Effects of weed removal by grass carp on the native fish populations in Lake Opouahi and Lake Tutira

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Contents

Executive summary **5**

1 Introduction **6**

2 Background **7**

3 Study sites **8**

3.1 Lake Opouahi 8

3.2 Lake Tutira 8

4 Methods **10**

5 Results **12**

5.1 Lake Opouahi 12

5.2 Lake Tutira 15

6 Discussion **19**

6.1 Lake Opouahi 19

6.2 Lake Tutira 20

6.3 Effects of weed removal by grass carp on native fish 22

7 Conclusions **24**

8 Recommendations **25**

9 Acknowledgements **25**

10 References **26**

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Executive summary

In order to eradicate the invasive and 'unwanted' macrophyte, *Hydrilla verticillata,* the herbivorous fish, grass carp (*Ctenopharyngodon idella*), was stocked into lakes Tutira, Waikopiro and Opouahi (Hawke's Bay) in December 2008. As a number of stakeholders were concerned about the effects of this change in lake ecology on the fish populations, the Ministry of Agriculture and Forestry commissioned monitoring studies to detect any change in the abundance or size of the native fish populations. Monitoring of native fish was carried out by NIWA in 2008 (pre-weed removal) and in 2011 (post-weed removal). Monitoring of trout (and the trout fishery) is being carried out by the Hawke's Bay Fish & Game Council.

The NIWA monitoring studies constitute the first surveys of the native fish populations in these lakes and have provided a useful and timely insight into the diversity of their fish faunas and the current status of the native fish species present. These studies were focussed on Lake Tutira (as it is next to and connected with Lake Waikopiro) and Lake Opouahi. The results revealed that both lakes are dominated by eels, with longfin eels (*Anguilla dieffenbachii*) predominating in Lake Opouahi and shortfin eels (*Anguilla australis*) in Lake Tutira. Size frequency distributions revealed a scarcity of juvenile eels in both lakes, indicating a recent problem with natural recruitment in Lake Opouahi but a long-term one in Lake Tutira, which has probably been stocked with shortfin eels some 20-50 years ago. Whereas, both lakes contain the common bully (*Gobiomorphus cotidianus*), a self-sustaining population of smelt (*Retropinna retropinna*) now occurs in Lake Opouahi and a self-sustaining population of banded kokopu (*Galaxias fasciatus*) occurs in Lake Tutira. Lake Tutira is routinely stocked with rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) to supplement the very limited natural recruitment, and Lake Opouahi is periodically stocked with rainbow trout. Lakes Tutira and Waikopiro also contain the introduced fish species (*Gambusia affinis*) and goldfish (*Carassius auratus*).

Removal of the weed beds in these lakes by grass carp increased the abundance of common bullies in the littoral zone of both lakes by an order of magnitude, and may have increased the use of this zone by shortfin eels in Lake Opouahi. Other native fish species (longfin eels, smelt, banded kokopu) are unaffected to date. As common bullies are a significant prey species for large eels and trout, their proliferation is expected to benefit these higher level predators.

Future monitoring to detect any long-term changes in the eel stocks will be compromised by reduced natural recruitment from the sea. Unless this is corrected for, it will result in a steady decline in eel abundance and this is a more significant issue for the sustainability of the eel stocks in these lakes than weed removal. As a consequence, recommendations deal primarily with this issue and any future monitoring will depend on their prior resolution.

1 Introduction

In order to eradicate the invasive and 'unwanted' weed species, *Hydrilla verticillata,* the herbivorous fish, grass carp (*Ctenopharyngodon idella*), was stocked into lakes Tutira, Waikopiro and Opouahi (Hawke's Bay) in December 2008. By April 2011, the grass carp had removed virtually all of the hydrilla present (Hofstra 2011). As a consequence, fish monitoring surveys were carried out in 2011 to duplicate the 2008 pre-weed removal surveys. These surveys were designed to identify any short-term changes in the fish populations as a consequence of weed removal. In this report, we compare the results of the 2008 and 2011 studies on native fish in Lakes Tutira and Opouahi to determine what changes in their populations may have occurred as a consequence of weed removal.

This report is restricted to an analysis of the effects of weed removal on the native fish species present because the Hawkes Bay Fish and Game Council are monitoring both the trout fishery and trout population in Lake Tutira to detect any change in growth, condition, or catch rates for this introduced fish. To supplement trout monitoring, NIWA collected data on the diet of trout caught during each fish survey. These data are not presented here but will be available for any Fish & Game Council reports on the trout fishery in Lake Tutira. Data on the status of goldfish (*Carassius auratus*) and gambusia (*Gambusia affinis*), which are both introduced and present in Lake Tutira, were not obtained during these surveys as stakeholders were not concerned with these fish. The post weed removal comparison of changes in invertebrates and weeds will be reported separately, and the Hawkes Bay Regional Council monitors water quality in the lakes should a pre- and post- weed removal analysis of water quality be required.

2 Background

The removal of all aquatic plants in lakes can affect lake ecology and especially invertebrate and vertebrate species that are dependent on aquatic plants either as a food source, as a substrate, or for protection from predators. The proposal by the Ministry of Agriculture and Forestry to use the herbivorous grass carp (*Ctenopharyngodon idella*) to eradicate the macrophyte, *Hydrilla verticillata*, in lakes Tutira, Waikopiro and Opouahi (Hawkes Bay) therefore raised a number of concerns for stakeholders, including the Regional Council, the Department of Conservation, local iwi, and the Hawkes Bay Fish and Game Council. Although it was generally accepted that eradication of hydrilla was required and that grass carp was the only tool capable of achieving this, these stakeholders were variously concerned about the effect of weed removal on the water quality, on the fish populations and on the avifauna of these lakes.

The Assessment of Environmental Effects (AEE) accompanying the proposal (Hofstra & Rowe 2008) indicated that there would be no adverse effect on the fish in these lakes because none of the species present depends on macrophytes. The AEE indicated that, based on experience in other New Zealand lakes, an increase in common bullies could be expected and, because bullies are a major prey species for piscivorous fish in lakes, this would benefit both trout and eels. However, before-and-after monitoring was recognised as a necessary component of this project and accordingly a baseline study of the fish populations was carried out in both autumn (May) and spring (November) 2008, before the introduction of grass carp occurred. This baseline survey was accompanied by separate but complementary baseline surveys of the macrophytes, invertebrates and aquatic birds for each lake.

Approvals to stock grass carp into the lakes were provided by the Department of Conservation (DOC), the Hawkes Bay Fish & Game Council and by the Ministry of Fisheries on the understanding that future monitoring would be undertaken to determine the effects of weed removal on various aspects of lake ecology including the fish populations. Accordingly, the baseline surveys carried out in 2008 were repeated in 2011. These surveys were designed to identify any significant changes in abundance of the eel and bully populations. However, they were also intended to provide data on other native species present. In addition to monitoring changes in abundance, the studies were also designed to assess changes in the size structure of the fish populations as this can indicate changes in recruitment. This report therefore compares the results of both the pre and post weed removal surveys to determine if changes in the native fish populations of Lake Tutira and Lake Opouahi have occurred.

Because the native fish populations of these lakes had not been surveyed before, the existing knowledge of native fish in Lake Tutira and especially Lake Opouahi was rudimentary and largely anecdotal. Accordingly, the 2008 and 2011 monitoring studies have not only allowed an assessment of the effects of weed removal on fish but have combined to provide new data and useful information on the status of the native fish populations in both lakes. This will inform future management of their fish and fisheries by local iwi, DOC, Fish & Game and the Ministry of Agriculture and Fisheries.

3 Study sites

3.1 Lake Opouahi

The main characteristics and attributes of Lake Opouahi are described in detail in Hofstra & Rowe (2008). In essence, Lake Opouahi is a small (ca. 6 ha, 24 m deep) lake at an altitude of 480 m above mean sea level. It is fed by a single inlet stream (the Waipapa) and has a single outlet (the Awatamatea). The surrounding land contains native forest and is in a Department of Conservation reserve, but the upper area of the catchment is in pasture and is farmed. At present, the lake and the native forest surrounding the lake are enclosed by a predator-proof fence and the enclosure is managed as a sanctuary for the growth of juvenile kiwi to adult size, at which point they are transferred to other predator-free sanctuaries.

This lake has not previously been studied to any great extent, but was known to contain a population of common bullies (*Gobiomorphus cotidianus*) and longfin eels (*Anguilla dieffenbachii*) (Rowe 1980). Rainbow trout (*Oncorhynchus mykiss*) were stocked into the lake by the Hawkes Bay Fish and Game Council in the 1980s in order to develop a fishery and common smelt (*Retropinna retropinna*) were later introduced to provide a food source for the trout.

Although nutrient inputs from the catchment are now relatively high (Hooper 1987), the lake is not yet affected by eutrophication to any great extent. It is characterised by relatively clear water (secchi disc depth of 10 m in spring, declining to 3 m in summer as plankton growth increases), but it does experience hypolimnetic deoxygenation at times. In 1980, it contained the exotic macrophyte *Elodea canadensis* (Rowe 1980) and by 1984, hydrilla was present and widespread, if patchy, in distribution.

3.2 Lake Tutira

Lake Tutira is much larger (174 ha) and deeper (max. depth 42 m), and it occurs at a lower altitude (155 m above mean sea level). It lies next to Lake Waikopiro to which it is connected via a small (ca. 20 m long) channel through a narrow embankment. As a consequence of their close proximity and short hydrological connection, Waikopiro is appended to Tutira and the two lakes have similar ecologies and fish faunas.

In contrast to Lake Opouahi, Lake Tutira and Waikopiro are both highly enriched, primarily as a consequence of changed land use (from native forest to pastoral farming), and both are eutrophic, suffering from poor water quality and algal blooms during summer months. Their main characteristics are described in Hofstra & Rowe (2008) and, as with Lake Opouahi, they also contain the two species of native eel, the common bully, and are stocked with trout. Smelt are not present in Lake Tutira or Waikopiro but these two lakes were known to contain the ‘unwanted’ invasive fish *Gambusia affinis*, and the more benign introduced goldfish (*Carassius auratus*).

Lake Tutira has several small inlet streams and the largest of these was the Papakiri Stream (Sandy Creek). The flow of this was diverted around the lake in order to reduce nutrient and sediment from the farmed catchment discharging directly into the lake (except during flood events). As a consequence, the main streams entering the lake today (apart from the small channel connecting Tutira with Lake Waikopiro) are the Kahikanui, Oporae, Church and an unnamed stream in the DOC camping round, south of the Oporae (Fig.3-1). The single lake outlet (Tutira Stream) enters the Mahiaruhe Stream which flows into the Waikoau River and thence to the sea via the Arapaoanui River.

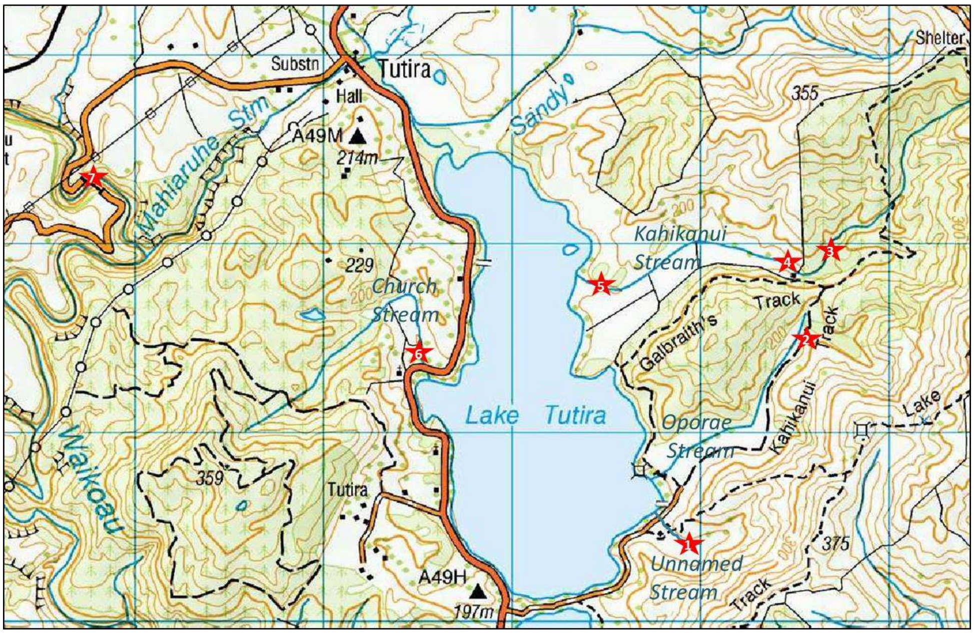

Figure 3-1: Main inlet streams for Lake Tutira (stars indicate locations of reaches sampled by electric fishing).

4 Methods

Ideally, before and after impact studies on fish populations in lakes are carried out for several years before and several years after an impact occurs. This multi-year approach is required because of the high level of variability in fish recruitment, mortality and growth caused by annual variations in weather patterns. Alternatively, sampling is carried out in a control lake to provide a check on such natural variation. This was not possible in lakes Tutira and Opouahi because of the lack of previous surveys, the short time-frames available, and the absence of any control lakes in this region. Fortunately, this lack of control over inter-annual variation will have had little effect on the results, because the two species of eels present are relatively long-lived and slow-growing compared to other fish. Their populations are therefore much less affected by inter-annual variation in weather conditions.

The main sampling method used for fish in the lakes was fyke netting. Small meshed (5 mm mesh) fyke nets are effective at sampling benthic species such as eels and common bullies, but also catch other littoral and limnetic species that periodically occur in lake littoral zones. In May and November 2008, a single, small-meshed, fyke net was set at each of eight locations spread around the edge of each lake. Subsequent analysis of results indicated that the variation in catch rates between sites was relatively high and would hinder future statistical comparisons. Consequently more nets/locations were required to adequately provide a measure of fish abundance, and in April and November 2011, 13 nets in total were placed at each of 13 locations in each lake. In addition, two coarse mesh (mesh size 20 mm) fyke nets were joined by their leaders and placed on the lake bed just above the hypolimnion on each occasion. This avoids deoxygenated water in the hypolimnion, where no fish exist.

The small-meshed fyke nets were baited (to attract eels) and set perpendicular to the shoreline in shallow water (0.5-3 m deep) at each of the sampling sites around the lake edge in the littoral zone. These sites were sampled on each occasion to avoid variation in catch rates due to locational affects (i.e., some locations in lakes consistently produce higher catch rates than others). The locations were checked using GPS coordinates and are shown for Lake Opouahi in Figure 4-1A and for Lake Tutira in Figure 4-1B. The coarse mesh fyke nets (also baited) were designed to sample eels in the deeper waters below the littoral zone. Two pairs of these coarse mesh fyke nets were placed in Lake Tutira because of its larger size; one at each end of the lake (Fig. 4-1B). All fyke nets were set in the evening and retrieved the following morning. All fish in each net were then identified to species and counted. Eels were anaesthetised, and then measured and weighed before being resuscitated and returned to the lake. Bullies were counted and returned to the lake, but a subsample was retained in order to measure their lengths for the determination of population size structure.

In addition to the baited fyke nets, a single, baited minnow trap (4 mm mesh size) was set at each littoral site, primarily to sample common bullies and so provide a check on the fyke net catches of bullies. At times, fyke net catches of bullies can be affected by the presence of large eels. Eels longer than ca. 500 mm are piscivorous and, if they are present in a net, they can deter bully entry, or they may enter a net and prey on the bullies already present. Both actions result in lower than expected numbers of bullies in the nets. Minnow trapping is not subject to this problem and so provides a useful check on bully abundance.

In addition to fish sampling in the lakes, the inlet streams were electric fished to detect the presence of juvenile eels and other fish species. In Lake Opouahi, the inlet stream was electric fished for a distance of approximately 100 m from above the walking track around the lake. The inlet tributary streams in Lake Tutira were also electric fished for a length of approximately 50 m (Fig. 3-1).

The lakes were sampled in both the autumn (May) and spring (November) of 2008 and, following weed removal, in the autumn (April) and spring (November) of 2011. This seasonal sampling was carried out to encompass seasonal variations in fish movements and life history. For example, sampling in autumn would be expected to record any influx of juvenile eels over summer months, whereas sampling in spring can detect the presence of winter and spring spawning fish (e.g., galaxiids and smelt). On each sampling occasion, Opouahi was sampled first to avoid any risk of transferring the invasive fish gambusia from Tutira to Opouahi in the nets. All fish nets are routinely bathed in a concentrated salt solution before and after use to ensure that any freshwater species are not inadvertently transferred from one location to another.

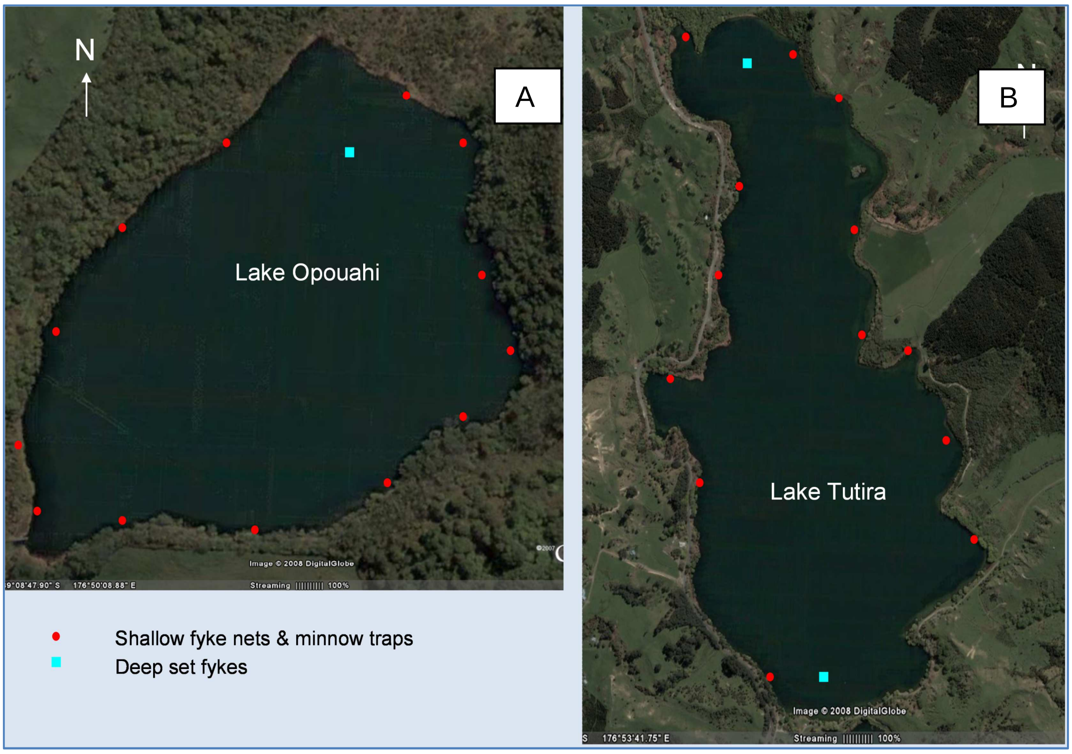

Figure 4-1: Location of sampling sites in (A) Lake Opouahi and (B) Lake Tutira in 2011.(Red dots indicate littoral sites for fyke nets and minnow traps; blue squares indicate sites for paired fyke nets in deeper water).

The mean catch per net (or catch per unit of effort, CPUE) was calculated for each species of fish for both the littoral fyke nets and the minnow traps. Where required, means were compared for each species and lake using analysis of variance (ANOVA). In addition, we examined the size structure of eels from length-frequency distributions and the condition of the eels (i.e., how fat they were) by examining length-weight plots for each population. Changes in common bully populations were assessed primarily by comparing changes in mean CPUE in fyke nets and through examination of size structure. Where appropriate, the mean CPUE for other fish species present was noted, and the catches (and sizes) of fish sampled by electric fishing recorded.

5 Results

5.1 Lake Opouahi

The mean CPUE for each species (and sampling method) is shown for Lake Opouahi in Table 5-1. The longfin eel was the dominant eel species in Lake Opouahi with mean catch rates ranging from 3.25 fish net^{-1} to 5.13 fish net^{-1}. There was no statistically significant difference in the mean catch rates among sampling dates (ANOVA, P = 0.582) and therefore no change in longfin eel abundance following weed removal in this lake.

Table 5-1: Mean catch per unit of effort (CPUE) and standard errors for each species and sampling method in Lake Opouahi on each date the lake was surveyed.

Species	Sample method	Mean catch per unit effort ± S.E.			
		Pre-weed removal		Post-weed removal	
		Autumn (May 2008) (n=8)	Spring (Nov 2008) (n=8)	Autumn (Apr 2011) (n=13)	Spring (Nov 2011) (n=13)
Longfin eel	Fyke net	3.25 ± 0.84	5.13 ± 0.99	4.92 ± 0.10	4.77 ± 0.68
Shortfin eel	Fyke net	0.25 ± 0.25	0.25 ± 0.25	0.54 ± 0.14	1.92 ± 0.50
Common bully	Fyke net	2.75 ± 0.98	6.00 ± 2.55	100 ± 35	284 ± 111
Common bully	Minnow trap	0.13 ± 0.13	1.00 ± 0.43	16.61 ± 4.50	35.8 ± 8.00
Smelt	Fyke net	0.00 ± 0.00	3.00 ± 1.75	0.0 ± 0.0	1.31 ± 0.51

In contrast, the mean CPUE for shortfin eel increased following weed control (ANOVA, P = 0.003). This increase was particularly noticeable in November 2011 when the number of shortfin eels captured more than tripled.

As differences in longfin eel size structure between the spring and autumn samples for each year were minimal, the length data were combined for each year. The length frequency distributions exhibited two main modes (in both 2008 and 2011), with peaks close to 500 mm and 750 mm respectively (Fig. 5-1). The range in eel size (350-850 mm) was also similar for each year.

Electric fishing along the sandy north western margin of Lake Opouahi revealed the presence of elvers. In autumn 2008, the density of elvers was ca. 0.5 m^{-1} along a 20 m length of the lake margin and elver size ranged from TL 130-265 mm. No elvers were recorded on subsequent surveys in this area despite electric fishing a longer (ca. 50 m) length of lake margin.

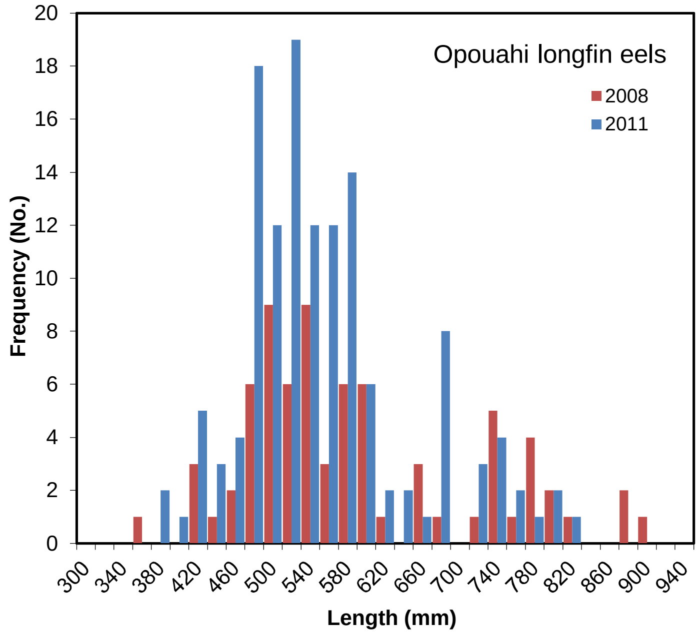

Figure 5-1: Length frequency distributions for longfin eels in Lake Opouahi in 2008 and 2011. (data for spring and autumn of each year showed little difference and were therefore pooled).

Plots of weight against length for the longfin eels exhibited a high degree of overlap for each sampling date (Fig. 5-2), indicating no major change in weight for a given length between 2008 and 2011. When length-weight plots were compared for longfin and shortfin eels in November 2011 it was apparent that, as in most mixed populations of eels, longfins were heavier (fatter) for a given length than the shortfins, and that this difference increased with eel size (Fig. 5-3).

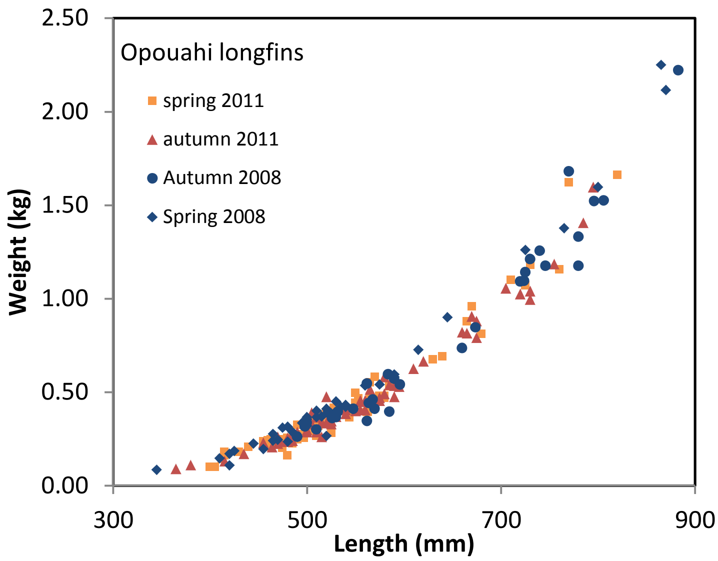

Figure 5-2: Length weight plots for longfin eels in Lake Opouahi on each sample date.

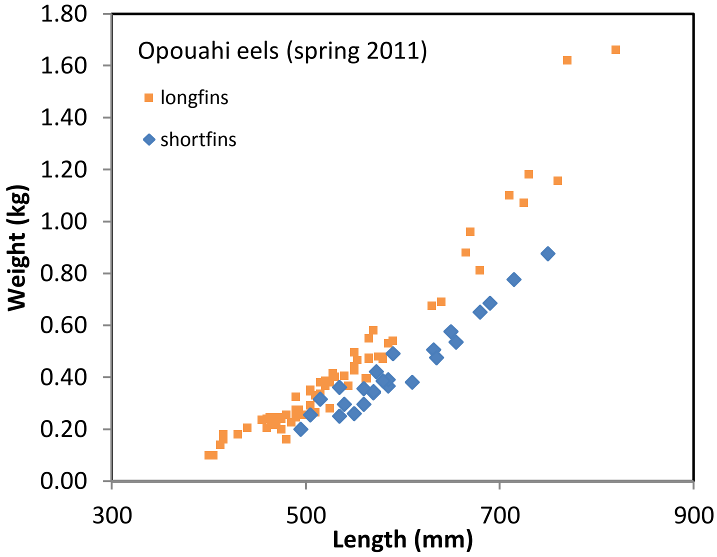

Figure 5-3: Length-weight plots for longfin and shortfin eels in Lake Opouahi in November 2011.

The mean CPUE for common bullies captured in the fyke nets in Lake Opouahi changed significantly with sample date (ANOVA, $P = 0.027$). The increase from 2.75 fish net^{-1} in May 2008 to 6.0 fish net^{-1} in November 2008, and then to 100 in April 2011 and 284 fish net^{-1} in November 2011 (Table 5-1) indicates an order of magnitude increase in bully abundance following weed removal. These data are reinforced by the results from minnow trapping, which also indicated a statistically significant increase in mean catch rates for common bully with time (Table 5-1, ANOVA, $P < 0.001$).

The size frequency distributions for common bully indicated that in 2008 most fish were relatively large, ranging in length from ca. 45 to100 mm in length (Fig. 5-4A). In 2011, smaller bullies (TL 30-60 mm) predominated (Fig. 5-4B) and the larger bullies (TL > 60 mm) had largely disappeared.

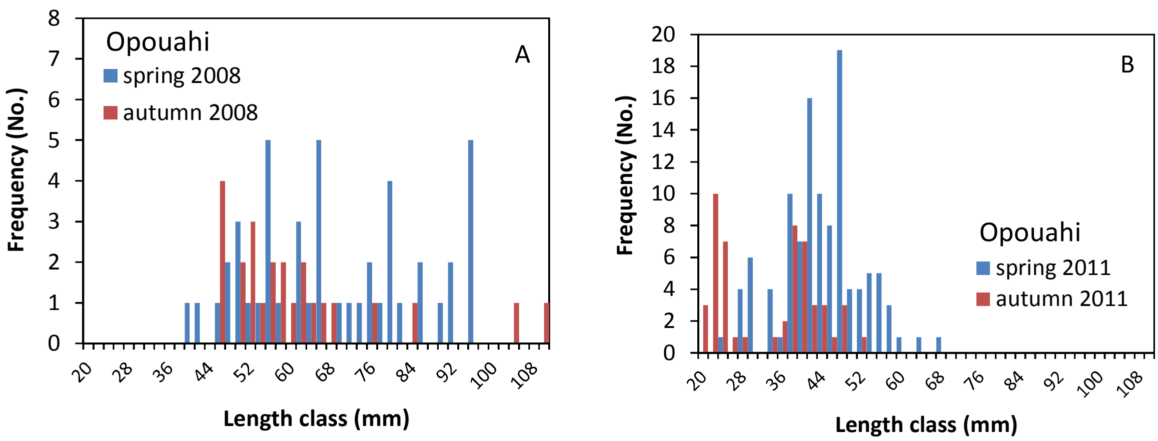

Figure 5-4: Length frequency distributions for common bullies sampled by fyke net in Lake Opouahi in; (a) 2008, and (b) 2011.

Juvenile bullies (TL 20-30 mm) were absent in 2008 but present in relatively large numbers in 2011 indicating that the increase in bully abundance was due primarily to an increase in the recruitment and survival of the smaller bullies.

Common smelt were present in Lake Opouahi and schools of juveniles (TL 40-50 mm) were observed under the jetty on each sampling date, but not captured. In contrast adult smelt (TL 60-80 mm) were captured in the fyke nets in both 2008 and 2011, but only in spring months (i.e., during the smelt spawning season).

No koura or freshwater crayfish (*Paranephrops planifrons*) were caught in the lake (either in fyke nets or minnow traps), but crayfish were common in the inlet stream during electric fishing. There was good habitat for galaxiid fish (e.g., koaro, *Galaxias brevipinnis*) in the inlet stream and lake but none were found.

5.2 Lake Tutira

The mean CPUE for each fish species (and sampling method) is shown for Lake Tutira in Table 5-2. In contrast to Lake Opouahi, shortfin eels predominated in Tutira and longfin eels were rare. The mean CPUE for the shortfin eels suggested that catch rates could be higher in autumn than in spring, but this was an artefact due to a few unusually high catch rates in autumn of each year. Overall there was no statistically significant difference in mean catch rate among any of the sampling dates (ANOVA, $P = 0.286$) indicating no change in eel abundance in Lake Tutira.

Overall 129 eels were captured in Tutira by shallow fykes compared with 229 in Opouahi. This reflects the generally lower CPUE of eels in Tutira than in Opouahi. The mean CPUE for all eels was significantly lower in Tutira in November 2008 and November 2011 (ANOVA, $P < 0.05$), but there was no difference between the lakes for May 2008, or April 2011 despite the lower value in April 2011.

Table 5-2: Mean catch per unit of effort (CPUE) and standard errors for each species and sampling method in Lake Tutira on each date the lake was surveyed.

Species	Sample method	Mean catch per unit effort ± S.E.			
		Pre-weed removal		Post-weed removal	
		Autumn (May 2008) (n=8)	Spring (Nov 2008) (n=8)	Autumn (Apr 2011) (n=13)	Spring (Nov 2011) (n=13)
Shortfin eel	Fyke net	6.13 ± 5.14	1.10 ± 0.38	3.08 ± 1.25	1.92 ± 0.50
Longfin eel	Fyke net	0.50 ± 0.50	0.00 ± 0.00	0.08 ± 0.08	0.08 ± 0.08
Common bully	Fyke net	64 ± 25	1232 ± 368	1253 ± 236	1418 ± 205
Common bully	Minnow trap	20.60 ± 6.19	59.40 ± 15.90	14.90 ± 3.41	19.00 ± 3.04
Banded kokopu	Fyke net	0.00 ± 0.00	2.50 ± 1.29	0.00 ± 0.00	1.31 ± 0.76

The length frequency distribution for shortfin eels in Lake Tutira (Fig. 5-5) was unimodal in both 2008 and 2011, and the median length of eels was similar (730 and 740 mm respectively). In both years, the length of shortfin eels ranged from ca. 550 to over 800 mm, indicating that the eels were all large adults. No juvenile eels or small adults (TL 100 to 500 mm) were captured by any method in the lake, nor by electric fishing in the tributary streams of this lake, despite the presence of suitable habitat. The absence of small eels and the presence of a restricted size range of large, adult shortfin eels, indicates a stocked population and a lack of annual recruitment.

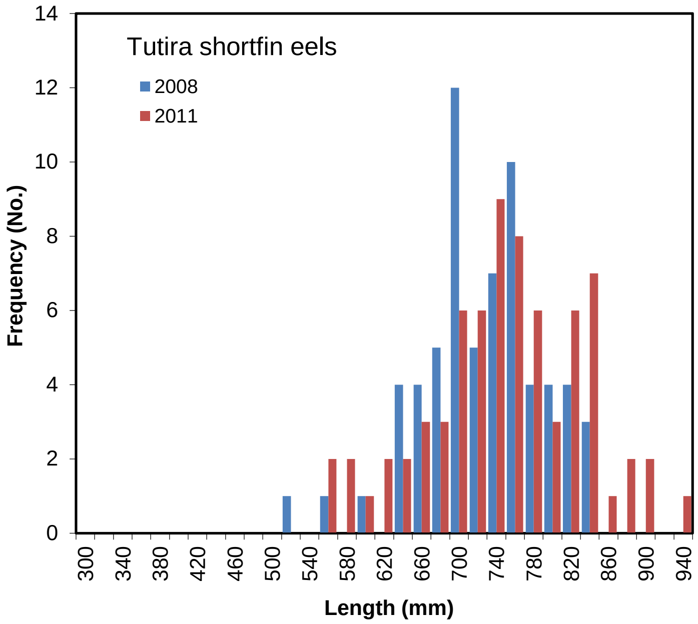

Figure 5-5: Length frequency distributions for shortfin eels in Lake Tutira in 2008 and 2011. (data for spring and autumn of each year showed little difference and were therefore pooled).

Only five longfin eels were captured in total in Lake Tutira (compared to 124 shortfins) and these ranged in length from 690 to 1200 mm. Three of these fish were over 1000 mm and therefore were the largest eels in the lake.

There was almost total overlap in the length weight plots for the shortfin eels sampled in 2008 and 2011 in Lake Tutira (Fig. 5-6) indicating that there has been no detectable change in weight for a given length.

As in Lake Opouahi, the mean fyke net catch rates for common bullies increased with time, from 64 fish net^{-1} in May 2008 to 1418 fish net^{-1} by November 2011. However, this pattern of increase was not duplicated in the mean catch rates for the minnow traps. These were lower in 2011 than in 2008, especially in spring (ANOVA, P = 0.009) and indicate either a change in distribution of bullies in shallow water, or a change in their vulnerability to trapping after weed removal. The mean CPUE of common bullies caught in fyke nets in Lake Tutira was an order of magnitude higher than in Lake Opouahi, indicating a much higher abundance in Tutira.

The bullies in Tutira were generally more numerous and smaller than in Opouahi, ranging from 20-45 mm in 2008, and from 20-30 mm in 2011 (Fig. 5-7). In 2008, most bullies ranged in size from 30-45 mm. This size class was also present in 2011 but was numerically overwhelmed by juvenile bullies in the 20-30 mm size class.

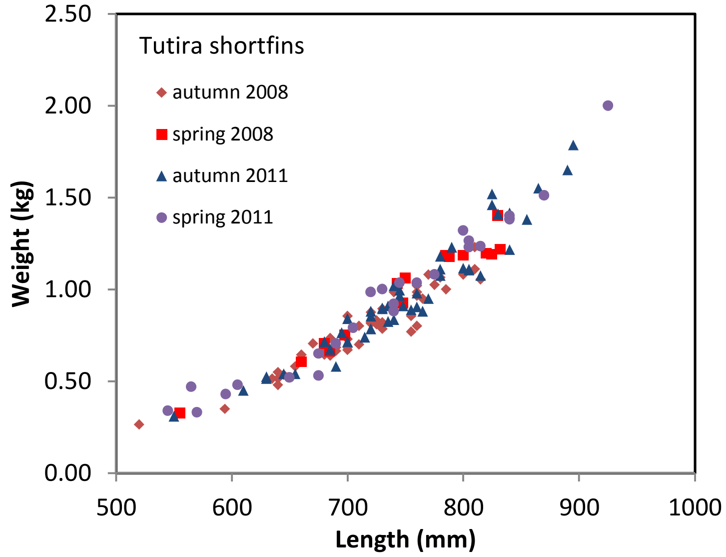

Figure 5-6: Length-weight plots for shortfin eels in Lake Tutira on each sampling date.

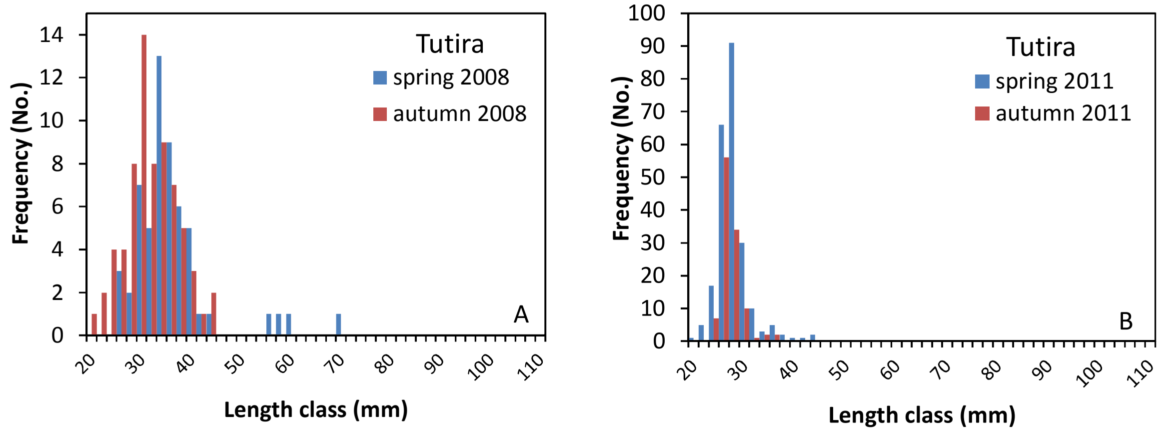

Figure 5-7: Length frequency distributions for common bullies sampled by fyke net in Lake Tutira in; (a) 2008, and (b) 2011.

Juvenile banded kokopu (TL 36-41 mm) were present in low numbers in the fyke nets in both November 2008 and November 2011, but not in May 2008 or April 2011 (Table 5-2).

Electric fishing in the inlet streams of Tutira produced only juvenile and adult banded kokopu. Eels and common bully were conspicuous by their absence. A relatively high density of adult banded kokopu (21 fish per 50 m of stream length surveyed) occurred in the small unnamed stream along the side of the DOC camping ground at the southern end of the lake (Site 1, Fig

3-1) in both April and November 2011. They ranged in length from 40-150 mm TL and so constitute a mix of post-migratory juveniles and adults. An unusually high density of adult and juvenile banded kokopu was also found at site 4 in the Kahikanui Stream (Fig. 3-1) in April 2011. This high density occurred just below the lower boundary of the pine plantation in a reach that was relatively exposed. No banded kokopu were found further upstream in reaches well shaded by mature pines, but recent floods and high water velocities may have displaced residents from the incised upper reaches of this stream down to the more exposed, lower reaches. If so, banded kokopu may prove to be as vulnerable as rainbow trout to downstream displacement through flood flows in the Tutira tributaries, despite re-forestation with pine trees. We noted that, whereas the streams under the pine plantation contained good pool habitat for banded kokopu, the instream cover (i.e., undercut banks, interstices between large boulders, and wood debris) preferred by banded kokopu (Rowe & Smith 2003) was lacking.

6 Discussion

6.1 Lake Opouahi

Eels

The species mix for eels in Lake Opouahi (dominance of longfins over shortfins) and the size structure of the populations (multimodal, with lengths ranging from 350 to 900 mm) indicate that a relatively unmodified population of eels occurs in this lake. The overall abundance of longfin eels and their condition were not changed by weed removal, but the catch of shortfin eels increased after weed removal.

In unmodified eel populations, longfin eels generally dominate shortfin eels in terms of both abundance and size. In Lake Opouahi, the longfins were not only more numerous than the shortfins but they were also fatter. A shift towards shortfins is generally associated with eel harvesting which tends to remove the more vulnerable, larger fish first (i.e., longfins) but this did not occur (to our knowledge) in Lake Opouahi - it is in a DOC reserve and so no commercial fishing is permitted. The size structure for longfins was very similar in 2008 and 2011, so there was no obvious emigration of large longfins out of the lake to spawn at sea. The increase in shortfins in 2011 was therefore due to weed removal, but as there was no evidence of increased recruitment (i.e., an influx of juveniles), it represents a change in the distribution or behaviour of the adult shortfin eels following weed removal. The size of the shortfins sampled in 2011 indicates that they were present in this lake in 2008, but did not enter the littoral nets at this time. The increased catch in 2011 indicates that the weed beds may have previously discouraged shortfins from feeding in the shallow (0-3 m deep) littoral zone.

Elvers were captured by electric fishing around the lake edge in May 2008 but not at other times and no juvenile eels (TL 200-300 mm) were caught in the lake between 2008 and 2011 (Fig. 5-1). A scarcity of elvers and juvenile eels generally indicates a lack of recent recruitment and, if this is occurring in Lake Opouahi, it could reduce adult eel abundance in the future.

Observations by a local farmer indicated that elvers can reach the concrete footing of the weir on the outlet stream and climb it, so they should be able to pass through the predator proof mesh above this weir, as the mesh size is ca. 5 mm. However, at times of high flow (which can result in high water velocities) the accumulation of debris may restrict elver passage through the mesh of this fence. In addition, the elver pass created from a pipe and a residual flow may not function properly during the elver migration season. Alternatively, recruitment may not be annual, or new recruits may pass through the mesh and now become more exposed to predation by large eels (and trout) in the lake. Some investigation of elver recruitment to this lake is therefore required to ensure that it is being maintained otherwise future monitoring of the effects of weed removal on the eel population will be compromised.

Common bully

As expected, the common bully population increased rapidly in Lake Opouahi as weed removal occurred. This has been observed in other lakes where grass carp were used to control macrophytic plants (Mitchell 1986; Rowe et al. 1999). Weed removal expands benthic habitat for bullies, and their food supply (chironomid larvae) increases. In addition, logs and rocks formerly covered by weed are exposed and increase the spawning substrate for bullies. As the bully is relatively short-lived (2-3 years), its greater abundance is generally due to an increase in recruitment or to juvenile survival and this was reflected in the change in size structure to smaller fish in both lakes. The common bully is a major prey species for adult trout, eels and some birds (e.g., shags, herons, bitterns, kingfishers) and, as weed removal also increases its exposure to predation, these predators can be expected to benefit from the increase in bullies caused by weed removal.

Common smelt

Smelt are a native fish, but were stocked into Lake Opouahi sometime between 1980 and 1990 as a food source for the stocked trout populations. The smelt population in Lake Opouahi is therefore introduced and it is now landlocked and self-sustaining. Small schools of juvenile smelt were readily observed in the littoral zone on most sampling occasions but were not captured as the fyke net mesh size was too large. The capture of large adult smelt in littoral fyke nets in spring months suggests that these fish are preparing to spawn at this time, but their absence in autumn months indicates that they are more limnetic at this time of year.

The introduction of smelt has caused the extinction of the native galaxiid or koaro (*Galaxias brevipinnis*) in a number of North Island lakes (Rowe 1993) and the presence of smelt in Lake Opouahi may explain the current absence of lacustrine galaxiids in this lake, or its inlet stream, despite the presence of good habitat. Its altitude and distance inland means that it would not be expected to be colonised by banded kokopu (*Galaxias fasciatus*) but it would be accessible to koaro (*Galaxias brevipinnis*). Although galaxiids may not have occurred in this lake historically (there are no historic records of their existence here), koaro do occur in tributaries of the Waikoau River above Lake Opouahi. This species, which is an excellent climber, is therefore very likely to have occurred in Lake Opouahi. It is inconceivable that it would not be able to access sites that are accessible to longfin eels and establish a self-sustaining, landlocked or diadromous, population in this lake as it has in numerous other New Zealand lakes. However, confirmation of its historic presence in Lake Opouahi will depend on oral knowledge from Maori and/or longtime local residents.

6.2 Lake Tutira

Eels

As in Lake Opouahi, the abundance of eels was not affected by weed removal, but the abundance of common bullies increased as weed removal occurred. Smelt are not present in Lake Tutira but, in contrast to Lake Opouahi, