Batkin reserve boat ramp 200 m downstream of Tuakau Bridge.

2.4 Tributaries

Many tributaries enter the lower Waikato River and drain a variety of habitats. The largest tributary, the Waipa River, drains 3059 km^2 of catchment to the south west and includes a multitude of bush streams, swamps, farm drains and small lakes. Other tributaries drain the larger shallow Waikato lakes (Waahi and Whangape streams), or extensive wetlands (Whangamarino River). Many smaller tributaries drain a wide range of watersheds along the length of the river. The tributaries form important links between a considerable area of diverse fish habitat, the Waikato River and the sea.

3. MATERIALS AND METHODS

3.1 Sampling

The sampling methods used in this study are fully described in Meredith *et al.* (1989). From October 1985 to December 1986, cylinder/cone plankton nets (0.3 mm mesh) were set across a transect in 5 positions and at two depths, at each sampling site. Nets were set and emptied at four hourly intervals over a 24 hour period. Sampling was carried out fortnightly at Huntly and monthly at both Clune Road and Tuakau. During April and May sampling was carried out fortnightly at Tuakau.

To examine the diel migration patterns of smelt and bully larvae in greater detail during peak migrations, samples were taken half hourly or hourly overnight from mid-river at Huntly on 13 April 1987, and again at Tuakau on the 11 May 1987.

3.2 Physical Parameters

Measurements of river profiles, water velocity and depth were taken on each sampling trip to allow calculation of flows and mass larval movements. Huntly Power Station records were used to monitor river discharge and temperature.

3.3 Larval Identifications

Larvae were identified from descriptions and type specimens presented by Meredith *et al.* (1989). Larvae previously described as "goldfish larvae" are now referred to as cyprinid larvae due to the increasing abundance of Koi carp (*Cyprinus carpio*) in the lower catchment. The catch of kokopu/koaro larvae could represent up to four species: koaro, banded kokopu, giant kokopu or short-jawed kokopu.

3.4 Tributary Surveys

Samples were taken from the Waipa, Mangawara, and Whangamarino rivers and the Waahi and Whangape streams on the 10/04/86. At each site samples were taken from two nets set at the surface. The nets were set from bridges for up to 30 minutes between dusk and midnight. On the same night, samples were also taken from the Waikato River at Hamilton and at Tuakau Bridge.

During, 1987 the Waahi Stream and Waipa River were sampled. In the Waahi Stream, a plankton net was set at the water surface, 25 m from the confluence with the Waikato River. In the Waipa River samples were taken at the confluence with the Waikato River at Ngaruawahia (Fig. 1). Two nets were set at the river surface and bottom in the Waipa River, and comparable samples taken in mid-stream of the Waikato River 50 m upstream of the confluence.

4. RESULTS

4.1 Physical Parameters

River temperatures at Huntly reached a maximum of 23°C in January and February, and a minimum of 9.5°C in July (Fig. 2). Greatest seasonal temperature changes occurred from March to June, and September to November. Floods caused rapid decreases of river temperature of up to 2°C in autumn. Due to the absorption of solar radiation and discharge of thermal effluent, water temperatures downriver of Huntly were at times up to 1.5 °C higher than those recorded at Huntly.

River discharge varied seasonally with lowest flows (200-220 $m^3.s^{-1}$) in autumn and highest flows in winter (1000+ $m^3.s^{-1}$) (Fig. 2). Two large floods, which occurred in January and July 1986, had a reoccurrence frequency of 10 and 15 years respectively (Waikato Valley Authority records).

Mean daily water velocities varied from 0.5 - 1.2 $m.s^{-1}$. Water velocities were slightly higher in the deeper channels than in mid-river or secondary channels. However, in the sampling zones within the mainstem, water velocities were remarkably uniform at all three sites.

River profiles were similar at Huntly and Clune Road where there were two channels and a shallow mid-river zone (Fig. 3). The mid-river zone was normally less than 2 m deep while the channels could be up to 4 m deep. The major channel was on the true right bank at the end of 1985, but by the end of 1986, the major channel was on the left bank of the river. Mobile uncompacted sediments predominated across the whole profile at these two sites.

At Tuakau, the river was narrower and had a more uniform cross-section (Fig. 3). The right channel was always the deepest and normally had a compacted substrate. Some variation in bottom profile occurred in the middle and left channel where the substrate was soft and mobile. The water depth at Tuakau was usually more than 3 m and sometimes reached 5 m.

4.2 Net Efficiency

The volume of water sampled varied with location and season (Table 1). These differences were caused by seasonal changes in the abundance of planktonic diatoms in the river (Davis and Simons 1984). Filtering performance of the nets became progressively worse downstream with increasing diatom biomass. The seasonal pattern was similar at all three sites, with poorest filtering efficiency from March to May, and in October/November.

4.3 Composition of the Catch

The species composition of the larval catches was similar at all three sites (Table 2), but the absolute number of each taxa caught varied between sites due to differences in both sampling effort and abundance.

The proportion of the larvae in the catch increased downstream as a result of increased recruitment, and a decrease in the number of eggs and post-larvae caught.

Smelt, bully and cyprinid larvae (in decreasing order of abundance) were common at all three sites. Larvae of kokopu/koaro were rare at Huntly and were not recorded from Clune Road, but 51 kokopu/koaro larvae were caught at Tuakau. Post-larval bully densities decreased downstream. Post-larval smelt densities were lower at the downstream sites, while post-larval cyprinids were rarely caught at any site.

4.4 Diel Patterns of Distribution

4.4.1 Eggs

Egg numbers in the drift either showed no day/night differences, or were collected in such low numbers that diel distribution patterns were considered unreliable (Table 3).

4.4.2 Larvae

Smelt

At all three sites, larval smelt were caught predominantly in darkness (Table 3, Fig. 4). At Huntly, the catch peaked at 8 p.m. and subsequently declined through the night. The catches at Clune Road peaked at midnight. At Tuakau catches were uniformly high throughout the night. Lowest catches were at midday at all three sites.

In the April 1987 diurnal sampling at Huntly, larval smelt densities were uniformly low for the three hours before dusk, and then increased markedly half an hour after sunset. Densities peaked one hour after sunset, at a level approximately ten times greater than daylight densities and then steadily declined, reaching a density only double the daylight densities by midnight (Fig. 5).

A similar diurnal pattern of larval smelt densities was exhibited at Tuakau from dusk to midnight (Fig. 5). After midnight densities continued to decrease but rose to a secondary peak at 4 a.m., before reaching low daytime levels at dawn.

Bullies

Most larval bullies were caught during darkness. At Huntly, peak catches occurred at 8 p.m., while densities at the downstream sites were high throughout the night. Low catches occurred throughout daylight hours with no distinct minima at any site (Table 3, Fig. 6).

In the April 1987 diurnal sampling at Huntly, larval bully densities increased after dusk. Densities then decreased until midnight, except for a secondary peak at 10 p.m. (Fig. 7). Only seven larvae were caught during the 12 hour diurnal sampling at Tuakau in May 1987, and consequently no diel pattern was discernible.

Cyprinids

Most larval cyprinids were caught at night. Peak catches occurred at midnight at all three sites. Lowest catches were recorded at either midday or 4 p.m. at Huntly, at 4 p.m. at Clune Road, but were uniformly low throughout the day at Tuakau (Table 3).

Kokopu/koaro

At Huntly and Tuakau, most kokopu/koaro larvae were caught between midday and 8 p.m.. None were caught at Clune Road (Table 4).

4.4.3 Post-Larvae

Post-larval smelt and bullies were caught predominantly at night (Table 3). Peak catches occurred at midnight, except for bullies which peaked at 4 a.m. at Clune Road.

4.5 Spatial Distributions

4.5.1 Larvae

Smelt

Smelt larvae showed distinct distribution patterns within the river at all three sites (Table 5). High concentrations occurred near the bottom in mid-river and in the right channel at Huntly and Tuakau, but at the surface in mid-river at Clune Road. Generally, lowest densities were found in the channels.

Densities of larvae on the left edge were not significantly different from those recorded in the adjacent channel at either Clune Road or Tuakau. At Huntly, densities in the left edge were higher than those recorded in both the left channel surface and the left channel bottom. At all three sites, densities in the bottom right channel were greater than those of the right edge.

Horizontal distribution patterns were evident at the river surface at all three sites, with the densities in mid-river exceeding those of the channels. At Huntly and Tuakau the right channel surface densities were greater than those of the left channel surface.

In the bottom water at Huntly, densities were greater in mid-river than in the channels, and the right channel densities exceeded those of the left. No difference was found at Clune Road, while at Tuakau, the left channel had significantly lower densities than either the middle of the river or the right channel.

Vertical stratification was evident in the river middle at Huntly, and in the river middle and right channel at Tuakau, with highest densities on the river bottom.

Bullies

Bully larvae showed marked in-river distribution patterns at Huntly and Tuakau, but were irregularly distributed at Clune Road (Table 6).

At both Huntly and Tuakau, larval densities were significantly higher at the edges of the river than in the adjacent channel, except that the right channel bottom was not significantly different from the right edge. No differences were observed between the right and left edges of the river at any of the sites.

At the river surface there were higher densities of larvae in mid-river and the right channel than in the left channel at Huntly. At Clune Road, mid-river surface densities exceeded those in the right channel but not the left. There were no significant horizontal distribution patterns on the river surface at Tuakau.

Horizontal distribution patterns were not evident in the bottom waters at any of the sites.

Vertical stratification was exhibited in at least one zone at each site with higher densities always found at the bottom of the river. This pattern was exhibited in the left channel and mid-river at Huntly, the right channel at Clune Road, and in both channels at Tuakau.

Cyprinids

At Huntly, more larvae were found at the edges of the river than in the channels, except that the right channel was not significantly different from the right edge. At the downstream sites no such distribution patterns were discerned (Table 7). At Huntly and Tuakau, the left edge had higher densities than the right edge.

In the surface waters at Tuakau, more cyprinid larvae were found in both the river middle and left channel than the right channel. There were no significant differences in the distribution patterns in the surface waters at Huntly or Clune Road. In the bottom waters at Huntly, larval densities were significantly higher in the right channel than the left one, but no significant pattern emerged in the bottom waters at Clune Road or Tuakau.

Vertical stratification was only exhibited at Huntly, where more cyprinid larvae were found at the bottom of the right channel than at the surface of the channel.

Kokopu/koaro

Few kokopu/koaro larvae were caught, hence statistical comparison of distributions was not considered appropriate. The kokopu/koaro larvae did, however, appear to be well distributed in the river both between zones and with depth. The margins were the only zones in which they were rarely caught (Table 8).

4.5.2 Post-Larvae

Smelt

Post-larval smelt were caught in all zones at all three sites (Table 9). At Huntly, post-larval smelt were equally distributed between the left and right channels. At Tuakau and Clune Road, more post-larvae were caught in the left channel. Few post-larval smelt were caught in the mid-river at Clune Road, and moderate numbers were caught at Tuakau and Huntly. Few post-larval smelt were collected at the edges of the river.

Bullies

Like post-larval smelt, post-larval bullies were caught in all zones at all three sites (Table 10). The channels were the most important zones for post-larval bullies, but the highest catch was registered on the left edge at Huntly near the outlet of Waahi Stream. More were caught in the left channel than the right channel at Huntly and Clune Road, while catches were equally distributed at Tuakau. Few post-larvae were found in the mid-river at the downriver sites.

4.6 Seasonal Distributions

4.6.1 Larvae

Smelt

Seasonal distribution patterns of smelt larvae were similar at all three sites (Fig. 8). The main migration began in March and peaked in April at Huntly and Tuakau, and in June at Clune Road. This autumn/winter migration ceased at the end of June at Huntly. At the two downstream sites, the migration continued at a much reduced rate from June to October. A secondary spring migration peak occurred in November 1985 and December 1986 at Huntly, but was not recorded at Clune Road and was barely discernible at Tuakau. Lowest densities occurred throughout the summer from late December to February at all sites.

Bullies

In 1986 there was a spring peak recorded at all three sites. A mid-autumn peak was recorded at Tuakau and Huntly, and to a much lesser extent at Clune Road. The lower result at Clune Road may be due to the mid-river bottom waters not being sampled during this period. A smaller peak was observed in early winter at all three sites (Fig. 9).

At Huntly, the November 1985 spring peak was the largest. At Clune Road the spring migration peak of October 1986 was the largest. At Tuakau the largest migration was recorded in April 1986. Lowest seasonal larval densities were recorded in January and February at all three sites.

Cyprinids

Cyprinid larvae showed a similar seasonal pattern of densities at all three sites (Fig. 10). In both 1985 and 1986, the major migratory peak occurred in spring. Larval densities were low throughout the summer. A minor peak occurred in autumn 1986 at all three sites before larval drift ceased for the winter.

Kokopu/koaro

During the autumn/winter months, kokopu/koaro larvae were caught on three occasions at Huntly, and on two occasions at Tuakau. The first catches were made in May, and the subsequent occurrences were in July and August (Table 8).

4.6.2 Post-Larvae

Smelt

At all three sites, peak densities of post-larval smelt were recorded in November or early December. Catches were sporadic throughout the summer and autumn, with a discernible autumn peak in March at both Huntly and Tuakau. Few post-larval smelt were caught from May to early November 1986 (Fig. 11).

Bullies

Peak densities of post-larval bullies occurred in late October 1986 at Clune Road, and early December 1986 at Huntly and Tuakau, and in December 1985 at Huntly. There was a second peak of abundance in January at Tuakau, and in March at both Huntly and Tuakau. Lowest abundance was in spring (September/October) (Fig. 12).

4.7 Total Population Sizes

4.7.1. Larvae

Smelt

During the peak of the migration, an estimated total of 18, 38 and 86 million smelt larvae per day passed the three sites respectively. Peak migration occurred in June at Huntly, and in April at Clune Road and Tuakau (Table 11).

The total annual larval smelt migration increased downriver. The estimated number of smelt larvae doubled between Huntly and Clune Road from 1241 to 2625 million, and again between Clune Road and Tuakau (2624 to 5553 million) (Table 12).

At all sites, the river middle carried over 50% of the migration. Of the remainder, the majority were found on the right side of the river (Table 12).

Bullies

The abundance of bully larvae also increased downstream. The number of larvae passing through the three sites peaked in spring at 1.4, 5.3 and 6.1 million larvae per day respectively, and at 1.8, 1.1 and 2.7 million larvae per day in winter (Table 11). At Tuakau the highest daily migration recorded was 7.8 million bully larvae per day in April 1986.

The total annual larval bully migration increased downstream from an estimated 209 million larvae per year at Huntly to 890 million larvae per year at Tuakau (Table 12).

At Huntly and Tuakau, the middle of the river was the most important migration zone for bully larvae (52 and 42% respectively), while at Clune Road, the left zone carried the most larvae (55%) (Table 12).

Cyprinid

At the peak of the cyprinid production in October, peak daily migrations varied from 1.3 million larvae per day at Huntly to 23.9 million and 4.8 million per day at Clune Road and Tuakau respectively (Table 11).

The annual larval drift did not increase steadily downstream. It was estimated that 73 million larvae passed Huntly in 1986, 848 million at Clune Road and 427 million at Tuakau (Table 12).

The distribution of cyprinid larvae varied between sites. The larvae were evenly distributed at Huntly, with the river middle carrying the greatest proportion (46%) of cyprinid larvae. At Clune Road, 61% moved in the left channel and at Tuakau, 56% moved in the right channel.

Other groups.

Total daily and annual migration sizes were not calculated for the kokopu/koaro larvae and post-larval groups as catches were too low to allow accurate estimations. Total population sizes of these groups would be insignificant compared to the three larval groups discussed above.

