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MIGRATION OF SMALL MIGRATORY FISH AND SHRIMPS PAST THE MODIFIED COOLING WATER OUTFALL AT HUNTLY

by

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SUMMARY

Bankside water velocities and excess temperatures immediately in front of the Huntly thermal power station outfall decreased significantly when the outfall ports were extended by one metre in winter 1988. Downstream of the outfall, during periods of low river levels, plume mixing was severely affected by the formation of sand bars. Bankside temperatures therefore remained high at low river levels.

The modifications of the outfall have allowed a slightly increased proportion of inanga to migrate along the left bank past the station outfall. Benefits for the other fish species were not conclusive possibly because conditions in the river were different in the post and pre modification study periods.

After the outfall was modified, during periods of low river flows, back-eddying caused water flows along the outfall sheet piling to move upstream. This confused fish swimming upstream against the river current. The outfall therefore, although improved by the modifications, remains a hindrance to fish migration.

It is recommended that the orientation of the outfall ports be slightly altered to minimise back-eddying and further ease fish passage. Such repositioning of the ports may also prevent sand deposition downstream of the outfall and decrease bankside temperatures.

1. INTRODUCTION

Migrations of inanga (*Galaxias maculatus*), banded kokopu (*G. fasciatus*), giant kokopu (*G. argenteus*), short-jawed kokopu (*G. postvectis*), koaro (*G. brevipinnis*). and common bullies (*Gobiomorphus cotidianus*), up the left bank of the Waikato River, were affected by high water velocities and turbulence at the Huntly power station's cooling water outfall (Stancliff *et al.* 1989). In addition, juvenile inanga, smelt (*Retropinna retropinna*) and freshwater shrimps (*Paratya curvirostris*) avoided the thermal plume in summer when its temperature rose above 26-27°C (Stancliff *et al.* 1989). All these species have the ability to move past the outfall, either by skirting the warm water plume (bullies, shrimps and smelt), or by crossing to the right margin (inanga and banded kokopu) (Stancliff *et al.* 1988b, Stancliff *et al.* 1989). However, since it was not known what proportion of migrating fish were able to do this, the outfall was modified in an attempt to alleviate any problems.

In March 1988, constrictor plates were inserted into the outfall ports, reducing port internal diameter from 914 mm to 707 mm, and increasing outlet velocity. The modifications increased outfall mixing efficiency and resulted in a 20-35% reduction in left-bank temperatures (Rutherford and Nagels 1988). However, there was a noticeable increase in turbulence near the outfall.

Further modifications were made in June 1988, when 1.0 m extension pipes were fitted to the outfall ports. The extensions did not affect the outfall mixing efficiency (Nagels and Rutherford 1988), but water velocities along the sheet-piling facade of the outfall structure were substantially reduced.

This study was undertaken to determine whether these modifications have improved the migration of fish past the outfall of the power station.

2. METHODS

2.1 Trapping

The upstream migration of five galaxiid species, smelt, common bullies, elvers and freshwater shrimps were monitored by trapping as described by Stancliff *et al.* (1988a). Although four stands were sampled at the beginning of the study, data from only two (Sites H and J, Fig. 1) were retained for analysis, (stand I, opposite the station, was regularly destroyed by floods, and stand C, below the outfall, became inefficient due to sand deposition).

Trapping was carried out between 2 September 1987 to 9 February 1988 (prior to outfall modification), and from 27 October 1988 to 22 February 1989 (after the outfall ports were extended).

The catch was analysed following Stancliff *et al.* (1988b). Catch per unit effort (CPUE) was defined as the number of fish, or the weight of shrimps (in grams), caught per trap per 24 hours.

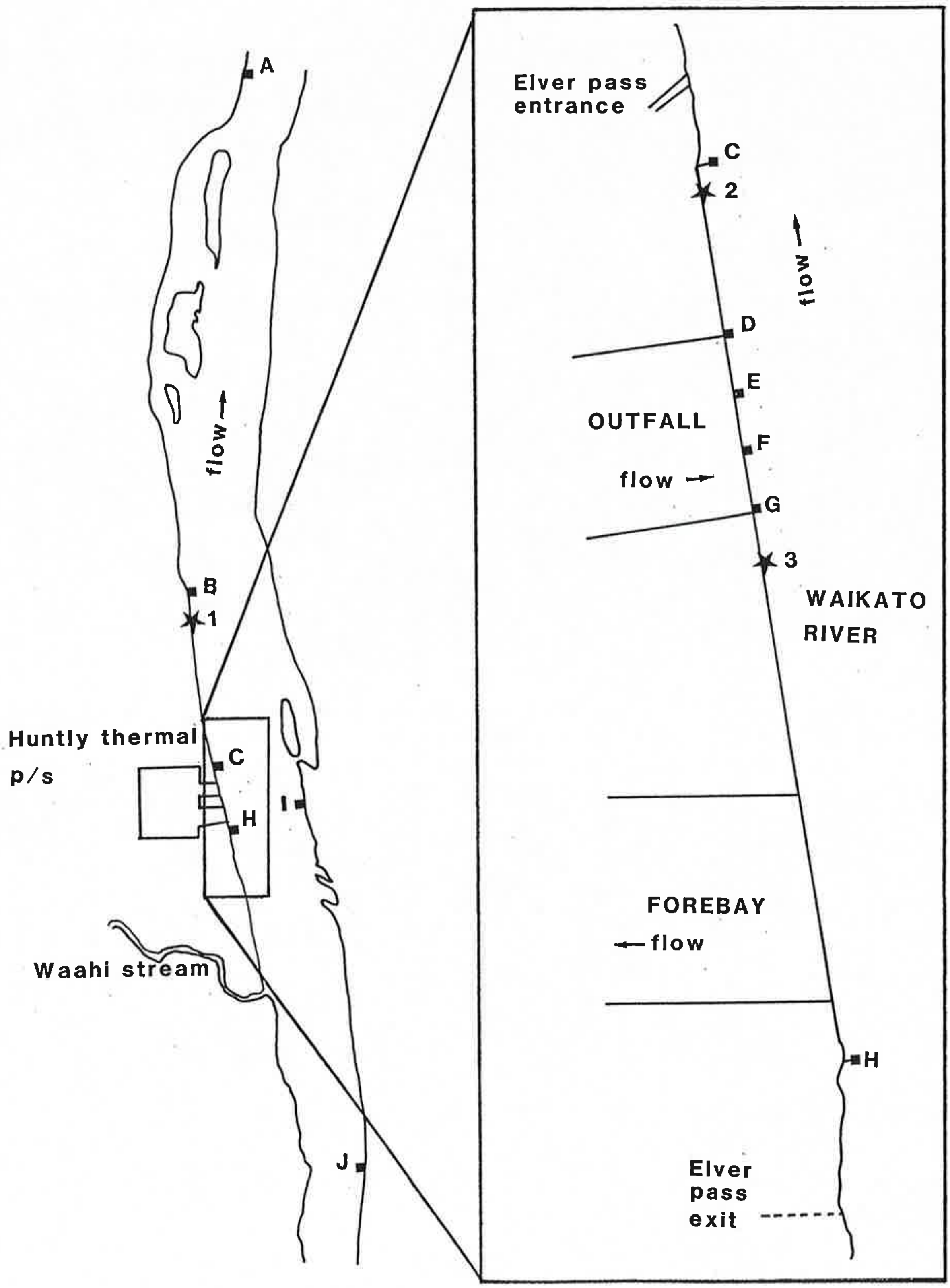

Figure 1. Location of sampling sites (letters) and of fish release sites (numbers) in the Waikato River near Huntly power station.

2.2 Mark-recapture experiments

Juveniles of inanga were batch marked by immersion in 0.05 g/l neutral red or 0.15 g/l bismark brown for 5-10 minutes. The solutions were continuously aerated during the marking process. The total numbers released were adjusted to account for mortality, which was estimated from subsamples kept in live-boxes for the duration of each experiment.

Marked fish were released in the thermal plume below Huntly power station (sites 1 and 2, Fig 1), and along the sheet-piling between the station's intake and outfall structures (site 3).

Trapping sites were monitored for at least 24 hours after each release. Recaptured marked individuals were counted and released about 20 m upstream of the recapture site.

2.3 Physical parameters

Records of river level and temperature, station generation and cooling water flow rates were obtained from the Huntly power station daily logs. In addition, bankside temperature measurements were taken at 08.00 and 15.00 hours from two sites below the outfall by station staff during week days from 4/11/88 to 28/04/89. Spot temperatures were also recorded on a number of occasions when traps were set.

To fully assess the effectiveness of the modifications it is necessary to account for variables such as cooling water flows[1] and changes in river ambient temperature, station generation and river levels. We can account for some of these factors by using the ratio:

$$\frac{\Delta T_i}{\Delta T_{cw}}$$

Where: ΔT_i = difference between temperature at point i and ambient river temperature.

ΔT_{cw} = difference between temperature of outfall cooling water and river ambient.

Water velocities along the sheet piling of the outfall structure were measured with a Gurley pigmy meter at site D, E, F and G (Fig. 1) on 24/6/87 (before modifications), 18/3/88 (with constrictor plates installed) and on four occasions between 28/6/88 and 14/3/89 (extension pipes installed).

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[1]Measurements made indicate that under the present station operating schedule, cooling water flow rates do not affect outfall mixing efficiency (Appendix 1).

