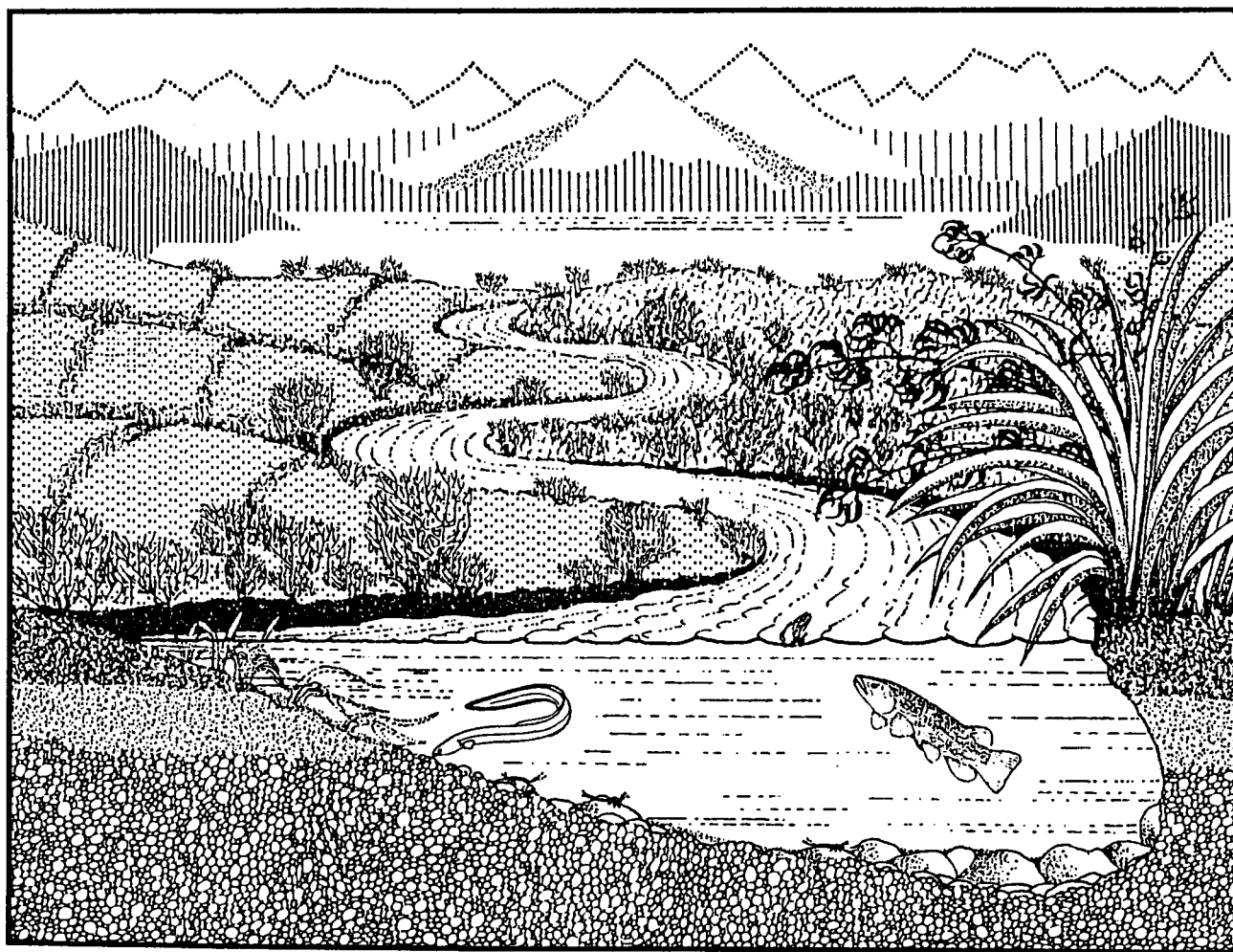


# New Zealand Freshwater Fisheries Report No. 95

## The whitebait fishery of the Waikato River





The whitebait fishery  
of the Waikato River

by

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## SUMMARY

This report documents the whitebait fishery in the Waikato Estuary and presents the results of a survey carried out during the 1984 and 1985 seasons. The study is part of a suite of biological investigations instituted by Electricorp to provide information for design criteria and statutory consents for a planned third thermal power station on the Waikato River.

Whitebait are the migratory juveniles of 5 species of native fish of the genus *Galaxias*. The Waikato fishery is unusual in that juveniles of the common smelt (*Retropinna retropinna*) are also caught and sold commercially, as "No. 2" whitebait. Smelt averaged 44% of the total catch weight over the 1974-85 seasons. In the 1984 and 1985 seasons, the galaxiid catch consisted of 93% inanga (*G. maculatus*), 7% banded kokopu (*G. fasciatus*), and negligible numbers of koaro (*G. brevipinnis*) and giant kokopu (*G. argenteus*).

The Waikato whitebait fishery is the most productive in the North Island, but the annual yield has decreased from an average of 46 000 kg (1931-50) to 14 000 kg (1968-85). The catch of smelt as well as galaxiid whitebait has declined, and a reduction in fish habitat is the most obvious contributing factor. Implementation of the lower Waikato flood protection scheme (1961-82), which halved the original area of the lower Waikato flood plain, has been the largest recent development affecting the fishery. A further decrease in catch is likely unless the habitat is conserved and restored.

About 75 full-time whitebaiters fished the river during the 1984-85 seasons, which is less than that estimated for the years before 1950. However, the number of recreational whitebaiters has increased 10-fold since 1950, and as many as 1000 whitebaiters may now fish the river at peak times. The local Tainui people have had a long association with the fishery, and it continues to be important to them.

The retail value of the catch was estimated at more than \$400,000 in 1984 and more than \$530,000 in 1985. In addition, whitebaiters made a substantial expenditure and investment on nets, whitebait stands, and baches at the river, and on boats used to gain access to the stands.

The timing of whitebait migrations into the river has not changed in at least the last 60 years. Inanga migrate as early as June or July, although the best catches are almost always taken during September and October. These migrations usually cease by early November. In the 1984 and 1985 seasons, other galaxiids were present in the catch from late August, and banded kokopu were most abundant during September. September and October were the peak months for smelt migration, and the runs continued into November in some years. The timing, intensity, and success of spawning during autumn are considered to be important factors in determining when whitebait will migrate into the river.

Large catches of galaxiid whitebait and smelt were taken during spring tides, and also after floods during the main migration period. Not all migrations could be explained in terms of tide or river flow. Tidal amplitude and river flow may influence the day-to-day migration of whitebait by changing the zone of reduced salinity around the river mouth. Reduction in the size and duration of floods in the Waikato, because of the retention of water for electricity generation, may mean that tidal effects are more important now than in the past.

There is no evidence from this or other studies that fluctuations in river temperature caused fluctuations in the day-to-day migration of whitebait. The Waikato River temperature rose to exceed the sea temperature in early October, but galaxiid whitebait and smelt continued to enter the river even though they were moving into warmer water. Therefore, the relatively small temperature increases (0.5-1.0°C) predicted for the estuary, because of the operation of the Huntly and proposed Clune Road thermal power stations, are unlikely to have a direct effect on the timing of whitebait migrations.

Increases in river temperature could affect migration timing indirectly by changing the time taken for whitebait to mature and spawn. Any such effect would be most noticeable near the power station discharges, where the temperature increases are greatest.

## 1. INTRODUCTION

In New Zealand, whitebait is the common name for the migratory juveniles of 5 native fish species of the genus *Galaxias*. These are inanga (*G. maculatus*), banded kokopu (*G. fasciatus*), koaro (*G. brevipinnis*), giant kokopu (*G. argenteus*), and short-jawed kokopu (*G. postvectis*), (Woods 1963; McDowall 1964, 1965, 1966a, 1966b). In some districts, juveniles of the common smelt (*Retropinna retropinna*) are also classed as whitebait (McDowall 1965, 1984).

From late winter to early summer, shoals of these fish migrate from the sea into fresh water. In estuaries and large streams, the fish are netted as they make their way upstream, thus forming the basis for local commercial fisheries and for a nationwide recreational fishery.

## 2. WHITEBAIT STUDIES

The biology and ecology of inanga have been well documented (Burnet 1965; Benzie 1968a, 1968b, 1968c, 1968d; McDowall 1968; McDowall *et al.* 1975), but comparatively little is known about the other species. Of these, banded kokopu have been the best described (Ots and Eldon 1975; Hopkins 1979a, 1979b; Mitchell and Penlington 1982), while giant kokopu (Jellyman 1979), koaro, and short-jawed kokopu have received little attention. However, the migration of galaxiid whitebait on the west coast of the South Island has been studied intensively (McDowall and Eldon 1980). McDowall (1984) provided a comprehensive review of whitebait research.

Studies on the genus *Retropinna* have been mainly taxonomic (e.g., Woods 1968; McDowall 1970a, 1972, 1979), but the basic features of smelt biology have also been described (Jolly 1967; McDowall 1972, 1978, 1979; Northcote and Ward 1985; Stephens 1986).

Information specific to the Waikato River whitebait fishery is sparse. In his survey of the species composition of the 1964 whitebait catch, McDowall (1965) found that, as well as galaxiids, large quantities of juvenile smelt were caught and sold commercially as "second class whitebait" or "porohe". McDowall (1968) included the

Waikato River in a regional analysis of length variation in inanga whitebait.

## 2.1 The Fishery

The Waikato River whitebait fishery is the most productive in the North Island, and has supported important commercial and recreational interests for many years (N.Z. Marine Department 1932-72). The fishery has been a traditional food source for the local Tainui tribes, who became involved commercially as early as 1887, when the first of 2 canneries was established on the river (McDowall 1984).

Almost all whitebaiting is carried out in the 30 km of river below the Tuakau Bridge (Fig. 1). Effort is concentrated in the reach from the Elbow to Hoods Landing, where the river widens to form a large multi-channelled delta.

Most whitebaiters fish with hand-held scoop nets, although the use of trap nets is increasing. Many fishermen build wooden platforms, or "stands", which extend from the river banks into the current. Stands often have buildings associated with them, ranging from simple shelters to permanent dwellings. Waikato whitebaiters are not required to register their stands or to furnish catch returns.

During the season (August to November inclusive), at least 2 whitebait buyers travel the river by boat. Most full-time and some part-time fishermen sell a portion of their catch to the buyers, who also bring in provisions for those residing on the river.

## 2.2 A Fishery under Stress?

In the last 100 years, most New Zealand rivers have suffered a substantial decline in their whitebait fisheries. This can usually be related to dramatic modifications of the catchments, such as clear felling of bush, drainage of swamplands, flood protection works, and water pollution, particularly in estuaries (McDowall 1984).

The Waikato whitebait fishery is no exception, as 83% of wetlands in the catchment disappeared between 1840 and 1976 (Cheyne 1981). Agriculture is now the dominant land use, and the quality of the river



water has declined owing to the effects of increased agricultural runoff and the more than 30 major effluent discharges below Lake Taupo (Marshall 1979).

The Waikato River is controlled by 8 hydro-electric dams, and flows in the lower river are largely influenced by demand for power generation (Ridall 1979). Flow regulation has reduced the magnitude and duration of floods, which have been shown to influence whitebait migration (McDowall and Eldon 1980).

The lower Waikato River also provides condenser cooling water for 2 thermal power stations, Meremere (210 MW) and Huntly (1000 MW). Both use a "once through" cooling system, with Huntly abstracting up to 38 m<sup>3</sup>/s and discharging the heated water back into the river at up to 11°C above the river ambient temperature. These discharges have the potential to disrupt whitebait migration and to further reduce the number of whitebait (Town 1983).

### 2.3 Purpose of the Study

Forecasts of an increase in the demand for electricity have led to planning for a third thermal power station on the Waikato River. Site investigations for the proposed station involved:

Phase 1 - defining suitable localities.

Phase 2 - determining suitable sites, site-related impacts, and design criteria.

Phase 3 - obtaining formal consents.

Fisheries studies were instituted by Electricorp as part of a suite of biological investigations to provide information for the decisions to be made in Phase 2 and for the statutory procedures of Phase 3.

This study was undertaken to:

1. Document the whitebait fishery in the estuary.
2. Compare the present catch and number of whitebaiters participating in the fishery with historical records.

3. Determine the species composition of the catch, and identify sources of recruitment.
4. Investigate any factors (including power station operation) which might influence the fishery.

Data on the migration of whitebait species in the river between Meremere and Huntly were collected during a reconnaissance survey (February 1984-April 1985), and are presented in Boubee *et al.* 1986. A further report, incorporating the results of a second summer's trapping at Huntly thermal power station (October 1985-April 1986) and detailing the biology of whitebait species in the vicinity of the present and proposed thermal power station sites, is being prepared.

### 3. METHODS

#### 3.1 Historical Records

Records of the number of whitebaiters present during each season, the timing of whitebait migrations, and the size of the catch, were obtained from Marine Department annual reports for the years 1931-50. More recent estimates of catch were obtained from Marine Department annual reports (1969-72), Fisheries Management Division (FMD) reports (1973-76), and FMD's Auckland files (1974-78).

Because no official records were available for the years 1979-85, catch figures were derived from the personal records of the 2 major buyers who were operating on the estuary. After discussions with buyers and fishermen, we assumed that 50% of the galaxiid whitebait and 80% of the smelt were sold to these buyers.

#### 3.2 Number of Whitebaiters

Sections of the river between Tuakau Bridge and Hoods Landing were surveyed by boat during 1984 (6 visits) and 1985 (1 visit). Counts were made of the number of usable stands, the number of stands occupied, and the number of people fishing. Observations by the buyers and fishermen were used to estimate the number of whitebaiters present at peak times.

### 3.3 Sample Collection

To analyse the species composition of the galaxiid catch, we obtained the assistance of people working in the fishery. Samples of 300-800 galaxiids were collected at various intervals throughout the 1984 and 1985 seasons. Extra samples of koaro and several samples of smelt were also taken.

In 1984, a fisherman stationed 2 km below the Elbow sub-sampled his catch on alternate days from 10 August to 28 October. He also took samples during July, by a special permit issued for this study. Samples were collected from both sides of the river.

In 1984, a buyer (Buyer 1) assisted by sub-sampling the catch purchased from whitebaiters between the Elbow and Hoods Landing. Samples were collected weekly from 31 August to 27 October.

In 1985, 3 people assisted with whitebait sampling. The fisherman collected samples weekly from 16 August to 16 October, as did Buyer 1 from 2 August to 13 October. Buyer 2 sub-sampled the catch from fishermen near the Tauranganui Marae and near Tuakau Bridge twice weekly from 4 August to 1 November.