4.8 Tributary Distributions

Catches of larvae from the tributaries in autumn 1986 were low in comparison to numbers caught in the mainstem (Table 13). These low catches were due in part to low water flows when the samples were taken. Smelt larvae were present in the mainstem of the Waikato River at Hamilton and Tuakau, but none were caught in any of the tributaries. Bully larvae were caught in three of the tributaries (Waipa, Mangawara, Whangape). No other larval groups were caught from the tributaries.

In the 1987 samples, catches varied greatly between the main river and the tributaries (Table 14). Smelt larvae were frequently caught in moderate densities at both mainstem sampling sites, but only one smelt larvae was caught from the tributaries. Bully larvae were caught in both the mainstem and the two tributaries, but were several times more abundant in the Waipa River and over 50 times more abundant in Waahi Stream than in the mainstem. Cyprinid larvae were caught in low densities in the main river while densities in the Waipa River and Waahi Stream were generally much higher.

5. DISCUSSION

5.1 Composition of the Catch

The species composition of the larval fish from the lower Waikato River was the same at Huntly, Clune Road and Tuakau. The fish community that reproduces in the lower river must therefore be homogeneous throughout the channelised reach sampled. As there is little information on the fish community of the lower 30 km of the river, it is not possible to determine the relative importance of the section studied to the total larval production.
Few fish eggs were collected from the downstream sites, which could indicate that few fish spawn there. However, it is more likely that the decline in egg numbers downstream is simply a reflection of the distance of the sampling sites from localised spawning grounds. Differences in substrate stability between sites may also have influenced egg densities.

Few post-larvae were caught in the reach sampled. This is likely to be because most riverine smelt larvae, and to a lesser extent bullies, move directly to the sea. Post-larvae utilizing the few existing rearing areas in the river, would only enter the areas sampled when caught by water velocities above their swimming speed.

5.2 Diel Distribution

5.2.1 Eggs

Neither smelt nor cyprinid eggs showed any significant diel distribution pattern. Diel distributions could only be expected if eggs were a buoyant dispersal stage and spawning activity was synchronised. The only species likely to exhibit this pattern in the Waikato River is the grass carp (*Ctenopharyngodon idella*), a recent introduction to the river fauna. However, Rowe and Schipper (1985) considered natural spawning of grass carp unlikely in New Zealand.

5.2.2 Larvae

Smelt

Most of the larval smelt migration occurred at night, but there were site specific differences in the timing of the migration peaks. The low catches during the day have been attributed to larvae resting on the substrate in mid-river during daylight (Meredith *et al.* 1989). If this is correct then the differences in migration pattern between sites could be caused by localised spawning, and variations in the intensity of hatching/emergence along the length of the river.

At Huntly, the peak of the migration occurred after dusk, suggesting a synchronised emergence from spawning grounds close to the sampling site. A change to peak catches at midnight at Clune Road may indicate a greater importance of recruitment from upstream than from localised hatching. By Tuakau the catch was uniform throughout the night, possibly because of a combination of upstream recruitment and localised spawning. Confirmation of this theory could be obtained by determining diel changes in the size (age) of larvae at downstream sites.

If light plays an integral role in the activity pattern of larval smelt, variations in light intensity during the night would also explain localised variations in catch. The increasing catch rate recorded at Tuakau at 4 a.m. on 4 May 1987, may have been caused by a variation in light intensity as a result of changes in cloud cover and moonlight. Further studies are needed to determine the effect of light on smelt behaviour and larval drift.

Bullies

Larval bully migrations were similar to larval smelt patterns, with migrations occurring primarily at night at all three sites. Bullies, therefore, also seem to regulate their downstream migration. A peak migration at dusk at Huntly, and uniform night time migrations at both Clune Road and Tuakau indicate a change from local hatching phenomena to a continuous recruitment pattern at downstream sites.

Cyprinids

Larval cyprinids also drifted at night. There was a midnight peak in numbers at both Huntly and Clune Road. These peaks may reflect drift from localised spawning/nursery sites upstream. The night time catches at Tuakau were uniform, indicating constant recruitment throughout the night.

Kokopu/koaro

Too few kokopu/koaro larvae were caught to determine any significant diel trends. As kokopu/koaro are thought to hatch in response to floods (Mitchell and Penlington 1982), and flood conditions allow little scope for resisting downstream displacement, the arrival of larvae within the mainstem of the river is likely to be independent of light cycle.

5.2.3 Post-Larvae

Most post-larval smelt and bullies were caught at night. This could be related to a loss of visual orientation at night (smelt), and increased activity at night (bullies). In addition, visual net avoidance is greatly reduced at night. A combination of these mechanisms is probably responsible for similar catch patterns occurring at all sites.

5.3 Spatial Trends

The spatial distribution of ichthyoplankton was not the same at all sites, and patterns were often difficult to discern at the downstream sites. This was, in part, because fewer samples were taken at the downstream sites. However, the instability of the riverbed and extensive river retraining works at the downstream sites may also have reduced spatial patterns. This was particularly so at Clune Road. Despite difficulties in determining specific spatial distribution patterns, some general conclusions are possible.

5.3.1 Larvae

Smelt

At all three sites, the mid-river was more important for smelt larvae than the channels or edges. This could indicate an active selection of the mid-river as a migration corridor. In addition, more larvae were caught at the bottom than the surface, and more eggs were caught in mid-river than in the channels or edges, which suggests more spawning sites may be available in the middle of the river.

In general more smelt larvae were caught in the right channel than the left. The left channel carries Waipa River water, Horotiu freezing works' effluent and Huntly Power Station's thermal effluent, which may affect the habitat choice of fish. Alternatively more sandbar spawning sites may have been available in the proximity of the right channel in 1986. However, subsequent work has shown that in some years, the left channel can also carry large numbers of eggs and larvae (Empson *et al.* in prep.). The cause of the density differences recorded therefore remains unclear.

Bullies

Unlike smelt, bully larvae were concentrated at the edges of the river at both Huntly and Tuakau. Significant numbers are found in mid-river, and more are found at the river bottom than the surface, but there is no well defined migration corridor.

The river edges are probably important spawning and rearing areas for bullies. Moreover, larvae from small tributaries are carried along the margins.

Cyprinids

There were substantial differences in the distribution of cyprinid larvae between sites. At Huntly, most larvae were caught in the edges but there was no such bias for the edges downstream. Cyprinids use the edges of the river for feeding and spawning (Boubee *et al*

1986). At Huntly, the high numbers may also reflect migration from Waahi Stream.

Kokopu/koaro

The few kokopu/koaro larvae caught were well distributed throughout the river. The margin was the only zone in which they were seldom caught. Kokopu/koaro complete their life-cycle at sea, and larvae may not seek refuge in the margins.

5.3.2 Post-Larvae

Smelt

Post-larval smelt were well distributed in the river at all three sites, but fewer were caught on the edges. They had similar morphological features to Lake Karapiro lacustrine stock (Ward *et al* 1989). These post-larvae may either be migrating directly downstream, or actively migrating to and from the mid-river regions much as adult smelt do (pers. obs.).

Bullies

Post-larval bullies were abundant in the edges at all sites, although they were also well distributed across the river profile. The increased numbers on the left side of the river at both Huntly and Clune Road could indicate that fish are flushed from the shallow Waikato lakes. The outlets of Lake Waahi and Lake Whangape enter the left bank of the Waikato River just upstream of the two sites.

5.4 Seasonal Trends

5.4.1 Larvae

Smelt

The smelt migration began in March and ended in July at all three sites. Spawning is likely to be controlled by day length and/or temperature. Although river temperatures vary downriver, and are affected by thermal discharges, the monthly sampling undertaken was not frequent enough to detect if autumn spawning was delayed downstream.

At all three sites, migration peaks in April and June were visible. This variation in the larval drift was probably caused by winter floods which would have disturbed spawning beds, While larval production ceased abruptly at Huntly at the end of June, a small but significant amount of production continued throughout the winter at the downstream sites. At Huntly, low water temperatures could have interrupted spawning until spring. Further downstream, solar radiation and the discharge from Huntly Thermal Power Station may have heated the river sufficiently to allow continuous spawning through the winter months. Studies of the temperature regime at downstream sites are required to confirm this.

There was no significant production of smelt larvae at any site during summer (December/February). It is possible that high summer temperatures limit spawning. Lake populations usually spawn in summer (Jolly 1967; Stephens 1984; Northcote and Ward 1985) possibly because peak temperatures are lower in the lakes than in the lower Waikato River.

An alternative explanation for the absence of summer spawning is that after the spring spawning, few smelt of reproductive age or condition remain in the river. Fish that are present in the river in summer are predominantly juvenile immigrants from the spring whitebait run (Stancliff *et al* 1988a, b), which will be unable to mature before the autumn.

Bullies

At all three sites, there was a migration of bully larvae in spring and in winter. A mid-autumn peak was recorded at Huntly and Tuakau, and to a much lesser extent at Clune Road. Bullies may live for two or more years, and produce at least three batches of oocytes (Stephens 1982). Sequential spawning of the different age groups may explain the multiple migrations of bully larvae.

In addition, there are also both diadromous and non-migratory bullies, lake and river populations, and both red-finned and common bullies in the catchment. Differential spawning of the different taxa could account for the separate peaks.

The onset of autumn spawning and timing of the respective peaks did not vary appreciably between sites. This suggests that in the Waikato River there is a single population responding to a well defined set of cues. Spawning occurred in autumn once river temperatures declined below 22°C and did not begin in the spring until river temperatures reached 12°C. Temperature, therefore, has some control over spawning, but other factors such as day length may also have some influence.

Few bully larvae were produced in summer. This may be due to the recovery period following the spring spawnings, but high summer temperatures could also reduce spawning viability.

Cyprinids

Spring spawning of cyprinids commenced in late September or early October, as temperatures reached about 16 °C. High summer temperatures did not prevent spawning but larval production was only moderate until a secondary peak occurred in autumn, when temperatures had dropped to 17 °C. Thus spawning throughout the river follows temperature patterns with spawning optima of 16-17 °C. Low winter temperatures precluded reproduction for 5 months of the year at all three sites.

Kokopu/koaro

As the catch of kokopu/koaro larvae could represent up to four species (koaro, banded kokopu, giant kokopu and short-jawed kokopu), the spread of catches from May to August may represent spawning of different species. Banded kokopu are known to spawn on floods from late April to June (Hopkins 1979), and are the most abundant of the kokopu species in the Waikato (Hanchet, MAF Fisheries, pers. comm.). Short-jawed kokopu are rare and are suspected to be the earliest spawning kokopu species (Eldon, MAF Fisheries, pers. comm.). Thus these two species are most likely to be represented in the May catches. Later catches (July /August) could be giant kokopu, koaro, or late spawnings of banded kokopu.

While the catch at Huntly closely followed floods, Tuakau catches were recorded more than a week after extensive flooding. Flood control measures in the Waikato involve holding flood water in the lowland lakes until the river water levels have receded. A delay to the downstream migration could thus be caused by the impounding.

The low number of kokopu/koaro larvae caught may indicate that the adults are relatively rare in the catchment. However sampling dates were not synchronised with floods, which is the period in which highest catches of kokopu/koaro larvae would be expected.

5.4.2 Post-Larvae

Smelt

As the post-larval smelt collected were morphologically similar to upstream hydro reservoir stocks, their seasonal distribution can be related to reproductive patterns of lacustrine fish rather than the riverine stocks. The first catches were made in November and the last in May. This timing corresponds well with the known lake spawning period of October to May (Stephens 1984, Ward *et al* 1989).

At the downstream sites catches were first made in early December. This suggests a slow rather than direct downstream drift. Thus, the post-larval smelt represent an addition to the resident fish population rather than a part of the concerted downstream migration.

Bullies

Post-larval bullies also represent a movement or dispersal of a resident component of the Waikato fish fauna. Highest catches were made just after the period of maximum larval bully production. However, the peaks were also related to floods when, presumably, bullies were flushed out of tributaries and edges by rising river levels. The year round catches indicate that production from riverine and lacustrine populations continues all year.

5.5 Total Population Sizes

By dividing the net annual production per reach by the length of the reach, an estimate of the annual larval production per kilometre of river-bed can be made (Table 15).

5.5.1 Larvae

Smelt

Peak production of larval smelt occurred at the downstream sites. This supports McDowall's (1978) suggestion that the lower reaches of rivers are the most important spawning areas for smelt. Nevertheless the contribution from the upper reaches is significant. In the Waikato, the reach above Huntly is believed to be important as a spawning area for smelt distributed in the upper catchment (Meredith *et al* 1989). The middle reaches may support a moderate amount of spawning from locally resident fish, with little enhancement from fish migrating into the area to spawn.

The total annual production of smelt larvae at Tuakau was estimated at 5.5 billion larvae per year. As the lower reaches supported the greatest production, and a further 30 km of the estuary were unsurveyed, total production for the river may have been as high as 9 billion larvae in 1986.

Potential returns to the whitebait fishery (assuming a 1% return) are approximately 72 tonnes. This is considerably more than the 4 tonnes estimated to have been harvested in 1986 (Stancliff *et al.* 1988a, b). Either catches represent only a small component of the returns with the bulk of the juvenile fish recolonising the catchment, or natural mortality may greatly exceed even 99 %.

Bullies

Like smelt, bully larvae showed extensive downstream recruitment. It was estimated that some 889 million larvae passed through Tuakau annually. The level of production from the estuarine reaches is unknown and cannot be readily predicted.

The highest production per kilometre of river-bed was found in the Tuakau reach (26.3 million/km), followed by Huntly (13.9 million/km) and Clune Road (7.4 million/km) (Table 15). These larvae originate not only from the mainstem but also from tributaries like the Waipa and Whangamarino rivers.

Cyprinid

Recruitment of cyprinid larvae was not uniform throughout the length of the river. Cyprinid adults are most abundant in the river margins and in slow flowing tributaries. The location of these habitats is expected to have affected larval catch.

Other groups

None of the other larval or post-larval groups were captured in sufficient quantities to enable accurate estimates of annual drift populations.

5.6 Tributary Distributions

High densities of bully and cyprinid larvae can flow out of small tributaries such as Waahi Stream. These larvae originate not only from the streams themselves but also from the lakes and swamps they drain. During freshes, large numbers of larvae are expected to be flushed from these areas.

Although smelt larvae were present throughout the river only one specimen was collected from the Waipa River. It thus appears that riverine smelt do not spawn in the tributaries sampled.

A notable feature of the Waipa River was the presence of vast numbers of zoea of the freshwater shrimp *Paratya curvirostris* in every sample from July until the end of the sampling in December. Freshwater shrimp are one of the most important food items of fishes in the river (Boubee *et al* 1986). The zoea drift to the estuary or sea to develop (Chapman and Lewis 1976).

5.7 Implications for Thermal Power Stations' Siting and Operations

The composition of the ichthyoplankton migration is the same from Huntly to Tuakau. Siting a power plant anywhere along this stretch of the river will affect the ichthyoplankton community. However, no group is especially vulnerable in isolated spawning zones or specialised habitat areas so as to need special protective consideration.
Diel and spatial patterns remain relatively unchanged downriver. Recommendations made to minimise impacts on the ichthyoplankton community will apply to all sites.

As ichthyoplankton densities were the lowest in the river channels,it is recommended that the river channels be utilised for all water acquisition and discharge purposes.

Seasonal patterns did not change greatly downriver. Thermal power station impacts on ichthyoplankton are greater during low river flows in autumn/early winter (March to June). Where possible, maintenance and outage should be scheduled at these times.

Kokopu/koaro were only captured in the winter months and are most common during floods. Because of low water temperature and the decreased chance of entrainment during winter floods, the impact on these rare native species is considered to be minimal.

Cyprinids spawn in summer. Thermal discharges will extend cyprinid spawning but are unlikely to adversely affect the population as McCrimmon (1968) suggests cyprinids can spawn at up to 32 °C.

Thermal discharges may extend smelt spawning seasons into the winter. While this does not represent any immediately identifiable hazard to the smelt populations, the long term effect of altering spawning timing on future population stability and whitebait production should be considered. Any further changes to spawning season may necessitate compensation measures.

While recruitment occurs throughout the river the most productive regions are below Clune Road. Entrainment impacts would be reduced if developments were sited as far upstream as possible.

Equally important is the siting of power plants in relation to tributaries. Both Huntly and Meremere Power Stations are not optimally sited as Huntly entrains all water originating from Waahi Stream, and Meremere used to discharge effluent along the bank across the mouth of the Whangamarino River. Intake structures of future developments should be well away from tributary mouths, and thermal effluent should be well mixed before reaching tributaries.

6. RECOMMENDATIONS

1. Ichthyoplankton were abundant throughout the length of the lower Waikato River. Therefore, thermal power developments at any point on the lower Waikato River have the potential to affect significant numbers of larval fish.

   RECOMMENDATION: Thermal power developments on the lower Waikato River should account for and minimise the impacts on ichthyoplankton.

2. Larval production increased fourfold between Huntly and Tuakau, with the greatest production in the Clune Road to Tuakau reach.

   RECOMMENDATION: Developments should be sited as far upstream as possible to minimise the proportion of larval production that is affected by entrainment. Developments should not be considered at the lower end of the river near Tuakau.

3. Spatial, diel and seasonal distribution patterns did not change appreciably downstream.

   RECOMMENDATION: Intake and outfall design and siting recommendations should be the same at any point on the river. Recommendations made for Huntly (Meredith *et al.* 1987) should be implemented at any future development.

4. Thermal effects of Huntly Power Station's outfall may have already changed the winter spawning habits of smelt in the lower river. Additional heat loading could further alter smelt spawning habits.

   RECOMMENDATION: The consequences of increased heat load to the river, or cumulative heat loads from multiple developments, on the biology of resident fish species should be considered for any future developments.

5. Tributary inflows carried considerable densities of ichthyoplankton, particularly bully

and cyprinid larvae.

RECOMMENDATION: Power stations, and their intake and outfall structures, should not be sited in the proximity of tributaries.

6. Smelt spawning sites appeared to be localised. It is important that thermal discharges do not impact on these spawning sites.

   RECOMMENDATION: Spawning sites should be located and thermal power station intake and outfall structures positioned so as to minimise impacts on these sites.

7. There is no information on ichthyoplankton production in the lower 30 km of the Waikato River and consequently it was not possible to determine the relative importance of the Huntly to Tuakau reach to the total larval production of the river.

   RECOMMENDATION: Studies should be undertaken to compare the ichthyoplankton drift at the river mouth to that at Tuakau.

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Table 1. Water volumes sampled and filtering efficiencies of plankton nets set in the Waikato River, October 1985 to December 1986. (Filtering efficiency of nets calculated by comparing water flows filtered with water flows adjacent to the net.)

	Huntly	Clune Road	Tuakau
Volume (m^3)			
Total	98106	46349	36934
Mean (per trip)	3563	3565	2462
Min.	406	847	159
Max.	7571	7459	6696
Efficiency			
Mean	48.5	46.9	34.1
Min.	6.2 (November)	9.8 (October)	3.1 (March)
Max.	83.8 (August)	81.0 (September)	77.4 (August)

Table 2. Composition of the ichthyoplankton catch in the Waikato River, 1985-1986. (Number caught and % of catch at each site.) Proportion of the various life stages captured at three sites.

	Site	Eggs		Larvae		Post larvae		Total	
		n	%	n	%	n	%	n	%
Smelt	H	103	31.6	3663	66.7	208	48.1	3974	63.6
	C	44	34.4	3192	72.0	38	26.4	3274	69.6
	T	19	52.8	4452	78.8	77	63.1	4548	78.2
Bullies	H	0	0.0	1170	21.3	215	49.6	1385	22.2
	C	0	0.0	691	15.6	105	72.9	796	16.9
	T	0	0.0	994	17.6	44	36.1	1038	17.9
Cyprinids	H	223	68.4	651	11.9	10	2.3	884	14.2
	C	84	65.6	551	12.4	1	0.7	636	13.5
	T	17	47.2	154	2.7	1	0.8	172	3.0
Galaxiids	H	0	0.0	10	0.1	0	0.0	10	0.0
	C	0	0.0	0	0.0	0	0.0	0	---
	T	0	0.0	51	0.9	0	0.0	51	0.9
All species	H	326	5.2	5494	87.9	433	6.9	6253	100.0
	C	128	2.7	4434	94.2	144	3.1	4706	100.0
	T	36	0.6	5651	97.3	122	2.1	5809	100.0

H = Huntly; C = Clune Road; T = Tuakau Bridge.

Table 3. Diel distribution (%) of the total ichthyoplankton catch from the Waikato River, 1985-86.

	Site	n	1200	1600	2000	0000	0400	0800	Day	Night
			% of catch							
EGGS										
Smelt	H	103	14.6	12.6	24.3	17.5	12.6	18.4	45.6	55.4
	C	44	13.7	31.8	6.8	22.7	9.1	15.9	61.4	38.6
	T	19	10.5	36.9	5.3	26.3	10.5	10.5	57.9	42.1
Cyprinids	H	223	14.3	8.1	7.6	11.6	30.0	28.3	50.7	49.3
	C	84	23.8	14.3	7.1	8.3	28.6	17.9	56.0	44.0
	T	17	29.4	47.0	0.0	11.8	5.9	5.9	82.3	17.7
LARVAE										
Smelt	H	3663	6.6	14.7	33.9	24.8	13.1	6.9	28.2	71.8
	C	3192	7.8	10.4	22.0	32.3	17.4	10.1	28.3	71.7
	T	4452	9.3	10.8	22.2	23.0	21.9	12.8	32.9	67.1
Bullies	H	1170	11.7	12.8	30.0	15.7	14.7	15.2	39.7	60.3
	C	691	8.3	12.0	25.5	26.7	19.3	8.2	28.5	71.5
	T	994	9.5	8.0	22.8	27.3	23.1	9.3	26.8	73.2
Cyprinids	H	651	4.5	3.7	9.5	38.2	28.7	15.4	23.6	76.4
	C	551	13.9	6.9	14.5	30.3	20.6	13.8	34.6	65.4
	T	154	7.1	8.5	23.4	29.9	25.3	5.8	21.4	78.6
POST-LARVAE										
Smelt	H	208	9.2	10.8	16.4	34.9	19.5	9.2	29.2	70.8
	C	38	18.7	9.4	18.8	28.1	9.4	15.6	43.7	56.3
	T	77	5.2	15.6	6.5	42.8	15.6	14.3	35.1	64.9
Bullies	H	215	10.7	8.4	14.4	31.6	20.5	14.4	33.5	66.5
	C	105	6.1	2.0	12.1	20.2	44.4	15.2	23.3	76.7
	T	44	11.4	9.1	15.9	31.8	18.2	13.6	34.1	65.9

H = Huntly; C = Clune Road; T = Tuakau Bridge.
n = Total number captured.

Table 4. Diel distribution (n) of the kokopu/koaro larval catch for the Waikato River, 1985-86.

Date	1200	1600	2000	0000	0400	0800
Huntly.						
22.05.86	1	1	0	0	0	0
14.07.86	0	3	2	0	1	0
25.08.86	0	1	1	0	0	0
Tuakau Bridge.						
28.05.86	11	4	1	1	0	3
08.07.86	4	6	14	3	2	2
TOTAL	16	15	18	4	3	5

Table 5. Comparison (one-tailed Wilcoxon Sign Rank Test) of densities of smelt larvae at different locations across transects of the Waikato River at Huntly, Clune Road and Tuakau, 1985-86.

	Huntly		Clune Rd		Tuakau	
Comparison	Sig.	Greater Of Pair	Sig.	Greater Of Pair	Sig.	Greater Of Pair
LE x Mean	NS		***	Mean	NS	
LS x Mean	***	Mean	NS		***	Mean
LB x Mean	***	Mean	NS		*	Mean
MS x Mean	NS		*	MS	NS	
MB x Mean	*	MB	NS		***	MB
RS x Mean	NS		*	Mean	**	Mean
RB x Mean	*	RB	NS		***	RB
RE x Mean	NS		NS		**	Mean
LE x RE	NS		NS		NS	
LE x LS	*	LE	NS		NS	
LE x LB	***	LE	NS		NS	
RE x RS	NS		NS		NS	
RE x RB	*	RB	*	RB	***	RB
LS x MS	*	MS	*	MS	*	MS
LS x RS	*	RS	NS		*	RS
MS x RS	NS		*	MS	*	MS
LB x MB	*	MB	NS		*	MB
LB x RB	***	RB	NS		*	RB
MB x RB	*	MB	NS		NS	
LS x LB	NS		NS		NS	
MS x MB	**	MB	NS		***	MB
RS x RB	NS		NS		***	RB

LE = left edge, LS = left channel surface, LB = left channel bottom, MS = mid-river surface, MB = mid-river near bottom, RS = right channel surface, RB = right channel near bottom, RE = right edge, Mean = mean of all river positions.
NS = not significant, * P <0.05, ** P <0.01, *** P <0.005.

Table 6. Comparison (one-tailed Wilcoxon Sign Rank Test) of densities of bully larvae at different locations across transects of the Waikato River at Huntly, Clune Road and Tuakau, 1985-86.

	Huntly		Clune Rd		Tuakau	
Comparison	Sig.	Greater Of Pair	Sig.	Greater Of Pair	Sig.	Greater Of Pair
LE x Mean	**	LE	NS		*	LE
LS x Mean	***	Mean	NS		**	Mean
LB x Mean	*	Mean	NS		NS	
MS x Mean	NS		NS		**	Mean
MB x Mean	NS		NS		NS	
RS x Mean	*	Mean	***	Mean	*	Mean
RB x Mean	NS		NS		NS	
RE x Mean	NS		NS		NS	
LE x RE	NS		NS		NS	
LE x LS	***	LE	NS		***	LE
LE x LB	***	LE	NS		*	LE
RE x RS	*	RE	NS		**	RE
RE x RB	NS		NS		NS	
LS x MS	**	MS	NS		NS	
LS x RS	*	RS	NS		NS	
MS x RS	NS		*	MS	NS	
LB x MB	NS		NS		NS	
LB x RB	NS		NS		NS	
MB x RB	NS		NS		NS	
LS x LB	*	LB	NS		*	LB
MS x MB	***	MB	NS		NS	
RS x RB	NS		*	RB	*	RB

LE = left edge, LS = left channel surface, LB = left channel bottom, MS = mid-river surface, MB = mid-river near bottom, RS = right channel surface, RB = right channel near bottom, RE = right edge, Mean = mean of all river positions.
NS = not significant, * P <0.05, ** P <0.01, *** P <0.005.

Table 7. Comparison (one-tailed Wilcoxon Sign Rank Test) of densities of cyprinid larvae at different locations across transects of the Waikato River at Huntly, Clune Road and Tuakau, 1985-86.

Sites	Huntly		Clune Rd		Tuakau	
Comparison	Sig.	Greater Of Pair	Sig.	Greater Of Pair	Sig.	Greater Of Pair
LE x Mean	**	LE	NS		NS	
LS x Mean	NS		NS		NS	
LB x Mean	*	Mean	NS		NS	
MS x Mean	NS		*	Mean	NS	
MB x Mean	NS		NS		*	Mean
RS x Mean	NS		NS		*	Mean
RB x Mean	*	RB	NS		NS	
RE x Mean	NS		NS		**	Mean
LE x RE	*	LE	NS		*	LE
LE x LS	***	LE	NS		NS	
LE x LB	***	LE	NS		NS	
RE x RS	**	RE	NS		NS	
RE x RB	NS		NS		NS	
LS x MS	NS		NS		NS	
LS x RS	NS		NS		*	LS
MS x RS	NS		NS		*	MS
LB x MB	NS		NS		NS	
LB x RB	***	RB	NS		NS	
MB x RB	NS		NS		NS	
LS x LB	NS		NS		NS	
MS x MB	NS		NS		NS	
RS x RB	**	RB	NS		NS	

LE = left edge, LS = left channel surface, LB = left channel bottom, MS = mid-river surface, MB = mid-river near bottom, RS = right channel surface, RB = right channel near bottom, RE = right edge, Mean = mean of all river positions.
NS = not significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$.

Table 8. Spatial distribution of kokopu/koaro larvae caught (n) from the Waikato River, 1985-86.

Date	LE	LS	LB	MS	MB	RS	RB	RE	Tot.
Huntly									
22.05.86	0	0	0	0	1	0	1	0	2
14.07.86	2	1	0	1	1	0	1	0	6
25.08.86	0	0	0	0	0	2	0	0	2
Tuakau									
28.05.86	0	0	4	3	5	1	6	1	20
08.07.86	0	6	2	9	3	1	10	0	31
Total	2	7	6	13	10	4	18	1	61

LE = left edge, LS = left channel surface, LB = left channel bottom, MS = mid-river surface, MB = mid-river near bottom, RS = right channel surface, RB = right channel near bottom, RE = right edge.

Table 9. Spatial distribution of the post-larval smelt catch from the Waikato River, 1985-86.

Site		LE	LS	LB	M	RS	RB	RE	Total
Huntly	n	17	47	25	32	47	34	6	208
	%	8.2	22.6	12.0	15.4	22.6	16.3	2.9	
Clune Rd	n	3	16	7	2	7	1	2	38
	%	7.9	42.1	18.4	5.3	18.4	2.6	5.3	
Tuakau	n	2	22	10	20	8	13	2	77
	%	2.6	28.6	13.0	26.0	10.4	16.8	2.6	

LE = left edge, LS = left channel surface, LB = left channel near bottom, M = mid-river, RS = right channel surface, RB = right channel near bottom, RE = right edge.

Table 10. Spatial distribution of the post-larval bully catch from the Waikato River, 1985-86.

Site		LE	LS	LB	M	RS	RB	RE	Total
Huntly	n	51	40	27	26	35	23	13	215
	%	23.7	18.6	12.6	12.1	16.3	10.7	6.0	
Clune Rd	n	19	20	29	7	17	5	8	105
	%	18.1	19.0	27.6	6.7	16.2	4.8	7.6	
Tuakau	n	8	6	7	3	2	7	11	44
	%	18.2	13.6	15.9	6.8	4.6	15.9	25.0	

LE = left edge, LS = left channel surface, LB = left channel near bottom, M = mid-river, RS = right channel surface, RB = right channel near bottom, RE = right edge.

Table 11. Estimated daily migrations of larval fish at three sites on the Waikato River, 1985-86.