3. RESULTS AND DISCUSSION

3.1 Physical parameters

In general, day-time waste heat production, cooling water flow rates and river ambient temperatures were similar for the two study periods (Table 1). However, river flows were substantially higher in the post modification period.

Table 1. Instantaneous river flow, cooling water (CW) flow, station heat rejection, river ambient and excess temperatures at Huntly before and after the power station outfall was modified. Locations of sampling sites are given in Fig. 1. Raw data in Appendix 2. Note: all measurements made between 09.00 and 13.00 hours.

DATE	RIVER FLOW (m^3s^{-1})	CW FLOW (m^3s^{-1})	HEAT REJECT. (MW)	RIVER AMBIENT (°C)	EXCESS TEMPERATURE (°C)				
					E	D	C	B	A
Unmodified									
n	33	33	33	33		11	33	28	25
Mean	302	28.53	914	18.0	-	6.5	3.7	3.1	2.3
Maximum	374	33.39	1057	23.5	-	8.2	6.1	4.5	3.2
Minimum	229	18.67	268	10.8	-	2.0	0.7	0.7	0.3
Modified									
n	24	24	24	26	20	20	24	21	18
Mean	418	29.96	880	18.1	1.2	3.2	3.8	3.0	2.4
Maximum	616	37.7	1220	22.0	2.0	5.8	5.6	4.8	3.8
Minimum	237	22.6	522	11.8	0.0	1.0	2.2	2.0	1.0

During the post-modification trapping period, night-time station generation (especially between 24.00 and 06.00 hours) was often below 200MW. In the pre-modification period it remained above 200MW at all times.

3.1.1 Water velocities

Before modifications were made, surface water velocities at the outfall progressively increased along the outfall wall, with the highest velocities (2.24 ms^{-1}) measured at an abutment just downstream of the last port (Table 2). With the addition of the constrictor plates surface water velocities along the wall of the outfall increased markedly (Table 2). Water in front of the outfall also became more turbulent due to stronger jetting (Plate 1).

Table 2. Water velocities along the sheet piling of the outfall at the Huntly thermal power station. Values in brackets are the range of 4 measurements).

		Before modification	With constrictor plates	With extension pipes
Date		24/08/87	18/03/88	28/06/88 - 14/03/89
River level (m)		107.30	107.37	107.30 - 108.15
CW flow rate (m^3s^{-1})		31.9	23.7	28.65 - 33.70
Velocity (ms^{-1})	Site D	2.24	1.90	0.26 (0.22-0.35)
	E	-	-	0.41 (0.22-0.68)
	F	0.52	0.95	0.30 (0.24-0.40)
	G	0.51	0.70	0.55 (0.30-0.95)

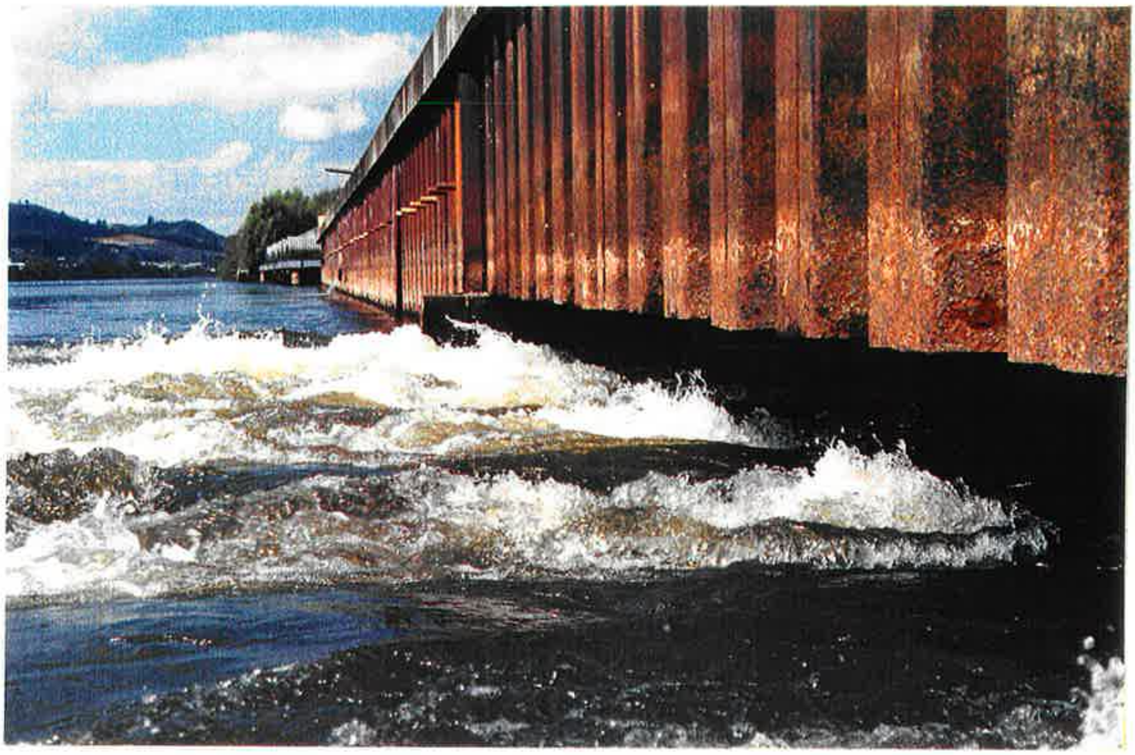

Plate 1. Upstream view of the Huntly power station outfall with the port constrictor plates installed. Note turbulence close to wall.

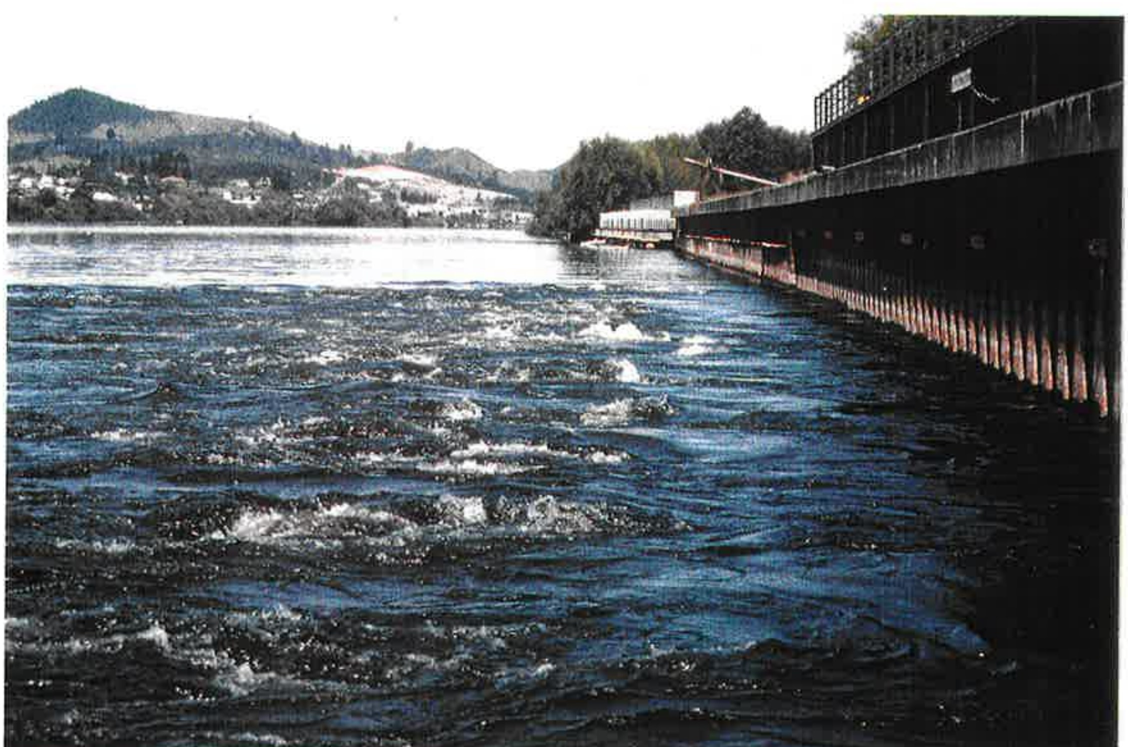

Plate 2. Upstream view of the Huntly power station outfall after the outfall ports were extended. Note low turbulence close to wall.

