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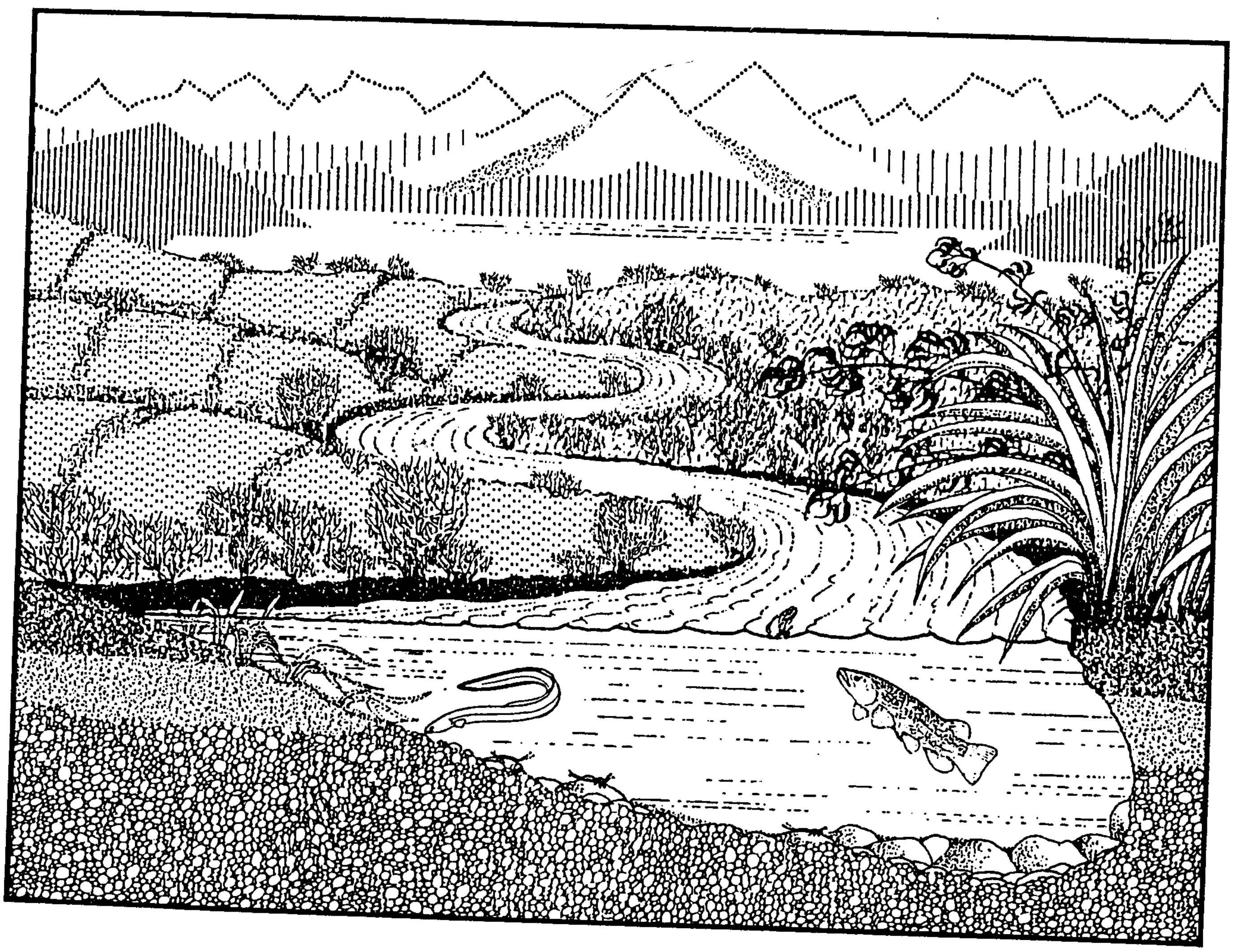

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Distribution of migratory fish and shrimps in the vicinity of the Waikato thermal power stations

by

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SUMMARY

The distributions of 4 galaxiid species, smelt, common bullies, and freshwater shrimps were determined during the upstream migrations of these species in the Waikato River in 1984 and 1985/86.

Juveniles of inanga, kokopu, smelt, and common bullies migrated mostly during daylight, but most shrimp movement occurred at night.

Juvenile galaxiids and smelt moved almost exclusively along the river margins, and in the uppermost metre of the water column. Smelt were caught more often in the river channel than galaxiids, and they appeared to do considerable channel-crossing. Only a small proportion of galaxiids normally migrate in the river channel, and, unlike smelt, galaxiids may have difficulty negotiating thermal and velocity barriers created along the margins by thermal power station intake and outfall structures.

The highest densities of common bullies and shrimps were found in the top 2 m of the water column along the river margins, but substantial numbers of both species moved upstream along the bottom of the river channel. The ability of common bullies and shrimps to rest on, or cling to, the substrate should allow them to avoid temperature and velocity barriers along the margins by moving in the river channel.

1. INTRODUCTION

At present, there are 2 thermal power stations on the Waikato River, Meremere (210 MW) and Huntly (1000 MW). Forecasts of increasing electricity demand have resulted in planning for a third station which may be situated at Clune Road (Fig. 1).

Fisheries studies were instituted by the Electricity Division of the Ministry of Energy (now Electricorp) as part of a series of biological investigations to provide information on siting and design criteria for the new station, and for the statutory consents required. This report is concerned with the distribution of whitebait species (galaxiids and smelt), common bullies, and freshwater shrimps during their upstream migrations, and with the ability of these species to negotiate thermal

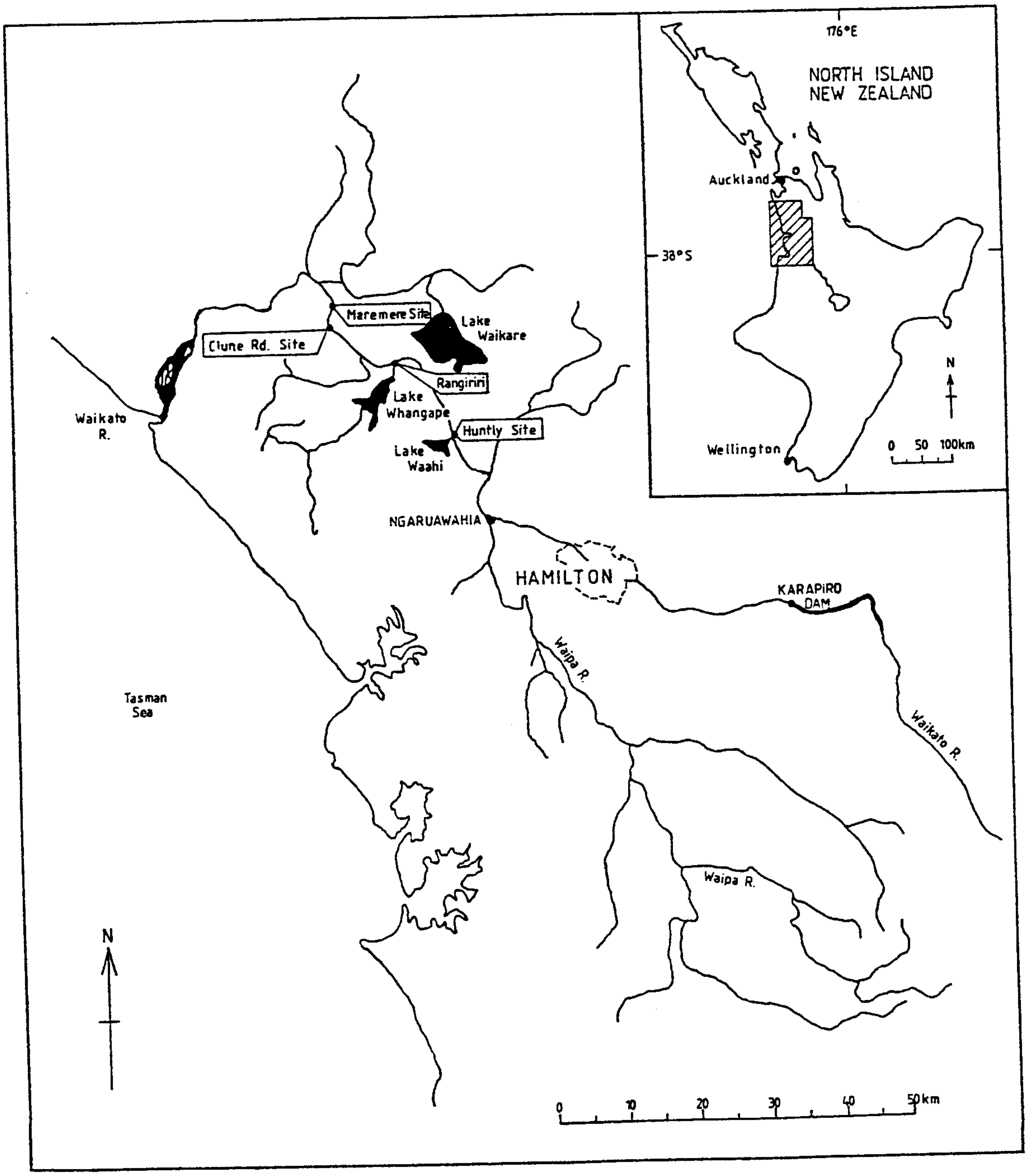

FIGURE 1. Map of the Waikato River, showing the existing and proposed thermal power station sites.

and velocity barriers created by power station intake and outfall structures.

Juvenile whitebait of 5 diadromous native fish species migrate into the Waikato River from the sea during late winter and spring. The whitebait fishery in the estuary is dominated by inanga (Galaxias maculatus) and common smelt (Retropinna retropinna), with small contributions by 3 other galaxiids, banded kokopu (G. fasciatus), giant kokopu (G. argenteus), and koaro (G. brevipinnis) (Stancliff et al. 1988). Fish that elude capture in the estuary continue moving upstream, and large numbers pass the existing and proposed thermal power station sites in spring and summer (Boubee et al. 1986).

Common bullies (Gobiomorphus cotidianus) spawn throughout the river and its subsidiary lakes and channels, with larval emergence peaking in October and November (Meredith et al. in prep.). The larvae drift downstream, and the juveniles migrate back upstream during spring and summer. This species does not have an obligatory marine phase in its life cycle (McDowall 1978), and the large migrations observed at Huntly (Boubee et al. 1986) may, in part, result from recruitment from lowland lakes and other bordering habitats.

Larvae of the freshwater shrimp (Paratya curvirostris) drift downstream to the estuary after hatching in spring and autumn (Carpenter 1982, Meredith et al. 1987). They grow into juveniles which then undergo seasonal upstream migrations. In the Waikato River, winter migration occurs as far upstream as Rangiriri (Fig. 1). This is followed by a much larger migration, from spring through to autumn, which moves further upstream (Boubee et al. 1986).

The aims of this study were:

(a) To determine the micro-distribution of fish and shrimps during their upstream migrations.

(b) To assess the possible impact of the existing and proposed thermal power stations on these migrations.

2. METHODS

In 1984, fish and shrimps were caught in 2-mm mesh traps with 0.5 m x 2.0 m openings (Fig. 2), set from the main river banks and from islands during 9 visits to sites at Huntly, Clune Road, and Meremere (Boubee et al. 1986). Each trap sampled the top 0.5 m of the water column.

From September 1985 to April 1986, 2-mm mesh traps with 0.5 m x 1.0 m openings (Fig. 3), which sampled 1 m of the water column, were set on a weekly basis from 4 stands near Huntly Thermal Power Station (Fig. 4, Sites A and C). The stands were solid wooden constructions which blocked off the entire margin to fish migration (Fig. 5). The water column could be sampled vertically by stacking several traps one upon the other, but traps were usually set only at the surface and the bottom of the stands. The larger, 0.5 m x 2.0 m traps used in 1984 were set from another 2 stands near Huntly Thermal Power Station (Fig. 4, Site B). Two of these traps were usually placed one upon the other, and catches in the top 0.5 m and in the 0.5-1.0 m interval were retained separately.

Because high current velocities forced fish and shrimps to negotiate the stands by moving close to their outer edges, we assumed that two 0.5 m x 2.0 m traps placed one upon the other (so that they sampled 1 m of the water column), were equivalent to one 0.5 m x 1.0 m trap (which also sampled 1 m of the water column).

On 20 occasions between October 1985 and March 1986, up to 9 traps (0.5 m x 1.0 m) were also set along transects across the bottom of the river channel, excluding the margins (Fig. 4). Traps were placed in each of 3 zones within the river channel. These were the main channel (width 60 m), the river middle or sandbar (width 110 m), and the minor channel (width 60 m) (Fig. 6). Each trap sampled 1 m of the river width.

All traps were set for a total of 24 hours at each visit. They were lifted several times during daylight, but were left in position overnight. The entrances were screened at night with 1-cm plastic mesh to prevent predation by eels. Day and overnight catches were recorded separately to allow diurnal migration patterns to be determined.

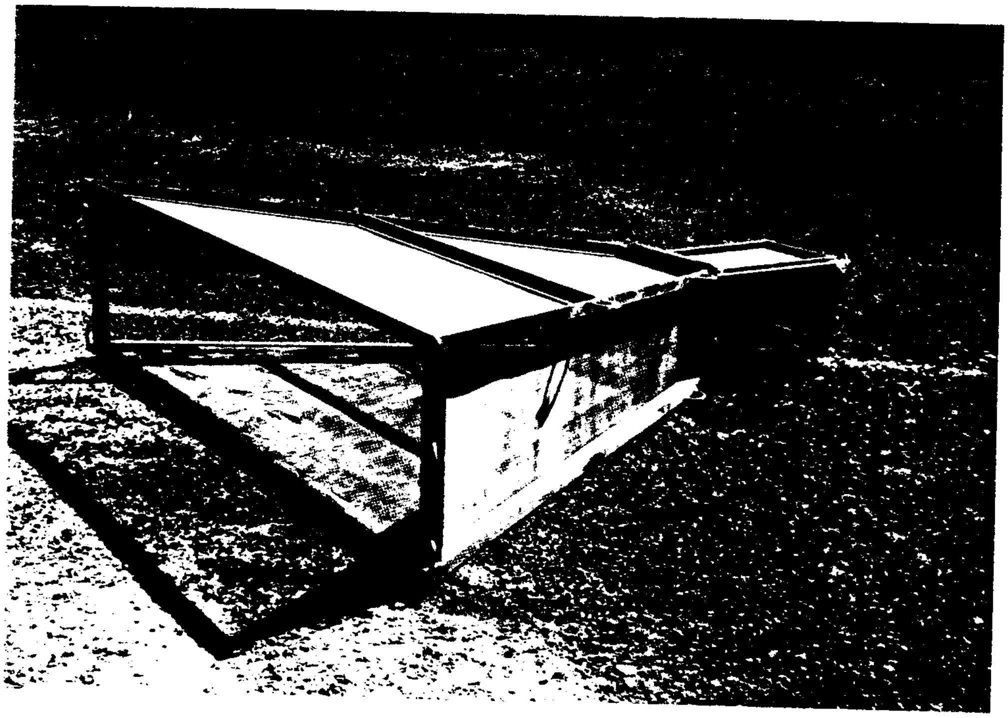

FIGURE 2. Type of trap (0.5 m x 2.0 m opening) set from main river banks and islands in 1984, and from stands at Huntly on the Waikato River, September 1985-April 1986.

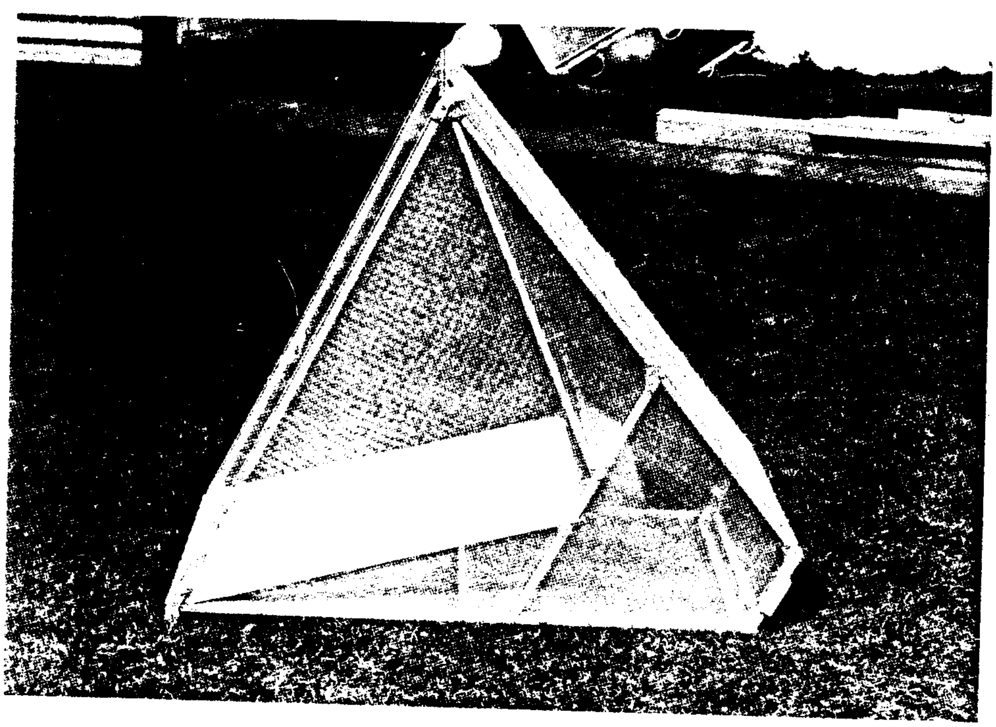

FIGURE 3. Type of trap (0.5 m x 1.0 m opening) set from stands and in transects at Huntly on the Waikato River, September 1985-April 1986.

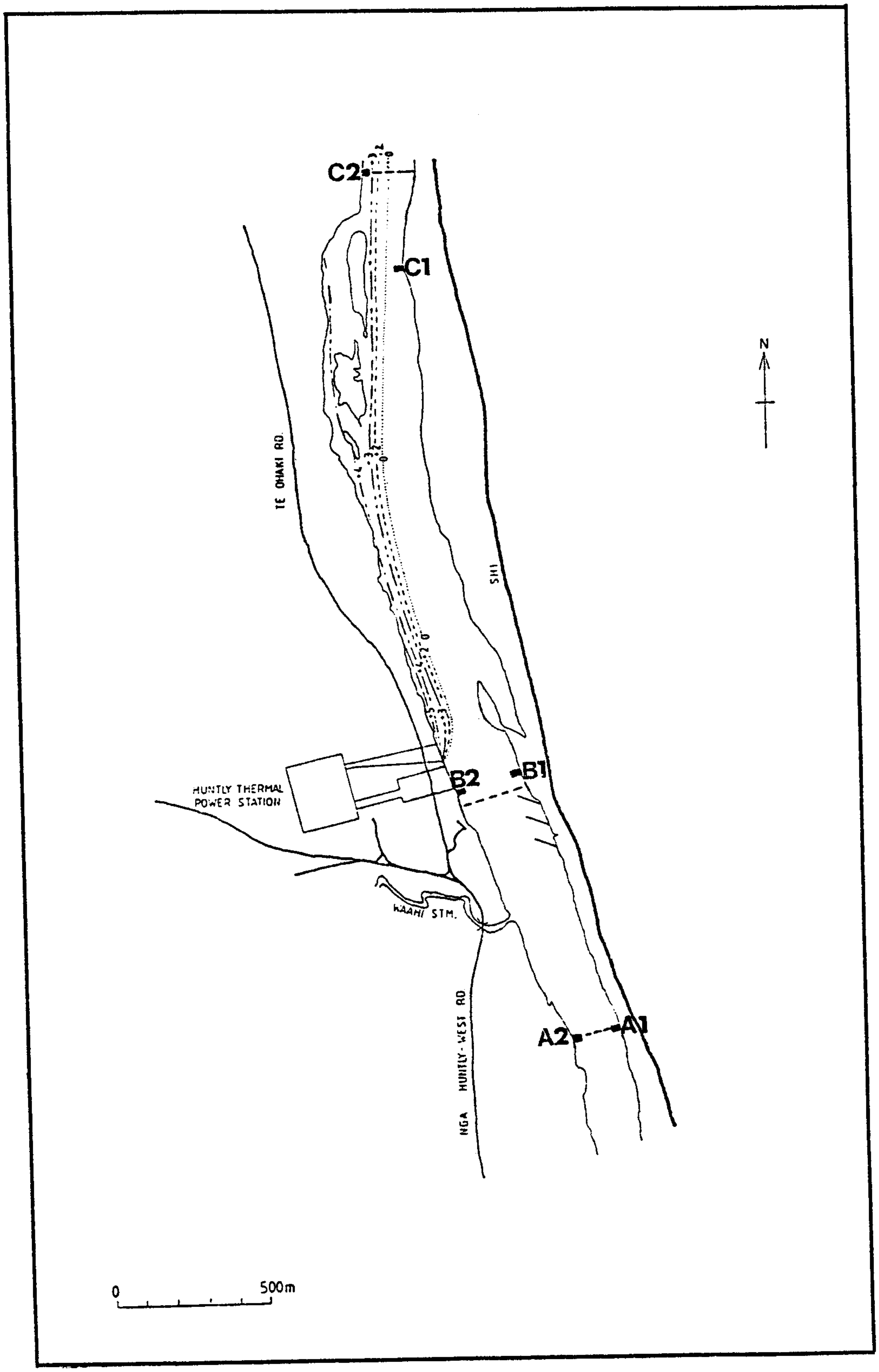

FIGURE 4. Location of stands and transects at Huntly on the Waikato River, September 1985-April 1986.
■ = stands, -- = transects.

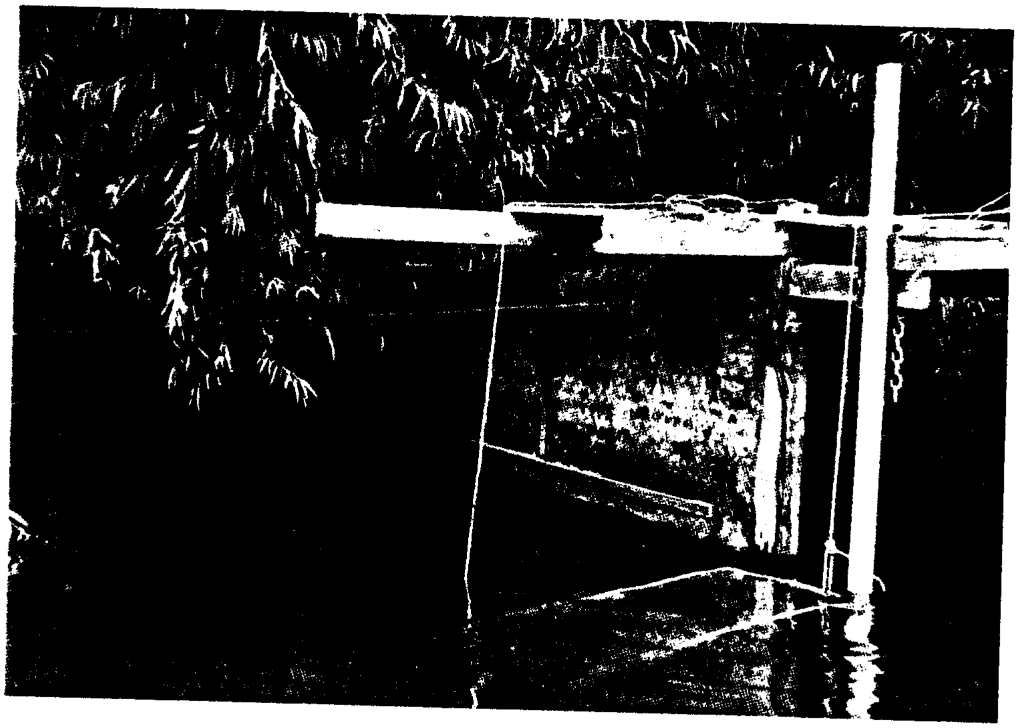

FIGURE 5. A stand at Huntly on the Waikato River.

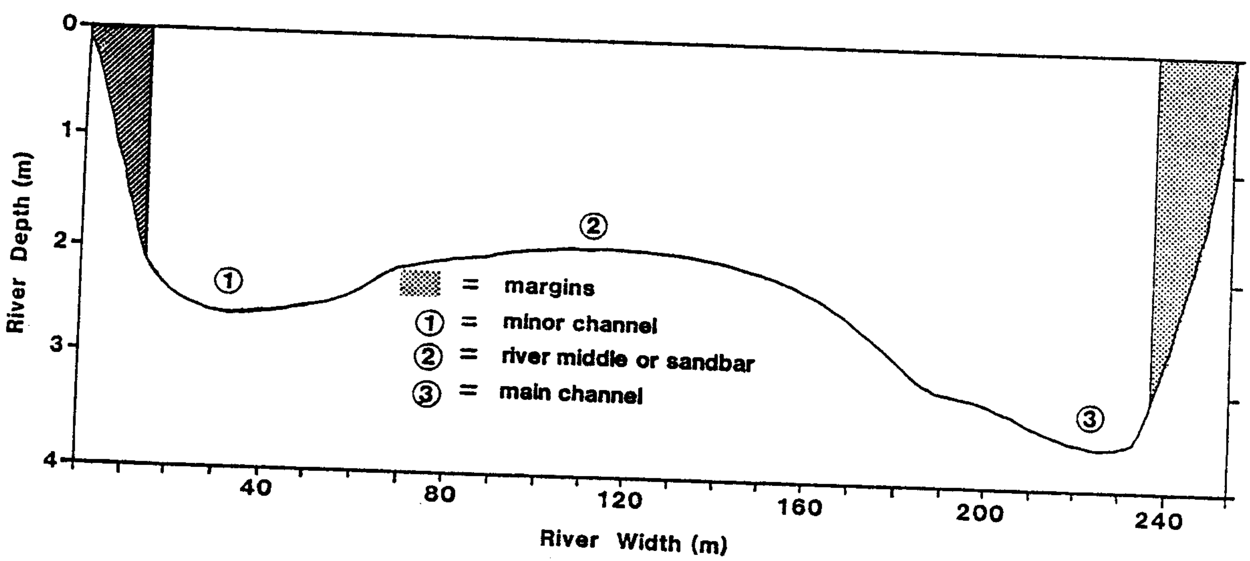

FIGURE 6. A typical profile of the Waikato River at Huntly, showing the various zones trapped, September 1985-April 1986.

When the catches were small, the number of each species was counted and subsamples were preserved for further analysis. The remainder were released upstream. When more than 500 fish were caught, a representative subsample was taken while the fish were being removed from the trap. The rest of the catch was weighed to the nearest 10 g and released upstream. The proportion (% by weight) of each species in the subsample and the mean weight of each species were then used to back-calculate the number of each species in the total catch.

Catch per unit effort (CPUE) was defined as the number of fish, or the weight of shrimp (in grams), caught per trap (or equivalent) per 24 hours.

All samples were fixed in 10% formalin and later transferred to 5% formalin for storage. At each sampling, when numbers allowed, the total lengths of at least 50 inanga and 50 smelt were measured to the nearest millimetre.

3. RESULTS

3.1 Cross-channel Distribution

Catches of galaxiids, smelt, bullies, and shrimps were higher along the main river banks than along the banks of islands (Table 1). However, smelt tended to avoid the traps and were confined to the margins less than the other species.

On islands, catches of inanga and banded kokopu were highest at Meremere (Table 1). At that site, 14% of the inanga catch and 36% of the banded kokopu catch were taken at Motutawa Island; 85% of the inanga catch and 80% of the banded kokopu catch from Motutawa Island were trapped along its true right bank. Adjacent to the island's right bank was an exposed sandbar, which had low water velocities downstream from it (Fig. 7).

Only 10 inanga and 44 smelt were caught in traps set along transects across the bottom of the river channel at Huntly (Table 2). In the same period, approximately 133 000 inanga and 28 700 smelt were caught in the top metre of the water column along the margins. The CPUEs, adjusted to

TABLE 1. Catch of fish and shrimps in traps set from main river banks and islands at 3 sites on the Waikato River, 1984.