Date	Smelt	Bullies	Cyprinids	Total
	(millions per day)			
Huntly				
04.12.85	0.94	0.41	0.83	2.18
16.12.85	0.07	0.08	0.35	0.51
30.12.85	0.10	0.14	0.13	0.37
09.01.86	nd	nd	nd	nd
21.01.86	0.04	0.05	0.07	0.16
04.02.86	0.08	0.04	0.16	0.28
18.02.86	0.11	0.03	0.28	0.42
04.03.86	0.21	0.12	0.08	0.40
17.03.86	6.16	0.33	0.44	6.93
01.04.86	10.81	0.65	0.00	11.46
14.04.86	16.51	1.37	0.00	17.88
29.04.86	8.11	1.10	0.00	9.21
13.05.86	10.72	0.20	0.00	10.92
22.05.86	1.98	0.01	0.00	1.99
08.06.86	18.37	1.63	0.00	20.00
19.06.86	10.76	1.82	0.00	12.58
03.07.86	1.86	0.25	0.00	2.11
14.07.86	0.78	0.20	0.00	0.98
04.08.86	0.29	0.17	0.00	0.46
25.08.86	0.23	0.57	0.00	0.81
09.09.86	0.72	1.36	0.01	2.10
23.09.86	0.41	1.20	0.00	1.61
08.10.86	0.34	0.94	0.07	1.35
22.10.86	0.12	0.56	1.33	2.00
05.11.86	0.00	0.18	0.54	0.72
19.11.86	1.02	1.10	1.21	3.41
03.12.86	2.71	0.79	0.23	3.73
Clune Road				
26.11.85	17.09	0.47	1.69	19.25
19.12.85	0.11	0.17	0.77	1.05
23.01.86	0.09	0.07	0.23	0.39
24.02.86	0.10	0.01	0.02	0.13
24.03.86	1.25	0.30	0.25	1.80
23.04.86	38.08	0.00	0.00	38.08
20.05.86	5.85	0.19	0.00	6.04
16.06.86	16.60	1.12	0.00	17.72
22.07.86	3.11	0.48	0.00	3.59
02.09.86	6.46	1.36	0.00	7.82
01.10.86	6.04	4.86	3.49	14.39
29.10.86	2.44	5.32	23.85	31.61
25.11.86	0.73	0.21	2.59	3.53
Tuakau				
12.12.85	1.39	2.24	0.71	4.34
16.01.86	0.06	0.75	0.05	0.86
10.02.86	0.46	0.41	0.59	1.05
12.03.86	9.96	1.80	0.24	12.00
08.04.86	67.65	3.90	0.45	72.00
23.04.86	86.15	7.82	0.00	93.97
05.05.86	66.93	3.78	0.00	67.71
28.05.86	7.49	0.16	0.00	7.65
25.06.86	28.90	1.71	0.00	30.61
08.07.86	4.35	0.90	0.00	5.25
17.08.86	6.17	2.71	0.00	8.88
16.09.86	6.78	3.99	0.01	10.78
14.10.86	3.95	6.08	4.80	14.83
11.11.86	0.00	0.00	3.17	3.17
09.12.86	4.38	1.36	0.37	6.11

nd = data unable to be calculated due to flood conditions

Table 12. Estimated annual migrations of larval fish at three sites and in three zones on the Waikato River, 1985-86.

Species	Site		Left	Middle	Right	Total
SMELT	Huntly	n	57.4	894.7	289.3	1241.4
		%	4.6	72.1	23.3	100.0
	Clune Rd	n	344.3	1883.2	397.2	2624.7
		%	13.1	71.7	15.2	100.0
	Tuakau	n	762.0	2940.5	1850.3	5552.8
		%	13.7	53.0	33.3	100.0
BULLY	Huntly	n	41.8	108.3	58.6	208.7
		%	20.1	51.8	28.1	100.0
	Clune Rd	n	233.8	152.2	42.5	428.5
		%	54.6	35.5	9.9	100.0
	Tuakau	n	184.7	374.5	330.4	889.6
		%	20.8	42.1	37.1	100.0
CYPRINID	Huntly	n	17.1	33.8	22.0	72.9
		%	23.4	46.4	30.2	100.0
	Clune Rd	n	518.1	245.1	84.6	847.8
		%	61.1	28.9	10.0	100.0
	Tuakau	n	61.1	128.4	237.2	426.7
		%	14.3	30.1	55.6	100.0

Table 13. Larval fish densities (No/100 m^3) in tributaries and the mainstem of the Waikato River, autumn 1986.

Tributary/Mainstem	Smelt	Bully
Waikato River, Hamilton.	3.5	0
Waipa River, Ngaruawahia.	0	10.9
Mangawara Stream	0	3.5
Waahi Stream	0	0
Whangape Stream	0	3.6
Whangamarino River	0	0
Mangatawhiri River	0	0
Waikato River, Tuakau.	26.3	0

Table 14. Larval fish densities (No/100 m³) in tributaries and the mainstem of the Waikato River, spring 1987.

Date	Huntly*	Ngaruawahia**	Waipa River	Waahi Stream
Smelt larvae				
30.07.87	23.2	33.9	0	0
14.10.87	2.8	0	0.6	0
29.10.87	1.7	12.8	0	0
17.11.87	0	0	0	0
02.12.87	0	3.6	0	0
22.12.87	1.6	0	0	0
Bully larvae				
30.07.87	5.4	2.6	0	0
14.10.87	1.9	6.1	3.6	676.5
29.10.87	8.6	16.3	76.8	502.4
17.11.87	2.9	0	4.7	833.3
02.12.87	1.6	17.9	19.7	474.0
22.12.87	0.8	0.7	8.3	248.6
Cyprinid larvae				
30.07.87	0	0	0	0
14.10.87	0.5	0	13.5	1264.7
29.10.87	4.3	3.5	14.9	62.2
17.11.87	0	8.0	61.1	92.6
02.12.87	0	0	2.8	23.1
22.12.87	0	3.5	4.2	33.9

* - Mean larval density over 6 sampling positions.
** - Larval densities in Waikato mainstem at Ngaruawahia.

Table 15. Estimated annual production (millions) of larvae in three reaches of the lower Waikato River, 1986.

Reach	Distance	Smelt		Bully	
	km	Total	No./km	Total	No./km.
Ngaruawahia to Huntly.	15	1241	82.7	208	13.9
Huntly to Clune Road.	30	1383	46.1	220.5	7.4
Clune Road to Tuakau.	17.5	2929	167.4	461.1	26.3
Ngaruawahia to Tuakau (mean)			88.8		14.2

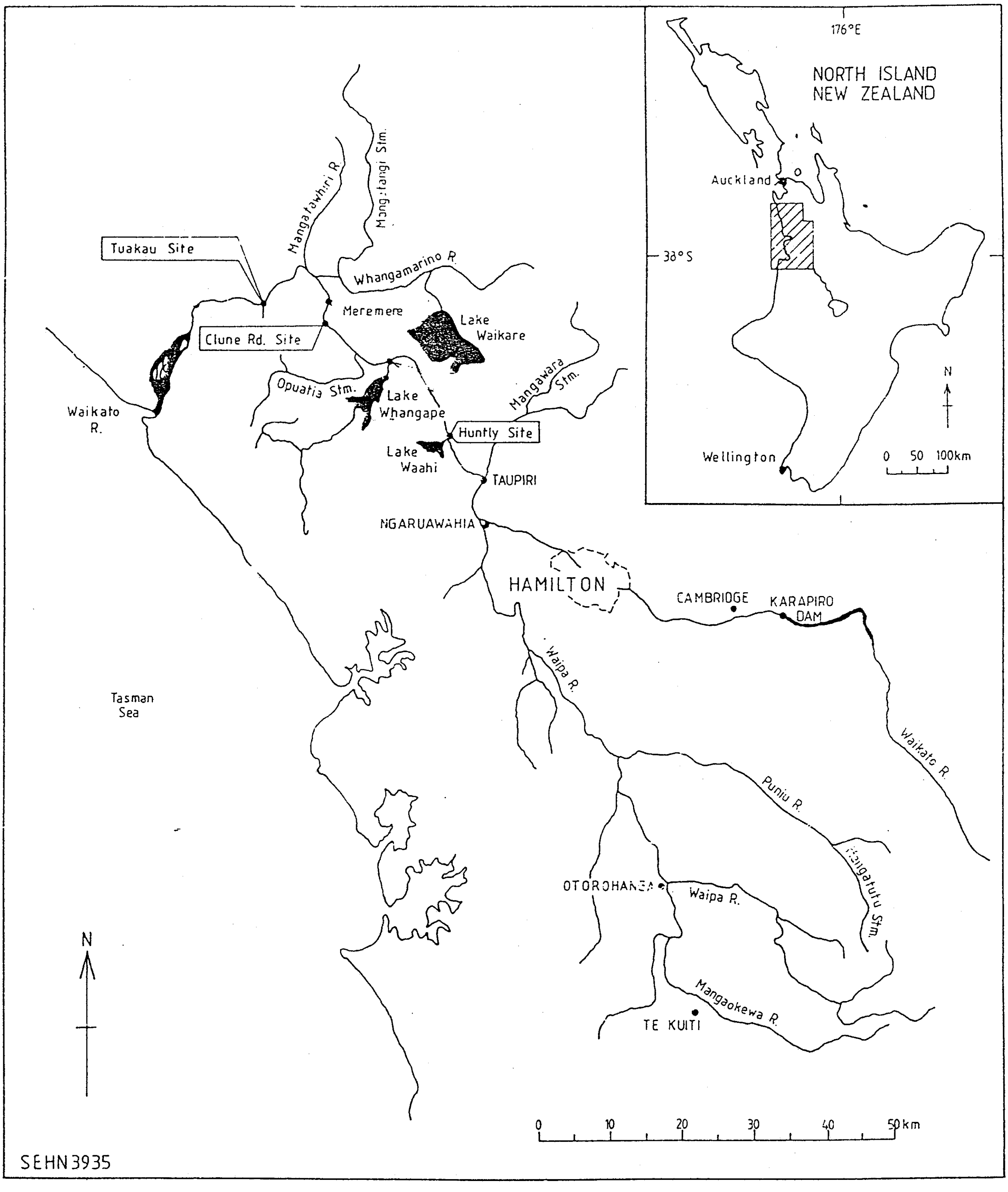

Fig. 1. Map of Waikato catchment showing sampling sites and major tributaries.

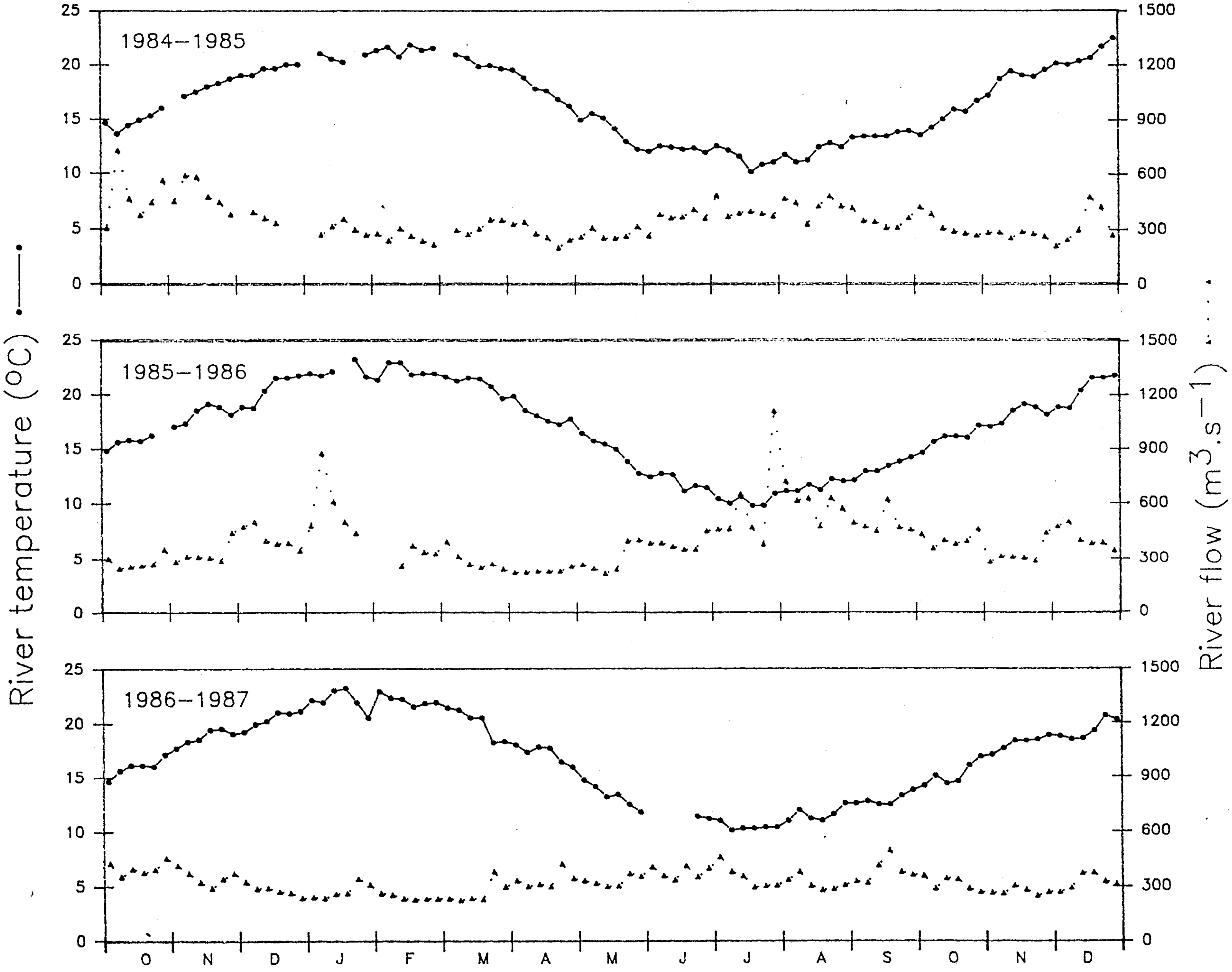

Fig. 2. River Temperature and river flow at Huntly, 1984-1987.