The fisherman caught whitebait in a trap net, and samples were taken as soon as fish were removed from the net. The buyers bought fish from whitebaiters who mostly used scoop nets. Each whitebaiter poured his or her catch into perforated "4-gallon" tins, and sorted it into galaxiid whitebait and smelt. Buyer 1 emptied the galaxiid whitebait into a vat, where they were washed and any remaining smelt removed. Samples were taken for us to analyse at this stage. Buyer 2 sorted the fish directly from the tins, and samples were taken from the sorted fish.

The mixing of fish by the buyers, and the fact that the fisherman sampled freshly caught fish, were considered sufficient to minimise any sampling bias caused by species stratification (McDowall and Eldon 1980).

### 3.4 Sample Preservation and Analysis

Initially, the samples were preserved in 10% formalin, and were later washed and transferred to 40% isopropyl alcohol for storage.

Only fresh-run whitebait were used to determine species composition. Fresh-run fish were distinguished from post-migratory juveniles by the absence of myotomal bands of melanophores on the trunk (McDowall and Eldon 1980). The galaxiid species were identified according to the descriptions given by McDowall (1964, 1966a, 1970b).

Sub-samples of at least 50 inanga and 20 banded kokopu were measured (total length (TL)  $\pm$  0.5 mm) and weighed ( $\pm$  0.5 g) at 2-4 day intervals where possible. When fewer than 20 banded kokopu were present in the samples, fish from 2-4 day's samples were combined. All koaro present in the samples were measured and weighed.

Condition factor (K) was calculated for fish of each species using the formula:

$$K = \frac{W 100}{L^3}$$

where W = weight in g, and L = total length in cm.

To account for variation in catch quantities with time and for size differences between species, the proportion (percentage by weight) of the 2 numerically dominant species in the galaxiid catch was calculated for each season (see Appendix I).

### 3.5 Physical Parameters

The Waikato Valley Authority (WVA) provided river flow data from Rangiriri (1968-85). Predicted tide heights were obtained from the N.Z. Nautical Almanac (1979-85). Temperature records for the river at Huntly were provided by the Huntly Borough Council (1979-83) and the Huntly thermal power station (1984-85), and for the Elbow by the Auckland Regional Authority (1979-85). Weekly mean sea temperatures in the Manukau/North Taranaki Bight were obtained from GOSSTCOMP satellite maps (1979-85). Rainfall data for the estuary came from N.Z. Meteorological Service records at Onewhero (1931-50 and 1968-84).

## 4. RESULTS

### 4.1 Size of the Catch

The estimates of annual whitebait catch, which include smelt, show a decline from an average of 46 000 kg for the period 1931-50, to 14 000 kg for 1968-85 (Fig. 2, Table 1). For the years 1951-67, catch figures were available only for the South Island's West Coast fishery, because of "difficulty in accounting for the catch of the increasing number of amateur fishermen in other districts" (N.Z. Marine Department 1952).

Nevertheless, comments in Marine Department reports indicate that the whitebait season on the Waikato was good in 1953, 1954, 1959, and 1961 (Table 1). It was very poor in 1971 and 1974, and 1 buyer stated that 1974 was the worst he had experienced. It is clear that the large yields present before 1950 have disappeared and that the catch has stabilised at a much lower level.

Buyers' records detailing the catch of galaxiids and smelt separately were available for the 1974-85 period only. In that time the catch of smelt averaged 5 400 kg, or 44% of the total catch (Table 2).

### 4.2 Number of Whitebaiters

The intensity of fishing on the Waikato River was difficult to assess because of the length and braided nature of the estuary. Most whitebaiters were present during the incoming tide, but their number varied considerably within this period, as the lower estuary was only fished early in the tide.

Our surveys, which did not coincide with the largest runs, show that there was great variation in the percentage of stands occupied (Table 3). The small numbers fishing on 7 October 1984, when whitebait were "running", reflected the fact that the tide was unfavourable at the time of the survey.

In total, 441 usable stands were recorded, and their distribution is given in Figure 3. On 4 occasions when whitebaiters were counted, the average number of fishermen per occupied stand was 1.6. Buyers and fishermen stated that virtually every stand was occupied on "peak" days.

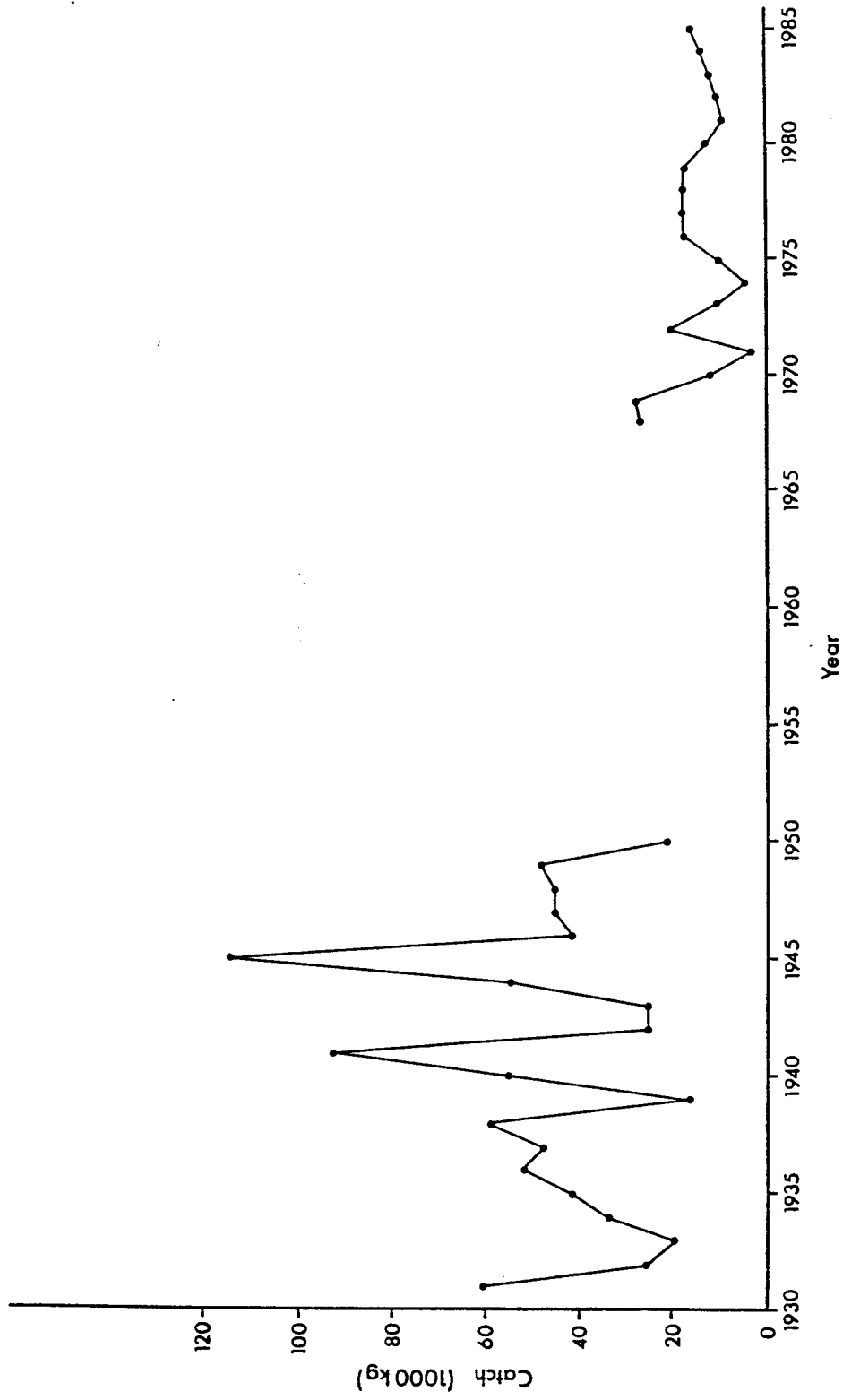


FIGURE 2. Fluctuations in the estimated whitebait catch (galaxiids and smelt) from the Waikato River, 1931-85. No data were available for 1951-67.

TABLE 1. Estimated whitebait catch (galaxiids and smelt) from the Waikato River, 1931-85.

Date	Catch (kg)	Comment
1931	60 124	
1932	26 167	
1933	19 651	
1934	32 836	
1935	40 931	
1936	52 385	
1937	47 396	
1938	59 615	
1939	16 393	
1940	55 135	
1941	92 960	
1942	24 538	
1943	24 538	
1944	54 625	
1945	113 935	
1946	40 473	
1947	45 156	
1948	44 889	
1949	48 313	
1950	21 840	
1951	-	"poor season"
1952	-	"poor season"
1953	-	"good season in most districts"
1954	-	"better than usual"
1955	-	"poorest for many years"
1956	-	"poor season"
1957	-	"poor season"
1958	-	"poor season"
1959	-	"generally good"
1960	-	
1961	-	"best recorded for many years"
1962	-	
1963	-	
1964	-	
1965	-	
1966	-	"poor season"
1967	-	"poor season"
1968	26 472	"best for 5 years"
1969	27 847	
1970	12 422	
1971	3 564	
1972	20 262	
1973	10 200	
1974	4 400	2 buyers tallied 2 189
1975	9 800	2 buyers tallied 6 222
1976	16 725	2 buyers tallied 13 697
1977	17 000	1 buyer tallied 8 472
1978	16 593	
1979	16 678	2 buyers tallied 10 254
1980	12 639	2 buyers tallied 8 054
1981	8 981	2 buyers tallied 5 819
1982	10 018	2 buyers tallied 6 763
1983	11 698	2 buyers tallied 7 003
1984	13 213	2 buyers tallied 8 410
1985	15 653	2 buyers tallied 9 146

TABLE 2. The proportion of smelt in the total whitebait catch from the Waikato River, 1974-85. Catch estimates were derived from buyers' purchases (Appendix II). No data were available for 1977-78.

Year	Estimated catch		% smelt in total catch
	Galaxiids (kg)	Smelt (kg)	
1974	2 508	1 169	31.8
1975	6 644	3 625	35.3
1976	6 842	12 845	65.2
1979	10 294	6 384	38.3
1980	6 856	5 783	45.8
1981	4 552	4 429	49.3
1982	4 170	5 848	58.4
1983	7 852	3 846	32.9
1984	7 200	6 013	45.5
1985	11 254	4 399	28.1
Mean	6 817	5 434	44.4

TABLE 3. Counts of whitebait stands and fishermen from sections of the Waikato River between the Elbow and Hoods Landing. (WD = weekday, WE = weekend, out = outgoing, in = incoming.)

Date	Day	Tide	No. of stands inspected	No. of stands occupied	No. of people fishing	Buyers' tallies (kg)
10/8/84	WD	out	140	9 ( 6%)	16	3.6
31/8/84	WD	full	189	30 (16%)	50	6.1
9/9/84	WE	in	189	127 (67%)	182	239.9
22/9/84	WE	in	140	46 (32%)	-	45.2
7/10/84	WE	out	410	37 ( 9%)	-	185.7
27/10/84	WE	full	140	84 (60%)	147	159.0
31/8/85	WE	full	90	81 (90%)	-	51.8

- = not recorded.

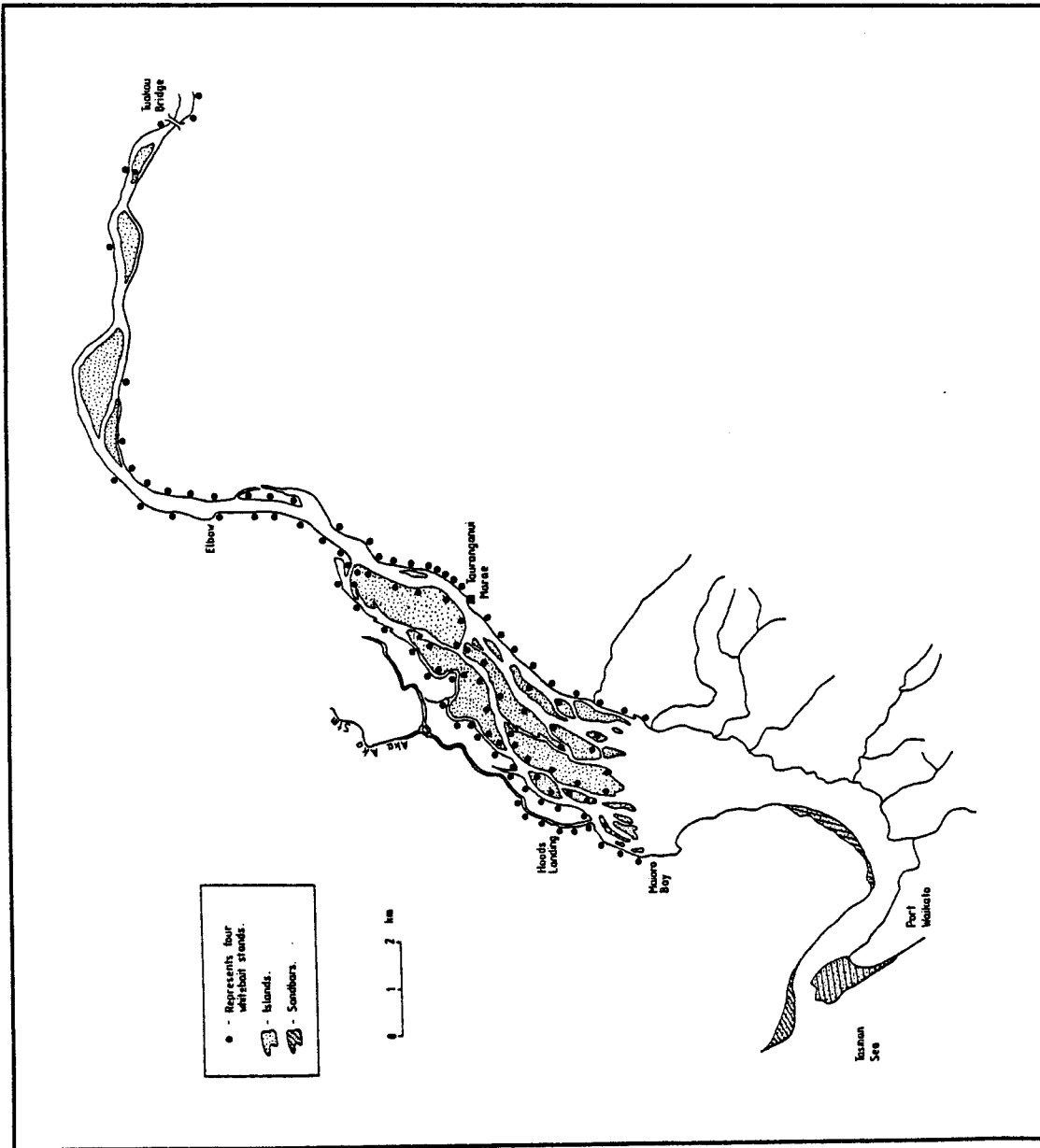


FIGURE 3. Distribution of whitebait stands recorded in the Waikato Estuary, 1984 and 1985.