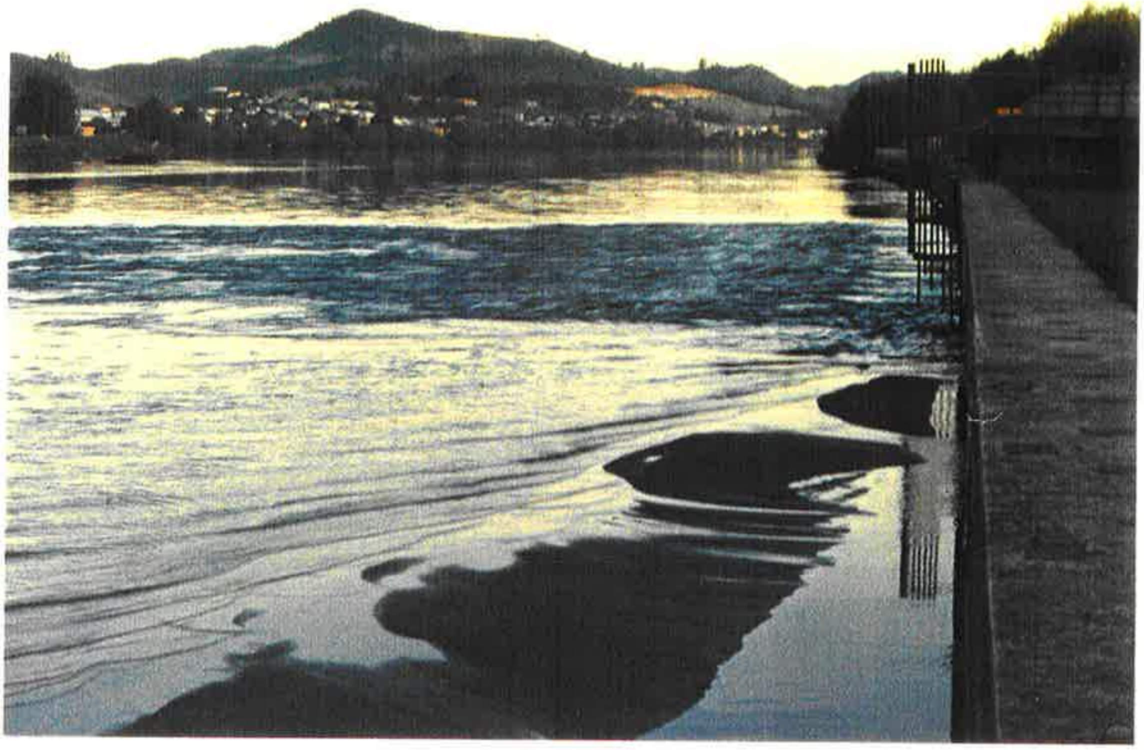

Plate 3. Upstream (top) and downstream (bottom) views of the sand bar that developed below the Huntly power station outfall after the ports were extended (Photographed 7/05/89).

The addition of the extension pipes resulted in a net decrease in turbulence close to the sheet piling (Plate 2). Highest bankside velocities were now recorded at the abutment at the upstream end of the outfall (Table 2). During periods of low river flows, back-eddies formed and resulted in water flowing upstream along part of the outfall. A low energy zone also developed downstream of the outfall and caused sand to deposit. By the end of the summer of 88/89 a large sand bar had formed (Plate 3).

3.1.2 Thermal plume temperatures

Before the outfall was modified, there were large fluctuations in temperatures along the sheet piling facade of the outfall and temperatures there often approached that of the unmixed cooling water. At the downstream end of the outfall, temperatures averaged 6.5°C (min. 2.0, max. 8.2) above ambient river temperatures (Table 1).Plume excess temperatures along the outfall facade, were lowered following the addition of the 1 m port extensions (Table 1). Temperatures near the upstream end of the outfall (Site G, Fig. 1), were close to ambient and there was now a progressive but small increase in temperature towards the downstream end of the outfall (Table 1, Appendix 3).

Although extending the outfall ports significantly decreased bankside temperatures along the outfall, bankside temperatures further downstream did not alter. Plotting the ratio $\Delta T_{50m}/\Delta T_{outfall}$ against water level shows that mixing was very much reduced after the modification (Fig. 2). Further, examination of the post-modification measurements show that poor mixing occurred largely during the low flows recorded in March (Fig. 3). Field observations indicate that the sand bar which had formed below the outfall caused the reduction in bankside mixing.

Because mixing was reduced at low water levels, and low water levels coincided with periods of high temperatures, the difference between bankside and ambient temperatures increased as ambient temperature increased (Fig. 4)

Bankside temperatures were also significantly elevated by low river levels further dowstream (Fig. 5). Again, the location and size of sand bars probably dictated the shape and intensity of the thermal plume (Appendix 4).

3.2 Fish and shrimp migrations

3.2.1 Inanga

Before the outfall was modified, most juvenile inanga (93.5% assuming catch efficiency of the two stands were the same) migrated upriver, past the Huntly power station, using the right bank. With the port extensions fitted, the proportion of migrants that used the left bank increased from 6.5% to 24.2% (Table 3). However, because of the large variations in catch recorded over the sampling period this overall small increase was not statistically significant (Wilcoxon signed-rank and Mann-Whitney tests).

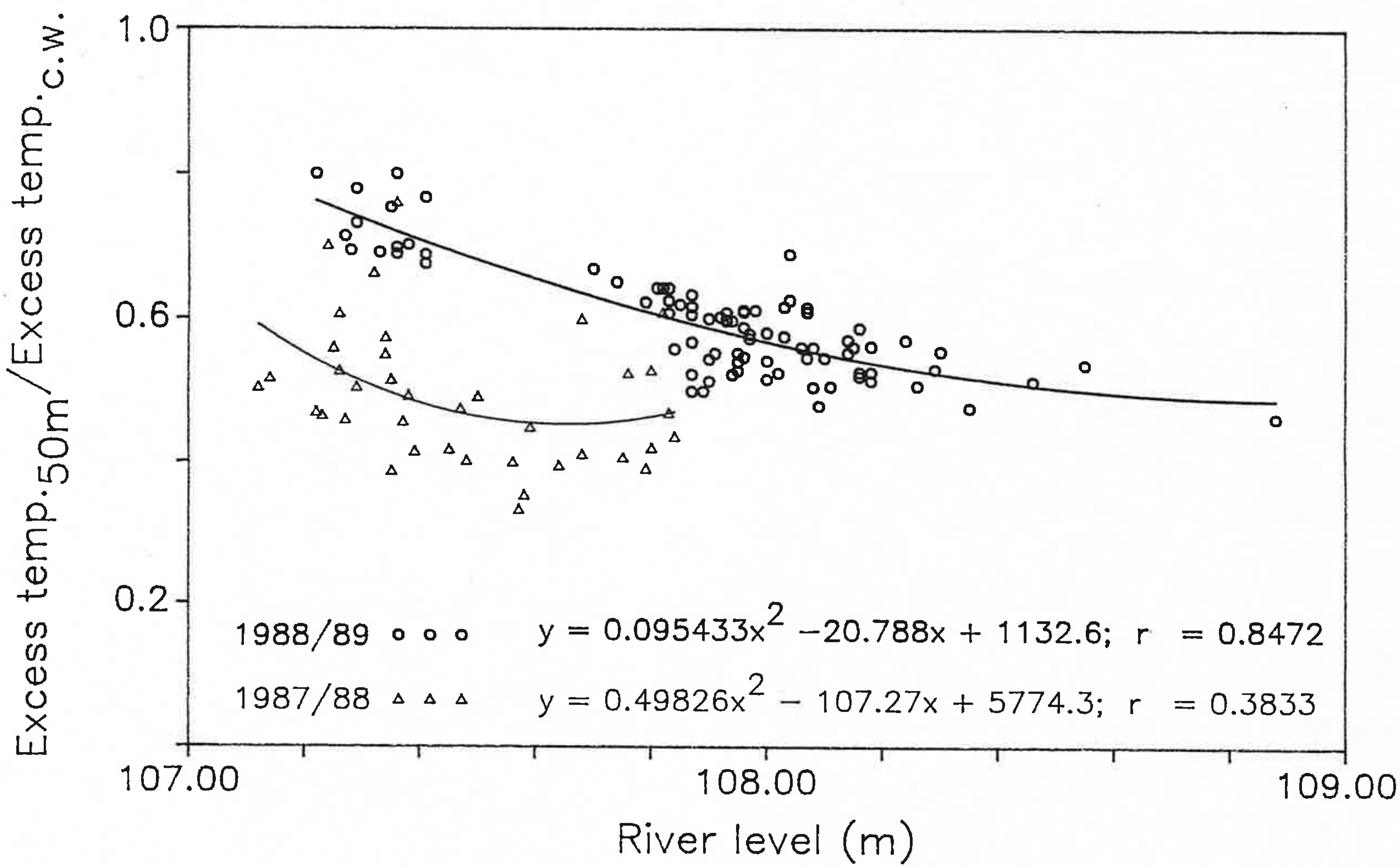

Figure 2. Change with river level in plume mixing as determined by the ratio of excess temperature 50 m below the Huntly power station (site C) to excess temperature of cooling water (cw). Excess temperatures are differences from river ambient. 1987/88 = pre-modification of the outfall, 1988/89 = post-modification.