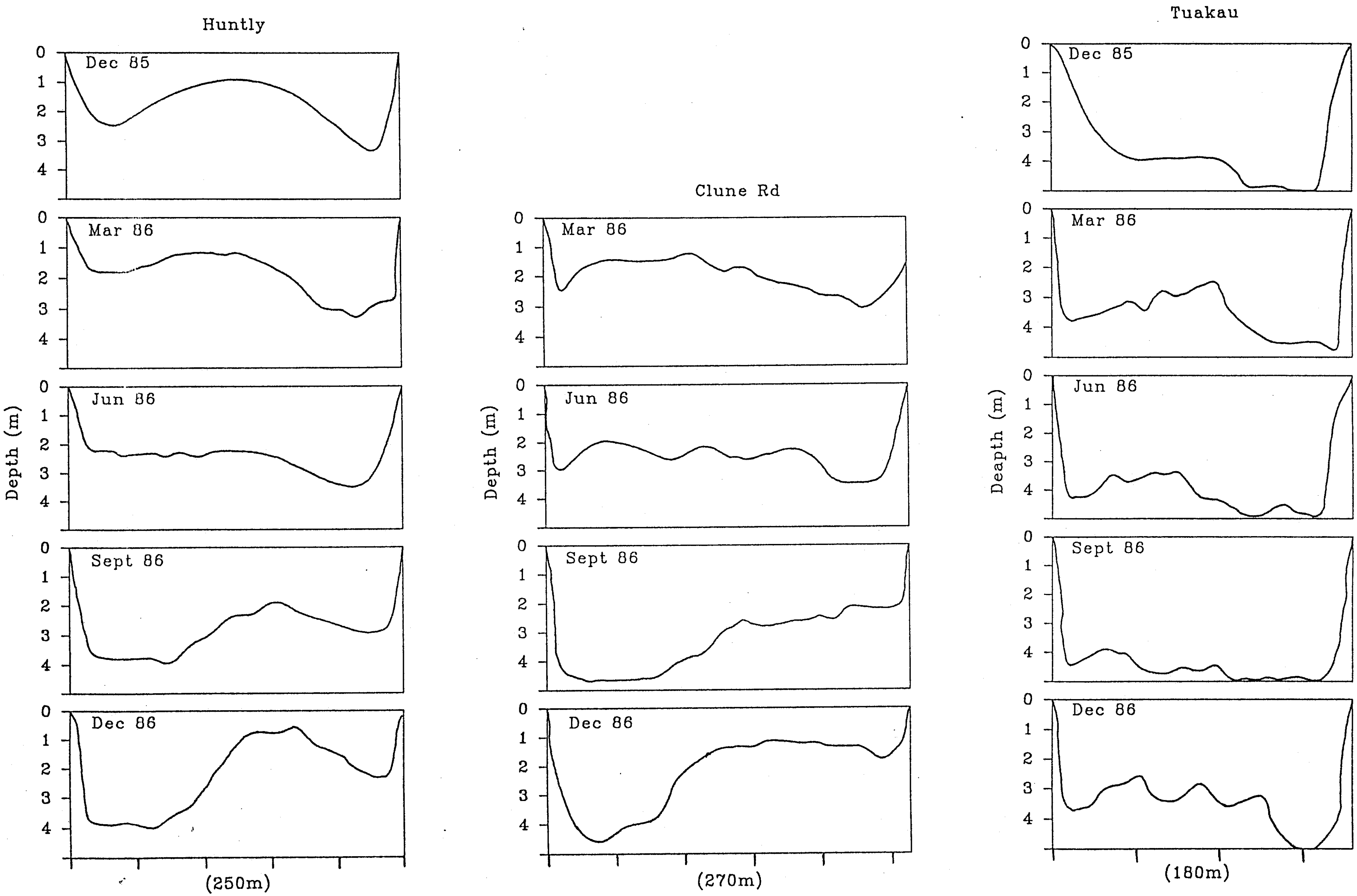

Fig. 3. Changes in river profiles at three sites on the lower Waikato River, 1985-1986.

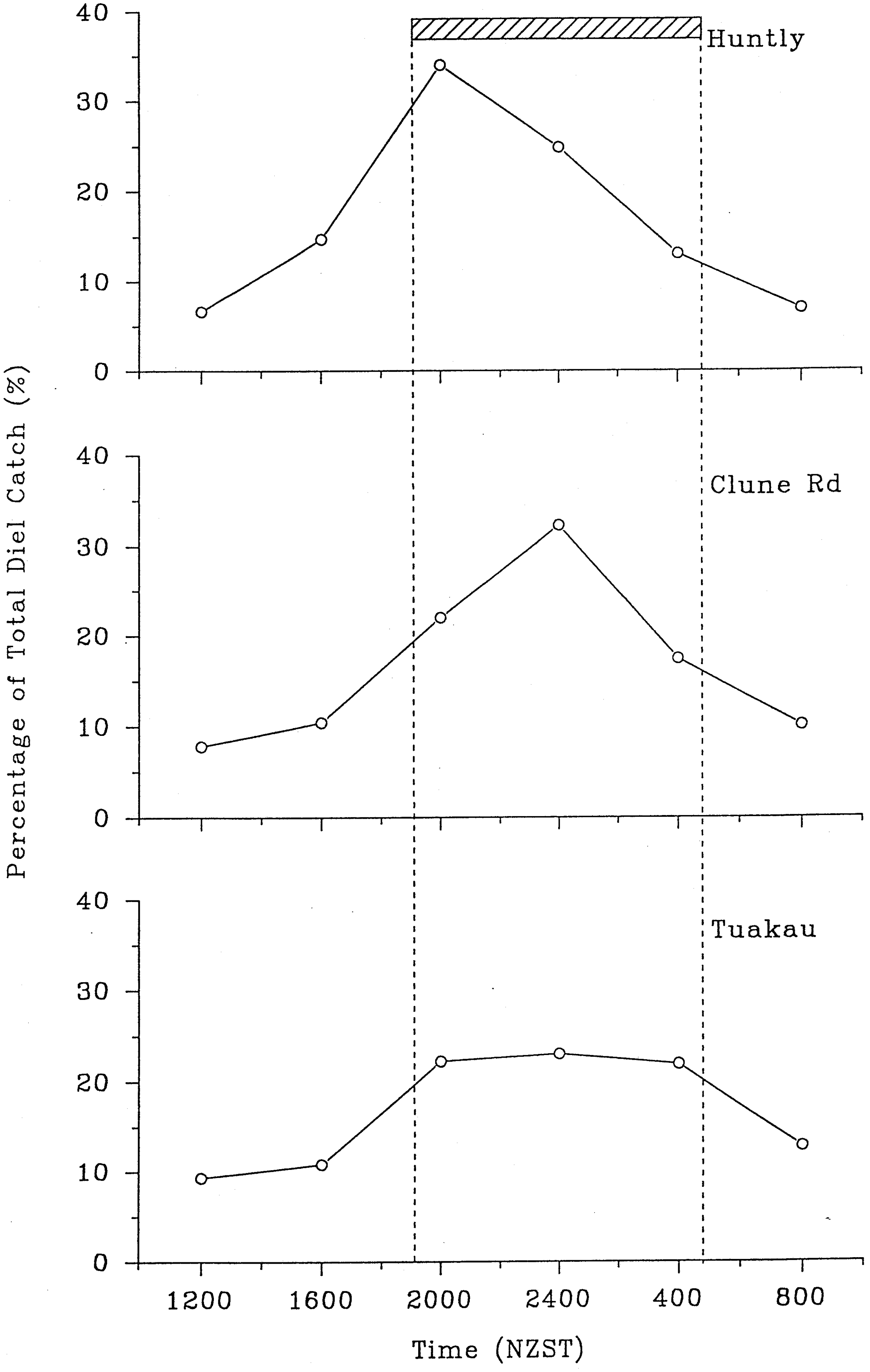

Fig. 4. Diel distribution of the total smelt larvae catch at three sites on the Waikato River, 1985-1986. (Hatched bar indicates period of darkness.)

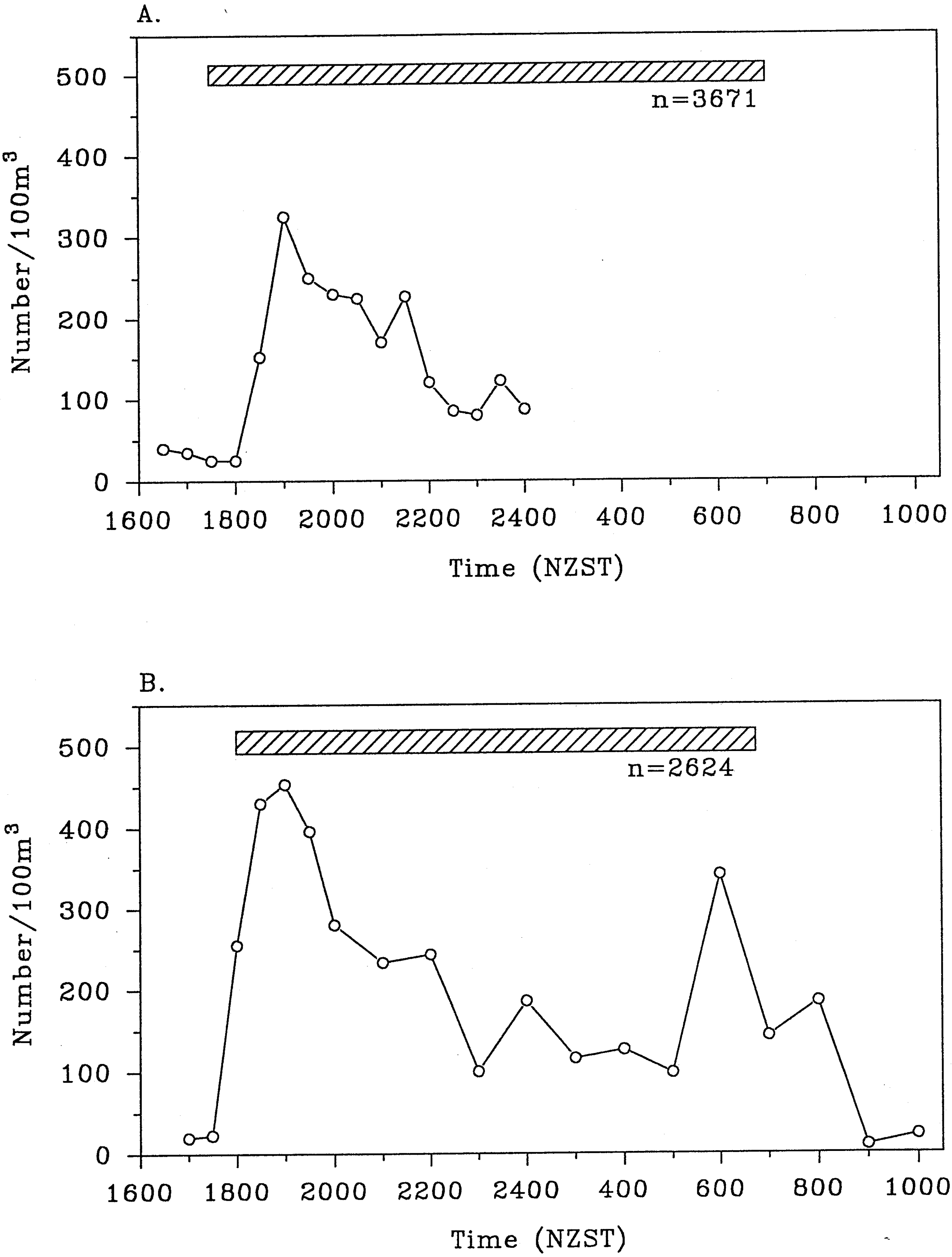

Fig. 5. Diel changes in smelt larvae abundance in the Waikato River at:
A. Huntly, 13 April 1987
B. Tuakau, 11 May 1987
(Hatched bar indicates period of darkness.)

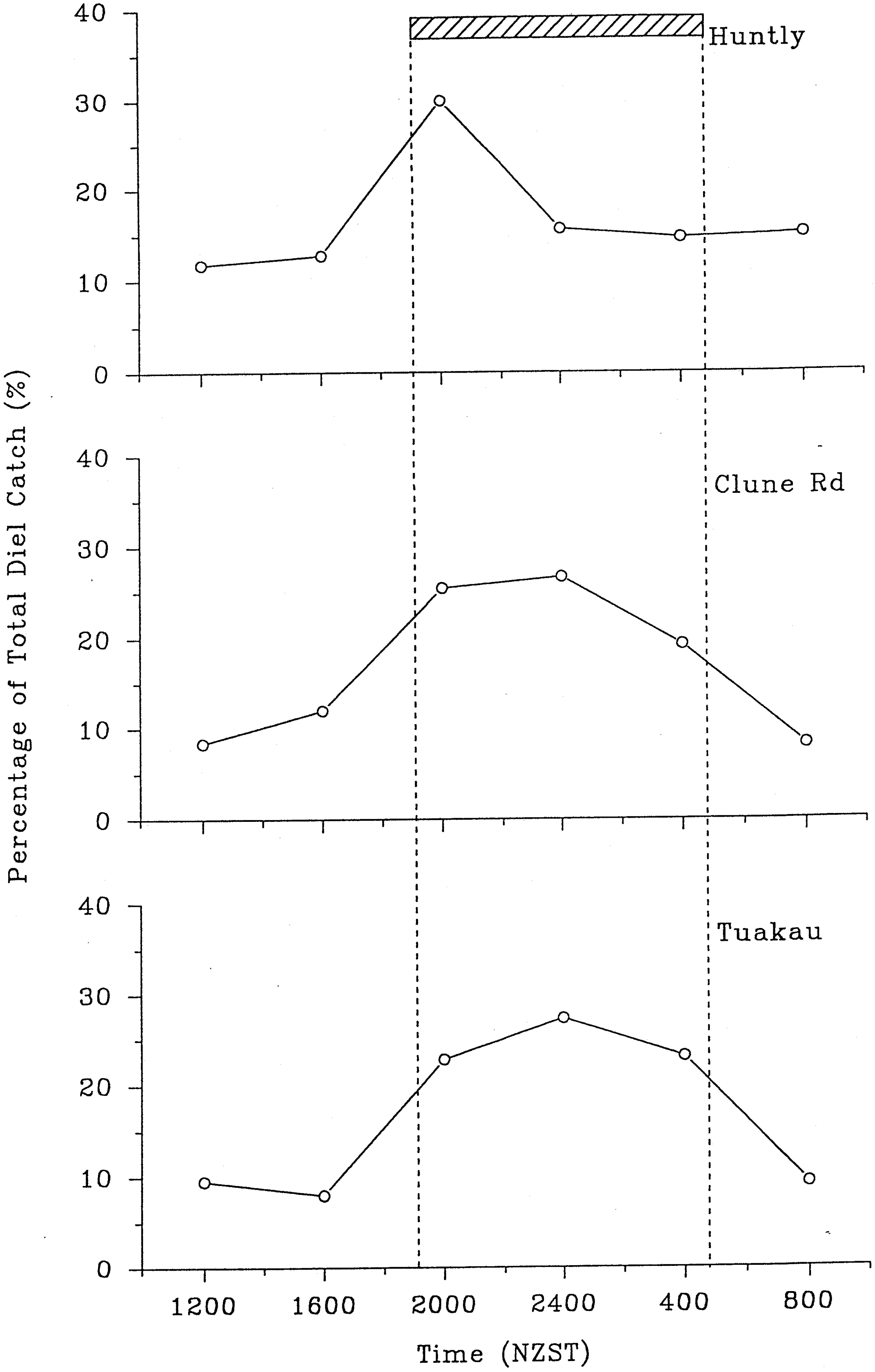

Fig. 6. Diel distribution of the total bully larvae catch at three sites on the Waikato River, 1985-1986. (Hatched bar indicates period of darkness.)

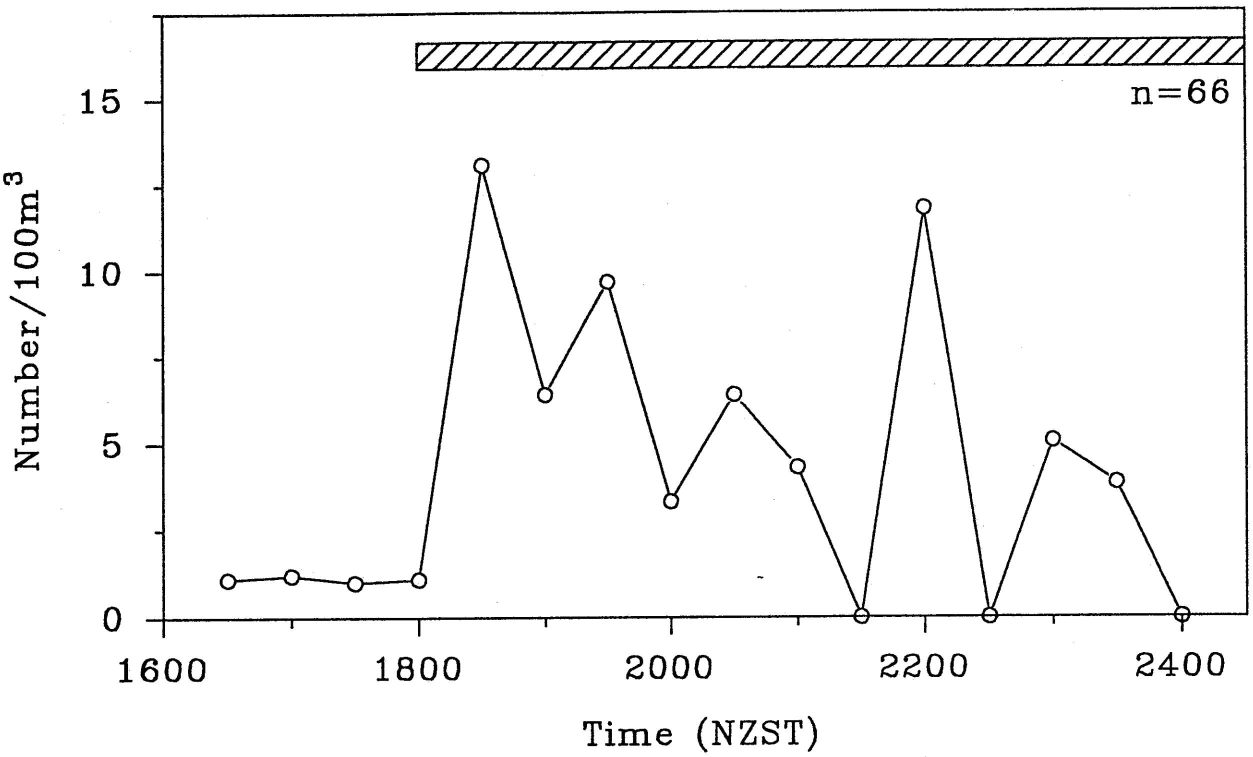

Fig. 7. Diel changes in bully larvae abundance in the Waikato River at Huntly, 13 April 1987. (Hatched bar indicates period of darkness.)