Site	No. of visits	Species	CPUE Main banks	CPUE Islands
Huntly	4	Inanga	233.5	5.0
		Kokopu	43.0	1.0
		Smelt	14.0	35.0
		Bully	356.0	85.0
		Shrimp	43.5	4.0
Clune Rd	5	Inanga	767.0	2.0
		Kokopu	331.0	2.0
		Smelt	252.0	7.0
		Bully	42.0	3.0
		Shrimp	10 346.0	145.0
Meremere	1	Inanga	101.0	16.5
		Kokopu	41.0	23.0
		Smelt	59.5	1.5
		Bully	34.5	21.0
		Shrimp	1 386.0	179.0

account for the width of each zone, confirmed that most inanga and smelt migrated along the margins, although smelt were more abundant than inanga in the river channel (Table 2). Juveniles of banded kokopu, giant kokopu, and koaro were caught only along the river margins.

Catches of common bullies and shrimps were also much lower on the bottom of the river channel than along the margins (Table 2). However, when CPUEs were adjusted to account for the width of each zone, substantial numbers of bullies were found to migrate upstream on the bottom of the main and minor channels. Large numbers of shrimps migrated upstream over the entire river bottom (Table 2).

3.2 Vertical Distribution

Along the margins, the uppermost metre of the water column was most important for the migration of galaxiids and smelt. In 5 sampling periods from a stand where the water column was 4 m deep, 93% of the inanga and 94% of the smelt caught were in the 0-1 m interval (Table 3). Juveniles of other galaxiid species were caught in this interval only.

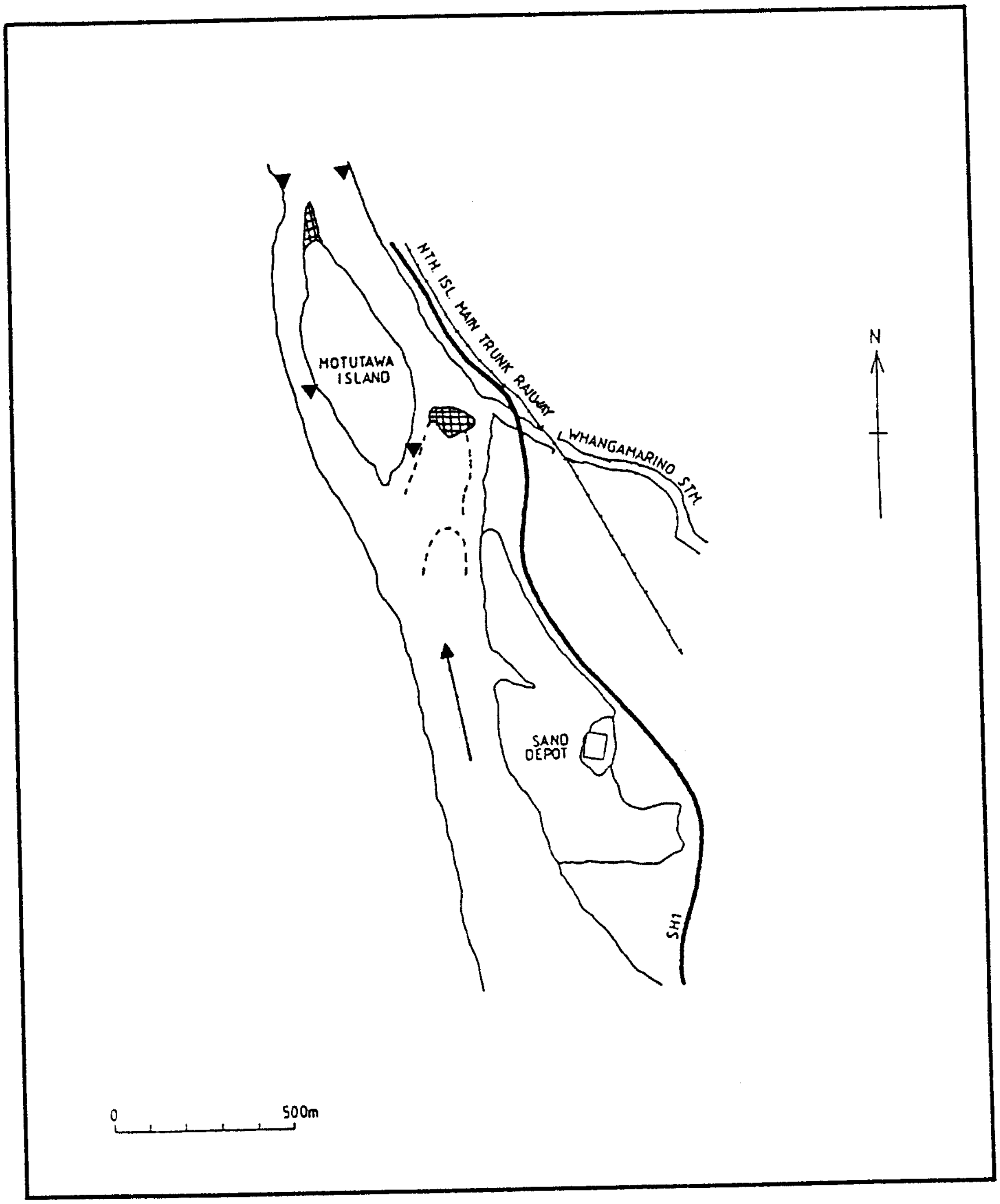

FIGURE 7. Position of traps set from Motutawa Island and from main banks at Meremere on the Waikato River, 1984. ⊞ = areas of low water velocity, --- = sandbar, ▼ = traps facing downstream, ⟶ = direction of current flow.

TABLE 2. Estimated daily average upstream migration of fish and shrimps in 5 river zones at Huntly on the Waikato River, 11 October 1985-17 March 1986. Because the entire width of the margin was trapped, migrations along the surface and bottom of both margins were estimated by doubling the CPUE. Migrations were otherwise estimated by multiplying the CPUE for each zone by the width of that zone.

Species	Site	No. of traps set	Total catch	CPUE	Zone width (m)	Migration per 24 hrs
Inanga	Margin surface	54	133 037	2 464.00	10	4 928
	Margin bottom	54	11 469	212.00	10	424
	Main channel	37	6	0.16	60	10
	River middle	35	0	0.00	110	0
	Minor channel	27	4	0.15	60	9
Smelt	Margin surface	54	28 695	531.00	10	1 062
	Margin bottom	54	1 133	21.00	10	42
	Main channel	37	16	0.43	60	26
	River middle	35	13	0.37	110	41
	Minor channel	27	5	0.19	60	11
Common bully	Margin surface	58	15 601	269.00	10	538
	Margin bottom	58	3 560	61.40	10	123
	Main channel	36	171	4.75	60	285
	River middle	34	9	0.26	110	29
	Minor channel	26	72	2.77	60	166
Shrimp	Margin surface	58	82 433	1 421.30	10	2 843
	Margin bottom	58	12 461	214.80	10	430
	Main channel	36	1 573	43.69	60	2 621
	River middle	34	343	10.09	110	1 110
	Minor channel	26	1 514	58.23	60	3 494

TABLE 3. Number and proportion of fish and shrimps caught in each depth interval when the entire margin was trapped, at Huntly on the Waikato River.

Species	Sampling date	No. caught 0-1 m	1-2 m	2-3 m	3-4 m
Inanga	28.11.85	8 409	3	2	22
	9.12.85	4 220	1 024	464	5
	21.1.86	11 033	193	0	26
	28.1.86	55	0	0	0
	4.3.86	7	0	0	0
	Total	23 724	1 220	466	53
	%	93.2	4.8	1.8	0.2
Smelt	28.11.85	199	1	2	13
	9.12.85	1 471	10	7	11
	21.1.86	206	63	0	3
	28.1.86	374	3	2	0
	4.3.86	31	8	0	14
	Total	2 281	85	11	41
	%	94.3	3.5	0.5	1.7
Common bully	28.11.85	41	32	9	18
	9.12.85	146	130	51	23
	21.1.86	24	200	15	33
	28.1.86	106	82	18	8
	4.3.86	47	27	6	3
	Total	364	471	99	85
	%	35.7	46.2	9.7	8.3
Shrimp	28.11.85	60	0	0	80
	9.12.85	980	1 505	500	362
	21.1.86	1 420	1 755	900	680
	28.1.86	100	200	100	0
	4.3.86	1 800	750	900	200
	Total	4 360	4 210	2 400	1 322
	%	35.5	34.2	19.5	10.8

The top 2 m of the water column along the margins were the most important for the migration of common bullies and shrimps. In the 5 sampling periods, 82% of bullies and 70% of shrimps moved within that zone (Table 3).

While inanga and common bullies were evenly distributed in the top metre of the water column, smelt and shrimps were significantly more abundant in the upper 0.5 m (Table 4).

A greater percentage of inanga and common bullies travelled near the bottom at the shallower sites, and, on occasion, more were caught near the bottom than at the surface (Tables 5 and 6). This trend was not apparent for shrimps (Table 7), and there was a consistently low percentage of smelt caught near the bottom, regardless of the water column depth (Table 8).

Inanga and smelt moving near the bottom were significantly larger than those moving near the surface (Table 9). Most smelt moving near the bottom were large adults.

3.3 Diurnal Patterns of Migration

The upstream migration of inanga, smelt, kokopu, and common bullies occurred mostly during daylight (Table 10). Shrimp migration usually occurred at night, although large numbers were caught during the day when migration peaked in mid February 1986.

4. DISCUSSION

4.1 Cross-channel Distribution

4.1.1 Galaxiids and Smelt

Mitchell (in prep.) found that juveniles of inanga, banded kokopu, and smelt from the Waikato River at Huntly had mean sustainable swimming speeds of only 0.19 m/s. Because mean current volocities in the Waikato River channel are 0.6-1.0 m/s (Meredith et al. in prep.), these species may use the low velocity margins or the boundary layer near the bottom of the river channel to minimise energy costs of upstream migration.

TABLE 4. Number and proportion of fish and shrimps caught in the top 0.5 m and in the 0.5-1.0 m interval at Huntly on the Waikato River, December 1985-March 1986. (Significance of differences also shown.)

Date	Inanga		Smelt		Common bully		Shrimp	
	0-0.5 m	0.5-1.0 m	0-0.5 m	0.5-1.0 m	0-0.5 m	0.5-1.0 m	0-0.5 m	0.5-1.0 m
9.12.85	25	45	36	13	27	20	10	0
16.12.85	684	1 572	5	0	7	0	980	420
23.12.85	4 874	1 894	473	51	30	70	2 265	110
30.12.85	1 732	6 624	478	40	248	240	3 000	263
13.1.86	6 668	4 086	0	0	62	1 021	0	64
14.1.86	2 209	6 458	150	135	74	17	800	50
15.1.86	1 859	2 370	158	90	67	8	610	0
20.1.86	8 716	11 011	167	292	231	33	4 633	2
21.1.86	4 681	3 157	360	96	78	91	5 562	620
28.1.86	3	8	161	110	7	74	2 301	690
4.2.86	29	9	107	61	45	158	3 830	120
13.2.86	127	677	123	91	101	300	4 765	1 255
18.2.86	71	10	274	13	106	44	3 705	761
26.2.86	9	5	48	27	23	11	4 012	1 115
4.3.86	11	3	45	29	20	13	2 530	350
11.3.86	35	24	29	26	14	25	2 026	803
Total	29 102	33 466	2 614	1 074	1 140	2 125	41 029	6 623
%	45.5	54.5	70.9	29.1	34.9	65.1	86.1	13.9
F value	0.13		5.01		0.88		22.72	
P	P >0.1		P <0.05		P >0.1		P >0.001	

TABLE 5. Change in distribution of inanga with decreasing river depth at Huntly on the Waikato River, October 1985-April 1986.

Sampling date	CPUE Site C1 surface	Site C1 bottom	Site A1 surface	Site A1 bottom	Site C2 surface	Site C2 bottom	Site A2 surface	Site A2 bottom
11.10.85	141	0	-	-	-	-	-	-
31.10.85	-	-	-	-	2 012	66	-	-
5.11.85	30	0	318	1	-	-	9	1
14.11.85	-	-	-	-	830	4	-	-
21.11.85	2 490	3	2 603	3	3 077	982	2 942	539
28.11.85	-	-	8 409	22	60	0	39	0
9.12.85	-	-	4 220	5	1	1	0	0
6.12.85	8 132	10	7 264	1 268	5 207	930	1 009	494
17.12.85	-	-	8 975	330	-	-	0	1
23.12.85	-	-	10 734	6	-	-	951	388
30.12.85	10 924	0	-	-	10 315	426	-	-
13.1.86	-	-	6 312	158	-	-	-	-
20.1.86	-	-	16 938	4	-	-	-	-
21.1.86	-	-	11 033	26	-	-	3 685	4 080
28.1.86	-	-	55	0	-	-	-	-
4.2.86	-	-	380	3	-	-	36	5
13.2.86	1 448	66	181	927	86	224	751	131
18.2.86	78	4	270	10	276	0	174	12
26.2.86	26	1	19	2	99	8	109	30
4.3.86	-	-	7	0	17	1	31	17
11.3.86	52	17	20	7	38	43	41	59
17.3.86	30	3	24	4	12	49	37	59
24.3.86	-	-	4	3	-	-	22	22
1.4.86	-	-	2	4	-	-	52	10
Total	23 351	104	77 768	2 783	22 030	2 734	9 888	5 848
%	99.6	0.4	96.5	3.5	89.0	11.0	62.8	37.2
River depth	4.5-5.5 m		3.5-4.5 m		3.0-4.0 m		2.0-3.0 m	

- = trap not set.

TABLE 6. Change in distribution of common bullies with decreasing river depth at Huntly on the Waikato River, October 1985-April 1986.

Sampling date	CPUE Site C1 surface	Site C1 bottom	Site A1 surface	Site A1 bottom	Site C2 surface	Site C2 bottom	Site A2 surface	Site A2 bottom
11.10.85	178	6	-	-	-	-	-	-
31.10.85	-	-	-	-	37	84	-	-
5.11.85	55	8	85	35	-	-	65	157
14.11.85	-	-	-	-	168	52	-	-
21.11.85	41	1	49	28	32	389	103	81
28.11.85	-	-	41	18	0	0	4	3
9.12.85	-	-	146	23	31	1	30	24
16.12.85	30	25	187	40	2 328	152	639	229
23.12.85	-	-	117	24	-	-	40	108
30.12.85	597	51	-	-	920	383	-	-
13.1.86	-	-	2 669	286	-	-	-	-
20.1.86	-	-	1 062	135	-	-	-	-
21.1.86	-	-	24	33	-	-	0	0
28.1.86	-	-	106	8	-	-	-	-
4.2.86	-	-	80	20	-	-	26	48
13.2.86	2 355	53	226	60	1 000	174	283	83
18.2.86	134	13	374	54	264	36	132	55
26.2.86	61	1	37	20	76	21	47	26
4.3.86	-	-	47	3	23	7	22	22
11.3.86	55	12	34	15	20	13	117	108
17.3.86	82	27	45	17	55	20	140	180
24.3.86	-	-	14	23	-	-	27	41
1.4.86	-	-	1	4	-	-	40	20
Total	3 588	197	5 344	846	4 954	1 332	1 715	1 185
%	94.8	5.2	86.3	13.7	79.2	20.8	59.1	40.9
River depth	4.5-5.5 m		3.5-4.5 m		3.0-4.0 m		2.0-3.0 m	

- = trap not set.

TABLE 7. Change in distribution of shrimps with decreasing river depth at Huntly on the Waikato River, October 1985-April 1986.

Sampling date	CPUE Site C1 surface	Site C1 bottom	Site A1 surface	Site A1 bottom	Site C2 surface	Site C2 bottom	Site A2 surface	Site A2 bottom
11.10.85	0	0	-	-	-	-	-	-
31.10.85	-	-	-	-	0	0	-	-
5.11.85	510	225	520	355	-	-	1 005	507
14.11.85	-	-	-	-	2 500	50	-	-
21.11.85	0	20	312	200	0	0	664	40
28.11.85	-	-	60	80	300	65	200	115
9.12.85	-	-	980	362	10	275	600	252
16.12.85	350	50	370	100	1 827	270	1 200	400
23.12.85	-	-	30	120	-	-	930	500
30.12.85	0	400	-	-	3 790	400	-	-
13.1.86	-	-	59	5	-	-	-	-
20.1.86	-	-	1 663	300	-	-	-	-
21.1.86	-	-	1 420	680	-	-	2 650	1 260
28.1.86	-	-	100	0	-	-	-	-
4.2.86	-	-	0	20	-	-	1 100	100
13.2.86	6 208	100	4 848	20	25 600	500	1 246	150
18.2.86	200	150	571	100	7 406	5	500	200
26.2.86	1 020	300	215	50	1 517	500	600	100
4.3.86	-	-	1 800	200	3 650	350	1 040	600
11.3.86	900	400	150	80	230	300	150	200
17.3.86	560	400	15	50	720	200	10	150
24.3.86	-	-	200	100	-	-	100	50
1.4.86	-	-	5	5	-	-	2	50
Total	9 568	2 045	13 318	2 827	47 550	2 915	11 997	4 674
%	82.4	17.6	82.5	17.5	94.2	5.8	72.0	28.0
River depth	4.5-5.5 m		3.5-4.5 m		3.0-4.0 m		2.0-3.0 m	

- = trap not set.

TABLE 8. Change in distribution of smelt with decreasing river depth at Huntly on the Waikato River, October 1985-April 1986.

Sampling date	CPUE Site C1 surface	bottom	Site A1 surface	bottom	Site C2 surface	bottom	Site A2 surface	bottom
11.10.85	12	0	-	-	-	-	-	-
31.10.85	-	-	-	-	3 425	80	-	-
5.11.85	74	0	140	22	-	-	121	3
14.11.85	-	-	-	-	32	65	-	-
21.11.85	404	0	17	40	205	26	51	4
28.11.85	-	-	199	13	1 036	0	845	8
9.12.85	-	-	1 471	11	5 655	2	5 013	30
16.12.85	371	25	1 565	109	391	101	1 433	125
17.12.85	-	-	0	0	-	-	10	0
23.12.85	-	-	45	10	-	-	1 373	85
30.12.86	1 276	0	-	-	344	31	-	-
13.1.86	-	-	122	1	-	-	-	-
20.1.86	-	-	129	9	-	-	-	-
21.1.86	-	-	206	3	-	-	0	0
28.1.86	-	-	374	0	-	-	-	-
4.2.86	-	-	232	4	-	-	15	25
13.2.86	181	0	326	28	12	29	30	3
18.2.86	169	0	204	9	684	3	5	28
26.3.86	23	1	157	20	21	11	13	23
4.3.86	-	-	31	14	69	11	16	30
11.3.86	5	1	47	7	60	18	8	27
17.3.86	4	1	30	2	3	8	2	10
24.3.86	-	-	2	11	-	-	0	0
1.4.86	-	-	0	0	-	-	7	2
Total	2 519	28	5 297	313	11 937	389	8 942	403
%	98.9	1.1	94.4	5.6	96.8	3.2	95.7	4.3
River depth	4.5-5.5 m		3.5-4.5 m		3.0-4.0 m		2.0-3.0 m	

\- = trap not set.

TABLE 9. Significance (ANOVA) of comparisons of mean total length of inanga and smelt caught near the surface and the bottom of stands at Huntly on the Waikato River, October 1985-January 1986.

	Inanga		Smelt	
	surface	bottom	surface	bottom
Mean total length (mm)	62.9	69.1	60.6	86.6
S.D.	10.1	17.9	12.3	16.4
n	2 148	98	796	53
F value	32.3		210.1	
P	P <0.001		P <0.001	

TABLE 10. Diurnal patterns of fish and shrimp migration at Huntly on the Waikato River, November 1985-March 1986. (Standard errors given in brackets, and significance of differences in mean catch also shown.)

Species	Mean catch per trap day	Mean catch per trap overnight	No. of 24-hour observations	P
Inanga	1 481 (234)	499 (109)	102	P <0.001
Smelt	299 (56)	7 (2)	104	P <0.001
Kokopu	32 (15)	3 (1)	6	P <0.05
Bully	123 (29)	59 (14)	119	P <0.05
Shrimp	284 (153)	807 (91)	130	P <0.001

In fact, galaxiids and smelt migrated almost exclusively along the margins. Only small numbers of inanga and smelt migrated upstream in the boundary layer near the bottom of the river channel, because these are free-swimming, shoaling fish which lack the ability to withstand high current velocities by clinging to the substrate. Trapping at Meremere indicated that galaxiids and smelt may utilise areas of low water velocity in the lee of islands and sandbars when crossing the river channel. The proportion of the migrations that do so is unknown.

Smelt appear to be more mobile than galaxiids because larger numbers were caught in the river channel. In addition, Boubee et al. (1986) found that smelt were very abundant in the lee of islands and sandbars, but galaxiids were rarely found there. These observations lead us to believe that the proportion of galaxiids that will normally cross the river channel is small.

Differences in the migratory behaviour of smelt and inanga were highlighted at Huntly during high water levels. For example, on 9 December 1985, a trap at Site A1 (Fig. 4) caught 4 220 inanga and 1 471 smelt. From the stand directly opposite (Site A2), which had water flowing between it and the bank, 5 013 smelt were caught, but no inanga. Almost certainly, inanga were moving in areas of low water velocity close to the banks, and smelt were not. Experiments in the Huntly Thermal Power Station elver pass also showed that smelt chose higher water velocities for migration than inanga (Boubee et al. in prep.a).

4.1.2 Common Bullies and Shrimps

Juvenile common bullies from the Waikato River had a mean sustainable swimming speed of only 0.24 m/s (Mitchell in prep.), yet many bullies were able to migrate in the river channel. Davison (1983) reported that prolonged swimming by common bullies caused rapid fatigue, because this species lacks red (aerobic) muscle. Therefore, common bullies probably avoided high current velocities by utilising the boundary layer near the river bottom. Bullies are well known for their habit of resting on the bottom (McDowall 1978), and, by spreading their large pectoral fins, they have been shown to rest passively at current velocities up to 0.44 m/s (Mitchell in prep.). When moving upstream in the river channel, common bullies probably adopt a strategy of short darting movements, interspersed with rests on the bottom.

Shrimps migrating upstream in the river channel probably do so by walking over the bottom. We observed shrimps swimming upstream in low velocity areas along the margins, and in areas of higher current velocity, they moved upstream by clinging to the substrate with the chelae on their walking legs. Shrimps have been observed to move against velocities of at least 1.4 m/s (Mitchell in prep.), and we have found them upstream from swift riffles and small waterfalls in tributary streams. Thousands have been reported to have climbed the ramp in the elver pass at Huntly Thermal Power Station (Mitchell and Saxton 1983). While shrimps are usually associated with weedbed habitats (Nielson 1972, Carpenter 1983), they are capable of migrating successfully along the bottom of the river channel in the Waikato.

4.2 Vertical Distribution

4.2.1 Galaxiids and Smelt

Most inanga and smelt, and all other galaxiids migrating upstream, did so in the uppermost metre of the water column along the river margins. Similarly, McDowall and Eldon (1980) found that 94% of galaxiid whitebait migrated in the first 1.2 m of the water column in the Waiatoto Estuary, South Westland.

McDowall (1968) described inanga as generalised carnivores which feed at the surface, in mid water, or on the bottom. He observed that feeding responses are based largely on visual cues. In the Waikato River, the percentage of inanga migrating near the bottom of the margins increased as the river depth decreased (Table 5). Higher light intensities near the bottom at these sites may encourage inanga to feed there.

The proportion of smelt moving near the bottom was always low compared to that at the surface, and did not vary with river depth (Table 8). This may be so because smelt feed on surface drift more than inanga do (Boubee et al. in prep. b). This habit may also explain the high densities of smelt present in the top 0.5 m of the water column.

4.2.2 Common Bullies and Shrimps

Common bullies and shrimps moved throughout the water column along the margins, but their densities were highest in the top 2 m.

Bullies are generally regarded as benthic species (McDowall 1978, Stephens 1978), but juvenile red-finned bullies swim more freely in mid water than the adults do (McDowall 1965). Juvenile common bullies apparently share this characteristic, which may be retained from their pelagic larval existence.

At times of peak shimp migration in the Waikato, a column of individuals can be observed moving close to each river bank, just below the surface (Shaw 1981, Boubee et al. 1986). These surface migrations probably occur throughout the migration period, because high densities of shrimps were always found in the top 0.5 m of the water column.

4.3 Diurnal Patterns of Migration

Most galaxiids and smelt migrated upstream during the day, a finding which agrees with that of McDowall and Eldon (1980) and Mitchell and Saxton (1983). However, up to 4 400 inanga were sometimes caught in overnight sets. McDowall and Eldon (1980) suggested that the upstream migration of galaxiid whitebait began as soon as the light level was high enough to allow visual orientation. Inanga caught in overnight sets (from 1700-1800 hours to 800-900 hours) may therefore have entered the traps in daylight.

Common bullies were active at all times in the Waikato River, although the largest migrations occurred during the day. In contrast, Stephens (1978) found that common bullies in the shallows of Lake Waahi were particularly abundant at night. Lake-resident upland bullies exhibited maximal feeding activity at night in spring, but during the day in summer (Staples 1975). Bullies therefore exhibited a variable pattern of diurnal activity.

Most shrimp migration occurred at night, as found by Mitchell and Saxton (1983) and Nielson (1972). Only at migration peaks did significant upstream movement occur during the day.

4.4 Impact of Thermal Power Stations

Both Huntly and Meremere Thermal Power Stations discharge large volumes of heated water along the margins, where the migration of galaxiids, smelt, common bullies, and shrimps is concentrated.

Work at Huntly has shown that the upstream migration of juvenile inanga and smelt is greatly reduced on the power station side of the river when the thermal plume temperature exceeds 26°C (Boubee et al. 1986, Boubee et al. in prep. c). High current velocities at the outfall also reduced the catches upstream from the station (Boubee et al. in prep. c). These thermal and velocity barriers are unlikely to seriously disrupt the upstream migration of smelt because of the ability of these fish to cross the river channel.

Juvenile galaxiids, however, are expected to have difficulty negotiating thermal and velocity barriers because these species are largely confined to the river margins. Short-term dye-marking experiments at Huntly revealed that a small proportion of inanga did cross over to the unaffected margin (Stancliff et al. in prep.). Longer-term marking experiments will be necessary to determine more accurately the proportion of the inanga migrations that negotiates the thermal plume.

Thermal discharges from Huntly Thermal Power Station also affect the summer upstream migrations of common bullies and shrimps. In early February 1987, common bullies moved through the thermal plume at temperatures of up to 28.5°C, but higher temperatures and/or current velocities at the outfall appeared to curtail their migration on the power station side of the river (Stancliff et al. in prep.). Shrimps are more thermally sensitive than inanga, smelt, or common bullies (Simons 1984), and avoidance of the thermal plume is thought to occur several hundred metres below the station's outfall.

Although dye-marking experiments did not demonstrate that common bullies and shrimps were able to move past Huntly Thermal Power Station in summer (Stancliff et al. in prep.), the cross-channel distributions of these species (Table 2) indicate that marked individuals may have avoided thermal and/or velocity barriers by moving around them on the bottom of the river channel. Upstream movement might then have continued in the channel, with few individuals returning to the river margin.

Avoidance of the thermally affected margin at Huntly will reduce the recruitment to populations of fish and shrimps in Lake Waahi, because the outlet stream of this lake enters the river just upstream from the power station. Recruitment of inanga to other populations upstream from Huntly, such as that in the Waipa Catchment, may also be reduced. On the other hand, recruitment of smelt, common bullies, and shrimps is unlikely to be affected, because the in-river distributions of these species should have returned to "normal" well downstream from the Waipa River confluence.

5. CONCLUSIONS

The upstream migrations of all 7 species were concentrated in the uppermost 2 m of the water column along the margins. The siting and design of any new thermal power station should aim to minimise the impact on this zone.

The in-river distributions of smelt, common bullies, and shrimps indicate that these species should be able to negotiate thermal and velocity barriers along the margins by moving in the river channel. However, in doing so, their changed distributions may reduce the recruitment to populations immediately upstream from power station sites.

Because the migration of galaxiid species is confined largely to the river margins, the provision of fishways along power station river bank structures may be necessary to safeguard the migratory pathways. The outfalls of Huntly and Meremere Thermal Power Stations should be modified to prevent the water temperature along the margins from exceeding 26°C.

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