Therefore, at least 700 whitebaiters would fish from stands at these times.

Although most fishing was done from stands on the river upstream from Hoods Landing, many whitebaiters also fished the 8.5 km of river between the islands and the mouth, where there were no stands. Thus, on peak days, as many as 1000 whitebaiters could be present.

Most whitebaiters are part-time or recreational fishermen, and only 75 full-time fishermen were present during the 1984 and 1985 seasons (buyers pers. comm.). Historical records show that, between 1931 and 1950, the river supported an average of 107 full-time and 65 part-time fishermen (Table 4). The increase in activity apparent in the 1945-46 seasons probably reflects the record season in 1945, together with the influx of returned servicemen.

TABLE 4. Number of full-time and part-time whitebaiters on the Waikato River, 1931-50. (N.Z. Marine Department 1932-51.)

Year	No. of whitebaiters	
	Full-time	Part-time
1931	120	50
1932	90	50
1933	60	50
1934	60	50
1935	70	50
1936	70	50
1937	70	50
1938	100	50
1939	80	40
1940	100	50
1941	80	50
1942	100	50
1943	100	50
1944	-	-
1945	200	250
1946	210	-
1947	127	70
1948	120	60
1949	130	65
1950	140	80
Mean	107	65

- = no data.

#### 4.3 Value of the Catch

Whitebait are the most highly priced fish in New Zealand. In 1984, galaxiids retailed at more than \$40 per kg and smelt at \$20 per kg. Given these figures and the estimated catch weights (Table 2), the potential value of the catch would have exceeded \$408,000 in 1984 and \$538,000 in 1985.

#### 4.4 Species Composition of the Galaxiid Catch

Inanga were the most common species in the galaxiid catch, making up 85.2% of the samples obtained during the 1984 season and 92.7% of those in 1985 (Table 5). They were the only species found in pre-season samples (16-28 July 1984).

Banded kokopu were a minor component of the samples (14.6% in 1984, 7.2% in 1985). In 1984, however, several samples taken between mid September and early October contained up to 74% of this species. They appeared first in late August and were most abundant in September. Their number declined during October.

Koaro appeared early in September, and were present sporadically until mid October. This species made up less than 0.2% of whitebait sampled (Table 5).

Only 2 specimens of giant kokopu were identified. They were found in samples from 24 and 28 October 1985.

Variations in the species composition of samples obtained from different sources on the same day are shown in Table 6. When the percentage of inanga was high, a single sample adequately described the species composition of the catch. However, when banded kokopu were abundant, this was not the case (e.g. 18 September-5 October 1984).

Accurate records of daily catch were needed to determine the weight of inanga and banded kokopu in the galaxiid catch. The buyers' and fisherman's daily catch data were significantly correlated ( $P < 0.01$ , Spearman's rank correlation. See Appendices III, IV, and V). Therefore, fluctuations in catch were well represented by the buyers' tallies, and their combined tallies were used in the analysis.

TABLE 5. Species composition of the galaxiid whitebait catch from the Waikato River, 1984 and 1985.

Year	Month	Inanga		Galaxiid species				Giant kokopu		No. of samples
		no.	%	Banded kokopu no.	%	Koaro no.	%	no.	%	
1984	Jul*	2 044	100.0	0	0.0	0	0.0	0	0.0	6
	Aug	2 334	99.1	21	0.9	0	0.0	0	0.0	5
	Sep	6 395	76.3	1 962	23.4	19	0.2	0	0.0	23
	Oct	7 352	90.4	771	9.5	12	0.1	0	0.0	22
	Season	16 081	85.2	2 754	14.6	31	0.2	0	0.0	50
1985	Aug	4 956	97.9	108	2.1	0	0.0	0	0.0	13
	Sep	3 910	86.1	625	13.8	6	0.1	0	0.0	11
	Oct	4 565	93.3	320	6.5	7	0.1	2	0.04	11
	Nov	264	98.5	4	1.5	0	0.0	0	0.0	1
	Season	13 695	92.7	1 057	7.2	13	0.1	2	0.01	36

\* = samples taken outside the open season.

TABLE 6. Variation in the percentage of inanga in samples from the Waikato River when 2 or more samples were taken on the same day.

Date	Fisherman left bank		Fisherman right bank %	Buyer 1 %	Buyer 2 %
	%	%			
13/8/84	100	-	100	-	-
9/9/84*	97	93	94	95	-
12/9/84	91	-	89	-	-
18/9/84	25	-	55	-	-
20/9/84	56	-	79	-	-
22/9/84	89	-	71	87	-
24/9/84	86	-	94	-	-
28/9/84	75	-	-	57	-
5/10/84	33	-	-	97	-
10/10/84	97	-	93	-	-
12/10/84	95	-	87	-	-
24/10/84	99	-	98	-	-
26/10/84	98	-	96	-	-
28/10/84	93	-	93	-	-
8/8/85	-	-	-	100	100
17/8/85	99	-	-	98	-
12/9/85	-	-	-	92	80
18/9/85	85	-	-	-	89
29/9/85*	88	90	88	-	-
3/10/85	88	-	-	97	-
13/10/85	99	-	98	97	99

\* = 2 left bank samples taken on the same day.

The percentage by weight of inanga in the galaxiid catch was 92.6% in 1984 (6670 kg) and 93.6% in 1985 (10 530 kg). Banded kokopu made up 7.4% of the catch weight in 1984 (530 kg) and 6.4% in 1985 (720 kg).

#### 4.5 Size at Migration

Smelt were significantly larger ( $P < 0.001$ , ANOVA) than other species in the whitebait catch (Table 7, Fig. 4). Inanga and koaro were similar in size, except that the latter were shorter than inanga in 1984 ( $P < 0.05$ ), and longer in 1985 ( $P < 0.01$ ). Both species were significantly larger than banded kokopu.

The mean length of inanga and banded kokopu varied within each season (Fig. 5, and Appendices VI and VII). Banded kokopu were smallest in October, and, in 1985, the mean length decreased steadily from late September.

TABLE 7. Mean length and weight of whitebait from the Waikato River, 1984 and 1985 seasons.

Mean	Inanga		Banded kokopu		Koaro		Smelt	
	1984	1985	1984	1985	1984	1985	1984	1985
Total length (mm)	50.04	49.91	41.19	41.10	49.38	50.68	54.14	54.95
S.D.	2.10	1.74	1.45	1.37	1.83	1.55	3.27	1.72
Weight (g)	0.35	0.40	0.26	0.28	0.50	0.56	0.74	0.84
S.D.	0.06	0.06	0.04	0.04	0.09	0.09	0.19	0.12
No. measured	1 306	1 100	727	537	52	101	226	124

Annual differences in length-weight relationships were apparent for all species, with the condition of whitebait being better in 1985 than in 1984 (Fig. 6, and Appendices VIII-XII). Condition factors also changed with season, and whitebait were usually in best condition during September (Appendices VIII-XII).

#### 4.6 Variation in the Timing of Migration

In 1984, only 5.5% of the inanga catch was taken in August (Fig. 7). Peak migration occurred from 7-18 October. In 1985, their migration began 2 weeks earlier, and 31% of the catch was taken in August. Peak migration occurred from 12-27 September.

Because inanga dominate the galaxiid catch in the Waikato, their migration pattern is reflected in the seasonal distribution of the total galaxiid catch. Buyer's records for the 1979-85 seasons (Fig. 8) show that runs often took place in August, but major migrations occurred during either September or October. Migration had usually ceased by early November.

Migration of banded kokopu began early in September in 1984, and in mid August in 1985. However, peak migration occurred from mid to late September in both years (Fig. 7).

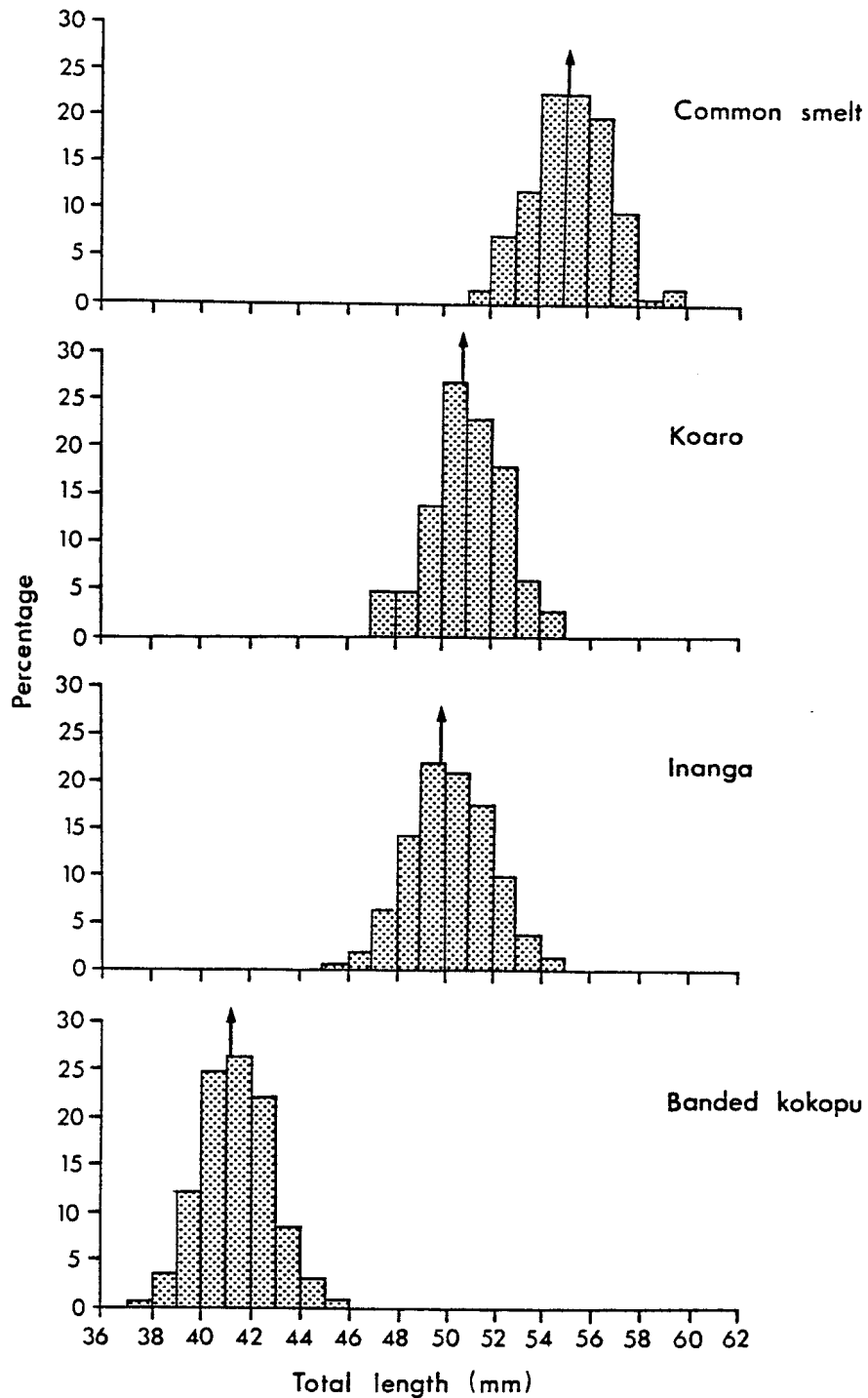


FIGURE 4. Length-frequency distribution of whitebait from the Waikato River, 1985. Arrows indicate mean length.

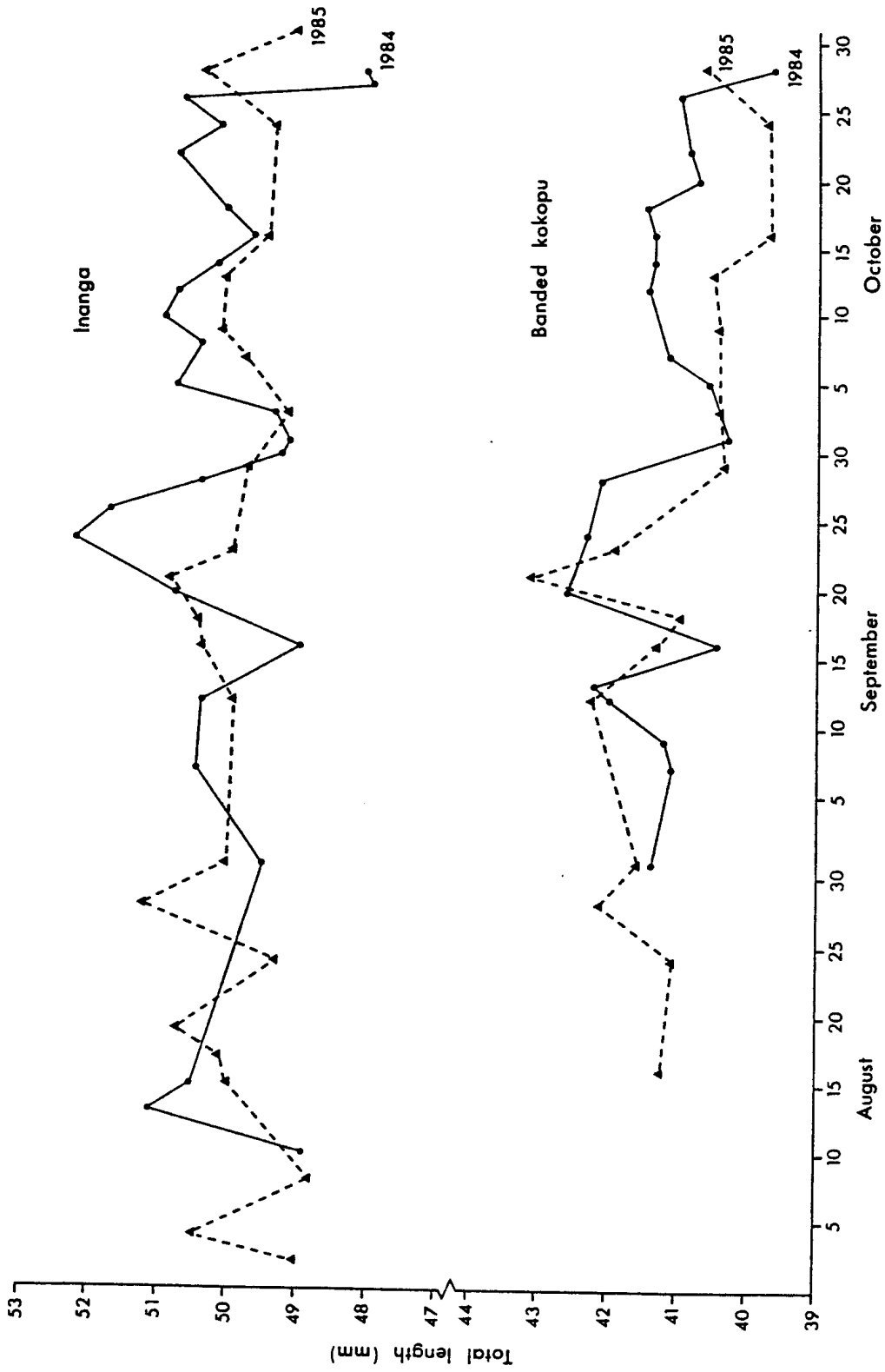


FIGURE 5. Seasonal variation in the mean length of inanga and banded kokopu from the Waikato River, 1984 and 1985.