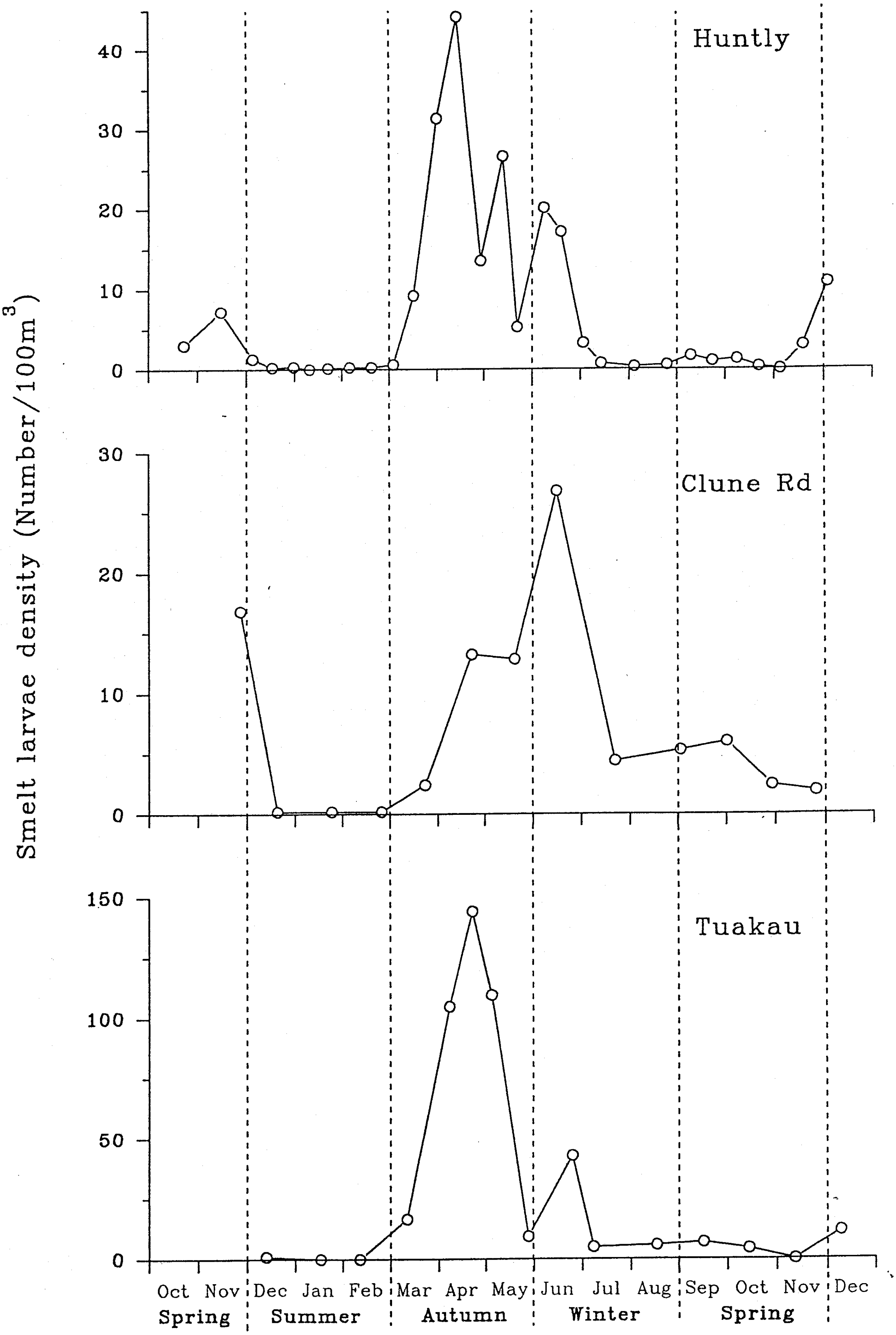

Fig. 8. Seasonal abundance of larval smelt at three sites on the Waikato River, 1985-1986.

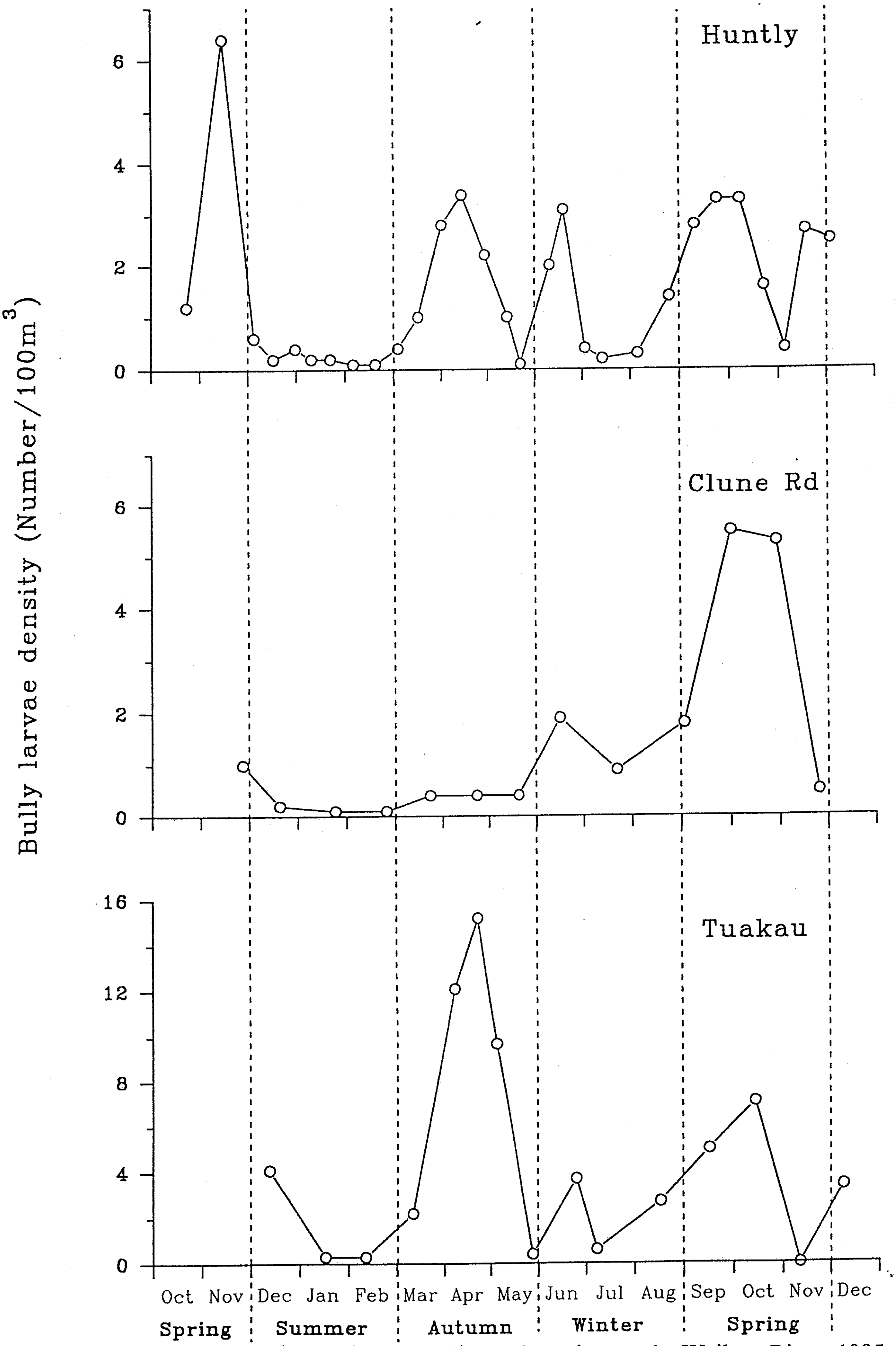

Fig. 9. Seasonal abundance of larval bullies at three sites on the Waikato River, 1985-1986.

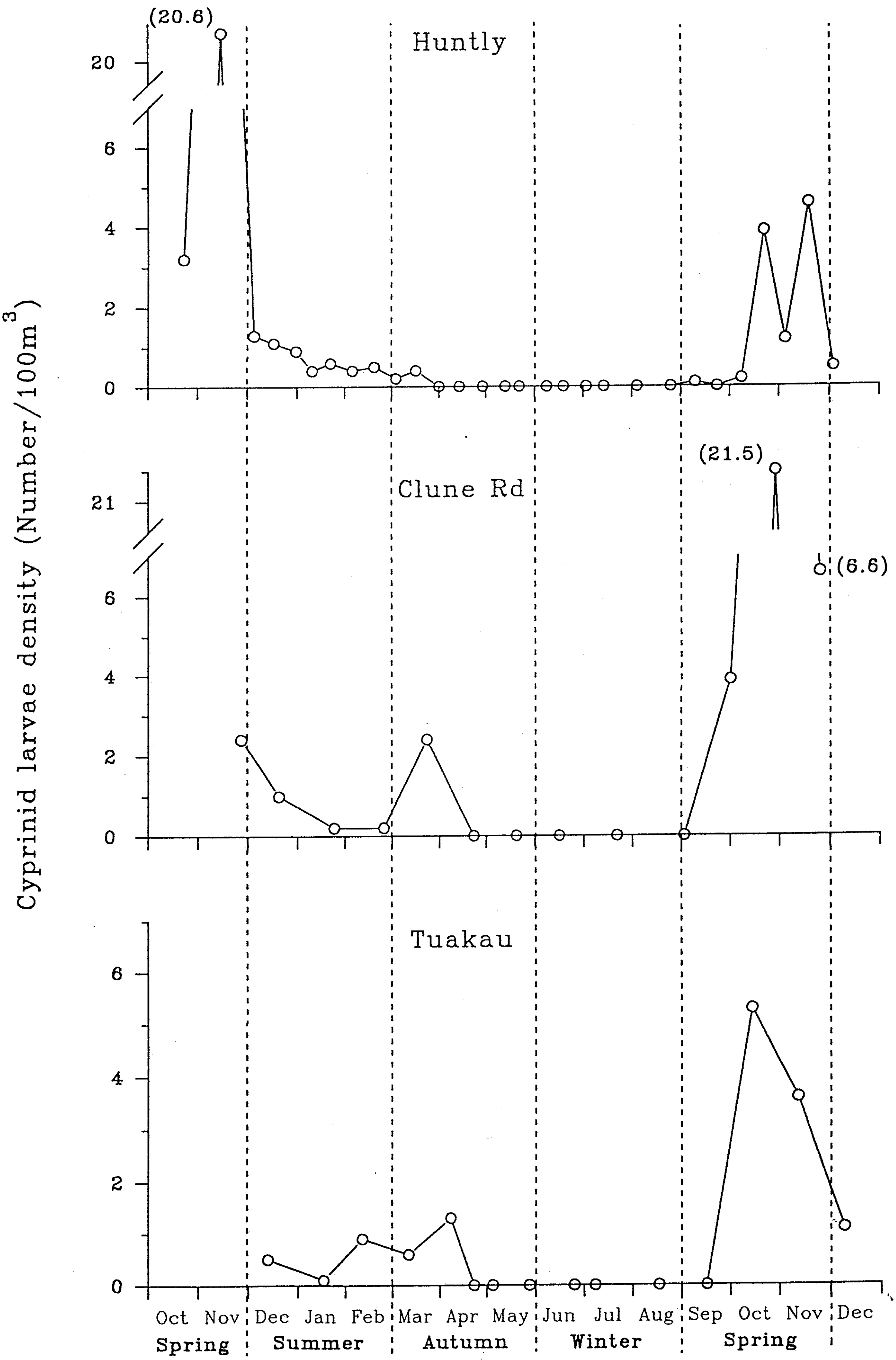

Fig. 10. Seasonal abundance of larval cyprinids at three sites on the Waikato River, 1985-1986.

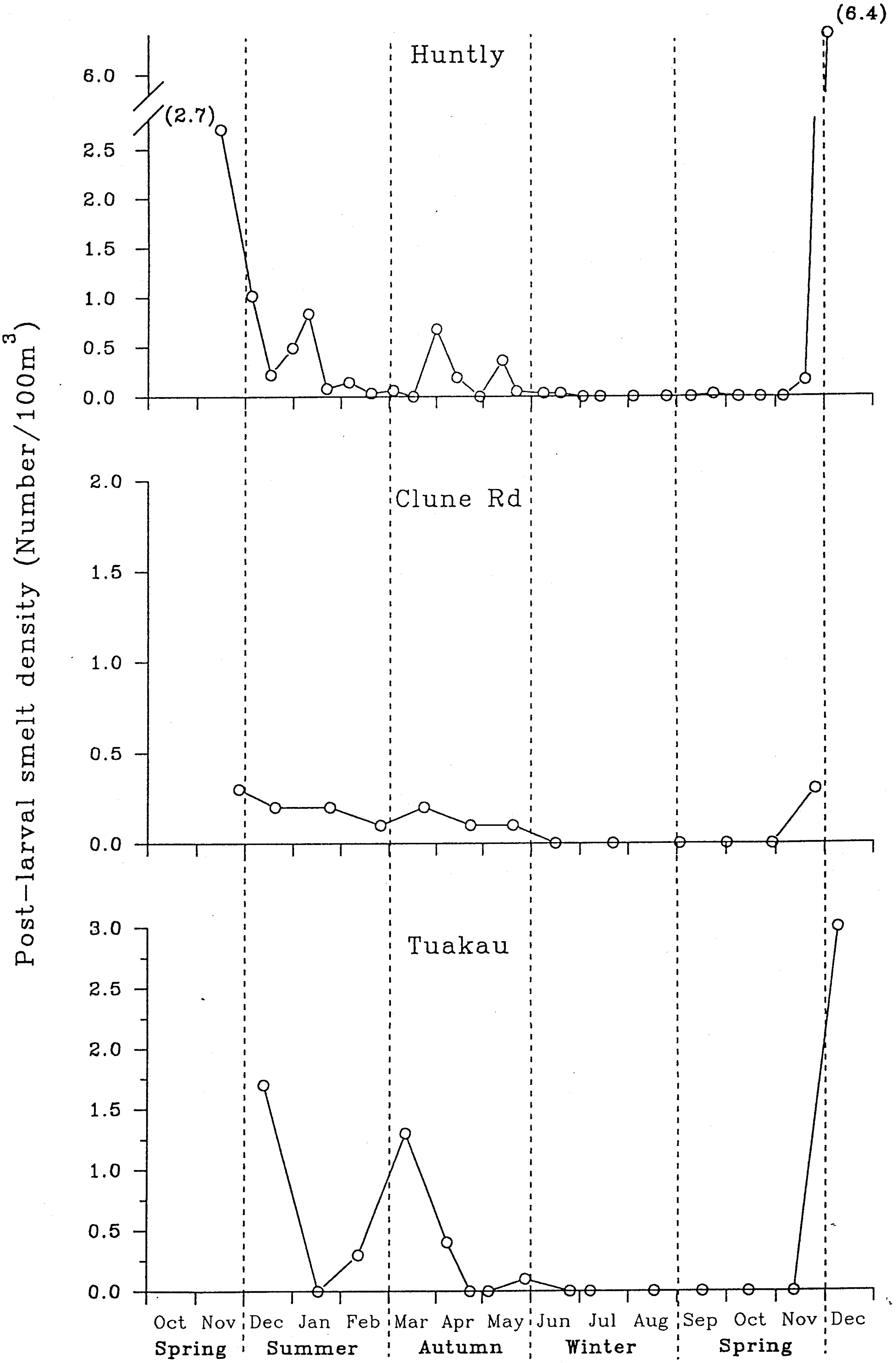

Fig. 11. Seasonal abundance of post-larval smelt at three sites on the Waikato River, 1985-1986.