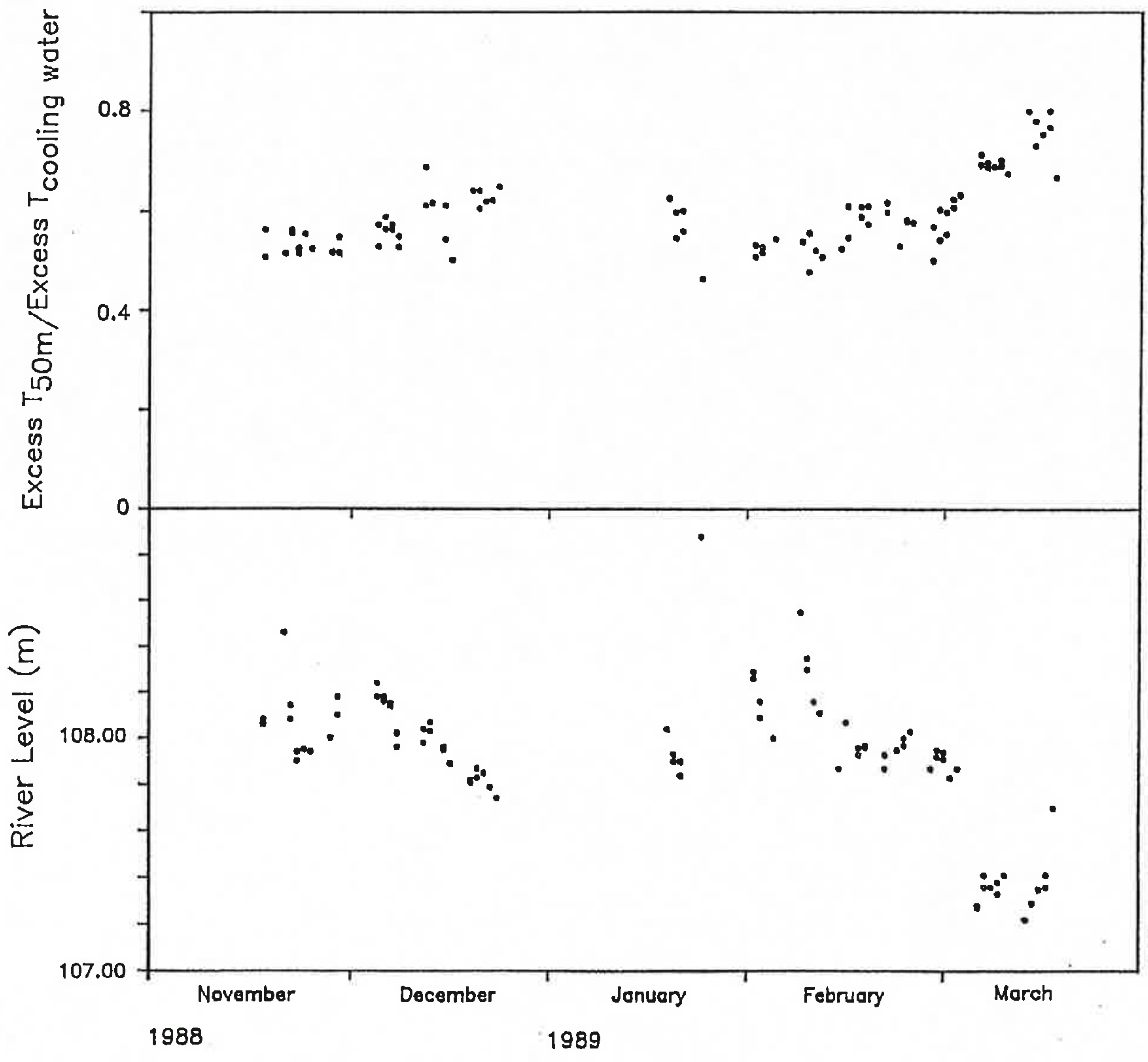

Figure 3. Change in plume mixing and river level at Huntly from November 1988 to March 1989. Plume mixing determined by the ratio of excess temperature 50 m below the Huntly power station outfall (site C) to excess temperature of cooling water. Excess temperatures are differences from river ambient.

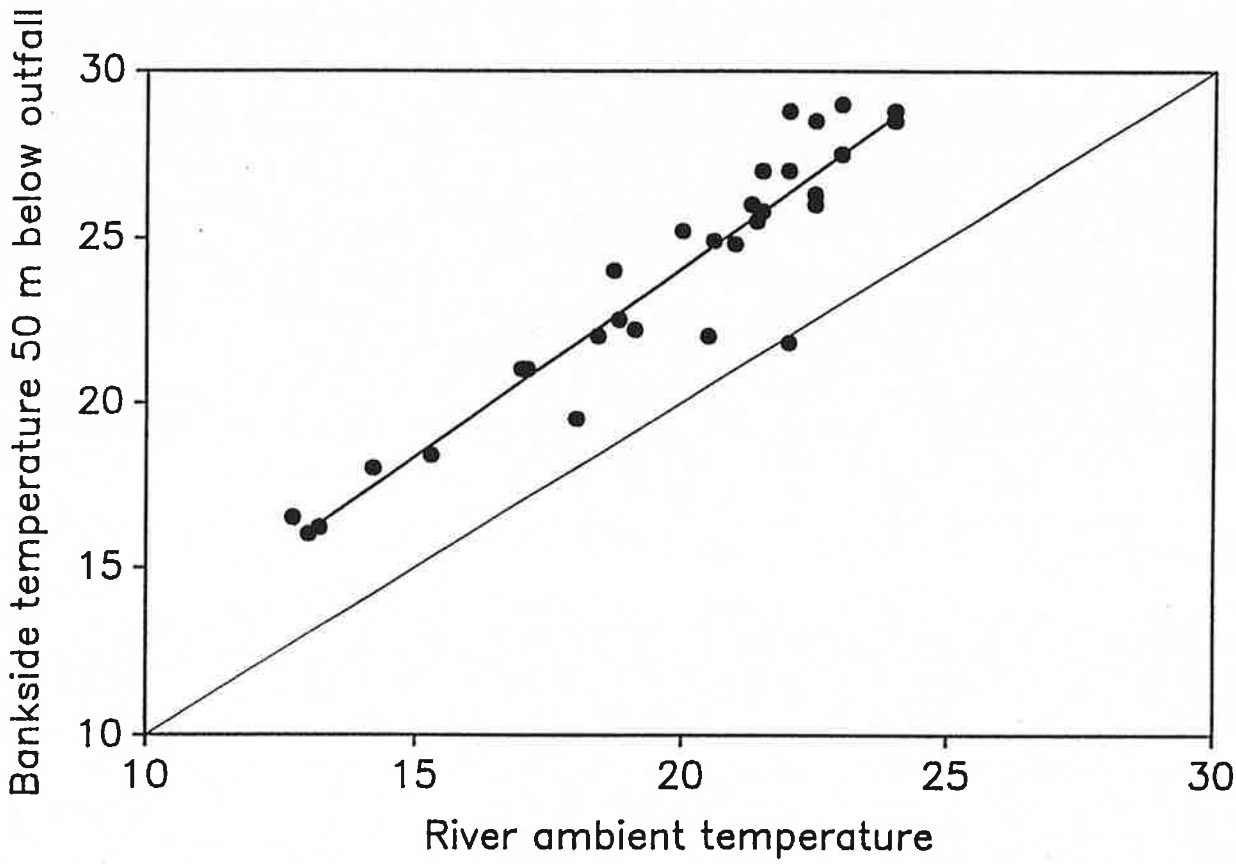

Figure 4. Relationship between river ambient temperature (^0C) and bankside temperatures 50 m below the Huntly power station outfall (site C) after the outfall was modified.