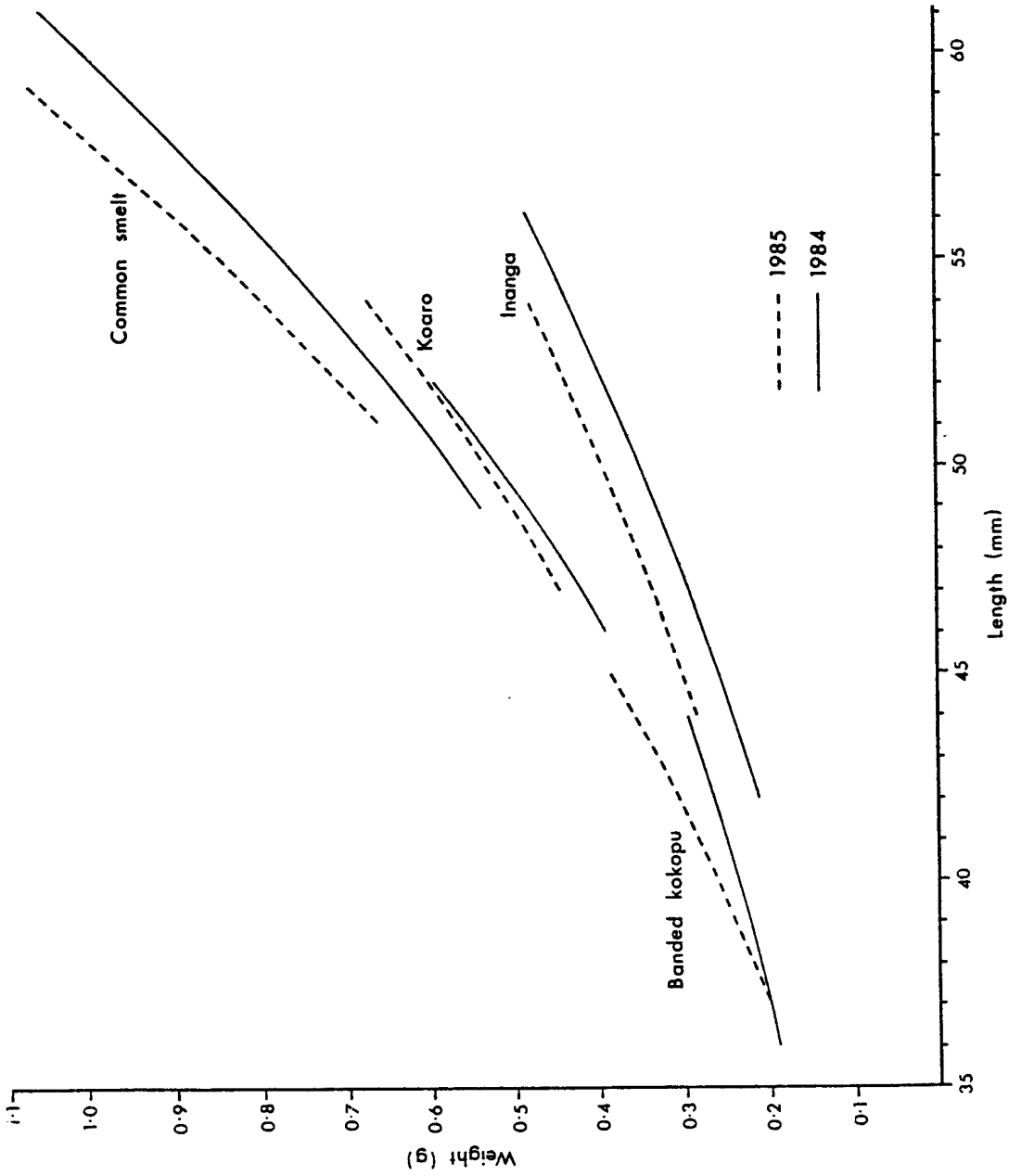


FIGURE 6. Variation in length-weight relationships of whitebait species from the Waikato River, 1984 and 1985.

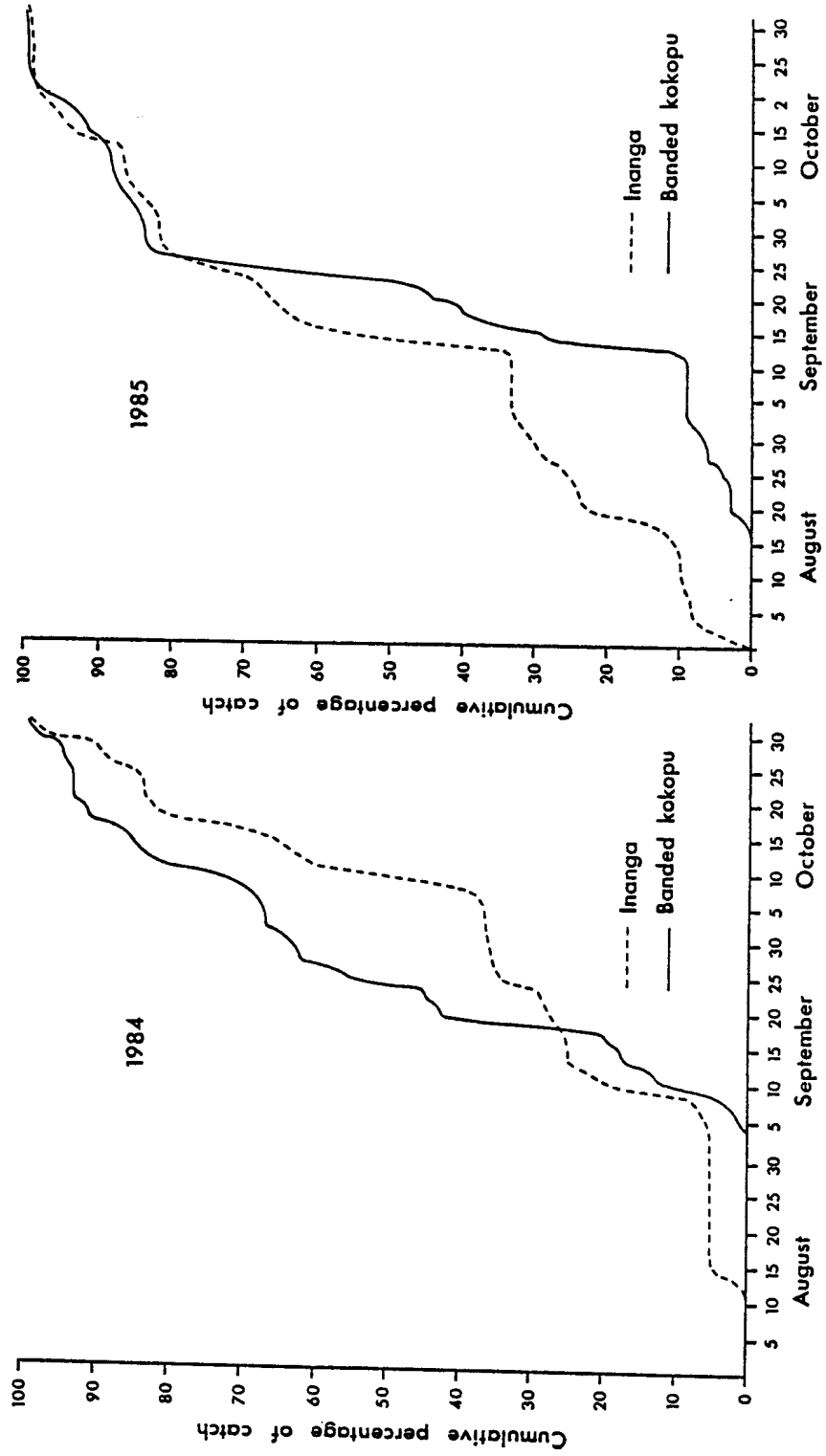


FIGURE 7. Seasonal distribution of catch of inanga and banded kokopu from the Waikato River, 1984 and 1985.

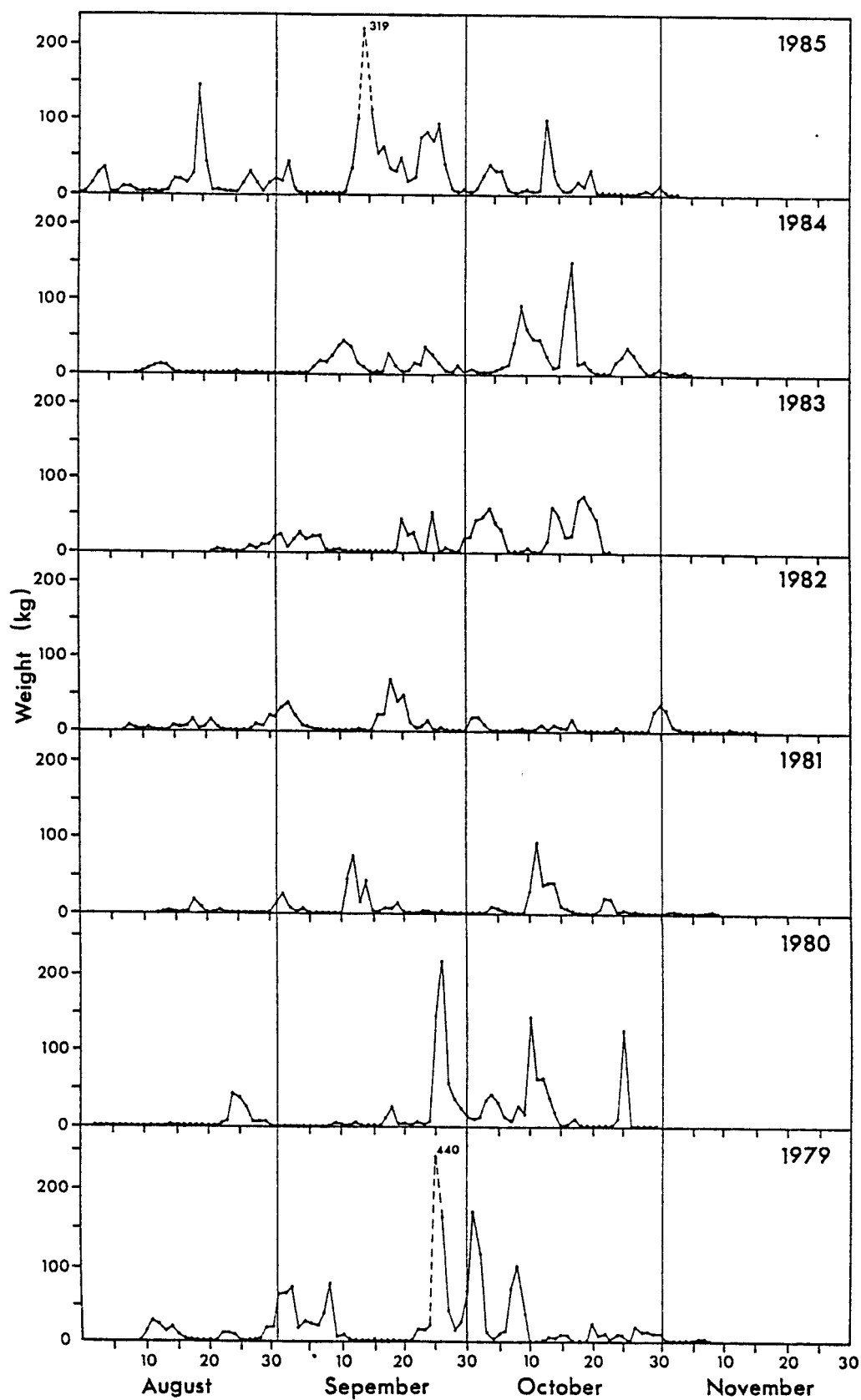


FIGURE 8. Daily purchases of galaxiid whitebait (Buyer 2) from the Waikato River, 1979-85.

Migration of koaro peaked in late September in 1984 and in early October in 1985. Giant kokopu were present only during late October.

Buyer's records show that there was virtually no smelt migration in August (Fig. 9). Major runs occurred during September and October, and in some years, substantial migrations continued on into November.

Historical records (Table 8) show that fishing normally began in July. The best catches of galaxiid whitebait and smelt were most frequently taken in September.

#### 4.7 Environmental Factors Affecting Whitebait Migration

##### 4.7.1 Tide Height

Daily galaxiid catch and tidal height were significantly correlated in 4 out of 7 years (Table 9). The correlation was positive in 1980, 1982, and 1985 (large catches were taken close to spring tides), and negative in 1983 (large catches were taken close to neap tides). In 1980, all of the major runs occurred during spring tides (Fig. 10). Although the 1981 correlation was not significant, large runs occurred during periods of increasing tidal height 4-5 days before spring tides.

The smelt catch fluctuated greatly from day to day (Fig. 11). Correlations between catch and tide were significant and positive in 1979 and 1982, and negative in 1981 (Table 9).

##### 4.7.2 River Flow and Rainfall

In several years, galaxiid and smelt catches were negatively correlated with high river flows (Table 10), which indicates that catches were low at the height of floods. Whitebait runs usually occurred when river levels were falling (Figs. 10 and 11).

When floods occurred in conjunction with spring tides, catches increased on the following neap tides, such as 23-25 August 1979 (Fig. 10) and 5-10 October 1983 (Figs. 10 and 11). River flows were usually stable or declining slowly when runs occurred close to spring tides (e.g., galaxiid catch 1980, smelt catch 1982).

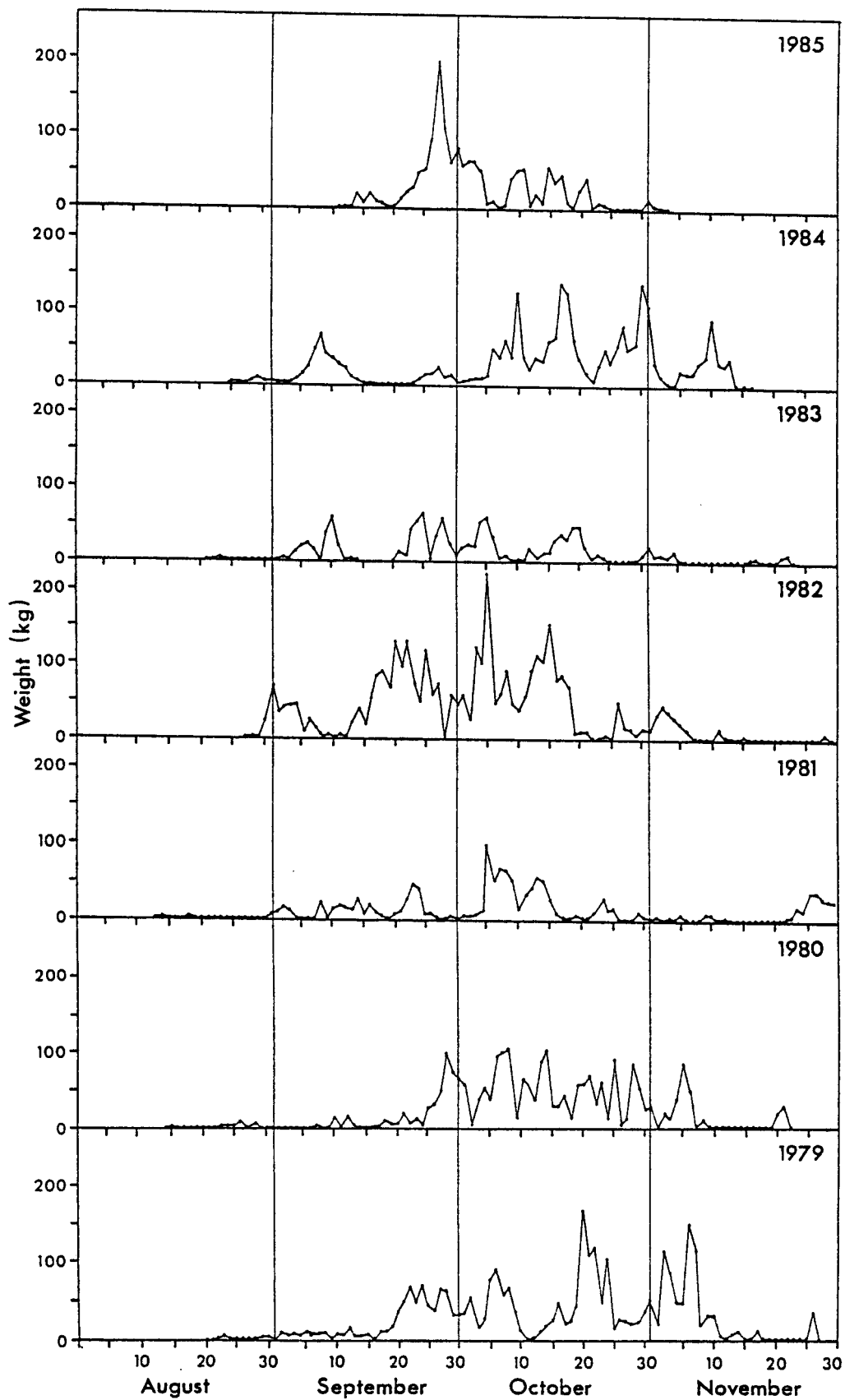


FIGURE 9. Daily purchases of smelt (Buyer 2) from the Waikato River, 1979-85.

TABLE 8. Timing of whitebait migrations into the Waikato River, 1931-50. (N.Z. Marine Department 1932-51.)

Year	Fishing began	Best period
1931	28 June	September
1932	3 June	September
1933	1 July	September
1934	22 July	Early October
1935	1 July	September
1936	July	September
1937	July	September
1938	1 July	September
1939	-	-
1940	1 July	September
1941	3 July	September and November
1942	27 July	October
1943	-	September
1944	July	November
1945	July	September
1946	July	September-October
1947	-	September
1948	-	September
1949	-	September-October
1950	-	August-October

- = not recorded.

TABLE 9. The significance of correlations (Pearson product moment) between daily whitebait catch and tidal height (predicted maximum) for the Waikato River, 1979-85 seasons.

Year	Galaxiid catch			Smelt catch		
	r	P	n	r	P	n
1979	0.025	NS	92	0.395	**	89
1980	0.415	**	66	0.100	NS	80
1981	0.097	NS	84	-0.207	*	93
1982	0.241	*	84	0.217	*	81
1983	-0.263	*	63	0.198	NS	67
1984	-0.060	NS	88	-0.035	NS	83
1985	0.251	*	95	0.041	NS	58

n = number of days compared.

NS = not significant.

\* = P < 0.05.

\*\* = P < 0.01.

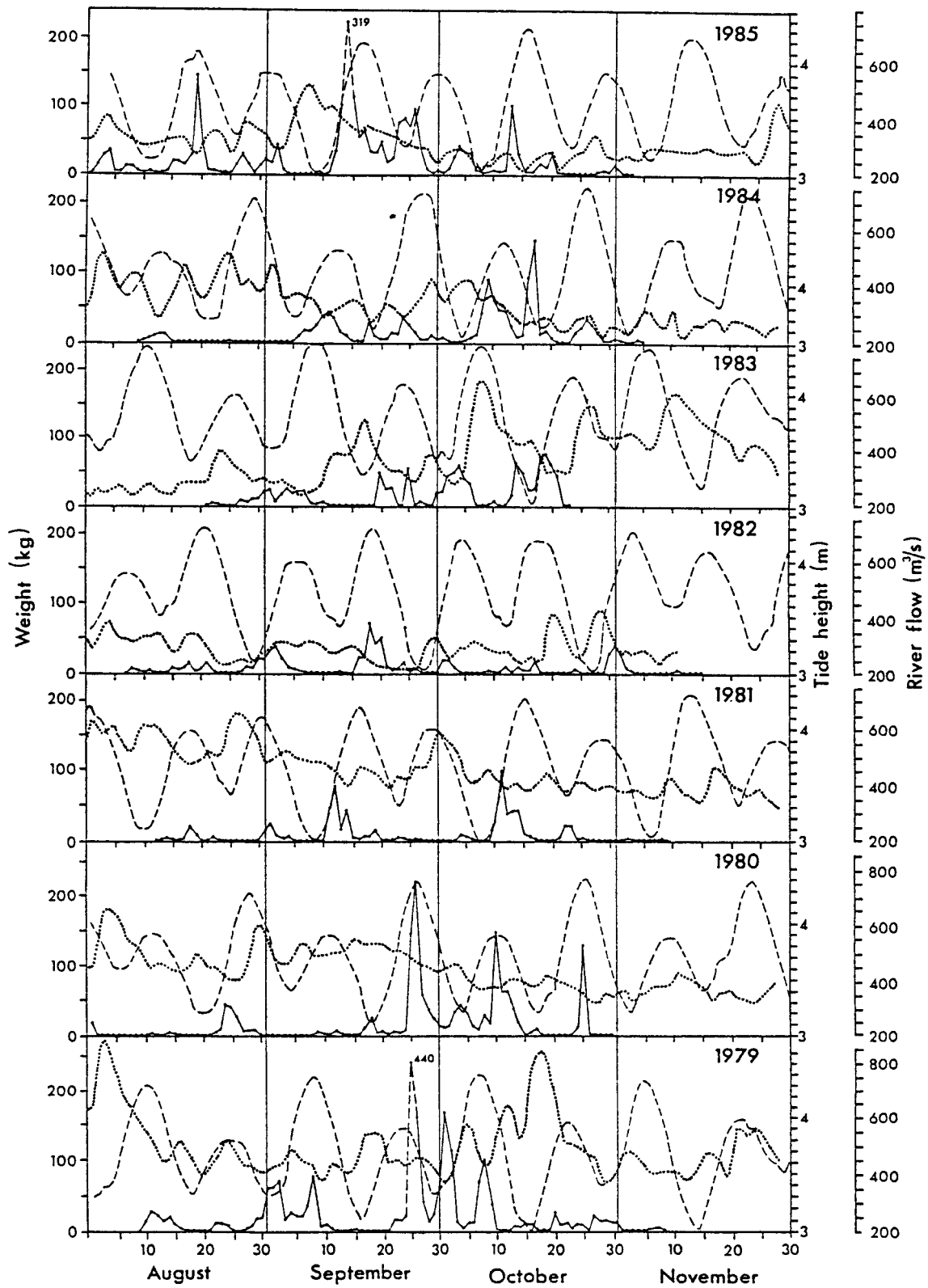


FIGURE 10. Relationship between galaxiid catch (solid lines), predicted tide height (dashed lines), and mean river flow (dotted lines) for the Waikato River, 1979-85 seasons.

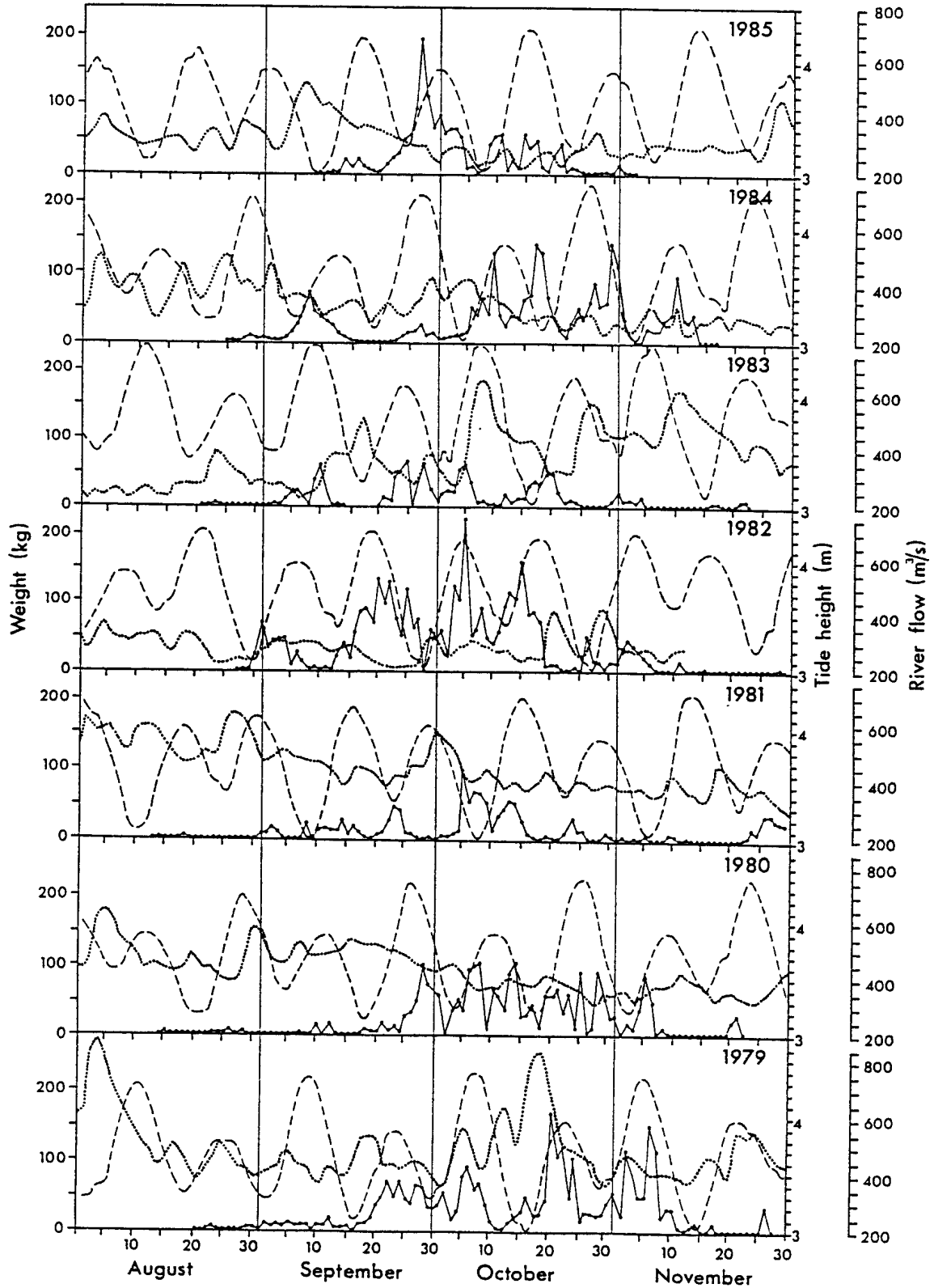


FIGURE 11. Relationship between smelt catch (solid lines), predicted tide height (dashed lines), and mean river flow (dotted lines) for the Waikato River, 1979-85 seasons.

TABLE 10. The significance of correlations (Pearson product moment) between daily whitebait catch and mean daily river flow for the Waikato River, 1979-85 seasons.

Year	Galaxiid catch			Smelt catch		
	r	P	n	r	P	n
1979	-0.181	NS	92	0.165	NS	89
1980	-0.231	NS	66	-0.459	**	80
1981	-0.227	*	84	-0.139	NS	93
1982	-0.217	*	84	-0.387	**	81
1983	-0.234	NS	63	-0.441	**	67
1984	-0.237	*	88	-0.382	**	83
1985	0.058	NS	95	-0.198	NS	58

n = number of days compared.

NS = not significant.

\* = P < 0.05.

\*\* = P < 0.01.

The first migration of galaxiid whitebait during each season followed freshes and floods (Fig. 10), but the catch did not increase after every flood early in the season (e.g., August 1980, 1981, and 1984), and there was little response to late season floods (e.g., October 1983).

Comments in Marine Department reports indicated that poor whitebait seasons often followed autumn droughts (March-May), or occurred when rivers were either very low or very high during spring (August-November).

Of the 8 years when poor catches were recorded, 5 coincided with an abnormally low rainfall (<215 mm total) in the estuary during the previous autumn, 1 with low spring rainfall, and 1 with extensive spring flooding (Table 11).

Correlations between the previous autumn's rainfall and whitebait catch were significant (Table 12), which indicates that the rainfall in the estuary being low at a time when inanga spawn did affect the whitebait catch. A similar relationship existed between autumn river flow and catch. Correlations between spring rainfall and catch, and river flow and catch, were not significant.

TABLE 11. Relationship between rainfall in the Waikato Estuary, mean river flow, and total whitebait catch, 1931-50 and 1968-85.

Year	Autumn		Spring		Estimated catch (kg)
	Rainfall (mm)	River flow (m <sup>3</sup> /s)	Rainfall (mm)	River flow (m <sup>3</sup> /s)	
1931	319	-	502	-	60 124
1932	395	-	257*	-	26 167**
1933	435	-	364	-	19 651**
1934	290	-	332	-	32 836
1935	396	-	474	-	40 931
1936	199*	-	504	-	52 385+
1937	328	-	313	-	47 396
1938	341	-	365	-	59 615
1939	191*	-	431	-	16 393**
1940	284	-	382	-	55 135
1941	339	-	519	-	92 960
1942	215*	-	417	-	24 538**
1943	172*	-	388	-	24 538**
1944	502	-	355	-	54 625
1945	394	-	337	-	113 935
1946	358	-	600	-	40 473
1947	313	-	440	-	45 156
1948	454	-	586	-	44 889
1949	352	-	334	-	48 313
1950	154*	-	399	-	21 840**
1968	474	325	553	441	26 472
1969	279	281	302	323	27 847
1970	337	190	711	520	12 422
1971	287	212	688	545++	3 564**
1972	522	344	330	369	20 262
1973	303	198	442	344	10 200
1974	200*	187	374	423	4 400**
1975	434	273	426	450	9 800
1976	344	310	597	534	16 725+
1977	447	271	429	430	17 000
1978	278	-	489	344	16 593
1979	372	374	559	493	16 678
1980	288	328	474	433	12 639
1981	364	295	509	452	8 981
1982	370	271	333	281	10 018
1983	356	223	413	376	11 698
1984	361	263	376	326	13 213
1985	-	256	-	309	15 653

- = no data.

\* = low autumn or spring rainfall.

\*\* = poor catch.

+ = large smelt catch.

++ = extensive spring flooding.

TABLE 12. The significance of correlations (one-tailed t-test) between rainfall in the Waikato Estuary, mean river flow, and total whitebait catch, 1931-50 and 1968-85. Data for the 2 periods were treated separately because of large differences in catch.

	Catch					
	r	1931-50 <sup>+</sup> (n = 20) t-test	P	r	1968-85 (n = 20) t-test	P
Autumn rainfall	0.340	1.77	*	0.424	2.16	*
Autumn river flow	-	-	-	0.583	3.48	**
Spring rainfall	0.096	-	NS	-0.201	-	NS
Spring river flow	-	-	-	-0.219	-	NS

+ = river flow data not available.

\* = P < 0.05.

\*\* = P < 0.01.

NS = not significant.

#### 4.7.3 River Temperature

There were no continuous records of river temperature for the Waikato Estuary, but monthly measurements were available for the Elbow. A linear relationship was found to exist between the Elbow records (1979-85) and measurements made at Huntly at 0800 hours (Fig. 12). River temperatures recorded by the fisherman during the 1984 season show that fluctuations at Huntly also occurred in the estuary (Fig. 13), the relationship being  $T_{\text{Estuary}} = 1.196 T_{\text{Huntly}} - 1.16^{\circ}\text{C}$  ( $r = 0.974$ ). Huntly data were therefore used to estimate temperatures in the estuary.

During the 1979-85 seasons, the river temperature at the Elbow was between  $10.4^{\circ}\text{C}$  and  $11.7^{\circ}\text{C}$  when the migration of galaxiid whitebait began. This temperature range did not represent a threshold for migration, as it was often exceeded in the weeks before migration. Migration ceased when the temperature was between  $15.5^{\circ}\text{C}$  and  $18.4^{\circ}\text{C}$ . Smelt migration began when the temperature was between  $10.7^{\circ}\text{C}$  and  $13.3^{\circ}\text{C}$ , and ceased between  $17.1^{\circ}\text{C}$  and  $19.8^{\circ}\text{C}$ .

River temperature rose gradually during the season until late October, when the rise was more rapid. Correlations (Pearson product moment) between temperature and catch were significant ( $P < 0.05$ ) in

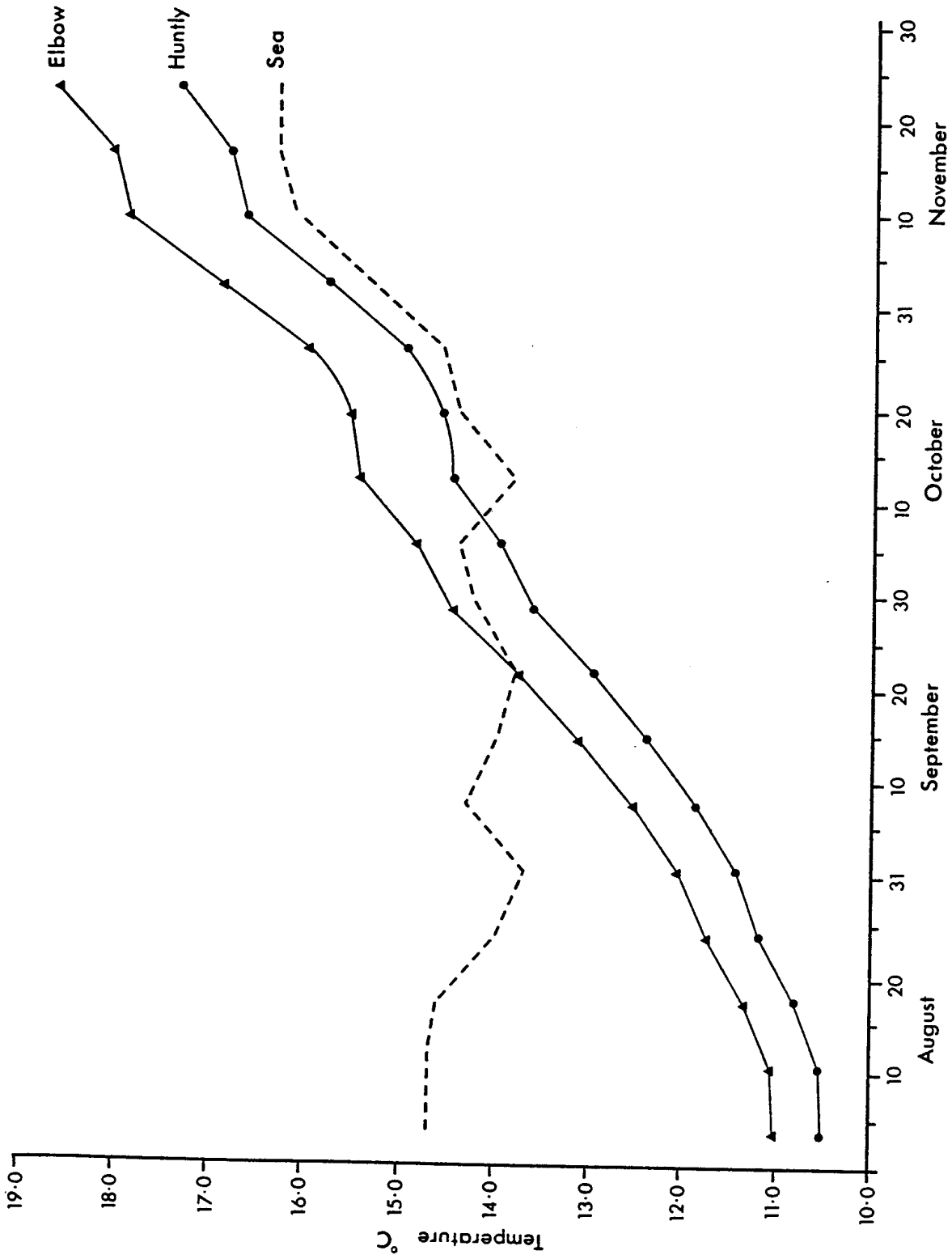


FIGURE Weekly mean river temperature at Huntly and the Elbow, and weekly mean sea temperature in the Manukau/North Taranaki Bight, 1979-85 seasons.

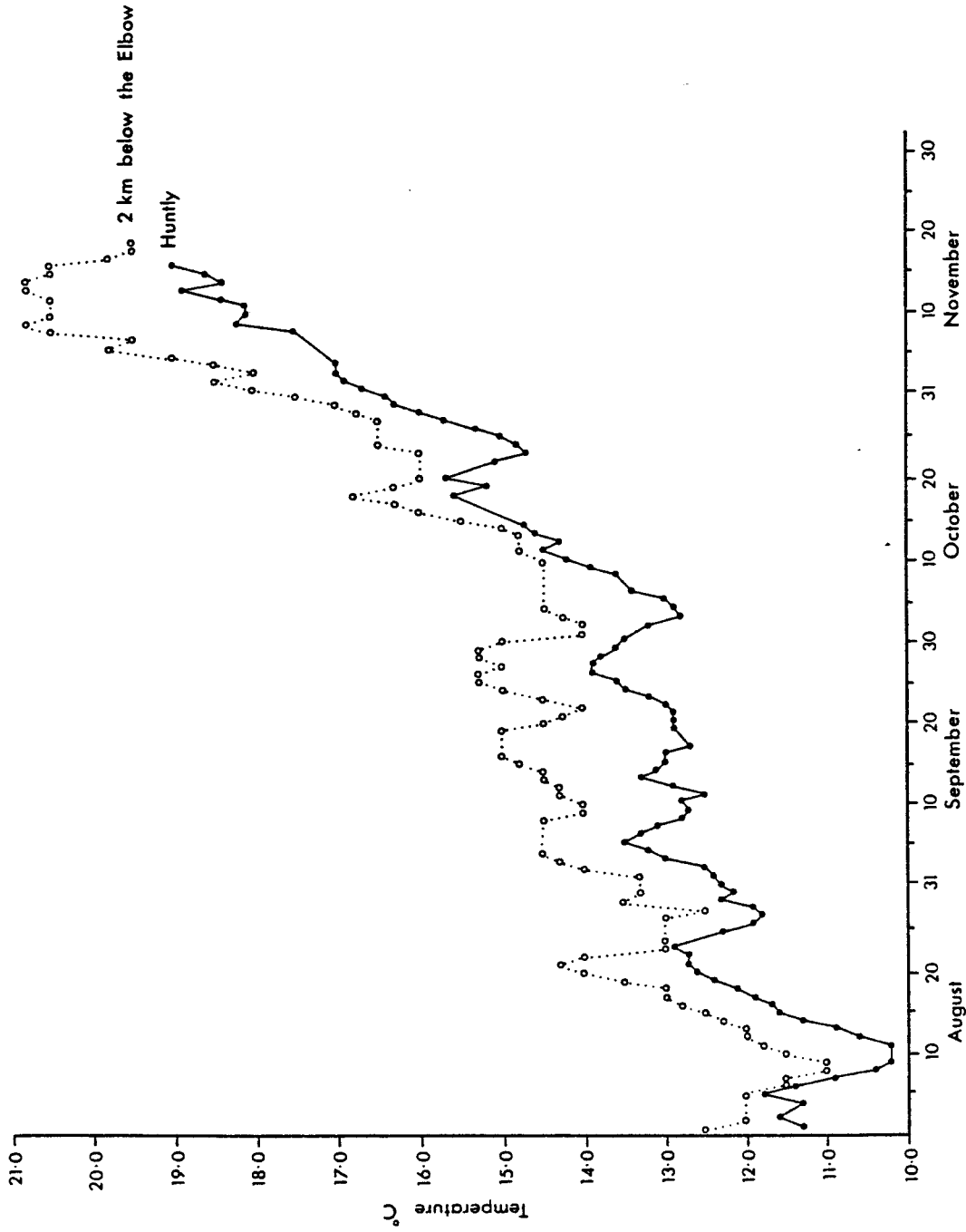


FIGURE 13. Waikato River temperature at Huntly and 2 km below the Elbow, 1984 whitebait season.

years when catch also increased as the season progressed. However, there was no evidence that temperature fluctuations caused fluctuations in catch.

The Waikato River was cooler than the sea during August and September (Fig. 12), so whitebait were migrating into cooler water at this time. By early October, they were migrating into warmer water.

## 5. DISCUSSION

### 5.1 Size of the Catch

Concern was expressed as early as the 1890s that New Zealand's whitebait fisheries were declining (Clarke 1899). Several times in the late 1920s and 1930s, the Marine Department reported that a general decline had occurred, and that overfishing was considered to be the primary cause. However, McDowall and Eldon (1980) found that there were broad, naturally-occurring fluctuations in whitebait fisheries, so that poor seasons did not necessarily mean that the fisheries were in decline.

With regard to the Waikato whitebait fishery, Mr E. C. Frost (founder of the Tuakau cannery) stated in 1927 that "good as it is, the fishery has deteriorated in comparison with the past" (N.Z. Marine Department 1929). Although there may have been a decline prior to the inception of records in 1931, none was apparent during the 1931-50 period. When records were again available (1968-85), the catch had decreased substantially. This suggests that a major decline in the fishery occurred after 1950.

Limited data indicate that smelt as well as galaxiid whitebait have declined. In 1936, a good season produced at least 31 400 kg of smelt, (N.Z. Marine Department 1937), but by 1976 only 12 850 kg were caught in a good season. Mr. L. Henry, a buyer from 1945 to the mid 1950s, and his successor Mr M. Keary, both agree that the smelt catch has decreased.

The fishery has been affected recently by the implementation of flood protection schemes from 1961 to 1982. Extensive areas of stopbanking, with flood gates and pumping stations, now exist along the lower Waikato River (Fig. 1). Roughly half the original area of flood

plain is now directly protected (Mulholland 1983), and a large amount of swamp has been converted into pasture (Harris 1983).

Major works were carried out in the Aka-Aka/Otaua area, where Henry (1959) observed inanga spawning, and further additions to that scheme are being considered (Mulholland and Knighton 1986).

Whitebait have been denied access to Lake Waikare since 1965, when control gates were installed (McLea 1986), and fish migration into Lake Waahi has been restricted by flood gates since 1978 (Kingett and Associates 1984).

Increased sand abstraction from the river since 1958 has caused the mean bed level at Mercer to drop by 1.3 m. This, in turn, has lowered the water level in the Whangamarino Swamp (Mulholland 1983). From 1974, work on the main channel has increased the channel capacity (Loveridge 1981) at the expense of the margins and backwaters.

These developments have all resulted in a loss of fish habitat, which McDowall (1984) considered to be the real cause of the decline in whitebait fisheries. The decrease in water quality of the Waikato River, which continued at least until the early 1970s (McBride and Rennés 1981), may also have affected the fishery.

A further decrease in catch is likely unless habitat is conserved and restored. For example, the provision of a fish pass on the outlet of Lake Waikare would substantially increase the habitat available to whitebait. Access to other waterways controlled by flood gates, and retention of backwater and margin habitats in the main river, are also a priority.

## 5.2 Number of Whitebaiters

Since 1950, the number of full-time whitebaiters has decreased while the number of those involved in recreational fishing has increased 10-fold. Up to 1000 whitebaiters may now be present on peak days. Full-time fishermen often predominate during the week, but on weekends, school holidays, or when word of a run has spread, recreational whitebaiters predominate. People from as far away as Tauranga visit the river each season. Local farmers often fish between milkings, and a substantial number of retired people utilise the resource.

### 5.3 Value of the Waikato Whitebait Fishery

The Waikato whitebait fishery has been an important economic resource for more than 100 years. In 1927, the N.Z. Herald reported that, on average, the industry on the Waikato was worth 10 000 pounds annually (N.Z. Marine Department 1929). McDowall (1968) found that the price of whitebait had risen steadily, but more rapidly than the cost of living, since the mid 1940s. When today's retail prices are adjusted for the consumer price index, it is apparent that the real value of galaxiid whitebait has more than doubled since McDowall's study was done. Therefore, although the catch from the river has declined, its real value has increased.

No one has assessed the economic impact of whitebait fisheries on the local communities. Outlay by Waikato whitebaiters includes the initial cost of nets and/or replacement mesh, that of materials used in construction and maintenance of stands and screens, and that of travel and accommodation. Large sums of money are also invested in the many baches on the river and in the boats used to gain access to the stands.

The Waikato River and its fisheries have long been of spiritual, economic, and recreational value to the Tainui people (Mahuta 1984). In pre-European times, whitebait were an important traditional food source (Best 1929, McDowall 1984). The cash economy which developed after European settlement meant that the fishery also became a major source of income. Tainui people from throughout the Waikato have retained their close association with the fishery, and buyers state that the full-time fisherfolk are still predominantly Maori.

### 5.4 Species Composition of the Galaxiid Catch

Buyers' records (1974-85) show that galaxiid whitebait averaged 56% of the total catch by weight, while smelt averaged 44%.

In 1984 and 1985, inanga were the numerically dominant galaxiid species (85.2% and 92.7%), while banded kokopu were a minor component (14.6% and 7.2%). Koaro and giant kokopu contributed little to the catch.

When the species composition of the galaxiid catch was calculated on the basis of weight rather than number, the contribution of banded

kokopu decreased from 14.6% to 7.4% in 1984 and from 7.2% to 6.4% in 1985. A factor contributing to this decrease was that banded kokopu weigh 30% less than inanga. However, the major cause in 1984 was the predominance of banded kokopu during periods of high sampling effort but low whitebait catch.

McDowall (1965) analysed 49 samples of whitebait collected from the Waikato River between mid August and mid November 1964. At this time, the sample composition by number was 98.1% inanga, 1.6% banded kokopu and giant kokopu, and 0.3% koaro.

Banded kokopu made up a greater proportion of the catch in 1984 and 1985 than in 1964. This change in species composition may simply reflect annual variation in relative abundance, but could also be due to a loss of habitat for inanga.

In the Waikato catchment, inanga habitat has been extensively reduced since 1960 by the implementation of flood protection schemes and the drainage of lowland swamp. Populations of banded kokopu are usually associated with forest cover (McDowall 1970b, 1982; Main *et al.* 1985). Therefore, banded kokopu habitat was reduced by timber milling, which began in the catchment during the late 1800s (Kingett and Associates 1984) and was substantially complete before the 1960s. Consequently, habitat loss has affected inanga more than banded kokopu since McDowall's 1964 survey was done.

### 5.5 Size at Migration

Smelt are the largest species in the whitebait catch, making up a greater proportion of the total catch by weight than by number. For example, in 1984, smelt made up 45.5% of the catch by weight, but 3 times as many galaxiid whitebait were caught in that year.

All species from the Waikato were in better condition in 1985 than in 1984. Had the same number of galaxiid whitebait been caught in each year, the weight of the galaxiid catch would have increased by 14.3% in 1985. McDowall and Eldon (1980) found that a decline in the size and condition of inanga accounted for a drop in catch of 25.6% from 1970 to 1971. They considered that the condition of whitebait is determined by the environment encountered at sea, with growth being slower and

mortality probably higher when food supplies or other factors are limiting.

#### 5.6 Variation in the Timing of Migration

No major changes in the timing of whitebait migration have occurred in at least the last 60 years. In 1929, the Marine Department proposed that commercial whitebaiting should be restricted to the period from 15 August to 31 October in the North Island. Most migration still occurs within this period.

Migrating inanga enter the Waikato River from at least July to November, with the largest catches being taken between early September and late October. This is slightly earlier than that found on the west coast of the South Island (McDowall and Eldon 1980).

Banded kokopu were most abundant in the Waikato during September, which is similar to the timing of migration into eastern Bay of Plenty rivers (Saxton *et al.* 1987). In South Westland, the largest catches were taken during late October and early November (McDowall and Eldon 1980).

An important factor determining the timing of peak migration may be the time of peak larval emergence. Banded kokopu larvae are known to hatch and move downstream during floods (Ots and Eldon 1975). Comparison of flows in the Waikato River from March to June in 1984 and 1985 shows that floods occurred at similar times. In both years, major runs of banded kokopu whitebait occurred over the same period.

The timing of inanga migration may also be related to the timing, intensity, and success of spawning by the adult fish. Inanga spawn amid vegetation which is covered by water only at high spring tides, and the eggs hatch when re-immersed by a later spring tide. Benzie (1968a) found that, during very high tides in 1960, inanga deposited their eggs high above the normal spawning areas. The eggs were never re-immersed, resulting in total loss of the spawning. Floods can also cause mortality by smothering the eggs with silt before they are ready to hatch (C.P. Mitchell pers. obs.). Such events could contribute to variations in the pattern of migration.

Catch records from the Waikato (Fig. 9) show that there were periods during each season when little migration occurred. One period in 1980 lasted from 27 August to 24 September. In that year, the mid-March spring tide when inanga were expected to have spawned measured 2.35 m at Hoods Landing (WVA records). However, the next 2 spring tides measured only 2.13 m and 1.77 m, and the eggs may not have been re-immersed. However, until we know the exact tides when spawning occurs and the location of spawning sites, we can only speculate about the effect of changes in tidal height and floods on spawning success, and thus on migration timing.

The abundance of larval smelt in the Waikato River appears to decline rapidly after floods (A.S. Meredith pers. comm.), which suggests that spawning success and the timing of smelt migration may be influenced by the size and frequency of floods during autumn and early winter. However, autumn floods in 1979 and 1981 did not alter the timing of smelt migrations during the following spring.

## 5.7 Environmental Factors Affecting Whitebait Migration

### 5.7.1 Tide, River Flow, and Rainfall

Whitebait migrations generally peaked close to spring tides, when the Waikato River flow was stable or declining. Catches were low at the height of floods, and runs occurring close to spring tides were sometimes interrupted by floods. Catches then increased when the river level fell. Not all peaks could be explained by tide or flow, and a large migration of both galaxiids and smelt occurred during stable flows and neap tides on 17 October 1984 (Figs. 10 and 11). A similar situation was found on the Rakaia River, where large catches were taken during or close to spring tides, but were interrupted by floods (Unwin and Davis 1983).

Benzie (1968a) and McDowall and Eldon (1980) found that large runs followed floods in South Westland rivers. As for the Waikato, the best catches were often taken with a fall in river level, and little migration occurred during peak flows, when turbidity was high. Their studies found no correlation between catch and tide.

McDowall and Eldon (1980) considered the initial inshore migration of whitebait to be a response to reduced salinity around river mouths.

The zone of reduced salinity increases greatly during floods, and increases also during spring tides. The Waikato River has a large estuary, and the outflow during spring tides may be sufficient to stimulate whitebait migration in the absence of flooding. Reduction in the size and duration of floods in the Waikato through retention of water for electricity generation could mean that the effects of tide on whitebait migration are more important now than they were in the past.

In the Waikato River, poor whitebait seasons generally followed autumn droughts. McDowall and Eldon (1980) found no correlation between total monthly rainfall and catch for South Westland rivers, but suggested that low rainfall during autumn may cause mortality among inanga eggs through the effects of desiccation. Indeed, Benzie (1968a) found that inanga eggs were killed by desiccation during hot periods, if the grass on spawning areas had been cropped short by cattle. Because air temperatures in the Waikato are 1-3°C warmer than those found in Benzie's study (N.Z. Meteorological Service records 1940-70), egg desiccation may be an important factor during droughts.

In 1936, the Waikato whitebait catch was relatively high (52 385 kg) despite a low rainfall in the previous autumn. In that year, smelt made up more than 60% of the total catch (N.Z. Marine Department 1937). Because smelt have "in river" spawning which appears to be more successful during low or stable autumn river flows, large smelt catches might be expected in years with a dry autumn or no floods. This was so in 1976, but not in 1982 and 1983, when stable autumn flows did not produce large catches. This suggests that other factors, such as the size of adult spawning stocks and conditions for growth in the sea (McDowall and Eldon 1980), were important in those years.

Abnormally low river flows during autumn may indirectly affect the size of the catch by dampening the productivity of coastal waters at a time when the larvae are going to sea. Fresh water flowing into the ocean produces strong circulating currents which bring nutrients closer to the surface, thus enhancing biological productivity (Heath and Shakespeare 1977).

#### 5.7.2 River Temperature

We found no evidence that fluctuations in the temperature of the Waikato River affected the day-to-day migration of whitebait. Benzie

(1968b) and McDowall and Eldon (1980) reached similar conclusions for other rivers.

The Waikato River temperature rose above the sea temperature in early October, so that, during the season, galaxiid whitebait and smelt migrated into both colder and warmer water. In South Westland rivers, whitebait moved into colder water throughout the period of migration (McDowall and Eldon 1980). In these southern rivers, migration usually ceased by mid November, only 1 or 2 weeks later than on the Waikato River. This suggests that the relationship between sea and river temperature is not important in determining the timing of migration.

Studies of the effects of the cooling water discharges from Huntly and the proposed Clune Road thermal power station (Rutherford 1985) predicted that in a low flow year, the river temperature in the estuary during winter would be 0.5-1.0°C above the ambient temperature. Such an increase is unlikely to have a direct effect on the timing of whitebait migration.

An increase in river temperature could affect the timing of migration indirectly by changing the time taken for whitebait to mature and spawn. Langford (1972) reported an advance in spawning time for some fish species living in thermal plumes. It is well known that an increase in temperature can shorten egg development time (Bagenal and Braum 1968, Benzie 1968c). This may be important for the large numbers of smelt which lay their eggs on sandbars downstream from the power station sites.

## 6. CONCLUSION

In recent years, the Waikato whitebait fishery has become increasingly popular with recreational whitebaiters, but it continues to hold strong traditional and economic ties for the Tainui people.

In spite of a decline in catch since 1950, the Waikato fishery for galaxiid whitebait still rivals the most productive rivers in South Westland, and the river supports the largest commercial smelt fishery in New Zealand. At present, the catch is stable at 10-15 tonnes, but without careful management of the river system as a whole and an

awareness that habitat modifications many kilometres from the estuary can still affect the fishery, the catch could decline even further.

The relatively small increase in temperature (0.5-1.0°C) predicted to occur in the estuary from the operation of the Huntly and proposed Clune Road thermal power stations, is unlikely to alter the timing of whitebait migration. However, the much greater increase which whitebait will encounter close to the power station sites will have the potential to adversely affect their upstream migration, and so to deny them an enormous area of habitat upstream.

## 7. RECOMMENDATIONS

### 7.1 River Temperature

The relatively large temperature increase (up to 6.5°C) which whitebait will encounter close to the power station sites will have the potential to affect the whitebait fishery by inhibiting the upstream migration of inanga and altering the spawning times for smelt.

#### Recommendation:

That the design and operation of thermal power stations minimise the rise in temperature which whitebait will encounter in the thermal plume.

### 7.2 Flood Gates and Culverts

Since 1965, whitebait have been denied access to Lake Waikare, the largest lake in the lower Waikato basin. Provision of a fish pass on the outlet would substantially increase the habitat available to whitebait species.

To offset the effects of increased flow in the river caused by Tongariro power development, Electricorp either partially or totally funded the construction of flood gates on the Awaroa River, the Aka-Aka and Otua Streams, and the Mawhitiwhiti and Eastern Drains adjacent to the estuary. Inanga are likely to spawn in these areas, but flood gates do restrict fish movement.

Recommendation:

That all flood gates and culverts in the lower Waikato catchment be inspected and modified if necessary to allow whitebait to gain access to streams and lakes bordering the river.

### 7.3 Habitat Protection

Since 1974, river retraining works, including willow clearing and berm widening, have been carried out to increase the channel capacity of the Waikato River. Although this decreases the threat of flooding, in the long term it reduces the productive margin and backwater habitats which are important feeding areas for inanga and smelt.

Recommendation:

That margin and backwater habitats in the main river be retained and enhanced.

### 7.4 Spawning Areas

Inanga spawn in the estuary amid vegetation which is normally submerged only by spring tides. This makes the eggs vulnerable to trampling by stock, river bank clearing, spraying operations, and smothering by oil-based pollutants. It is important that spawning areas are identified so that the impact of land development and pollution can be assessed.

Drain and willow clearing operations would have the least impact if they were carried out in mid winter, when most spawning has ceased and the juveniles have not yet entered the river in large numbers.

Smelt spawn on sandbars in the river. Although sandbars are widely distributed below Ngaruawahia, river training and sand extraction may already be affecting the success of smelt spawning. It is important to recognise the role of sandbars in the life cycle of this valuable whitebait species.

Recommendation:

That whitebait spawning areas be identified and protected.

### 7.5 Adult Habitat for Banded Kokopu

Banded kokopu make a significant contribution to the galaxiid whitebait catch. but major populations of adults have not been identified.

#### Recommendation:

That important habitats for banded kokopu be identified and protected.

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## APPENDIX I. Species composition by weight of the galaxiid catch.

The species composition, by weight, of the 2 numerically dominant species in the galaxiid catch was calculated for the 1984 and 1985 seasons from:

$$PW_a = \frac{C_{ai} t_i 100}{T} \quad \text{where:}$$

$PW_a$  = % by weight of species "a" in the catch;

$T$  = combined buyers' tallies representing total galaxiid catch for the season;

$t_i$  = galaxiid catch on day  $i$ ;

$C_{ai}$  = % composition by weight of species "a" on day  $i$ ; calculated from:

$$C_{ai} = \frac{P_{ai} W_a 100}{(P_{ai} W_a) + (P_{bi} W_b)} \quad \text{where:}$$

$P_{ai}, P_{bi}$  = sample composition, by number, of species "a" and species "b" on day  $i$ ;

$W_a, W_b$  = mean weight for fish of species "a" and species "b" for for the season.

When a catch was recorded but no samples were obtained, species composition was taken as the mean of the previous and following samples.

APPENDIX II. Buyers' purchases of galaxiids and smelt from the Waikato River, 1974-85. No data were available for 1978.

Year	Buyer	Galaxiids (kg)	Smelt (kg)
1974	1	1 045	516
	2	209	419
1975	1	2 874	2 053
	2	448	847
1976	1	2 946	7 718
	2	475	2 558
1977	1	4 229	4 243
1979	1	3 018	2 152
	2	2 129	2 955
1980	1	1 975	2 280
	2	1 453	2 346
1981	1	1 588	2 367
	2	688	1 176
1982	1	1 324	2 145
	2	761	2 533
1983	1	2 896	1 995
	2	1 030	1 082
1984	1	2 348	2 414
	2	1 252	2 396
1985	1	3 481	1 953
	2	2 146	1 566

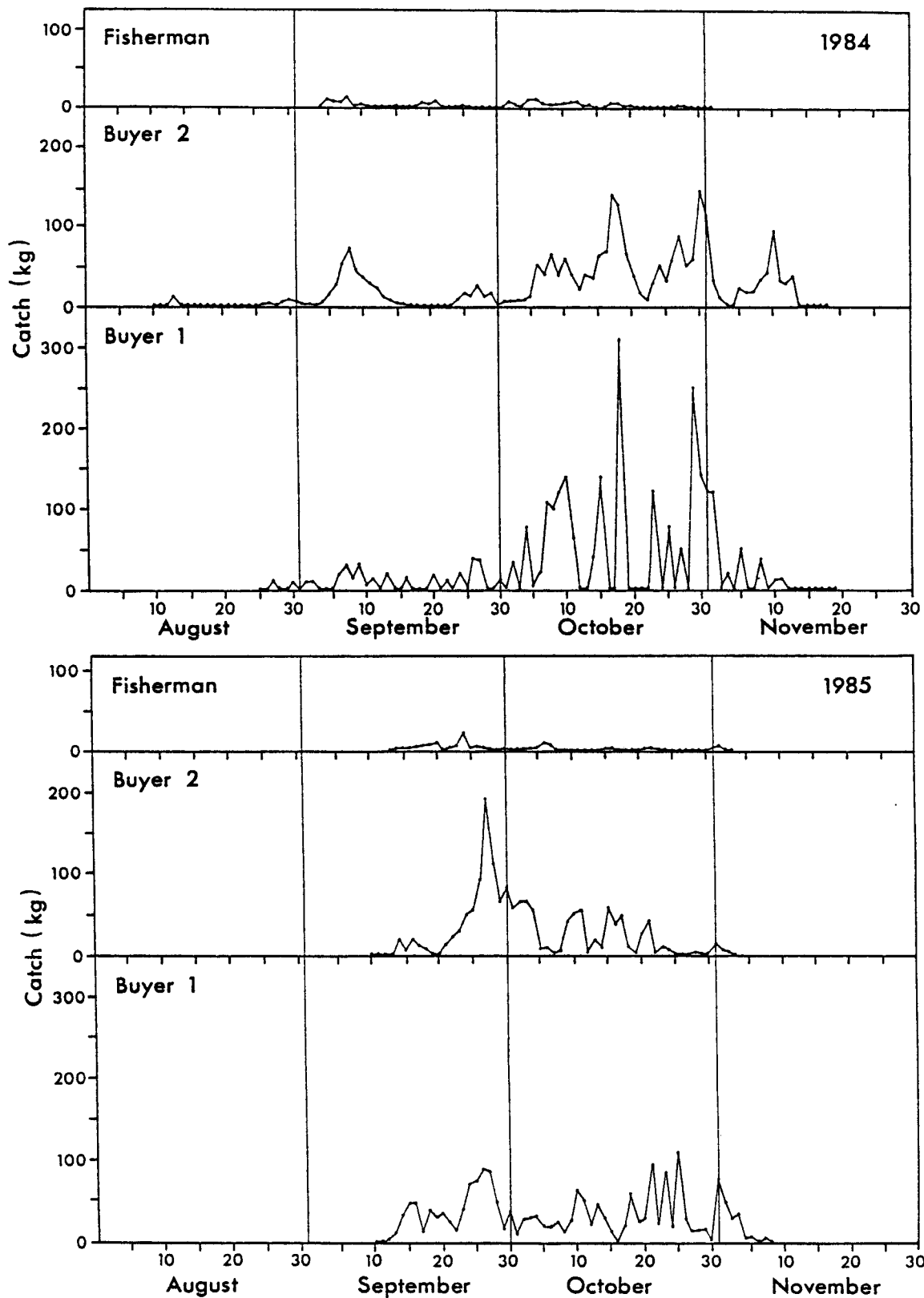
APPENDIX III. Correlations (Spearman's rank) between the fisherman's and buyers' daily catch records (galaxiids and smelt) from the Waikato River, 1984 and 1985.

Catch comparison	1984				1985			
	Galaxiids r	P	Smelt r	P	Galaxiids r	P	Smelt r	P
Fisherman/Buyer 1	0.592	***	0.304	**	0.630	***	0.662	***
Fisherman/Buyer 2	0.710	***	0.364	***	0.612	***	0.670	***
Buyer 1/Buyer 2	0.544	***	0.483	***	0.732	***	0.865	***
n	96		93		94		59	

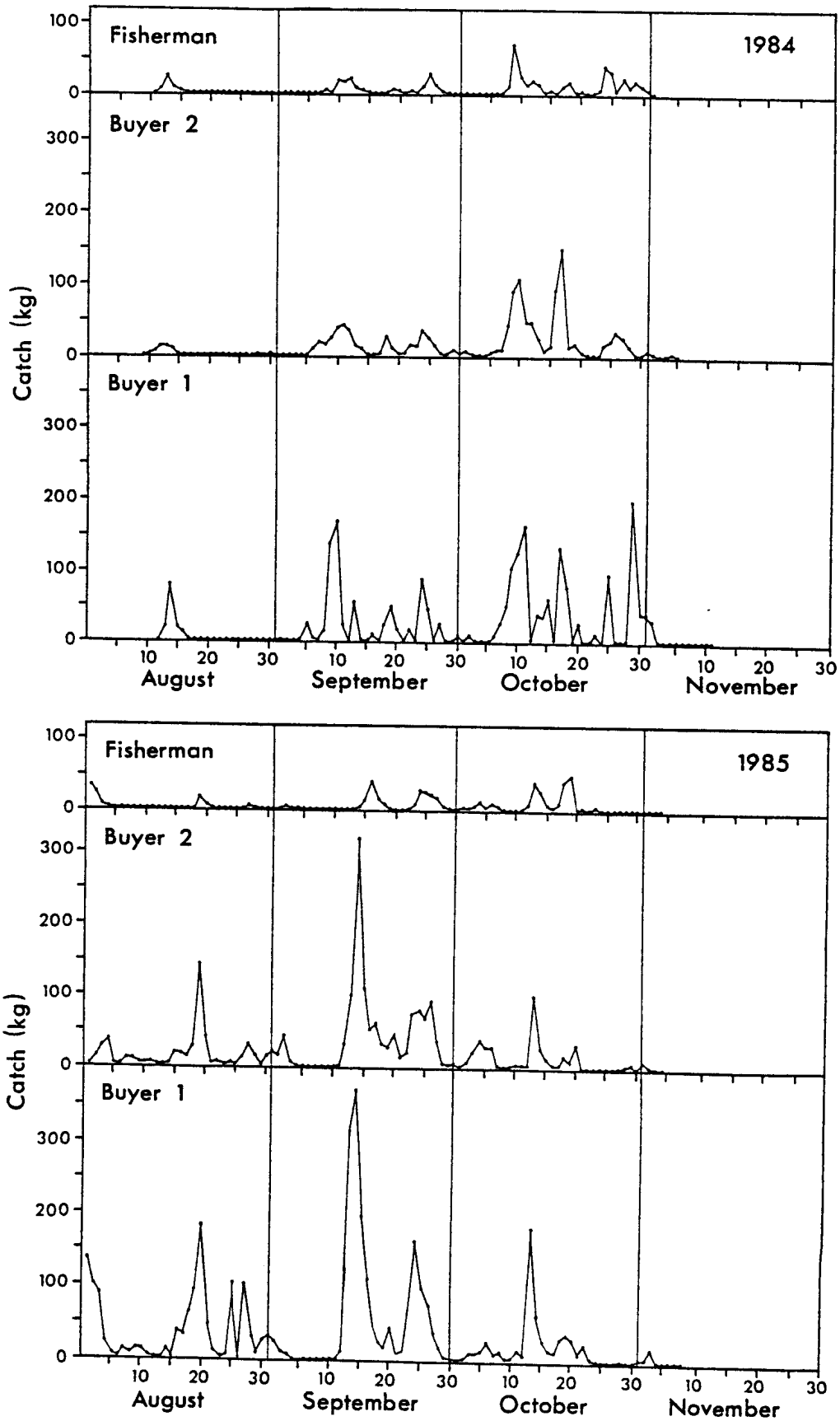
\*\* = P < 0.01.

\*\*\* = P < 0.001.

## APPENDIX IV. Synchrony in the smelt catch from the Waikato River, 1984 and 1985.



## APPENDIX V. Synchrony in the galaxiid catch from the Waikato River, 1984 and 1985.



APPENDIX VI. Length-frequency distributions for inanga and banded kokopu whitebait from the Waikato River, at monthly intervals, 1984 and 1985 seasons.

Length (mm)	Inanga							Banded kokopu				
	Jul	1984		1985			Oct	1984		1985		Oct
		Aug	Sep	Oct	Aug	Sep	Oct	Sep	Oct	Aug	Sep	Oct
36									1			
37									2			2
38								6	15		2	16
39								20	68	4	14	46
40								73	104	18	47	67
41								84	91	34	71	36
42				1				83	52	28	69	20
43	1			1				71	28	10	32	3
44	2		1	4	1			24	3	2	12	1
45	11		4	14	4	2	3	2		1	2	
46	13	9	9	38	14	3	7					
47	24	15	31	48	30	15	27					
48	43	22	34	82	65	28	64					
49	39	33	72	136	83	75	85					
50	31	35	74	156	89	68	73					
51	25	26	69	108	76	62	57					
52	9	22	63	77	52	28	28					
53	2	7	33	31	29	9	4					
54	0	5	14	12	7	9	2					
55	1	1	5	7		0						
56			3	4		1						
n	201	175	412	719	450	300	350	363	364	97	249	191
Mean	48.87	49.94	50.42	49.86	49.97	50.16	49.61	41.68	40.71	41.56	41.58	40.23
S.D.	1.95	1.95	2.09	2.11	1.87	1.67	1.57	1.39	1.34	1.13	1.27	1.20

APPENDIX VII. Comparisons of monthly mean lengths of inanga and banded kokopu whitebait from the Waikato River, 1984 and 1985. (Test of significance ANOVA.)

	Inanga						Banded kokopu					
	1984			1985			1984			1985		
Jul	Aug ***	Sep ***	Oct ***	Aug	Sep NS	Oct **	Sep	Oct ***	Aug	Sep NS	Oct ***	
Aug		**	NS	Sep		***			Sep		***	
Sep			***									

\*\*\* = P < 0.001.

\*\* = P < 0.01.

NS = not significant.

APPENDIX VIII. Frequency of condition factors for whitebait species from the Waikato River, 1984 and 1985.

Condition	Inanga		Banded kokopu		Koaro		Smelt	
	1984	1985	1984	1985	1984	1985	1984	1985
0.18	1	1						
0.20	22	0						
0.22	64	2						
0.24	182	18	2					
0.26	233	50	9					
0.28	335	158	12			1	1	
0.30	228	193	59		1	0	0	
0.32	136	286	89	5	4	1	0	
0.34	80	193	104	15	2	6	1	
0.36	19	121	120	41	5	11	1	1
0.38	4	58	98	66	6	7	7	1
0.40	2	15	140	158	8	9	22	1
0.42		3	42	108	11	10	24	5
0.44		1	30	79	1	16	29	8
0.46		0	13	31	7	20	48	14
0.48		0	9	7	3	7	28	16
0.50		1		1	3	3	26	17
0.52				1	0	6	18	25
0.54					1	2	11	10
0.56						1	5	10
0.58						1	2	9
n	1 306	1 100	727	512	52	1	224	124
Mean	0.280	0.320	0.365	0.407	0.409	0.432	0.463	0.507
S.D.	0.034	0.034	0.044	0.031	0.052	0.057	0.048	0.052

APPENDIX IX. Inter-seasonal comparisons of mean condition factor (K) for whitebait species from the Waikato River, 1984 and 1985. (Test of significance ANOVA.)

Species	K		n	F	P
	1984	1985			
Inanga	0.280	0.320	2 460	815.76	***
Banded kokopu	0.365	0.407	1 239	345.91	***
Koaro	0.409	0.432	153	5.44	*
Smelt	0.463	0.507	348	62.97	***

\*\*\* = P <0.001.

\* = P <0.05.

APPENDIX X. Length-weight regression equations for whitebait species from the Waikato River, 1984 and 1985. Lwt = Log<sub>10</sub> weight (g), Lt1 = Log<sub>10</sub> total length (mm).

Species	1984		1985	
	Equation	r	Equation	r
Inanga	Lwt = -5.35 + 2.88 Lt1	49.9	Lwt = -4.82 + 2.60 Lt1	42.3
Banded kokopu	Lwt = -4.23 + 2.25 Lt1	30.2	Lwt = -5.87 + 3.30 Lt1	65.3
Koaro	Lwt = -6.23 + 3.50 Lt1	50.0	LwT = -5.30 + 2.96 Lt1	30.6
Smelt	LwT = -5.49 + 3.09 Lt1	73.1	Lwt = -5.78 + 3.28 Lt1	49.1

APPENDIX XI. Frequency of condition factors for inanga and banded kokopu whitebait from the Waikato River, at monthly intervals, 1984 and 1985 seasons.

Condition factor (k)	Inanga				Banded kokopu							
	1984 Jul	1984 Aug	Sep	Oct	1985 Aug	1985 Sep	Oct	1984 Sep	1984 Oct	1985 Aug	1985 Sep	Oct
0.18						1						
0.20	2	3	3	1		0						
0.22	18	3	13	16		2						
0.24	25	18	44	48	5	7	6	2				
0.26	41	35	61	120	23	18	9	4	5			
0.28	63	52	107	137	67	35	56	10	2			
0.30	31	33	90	176	75	37	81	33	26			
0.32	18	22	53	105	102	81	103	53	36	1		4
0.34	3	7	29	61	89	50	54	46	58	3		12
0.36		2	9	44	62	35	24	67	53	5	8	28
0.38			2	8	17	28	13	48	50	11	20	35
0.40			1	2	7	5	3	58	82	31	67	60
0.42				1	2	1	0	12	30	23	55	30
0.44					0		1	21	9	16	50	13
0.46					0			8	5	5	19	7
0.48					0			1	8	2	4	1
0.50					1						0	1
0.52											1	
n	201	175	412	719	450	300	350	363	364	97	224	191
Mean	0.273	0.282	0.287	0.275	0.321	0.322	0.316	0.360	0.369	0.410	0.417	0.394
S.D.	0.030	0.030	0.032	0.035	0.034	0.037	0.030	0.045	0.043	0.030	0.027	0.032

APPENDIX XII. Comparisons of monthly mean condition factors for inanga and banded kokopu whitebait from the Waikato River, 1984 and 1985. (Test of significance ANOVA.)

	Inanga			Banded kokopu							
	1984			1985		1984		1985			
	Aug	Sep	Oct		Sep	Oct		Oct		Sep	Oct
Jul	**	***	NS	Aug	NS	*	Sep	**	Aug	*	***
Aug		NS	*	Sep		*			Sep		***
Sep			***								

\*\*\* = P < 0.001.

\*\* = P < 0.01.

NS = not significant.

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