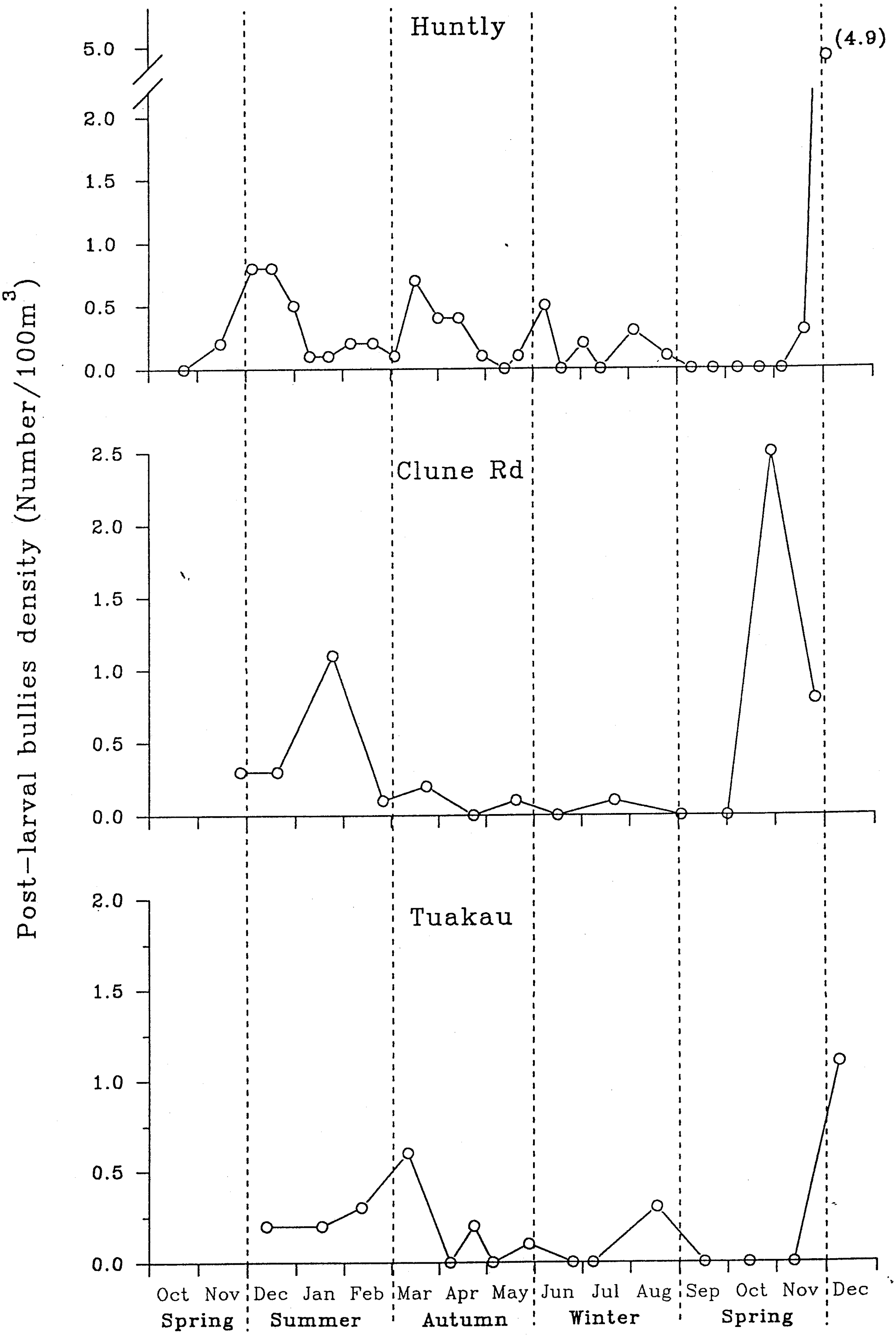

Fig. 12. Seasonal abundance of post-larval bullies at three sites on the Waikato River, 1985-1986.

APPENDICES

Appendix 1A. Mean densities of smelt larvae in the Waikato River at Huntly, October 1985 to December 1986.

	No./100m³									n
DATE	LE	LS	LB	MS	MB	RS	RB	RE	Mean	
22.10.85	2.0	0.5	0.3	0.3	ns	0.0	0.3	0.0	0.3	8
14.11.85	4.8	7.8	10.7	7.1	ns	7.8	5.8	2.0	7.2	34
04.12.85	1.5	1.0	0.8	1.3	ns	1.4	1.7	10.5	1.3	53
16.12.85	0	0.2	0	0.3	ns	0.3	0.1	0.7	0.2	11
30.12.85	0.4	0.3	0	0.6	ns	0.4	0.4	0	0.3	20
09.01.86	0	0.1	0	0	ns	0	0	0	0.0*	1
21.01.86	0.1	0	0	0	ns	0.1	0.5	0	0.1	5
04.02.86	0	0.2	0	0	ns	0.1	1.1	0	0.2	8
18.02.86	0	0	0	0.3	ns	0.6	0.3	0	0.2	6
04.03.86	0	0.9	0.4	0.9	ns	0.4	0.3	0	0.6	22
17.03.86	0.9	7.5	1.4	42.1	ns	9.1	5.0	2.1	9.2	117
01.04.86	2.8	6.3	1.2	107.5	ns	38.3	31.4	2.2	31.3	415
14.04.86	17.0	11.0	9.3	137.1	ns	100.0	51.9	16.7	44.0	465
29.04.86	7.6	5.0	5.1	30.8	ns	7.2	28.9	35.7	13.5	223
13.05.86	16.4	9.5	3.3	37.5	ns	51.3	222.0	100.0	26.6	295
22.05.86	56.5	4.6	2.6	1.8	3.9	2.1	10.9	5.6	5.2	98
08.06.86	6.2	5.1	3.9	18.4	129.4	9.7	22.0	29.5	20.1	791
19.06.86	26.2	1.2	2.1	24.8	55.7	9.3	32.1	22.1	17.1	604
03.07.86	5.3	2.1	1.8	2.3	6.6	4.3	3.5	2.5	3.2	140
14.07.86	1.0	0.2	0.4	0.5	2.9	0.3	1.1	1.1	0.7	52
04.08.86	0.4	0.1	0.3	0.1	0.7	0.5	0.7	0	0.3	26
25.08.86	1.6	0.3	1.0	0.5	0.2	0.3	0.2	0.7	0.5	28
09.09.86	1.9	2.7	2.6	2.2	0.6	0.6	0.1	2.8	1.6	82
23.09.86	3.1	1.4	0.9	0.5	1.1	0.7	0.4	1.9	1.0	50
08.10.86	6.3	0.4	1.0	0.9	2.8	0	1.5	0	1.2	36
22.10.86	0	0	0.4	0	1.1	0.4	0.4	0	0.3	10
04.11.86	0	0	0	0	0	0	0	0	0.0	0
18.11.86	5.9	2.2	4.5	4.8	ns	1.3	2.8	2.3	2.9	18
03.12.86	7.1	7.5	9.8	2.1	ns	22.2	17.9	0	10.8	44

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface ; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; n = Total number of larvae caught; ns = Not sampled; * = Densities <0.05.

Appendix 1B. Mean densities of bully larvae across a transect at Huntly, October 1985 to December 1986.

	No./100m³									n
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean	
22.10.85	6.1	0.3	0.7	3.3	ns	2.5	0.3	1.3	1.2	31
14.11.86	52.3	5.2	19.0	21.4	ns	4.3	8.7	8.0	6.4	61
04.12.85	0.5	0.2	0.5	0.3	ns	0.7	0.5	15.8	0.6	24
16.12.85	0.9	0.1	0.1	0.1	ns	0.3	0.1	3.3	0.2	14
30.12.86	0	0.5	0	0.7	ns	0.5	1.3	0	0.4	24
09.01.86	2.2	0.1	0.1	0.1	ns	0.1	0.4	0	0.2	11
21.01.86	1.2	0	0.2	0	ns	0.1	0	3.3	0.2	15
04.02.86	0	0.2	0.1	0.1	ns	0	0	0	0.1	4
18.02.86	0	0	0	0	ns	0.2	0.3	0	0.1	2
04.03.86	3.1	0.1	0.3	0.4	ns	0	1.0	8.1	0.4	13
17.03.86	2.6	0.3	0.7	2.3	ns	0	0	2.1	1.0	13
01.04.86	1.4	0.9	2.1	6.2	ns	1.9	2.0	4.3	2.8	37
14.04.86	0	0.3	1.1	10.5	ns	5.7	9.6	0	3.4	26
29.04.86	8.5	0.2	0.3	3.6	ns	0	5.3	9.5	2.2	36
13.05.86	3.3	0.5	0.9	1.4	ns	0	0	0	1.0	11
22.05.86	4.3	0	0	0	ns	0	0	0	0.1	2
10.06.86	3.1	0.9	0.6	0.8	10.4	1.5	4.7	2.3	2.0	78
19.06.86	0	0.8	1.2	4.1	8.0	1.2	8.4	2.6	3.1	109
03.07.86	0	0.3	0	0.4	0.6	0.8	1.1	0	0.4	18
14.07.86	0	0.1	0.1	0.4	0.3	0	0.5	1.1	0.2	14
05.08.86	0.4	0.2	0.3	0.1	0.3	0.4	0.3	0	0.3	20
25.08.86	1.8	0.6	0.9	0.8	0.9	2.3	1.0	1.3	1.4	74
09.09.86	6.8	2.0	2.8	0.8	0.9	1.5	0.7	136.1	2.8	121
23.09.86	11.8	3.7	2.8	1.7	2.0	3.8	2.0	12.4	3.3	172
07.10.86	27.5	2.7	2.5	2.2	4.0	1.4	1.9	12.5	3.3	104
22.10.86	8.7	0.3	1.5	1.4	3.2	0.9	0.8	2.6	1.6	50
04.11.86	0	0	0	0	3.3	0	0	0	0.4	2
17.11.86	11.8	0.6	3.6	7.1	ns	1.3	4.2	0	2.7	17
03.12.86	0	2.8	2.8	2.1	ns	3.7	2.6	0	2.5	10

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface ; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; n = Total number of larvae caught; ns = Not sampled.

Appendix 1C. Mean densities of cyprinid larvae across a transect at Huntly, October 1985 to December 1986.

	No./100m³									n
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean	
22.10.85	12.5	1.3	1.9	4.0	ns	4.8	4.0	12.5	3.2	82
14.11.85	54.2	36.4	17.9	15.7	ns	5.2	24.6	26.0	20.6	100
04.12.85	5.2	0.9	0.3	1.0	ns	0.8	3.1	2.6	1.3	53
16.12.85	6.8	0.6	0.2	0.4	ns	0.5	2.4	6.0	1.1	59
30.12.85	1.4	1.1	0.5	0.4	ns	0.6	1.3	16.7	0.9	54
09.01.86	1.4	0.3	0.3	0.4	ns	0.1	0.4	0	0.4	22
21.01.86	3.7	0.1	0.2	0	ns	0	0.2	3.3	0.6	38
04.02.86	0.2	0.3	0.5	0	ns	0.4	1.7	0	0.4	17
18.02.86	0.2	0.1	0.4	0.6	ns	0	2.1	12.5	0.5	18
04.03.86	0	0.3	0	0	ns	0.5	0.6	0	0.2	7
17.03.86	0.9	2.2	0.9	2.7	ns	1.9	0	0	0.4	26
01.04.86	0	0	0	0	ns	0	0	0	0.0	5
14.04.86	0	0	0	0	ns	0	0	0	0.0	0
29.04.86	0	0	0	0	ns	0	0	0	0.0	0
13.05.86	0	0	0	0	ns	0	0	0	0.0	0
22.05.86	0	0	0	0	ns	0	0	0	0.0	0
08.06.86	0	0	0	0	ns	0	0	0	0.0	0
19.06.86	0	0	0	0	ns	0	0	0	0.0	0
03.07.86	0	0	0	0	ns	0	0	0	0.0	0
14.07.86	0	0	0	0	ns	0	0	0	0.0	0
04.08.86	0	0	0	0	ns	0	0	0	0.0	0
25.08.86	0	0	0	0	ns	0	0	0	0.0	0
09.09.86	0.2	0.1	0	0	0	0	0	0	0.1	3
23.09.86	0	0	0	0	0	0	0	0	0.0	0
08.10.86	5.0	0.2	0	0.3	0	0.2	0.2	0	0.2	8
22.10.86	75.9	2.2	1.5	3.8	5.7	4.5	5.3	2.6	3.9	122
04.11.86	0	0	0	0	10	0	0	0	1.2	6
18.11.86	50.0	0	0.9	9.5	ns	0	2.0	5.5	4.6	29
03.12.86	0	0	0	2.1	ns	0	1.3	0	0.5	2

LE =Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; n = Total number of larvae caught; ns = Not sampled.

Appendix 1D. Mean densities of post-larval smelt across a transect at Huntly, October 1985 to December 1986.

				No./100m^3					
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
22.10.85	ns	ns	ns	ns	ns	ns	ns	ns	ns
14.11.85	0	0	8.3	0	ns	5.2	0	0	2.7
04.12.85	0.5	1.7	0.4	0.4	ns	0.7	1.9	7.9	1.0
16.12.86	3.4	0.7	0	0.3	ns	0.3	0.1	0	0.2
30.12.86	0.8	0.4	0.6	0.5	ns	0.4	0.3	0	0.5
09.01.86	0.7	1.2	0.2	1.1	ns	0.9	0.9	1.5	0.8
21.01.86	0.3	0	0	0.1	ns	0	0.2	0	0.1
04.02.86	0	0	0	0	ns	0.5	0.3	3.3	0.1
18.02.86	0	0	0	0.1	ns	0	0	0	0
04.03.86	0	0.1	0	0	ns	0.2	0	0	0.1
17.03.86	0	0	0	0	ns	0	0	0	0
01.04.86	0	0	0.2	0.7	0	4.7	0	2.2	0.7
14.04.86	0	0	0	0.4	0	2.9	0	0	0.2
29.04.86	0	0	0	0	0	0	0	0	0
13.05.86	0	3.0	0	1.7	0	2.6	0	0	0.4
22.05.86	0	0	0	0	0	0.4	0	0	0.1
08.06.86	0	0	0	0	0	0.5	0	0	0
19.06.86	0	0	0.1	0	0	0	0	0	0
03.07.86	0	0	0	0	0	0	0	0	0
14.07.86	0	0	0	0	0	0	0	0	0
04.08.86	0	0	0	0	0	0	0	0	0
25.08.86	0	0	0	0	0	0	0	0	0
09.09.86	0	0	0	0	0	0	0	0	0
23.09.86	0	0.1	0	0	0	0	0	0	0
08.10.86	0	0	0	0	0	0	0	0	0
22.10.86	0	0	0	0	0	0	0	0	0
05.11.86	0	0	0	0	ns	0	0	0	0
19.11.86	0	0	0	0	ns	0.7	0	0	0.2
03.12.86	0	3.7	5.6	8.5	ns	7.4	12.8	0	6.4

LE =Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1E. Mean densities of post-larval bullies across a transect at Huntly, October 1985 to December 1986.

				No./100m^3				
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
22.10.85	ns	ns	ns	ns	ns	ns	ns	ns	ns
14.11.85	0	1.3	0	0	ns	0	0	0	0.2
04.12.85	2.1	0.5	0.5	0.5	ns	0.8	1.0	2.6	0.8
16.12.86	0.9	0.9	0.3	0.5	ns	0.6	0.9	4.0	0.8
30.12.86	1.2	0.2	0.2	0.1	ns	0.8	0.4	8.3	0.5
09.01.86	0.7	0.1	0.1	0.2	ns	0.1	0.1	0	0.1
21.01.86	0.6	0	0.1	0.2	ns	0	0	0	0.1
04.02.86	0.2	0.2	0.2	0	ns	0.1	0	3.3	0.2
18.02.86	0.7	0.1	0	0	ns	0.4	0	0	0.2
04.03.86	1.0	0.1	0.1	0.1	ns	0.2	0	0	0.1
17.03.86	1.8	0.6	0	0.6	ns	0	1.7	2.1	0.7
01.04.86	0	0	0.7	0.7	ns	0	0	0	0.4
14.04.86	0	0	0	1.3	ns	0	1.9	0	0.4
29.04.86	0.9	0	0	0	ns	0	0	0	0.1
13.05.86	0	0	0	0	0	0	0	0	0
22.05.86	0	0.2	0	0	0.8	0	0	0	0.1
08.06.86	1.0	0	0	0	0.3	0	0	0	0.5
19.06.86	0	0.1	0	0	0	0	0	0	0 *
03.07.86	2.2	0	0.2	0.1	0	0	0	0	0.2
14.07.86	1.0	0	0	0	0	0	0	0	0 *
04.08.86	1.1	0.3	0.3	0.2	0	0.1	0	0	0.3
25.08.86	0.8	0	0.2	0	0	0	0	0	0.1
09.09.86	0.4	0.1	0	0	0	0	0	0	0 *
23.09.86	0	0.1	0	0	0	0	0	0	0 *
08.10.86	1.3	0	0	0	0	0	0	0	0 *
22.10.86	0	0	0	0	0	0	0	0	0
05.11.86	0	0	0	0	ns	0	0	0	0
19.11.86	2.9	0	0	0	ns	0.7	0	0	0.3
03.12.86	3.6	3.6	2.8	6.4	ns	9.3	2.6	9.5	4.9

* densities < 0.05

LE =Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1F. Mean densities of smelt larvae across a transect at Clune Road, 1985-1986.

				No./100m³					
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
26.11.85	2.6	3.8	3.5	9.4	ns	65.6	3.1	73.6	16.8
19.12.85	0.0	0.0	0.1	0.7	ns	0.0	0.0	0.0	0.2
23.01.86	0.3	0.1	0.1	0.1	ns	0.4	0.7	0.8	0.2
24.02.86	0.0	0.2	0.0	0.7	ns	0.4	0.0	0.4	0.2
24.03.86	0.0	3.2	4.4	11.6	ns	0.0	1.7	0.0	2.4
23.04.86	3.0	3.1	4.5	343.3	ns	12.5	17.8	5.6	13.2
20.05.86	5.6	5.3	2.7	47.8	ns	7.2	23.4	2.3	12.8
16.06.86	11.8	8.7	8.1	73.9	37.7	8.1	11.7	0.0	26.8
22.07.86	1.8	0.3	1.8	9.4	9.1	3.3	4.4	3.5	4.4
02.09.86	4.8	10.3	8.3	6.5	8.8	1.3	1.2	1.8	5.3
01.10.86	3.5	9.1	10.2	8.9	8.2	2.3	1.6	0.8	6.0
29.10.86	2.4	2.0	3.2	4.1	0.0	1.5	7.7	0.0	2.4
25.11.86	3.2	3.1	0.0	0.0	0.0	0.0	6.9	3.8	1.9

Note. LE =Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not Sampled.

Appendix 1G. Mean densities of bully larvae across a transect at Clune Road, 1985-1986.

				No./100m³					
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
26.11.85	10.4	0.3	1.8	0	ns	0	1.9	0	1.0
19.12.85	2.4	0.1	0.2	0.3	ns	0	0.7	0	0.2
23.01.86	0.2	0	0	0.3	ns	0	0	5.8	0.1
24.02.86	0.6	0	0.1	0	ns	0	0	0.9	0.1
24.03.86	0	1.1	0	0	ns	0	1.7	0	0.4
23.04.86	3.0	0.2	0.2	3.0	ns	0.2	1.2	0	0.4
20.05.86	0	0	0	2.2	ns	0	0.8	0	0.4
16.06.86	3.8	0.9	0.4	3.6	2.9	1.8	1.0	0	1.9
22.07.86	1.2	0	0.9	1.6	0.2	0.7	0.6	0.9	0.9
02.09.86	9.3	2.8	2.5	0.2	0.2	1.8	1.4	1.2	1.8
01.10.86	7.0	7.3	9.1	5.9	6.2	2.6	1.7	4.2	5.5
29.10.86	2.4	5.4	11.7	2.7	6.3	2.2	5.1	2.5	5.3
25.11.86	0	0	0.7	0	0	0	2.8	1.9	0.5

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1H. Mean densities of cyprinid larvae across a transect at Clune Road, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
26.11.85	5.2	1.5	3.1	2.2	ns	4.4	3.1	1.8	2.4*
19.12.85	0	0.7	0.6	0.7	ns	4.4	2.0	1.2	1.0
23.01.86	0.5	0	0.1	0	ns	0.1	0.7	3.3	0.2
24.02.86	0.6	0	0.2	0	ns	0	0	0.9	0.2
24.03.86	3.1	2.2	2.2	0	ns	1.4	0	50.0	2.4
23.04.86	0	0	0	0	ns	0.2	0	0	0
20.05.86	0	0	0	0	ns	0	0	0	0
16.06.86	0	0	0	0	0	0	0	0	0
22.07.86	0	0	0	0	0	0	0	0	0
02.09.86	0	0	0	0	0	0	0	0	0
01.10.86	4.0	9.5	6.4	2.8	2.6	1.9	1.3	1.1	3.9
29.10.86	0	59.7	22.7	18.9	16.7	9.0	15.4	3.3	21.5
25.11.86	35.5	1.6	3.0	7.1	4.4	8.9	11.1	9.6	6.6

* limited sampling.

LE =Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1I. Mean densities of post-larval smelt across a transect at Clune Road, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
26.11.85	1.3	0.0	0.4	0.0	ns	3.3	0.6	0.0	0.3*
19.12.85	2.4	0.1	0.2	0.1	ns	0.7	0.0	0.3	0.2
23.01.86	0.0	0.7	0.2	0.0	ns	0.0	0.0	0.8	0.2
24.02.86	0.0	0.3	0.1	0.0	ns	0.2	0.0	0.0	0.1
24.03.86	0.0	1.1	0.0	0.0	ns	0.0	0.0	0.0	0.2
23.04.86	0.0	0.2	0.0	0.0	ns	0.0	0.0	0.0	0.1
20.05.86	0.0	0.0	0.0	0.0	ns	0.2	0.0	0.0	0.1
16.06.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.07.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
02.09.86	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0#
01.10.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.10.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.11.86	3.2	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.3

* limited sampling
# mean < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1J. Mean densities of post larval bullies across a transect at Clune Road, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
26.11.85	0.0	0.2	0.9	0.7	ns	0.0	0.0	0.0	0.3*
19.12.85	0.0	0.1	0.1	0.2	ns	1.4	0.7	0.3	0.3
23.01.86	2.6	0.9	1.6	0.1	ns	0.8	0.0	4.2	1.1
24.02.86	0.0	0.0	0.1	0.0	ns	0.2	0.0	0.0	0.1
24.03.86	0.0	0.0	0.0	0.0	ns	0.5	0.0	0.0	0.2
23.04.86	0.0	0.0	0.0	0.0	ns	0.0	0.0#	0.0	0.0#
20.05.86	0.0	0.0	0.0	0.0	ns	0.3	0.3	0.0	0.1
16.06.86	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0#
22.07.86	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.1
02.09.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
01.10.86	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0#
29.10.86	4.9	0.0	0.0	0.0	0.0	0.0	1.3	0.0	2.5
25.11.86	0.0	0.5	0.7	0.0	0.0	1.6	0.0	3.8	0.8

* limited sampling
\# mean < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1K. Mean densities of smelt larvae across a transect at Tuakau, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
12.12.85	4.2	0.8	0.2	0.2	ns	0.2	0.9	0.0	0.9
16.01.86	0.0	0.0	0.0	0.01	ns	0.0	0.5	0.0	0.1
10.02.86	0.0	0.0	0.0	2.5	ns	5.6	0.0	0.0	0.1
12.03.86	0.0	7.8	4.2	18.6	39.1	11.2	31.1	0.0	16.5
08.04.86	131.6	42.5	353.8	155.5	251.3	62.1	195.2	47.4	104.9
23.04.86	36.1	16.6	78.5	103.3	686.7	49.3	345.5	63.6	144.1
05.05.86	48.8	31.5	88.0	49.5	215.0	61.9	280.0	33.3	109.6
28.05.86	15.9	2.1	3.3	7.6	15.6	4.3	26.1	5.1	9.3
25.06.86	28.9	7.9	15.2	26.1	86.1	22.6	110.0	22.7	42.9
08.07.86	10.9	1.0	7.5	2.4	5.8	2.1	8.5	9.8	4.9
17.08.86	3.0	4.4	1.1	4.5	8.3	2.9	16.6	4.6	5.7
16.09.86	1.7	2.3	1.4	8.8	16.4	3.8	9.6	8.1	6.8
14.10.86	1.0	2.7	2.5	3.0	9.7	5.1	5.3	2.5	4.3
11.11.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.12.86	7.1	25.0	15.0	4.8	12.0	3.1	4.5	0.0	11.6

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1L. Mean densities of bully larvae across a transect at Tuakau, 1985-1986.

				No./100m^3					
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
12.12.85	8.3	1.3	2.0	0.7	ns	1.3	3.5	19.2	4.1
16.01.86	1.0	3.7	0.5	0.0	ns	0.1	0.2	3.0	0.3
10.02.86	0.0	0.0	0.0	2.5	ns	0.0	0.0	0.0	0.3
12.03.86	0.0	0.0	0.0	0.0	0.0	22.3	0.0	0.0	2.2
08.04.86	26.3	5.5	22.1	10.5	2.6	4.8	18.7	10.5	12.1
23.04.86	36.1	2.1	27.4	3.7	61.9	4.0	25.1	40.9	15.2
05.05.86	16.3	2.9	3.5	1.1	26.6	2.3	26.7	5.6	9.7
28.05.86	1.6	0.5	0.0	0.0*	0.0*	0.0	0.8	0.6	0.4
25.06.86	2.4	0.7	6.1	1.1	5.1	3.0	6.8	5.9	3.7
08.07.86	3.8	0.2	1.2	0.2	0.2	0.1	0.6	3.7	0.6
17.08.86	7.6	2.4	3.2	1.6	3.2	1.8	5.2	2.8	2.7
16.09.86	2.3	1.5	6.6	3.7	8.1	1.3	4.6	24.9	5.0
14.10.86	5.1	3.6	6.4	4.3	13.1	3.9	13.6	4.1	7.1
11.11.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.12.86	7.1	4.2	0.0	4.8	1.3	4.2	0.0	18.8	3.4

* density < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1M. Mean densities of cyprinid larvae across a transect at Tuakau, 1985-1986.

				No./100m^3					
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
12.12.85	4.2	0.7	0.0	0.6	ns	0.5	0.0	0.0	0.5
16.01.86	0.0	0.4	0.1	0.0*	ns	0.0*	0.0	0.0	0.1
10.02.86	0.0	1.0	2.5	2.5	ns	0.0	0.0	0.0	0.9
12.03.86	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.6
08.04.86	8.8	3.7	0.0	2.1	0.0	0.0	0.0	0.0	1.3
23.04.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
05.05.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25.06.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.07.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17.08.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.09.86	0.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0*
14.10.86	5.1	3.6	2.8	4.9	5.0	4.3	13.3	3.3	5.3
11.11.86	40.0	3.2	2.8	10.6	0.0	1.5	5.6	2.9	3.6
09.12.86	0.0	2.1	2.5	0.0	1.3	0.0	0.0	0.0	1.1

* density < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1N. Mean densities of post-larval smelt across a transect at Tuakau, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
12.12.85	8.3	2.1	1.1	1.7	ns	1.0	2.5	7.7	1.7
16.01.86	0.0	0.0	0.1	0.1	ns	0.0	0.0	0.0	0.0*
10.02.86	0.0	0.0	2.5	0.0	ns	0.0	0.0	0.0	0.3
12.03.86	0.0	0.0	0.0	2.3	0.0	0.0	4.4	0.0	1.3
08.04.86	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.4
23.04.86	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0*
05.05.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.1
25.06.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.07.86	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0*
17.08.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.09.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.10.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.11.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.12.86	0.0	0.0	2.5	4.8	1.3	6.3	13.6	0.0	3.0

* density < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.

Appendix 1O. Mean densities of post-larval bullies across a transect at Tuakau, 1985-1986.

	No./100m³								
Date	LE	LS	LB	MS	MB	RS	RB	RE	Mean
12.12.85	4.2	0.2	0.2	0.0	ns	0.0	0.6	0.0	0.2
16.01.86	2.1	0.0	0.1	0.0	ns	0.1	0.2	1.8	0.2
10.02.86	0.0	0.0	0.0	0.0	ns	0.0	2.6	0.0	0.3
12.03.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.6
08.04.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.04.86	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.2
05.05.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.05.86	0.0	0.0	0.2	0.2	0.0	0.0	0.2	0.0	0.1
25.06.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
08.07.86	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0*
17.08.86	0.0	0.3	0.2	0.2	0.0	0.0	0.4	1.2	0.3
16.09.86	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0*
14.10.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.11.86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
09.12.86	7.1	0.0	2.5	4.8	0.0	0.0	0.0	0.0	1.1

* densities < 0.05

LE = Left edge; LS = Left channel surface; LB = Left channel near bottom; MS = Middle surface; MB = Middle bottom; RS = Right channel surface; RB = Right channel near bottom; RE = Right edge; ns = Not sampled.