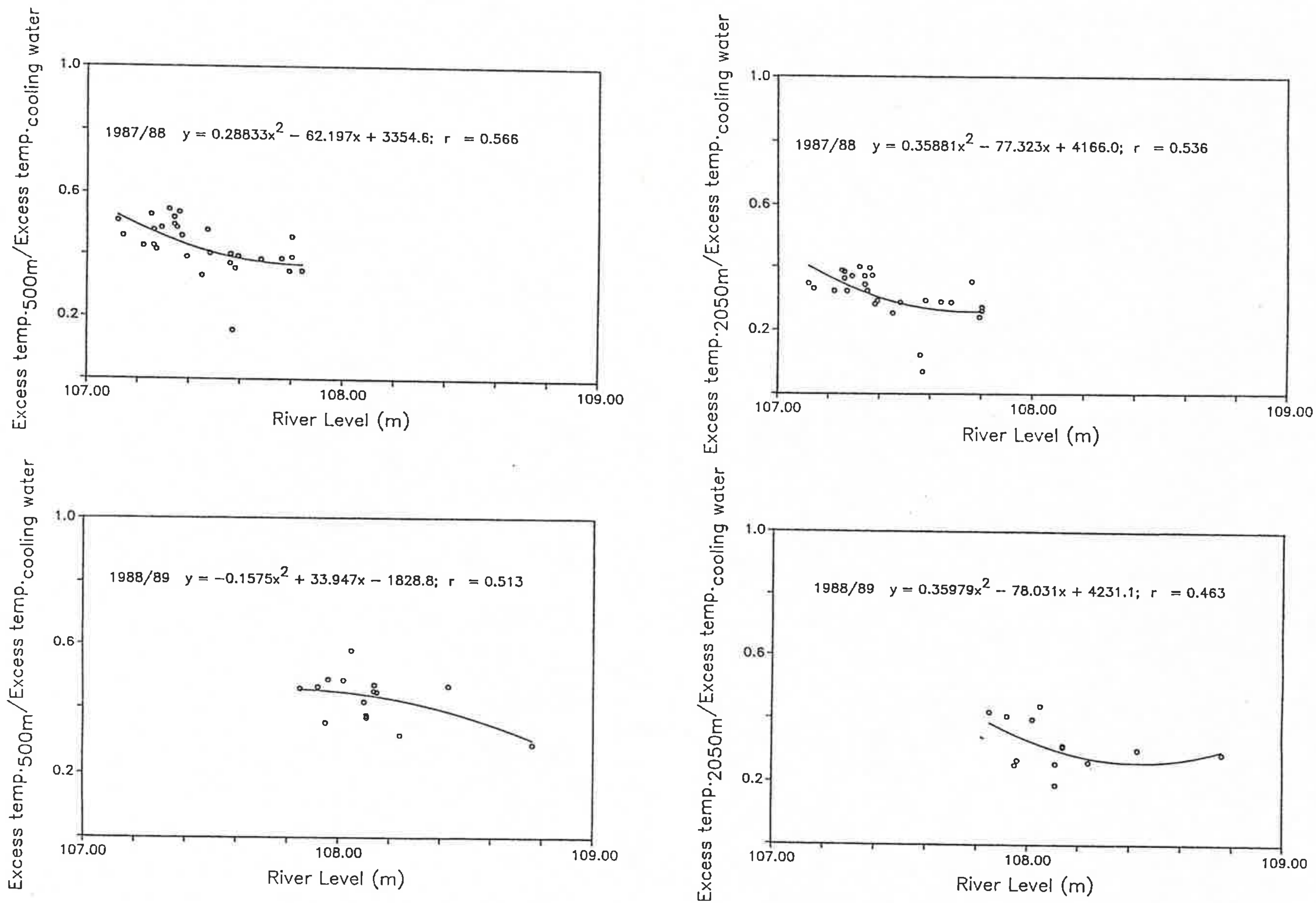

Figure 5. Change with river level in plume mixing as determined by the ratio of excess temperature 500 m (site B) and 2050 m (site A) below the Huntly power station to excess temperature of cooling water. Excess temperatures are differences from river ambient. 1987/88 = pre-modification of the outfall, 1988/89 = post-modification.

Table 3. Total catch of fish and shrimps in traps set for 24 hours at Huntly before (number of sets = 17) and after (number of sets = 12) the outfall ports were extended. Percentage of catch made on the banks is given in brackets. Raw data given in Appendix 5.

Species	Outfall extension	Total catch Left bank	Total catch Right bank
Inanga	Pre	957 (6.5)	13820 (93.5)
	Post	8052 (24.2)	25274 (75.8)
Banded kokopu	Pre	35 (34.0)	68 (66.0)
	Post	90 (19.7)	368 (80.3)
Common bully	Pre	904 (45.3)	990 (54.7)
	Post	5340 (56.6)	4095 (43.4)
Elvers	Pre	257 (85.1)	45 (14.9)
	Post	190 (96.0)	8 (4.0)
Shrimps	Pre	2573 (76.9)	771 (23.1)
	Post	2922 (39.4)	4492 (60.6)

The effect of power station generation on the migration of inanga was also monitored during two power station shut downs in December 1988. Very little difference in the migration of inanga was recorded on the first shut down (9/12/88), but on the second (14/12/88), there was a marked percentage increase in the catch on the left bank (Table 4). The river on 9/12/88 was rising and water along the left margin was noticeably discoloured by the inflowing Waahi Stream. River levels on the 13-14 December were stable. Furthermore, substantial cooling water was still being discharged on 9/12/88 while on 14/12/88 this had virtually stopped.

Table 4. Catch of inanga at Huntly with the power station operating and with the station turned off. Note: the station generation given is the range of loads that occurred during daylight (when inanga migrate). Figures in brackets are percentages of total catch.

Date	Station generation (MW)	C.W. flow rate (m^3s^{-1})	Inanga catch Left bank	Inanga catch Right bank
8.12.88	366-744	32.3	367 (14.3)	2196 (85.7)
9.12.88	Nil	14.7	315 (14.1)	1920 (85.9)
13.12.88	532-814	36.3	165 (4.2)	3786 (95.8)
14.12.88	Nil	5.5	2541 (54.2)	2150 (45.8)

C.W. flow = station cooling water flows

Prior to outfall modification, when marked inanga were released approximately 550 m below the outfall (site 1), few fish (0 - 1.5%) were recaptured on the left bank directly upstream of the power station. Most of the recaptures were made on the opposite river margin (Table 5). After the outfall was modified, the percentage recaptured along the left bank upstream of the station increased from 0.36 to 6.16%. This is however still well below the 53.8% obtained when the station was shut down by industrial action on 14/12/88.

The proportion of marked inanga recapture along the left bank upstream of the station was lower when released just below the outfall (site 2, Fig. 1), than when released upstream of the outfall (site 3). Furthermore, a greater proportion of inanga crossed to the right margin when released downstream of the outfall than when released above the outfall (Table 6). Therefore although conditions have improved, the modified outfall still hinders the migration of inanga.

Table 5. Percentage recaptures of marked inanga released downstream of Huntly power station prior to and after modification of the outfall. Percentage recaptures obtained when the station was shut down is also shown. The station generation is the range of loads that occurred in daylight.

Releases			Generation (MW)			% Recaptured		% of recaptures crossing river
Date	n	Site	Mean	Min	Max	Left bank (site H)	Right bank (site J)	
Unmodified								
3.09.87	400	1	726	743	750	0.00	4.25	100.0
9.09.87	3259	1	612	629	650	0.03	0.03	50.0
22.09.87	2067	2	510	499	753	0.10	0.58	85.3
6.10.87	2049	1	720	690	740	0.15	6.70	97.8
20.10.87	1333	1	711	668	746	1.50	5.40	78.3
Modified								
1.11.88	1900	1	483	372	718	1.47	7.11	82.9
7.11.88	147	2	556	129	745	6.80	4.76	41.2
16.11.88	297	2	565	226	735	8.08	6.73	45.4
22.11.88	114	2	565	113	687	5.26	0.88	14.3
7.12.88	1684	2	693	346	737	13.36	2.55	16.0
22.12.88	2998*	2	466	188	715	4.97	0.73	12.8
Shut down								
14.12.88	2771	2	0	0	0	53.81	1.52	2.8

* = monitored for only 4 hours after release.
n = number released

Table 6. Percentage recaptures of marked inanga released downstream (site 2, Fig. 1) and upstream (site 3, Fig. 1) of the modified power station outfall.

Releases			% Recaptured		% of recaptures crossing river
Date	n	Site	Left bank (site H)	Right bank (site J)	
7.11.88	147	~~upstream~~ ds	6.80	4.76	41.2
7.11.88	118	~~downstream~~ us	19.49	1.69	8.0
16.11.88	297	~~upstream~~ ds	8.08	6.73	45.4
16.11.88	149	~~downstream~~ us	32.21	3.36	9.4
7.12.88	1684	~~upstream~~ ds	13.36	2.55	16.0
7.12.88	1210	~~downstream~~ us	15.29	1.32	7.9

3.2.2 Banded Kokopu

Only small numbers of kokopu were caught during the study particularly in 1987/88. As a consequence it was not posssible to determine with any accuracy, differences between numbers migrating up the left and right bank before the outfall was modified. After the modifications 80% migrated along the right bank. This propotion is very close to that recorded for inanga and it is likely that kokopu were affected in a similar way to inanga.

3.2.3 Common bullies

About equal numbers of bullies were caught along the right and left bank both before and after the outfall was modified (Table 3).

3.2.4 Elvers

As the traps were set at the surface of the water column, they did not target elvers and only small numbers were captured. Most were caught on the right bank (the shallowest sites).

3.2.5 Shrimps

Shrimp captures prior to the outfall modifications were highest on the left bank of the river than on the right (Table 3). After the modifications, a much larger proportion of the catch was made on the right bank. Unlike the fish, shrimps appear to have been detrimentally affected by the modification but it is more likely that factors independent of power station outfall caused the change in distribution.

4. CONCLUSIONS

Because conditions in the river are constantly changing and station generation is variable, there are real difficulties in assessing the success of the outfall modifications in term of fish passage.

Both water velocities and temperatures immediately in front of the outfall decreased considerably with the port extensions. However, these benefits were negated during periods of low flows by the development of back-eddies and the formation of a sand bar below the outfall. The back-eddies reverse the direction of water movement and so confuse fish migrating upstream against water currents. The sand bar results in lower plume mixing and hence higher bankside temperatures downstream of the outfall.

After the outfall ports were extended, we recorded a small improvement in the migration of inanga on the left bank. The effects on elvers and bullies (which have fewer problems negotiating the outfall) were negligeable. Although it is possible that the modifications benefitted inanga more than the others fish species it is also likely that the changed environmental conditions (higher flows, reduced generation etc.) affected the catch.

Similarly, the decline in the proportion of shrimps using the left bank after the outfall was modified may have been due to a reduction in migration or to a change in trap efficiency related to the changed river conditions.

In all events, the decrease in both temperature and turbulence immediately in front of the outfall has probably resulted in some improvement in fish migration. To further improve upstream passage it is recommended that the outfall ports be slightly redirected so as to reduce the problem of back-eddying and sand deposition at the outfall.

5. ACKNOWLEDGEMENTS

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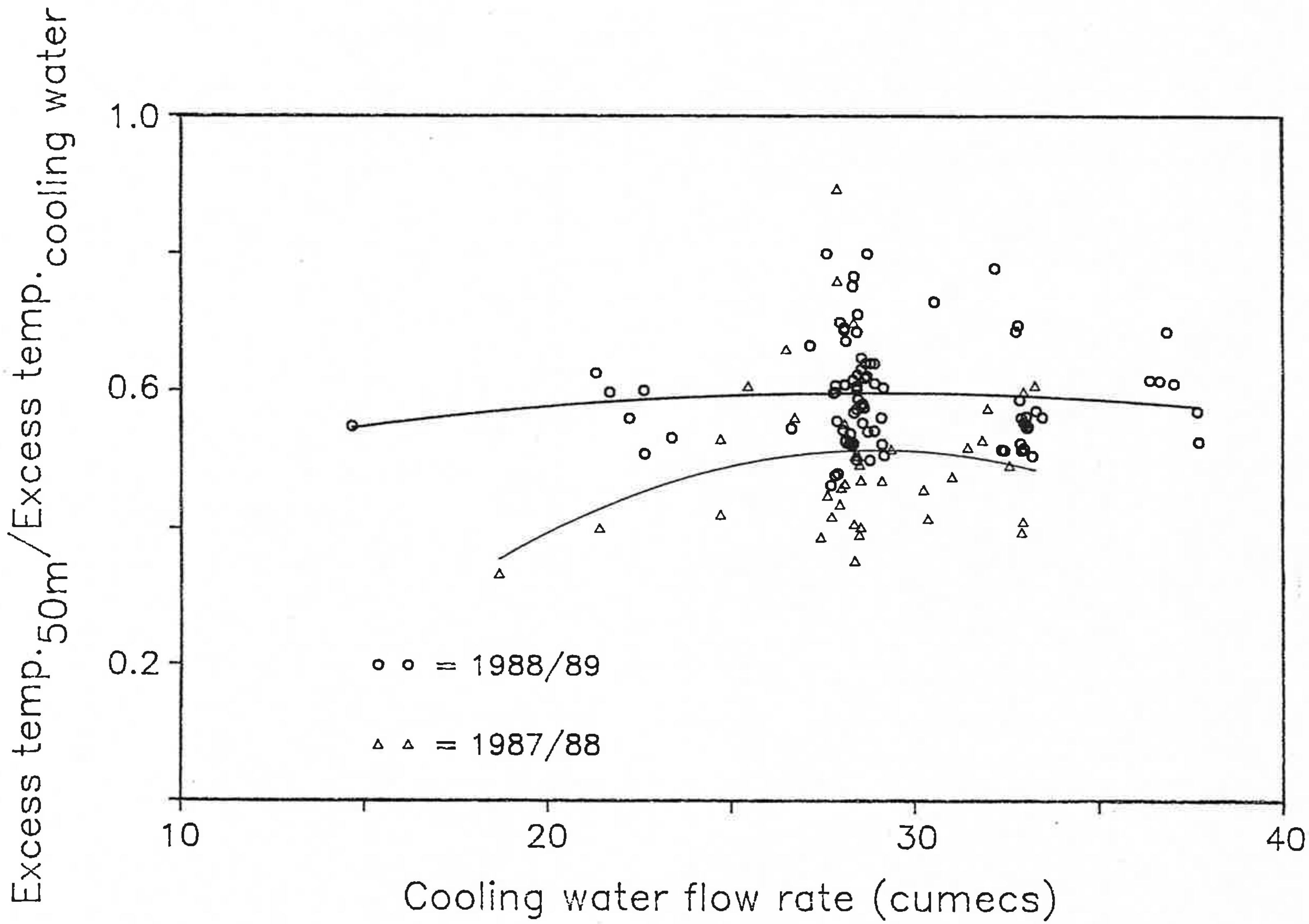


Appendix 1. Change in plume mixing with cooling water flow rate. Plume mixing determined by the ratio of excess temperature 50m below the Huntly power station (site C) to excess temperature of cooling water. Excess temperatures are differences from river ambient. 1987/88 = pre-modification of the outfall, 1988/89 = post-modification.

Appendix 2. Instantaneous river flow, cooling water flow, station heat rejection, river ambient and excess temperatures at Huntly before and after the power station outfall was modified. Locations of sampling sites are given in Fig. 1.

DATE	RIVER FLOW (m^3s^{-1})	CW FLOW (m^3s^{-1})	HEAT REJECT. (MW)	RIVER AMBIENT (°C)	EXCESS TEMPERATURE (°C) E	D	C	B	A
Unmodified									
25/06/87	339	32.94	972	10.8	-	-	4.2	-	-
26/06/87	365	32.25	968	10.8	-	-	4.2	3.9	-
8/09/87	323	27.60	1020	13.0	-	7.0	4.0	3.5	-
8/09/87	320	27.82	1030	12.5	-	7.5	4.3	3.5	2.5
9/09/87	330	27.94	899	12.8	-	-	3.4	2.7	-
21/09/87	360	28.47	1034	12.8	-	7.2	3.4	3.0	2.1
21/09/87	353	28.33	1036	13.5	-	-	3.5	-	-
5/10/87	270	27.98	1040	14.0	-	7.0	4.0	3.6	2.8
6/10/87	304	28.08	1040	14.5	-	-	3.5	3.5	2.5
19/10/87	288	28.51	1030	15.0	-	-	3.4	3.2	2.4
19/10/87	286	30.21	1033	15.8	-	8.2	3.7	3.7	3.0
3/11/87	282	27.42	1057	18.2	-	-	3.6	3.0	2.0
4/11/87	299	27.72	1047	17.2	-	-	4.0	3.0	2.3
16/11/87	340	32.92	1015	18.0	-	-	3.0	2.8	2.1
17/11/87	301	32.55	1027	18.0	-	-	3.7	-	-
30/11/87	232	31.41	1027	18.0	-	7.5	4.5	4.0	3.0
30/11/87	229	28.44	1045	19.6	-	-	4.4	4.4	3.0
1/12/87	247	28.51	1037	18.1	-	-	4.1	3.7	2.8
14/12/87	366	33.39	967	19.1	-	-	2.9	1.8	1.8
14/12/87	357	28.17	669	19.8	-	-	3.0	2.2	2.0
15/12/87	367	24.69	681	19.0	-	7.0	3.5	3.0	1.8
30/12/87	317	18.67	365	20.5	-	2.0	1.5	0.7	0.3
31/12/87	314	21.41	268	20.5	-	-	1.0	1.0	0.3
12/01/88	370	31.96	974	20.6	-	6.4	4.2	3.6	2.5
14/01/88	374	29.08	1037	21.1	-	6.1	3.9	-	-
4/02/88	254	25.44	637	22.6	-	-	3.7	2.9	2.2
4/02/88	253	26.71	626	23.0	-	-	3.2	3.0	2.2
5/02/88	271	29.34	780	22.0	-	-	3.2	3.0	2.0
9/02/88	266	26.47	796	23.5	-	5.5	4.5	3.7	2.7
23/02/88	269	28.08	1028	21.0	-	-	4.8	4.5	3.2
23/02/88	272	27.86	888	21.8	-	-	5.4	3.8	2.8
2/03/88	250	28.31	1039	20.5	-	-	6.1	-	-
14/03/88	260	28.35	1040	20.8	-	-	4.4	4.2	3.2
Modified									
28/06/88	360	33.70	1029	12.0	1.4	1.2	-	-	-
22/08/88	616	37.70	1220	12.0	0.0	3.0	3.0	2.1	2.1
5/09/88	470	29.00	913	11.8	0.0	3.2	3.2	2.4	2.0
14/09/88	427	27.80	785	13.2	0.0	2.8	2.8	2.8	-
28/09/88	-	-	-	14.9	1.6	2.6	3.1	2.1	2.1
17/10/88	-	-	-	15.0	-	1.0	2.2	2.2	-
27/10/88	507	28.70	857	16.0	-	-	2.5	-	-
1/11/88	417	28.20	816	16.5	1.0	-	3.5	3.3	2.7
7/11/88	436	29.10	1042	16.0	2.0	-	4.0	-	-
16/11/88	446	32.80	941	16.8	1.2	-	4.0	3.2	2.2
17/11/88	449	28.80	697	18.2	0.0	-	3.4	2.6	-
22/11/88	439	33.00	862	18.8	0.6	1.2	3.3	2.3	1.6
23/11/88	393	28.60	832	19.0	1.0	2.5	4.0	3.2	2.8
30/11/88	522	32.80	826	18.2	-	3.3	3.8	2.8	1.8
7/12/88	446	33.20	972	19.6	1.6	3.6	4.2	3.3	2.2
13/12/88	424	36.20	989	19.8	2.0	4.2	4.4	3.7	2.8
15/12/88	401	28.90	941	20.0	2.0	3.0	4.5	2.8	2.0
15/12/88	402	28.90	700	20.5	2.0	2.9	3.5	-	-
21/12/88	377	28.60	911	20.8	1.7	4.0	4.7	3.4	3.1
22/12/88	364	28.70	947	20.5	-	4.5	-	-	-
16/01/89	440	22.60	522	22.0	1.0	2.8	3.0	2.0	1.0
2/02/89	415	28.00	600	22.0	1.0	3.8	3.3	3.0	2.0
22/02/89	402	28.39	986	21.0	2.0	5.0	5.0	4.0	2.2
14/03/89	260	30.6	985	21.2	1.3	5.8	5.6	4.3	3.8
22/03/89	318	26.4	1030	19.2	-	3.8	5.3	4.8	3.8
28/03/89	237	32.13	846	20.6	-	-	5.4	3.7	3.3

Appendix 3. River flow, station heat rejection, river ambient and excess temperatures at Huntly after the power station outfall was modified. Locations of sampling sites are given in Fig 1. Note: all data recorded outside of present study period.

Date	River flow m^3s^{-1}	Heat rej. (MW)	River amb. (^0C)	Site or distance downstream						
				G	F	E	D	C	B	A
01-06-89	365	1308	11.8	--	--	--	13.0	16.0	15.2	14.8
03-10-89	387	989	16.0	16.0	15.5	16.0	16.0	16.3	--	--
03-11-89	453	663	17.0	--	--	17.0	--	18.0	--	--
07-11-89	382	647	18.0	18.0	--	18.0	18.0	18.5	18.5	--
27-11-89	330	1086	18.5	--	--	--	--	20.5	--	--
30-11-89	369	1048	18.0	--	--	--	20.5	20.5	--	--
17-01-90	315	--	21.0	--	22.0	23.0	23.0	23.5	21.0	--
18-01-90	364	666	21.0	--	21.0	22.0	22.0	22.0	21.0	--
24-01-90	300	667	21.0	21.0	--	21.5	21.5	21.5	--	--
25-01-90	297	667	22.0	--	--	23.0	23.0	22.5	--	23.0
			Mean ΔT	0.0	0.3	0.6	1.0	1.5	1.4	1.6
			Max. ΔT	0.0	1.0	2.0	2.5	4.2	3.4	3.0
			Min. ΔT	0.0	0.0	0.0	0.0	0.3	0.3	0.8

Appendix 4. Temperature measurements taken in the Huntly power station thermal plume after the outfall was modified in winter 1988. (note: data from outside present study period included).

Date: 14/03/89
Ambient Temp.: 21.2 °C (left bank)
River level: 107.30 m
Heat rejection: 971 MW

Distance (m)	4/4	3/4	1/2	1/4	0
0					21.2
Outfall					27.0
50	20.4	20.4	22.4	24.0	26.8
500		21.2	21.3	24.0	25.5
2500	21.2	21.5	23.8	25.0	25.0

Distance across river

Date: 22/03/89
Ambient Temp.: 19.5 °C (left bank)
River level: 107.5 m
Heat rejection: 838 MW

Distance (m)	4/4	3/4	1/2	1/4	0
0					19.5
Outfall					23.0
50				22.0	24.4
500				19.8	24.0
2500				20.3	23.0

Distance across river

Appendix 4. cont.

Date: 3/10/89
Ambient Temp.: 16.0 ^{0}C (left bank)
River level: 107.72 m
Heat rejection: 980 MW

4/4	3/4	1/2	1/4	0	Distance (m)
		15.5		16.0	0
				16.0	Outfall
		16.0	16.8	16.3	50
	15.8	16.5	17.0	16.3	500
				16.8	2500

Distance across river

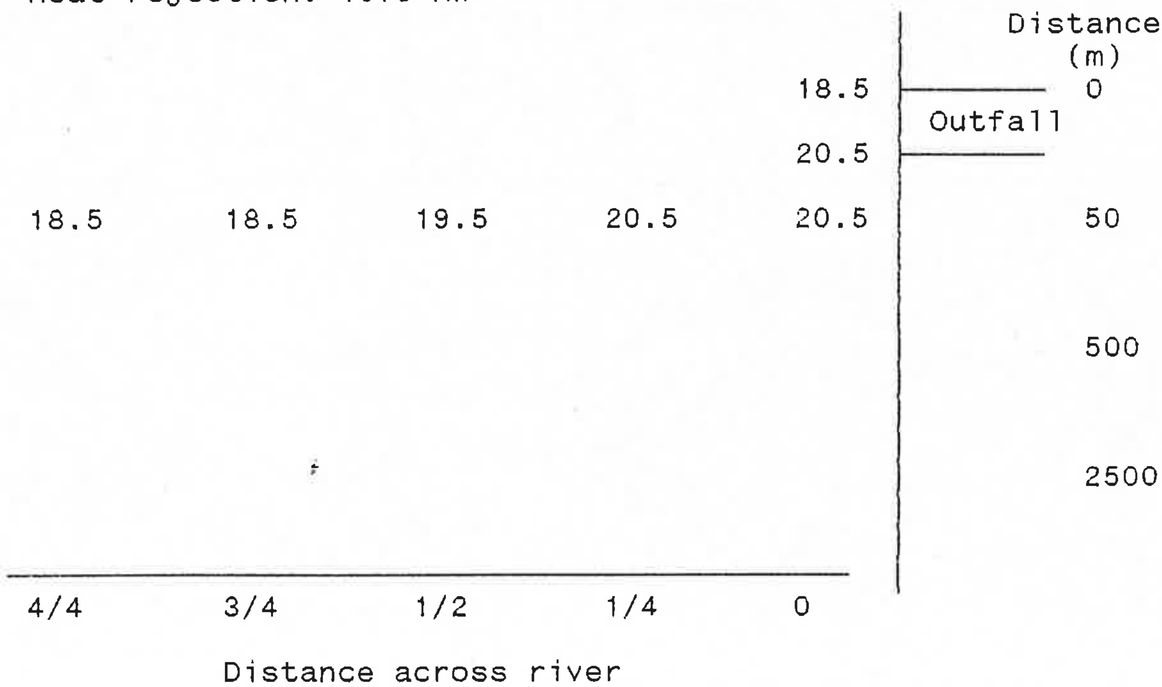
Date: 7/11/89
Ambient Temp.: 18 ^{0}C (left bank)
River level: 107.87 m
Heat rejection: 630 MW

4/4	3/4	1/2	1/4	0	Distance (m)
				18.0	0
				18.0	Outfall
17.5	18.8	18.5	18.3	18.5	50
18.0	18.5	18.5	18.8	18.5	500
					2500

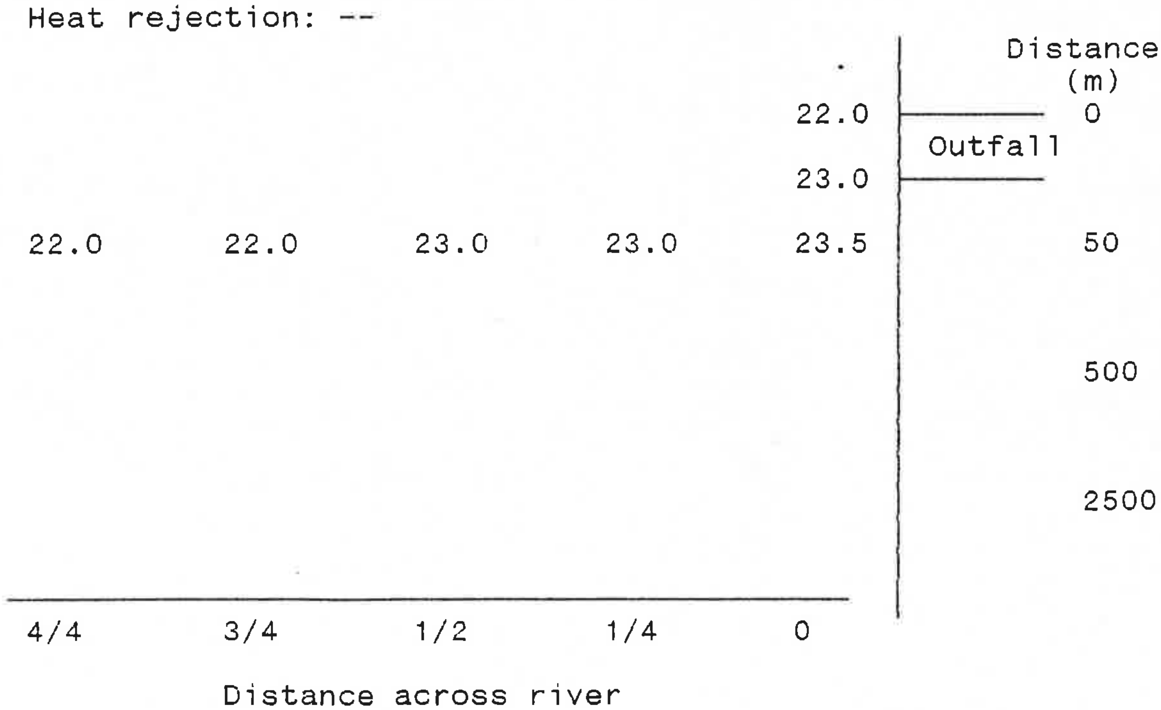
Distance across river

Appendix 4. cont.

Date: 27/11/89
Ambient Temp.: 18.5 ^{0}C (left bank)
River level: 197.6 m
Heat rejection: 1075 MW

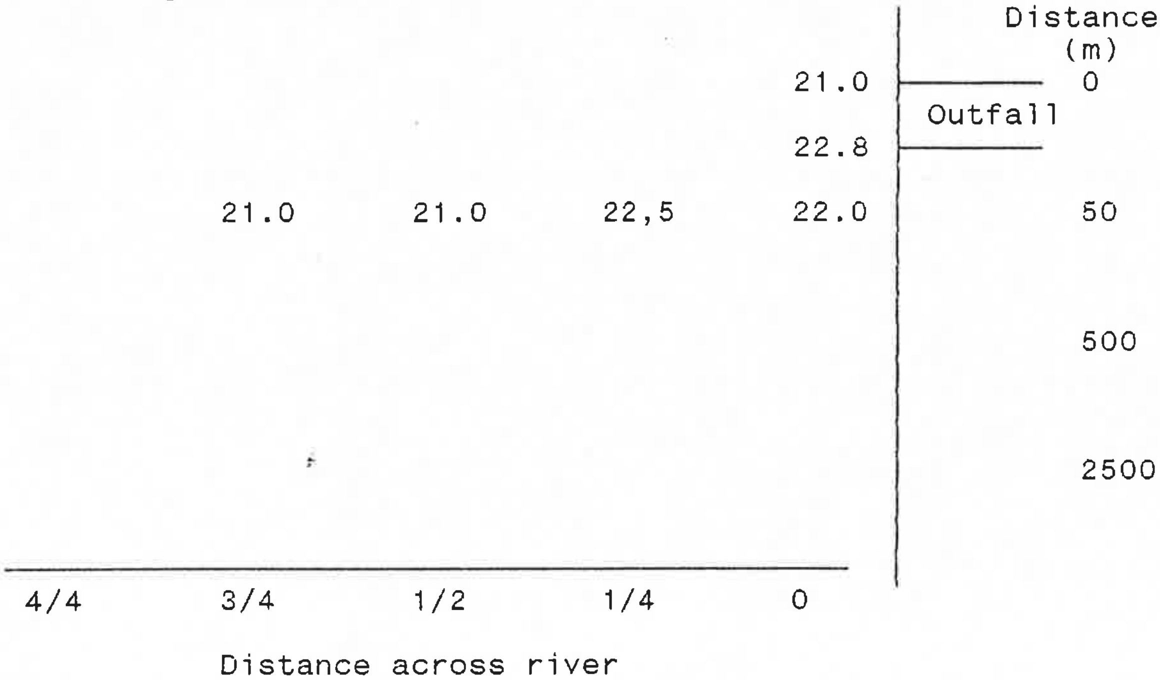


Date: 17/01/90
Ambient Temp.: 21 ^{0}C (left bank)
River level: 107.57 m
Heat rejection: --

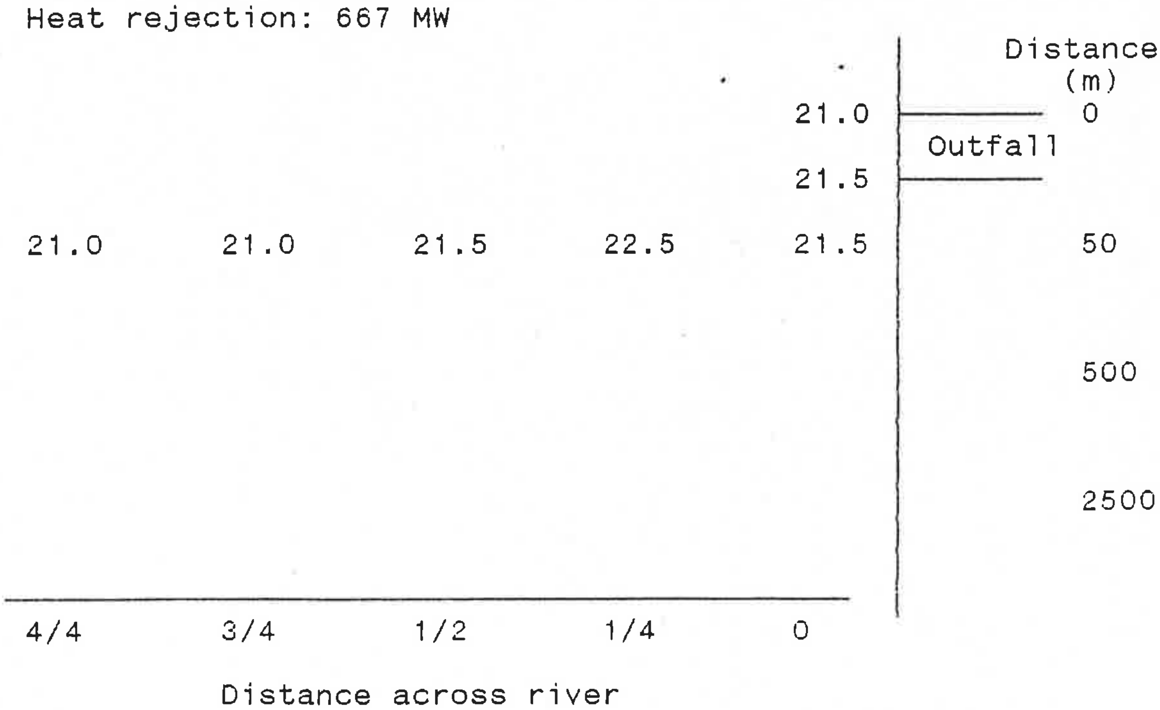


Appendix 4. cont.

Date: 18/01/90
Ambient Temp.: 21 ^{0}C (left bank)
River level: 107.8 m
Heat rejection: 660 MW



Date: 24/01/90
Ambient Temp.: 21 ^{0}C (left bank)
River level: 107.5 m
Heat rejection: 667 MW



Appendix 5A. Catch of inanga at Huntly before and after modifications of the outfall ports.

Date	Left bank (site H)	Right bank (site J)
Unmodified		
2.09.87	1	181
3.09.87	4	71
8.09.87	7	170
9.09.87	34	10
21.09.87	2	77
22.09.87	4	24
5.10.87	8	70
6.10.87	10	17
19.10.87	52	618
20.10.87	44	62
4.11.87	97	3968
16.11.87	115	2835
30.11.87	302	941
14.12.87	132	3881
12.01.88	43	819
4.02.88	74	52
9.02.88	28	24
Modified		
27.10.88	1	163
1.11.88	112	560
2.11.88	63	521
16.11.88	480	806
22.11.88	56	309
7.12.88	452	2385
8.12.88	367	2196
13.12.88	165	3786
21.12.88	5236	10400
16.01.89	926	3153
2.02.89	193	951
22.02.89	1	44

Appendix 5B. Catch of banded kokopu at Huntly before and after modifications of the outfall ports.

Date	Left bank (site H)	Right bank (site J)
Unmodified		
2.09.87	0	0
3.09.87	0	0
8.09.87	0	0
9.09.87	0	0
21.09.87	0	15
22.09.87	0	8
5.10.87	10	9
6.10.87	6	11
19.10.87	7	3
20.10.87	1	17
4.11.87	11	4
16.11.87	0	1
30.11.87	0	0
14.12.87	0	0
12.01.88	0	0
4.02.88	0	0
9.02.88	0	0
Modified		
27.10.88	7	97
1.11.88	14	27
2.11.88	21	98
16.11.88	35	89
22.11.88	13	57
7.12.88	0	0
8.12.88	0	0
13.12.88	0	0
21.12.88	0	0
16.01.89	0	0
2.02.89	0	0
22.02.89	0	0

Appendix 5C. Catch of common bullies at Huntly before and after modifications of the outfall ports.

Date	Left bank (Site H)	Right bank (Site J)
Unmodified		
2.09.87	17	14
3.09.87	14	25
8.09.87	6	10
9.09.87	9	7
21.09.87	7	217
22.09.87	9	209
5.10.87	21	30
6.10.87	12	39
19.10.87	22	22
20.10.87	16	78
4.11.87	68	0
16.11.87	41	32
30.11.87	53	40
14.12.87	71	28
12.01.88	-	-
4.02.88	379	125
9.02.88	159	114
Modified		
27.10.88	16	6
1.11.88	40	9
2.11.88	57	47
16.11.88	70	116
22.11.88	60	270
7.12.88	43	124
8.12.88	106	592
13.12.88	-	-
21.12.88	2581	886
16.01.89	753	1200
2.02.89	1578	710
22.02.89	36	135

Appendix 5D. Catch of elvers at Huntly before and after modifications of the outfall ports.

Date	Left bank (Site H)	Right bank (Site J)
Unmodified		
2.09.87	3	0
3.09.87	-	-
8.09.87	-	-
9.09.87	1	0
21.09.87	145	11
22.09.87	46	0
5.10.87	2	0
6.10.87	-	-
19.10.87	0	0
20.10.87	2	0
4.11.87	0	0
16.11.87	18	0
30.11.87	9	0
14.12.87	1	0
12.01.88	-	-
4.02.88	30	0
9.02.88	0	34
Modified		
27.10.88	-	-
1.11.88	-	-
2.11.88	-	-
16.11.88	8	2
22.11.88	15	4
7.12.88	16	0
8.12.88	1	0
13.12.88	-	-
21.12.88	-	-
16.01.89	61	0
2.02.89	23	0
22.02.89	66	2

Appendix 5E. Catch of shrimps at Huntly before and after modifications of the outfall ports.

Date	Left bank (Site H)	Right bank (Site J)
Unmodified		
2.09.87	20	5
3.09.87	103	100
8.09.87	20	0
9.09.87	10	20
21.09.87	100	160
22.09.87	25	70
5.10.87	0	30
6.10.87	0	110
19.10.87	100	10
20.10.87	110	120
4.11.87	150	0
16.11.87	150	50
30.11.87	5	0
14.12.87	30	76
12.01.88	150	0
4.02.88	1350	20
9.02.88	250	0
Modified		
27.10.88	–	–
1.11.88	–	–
2.11.88	–	–
16.11.88	150	0
22.11.88	660	400
7.12.88	50	700
8.12.88	270	230
13.12.88	230	50
21.12.88	255	20
16.01.89	450	282
2.02.89	237	1740
22.02.89	620	1070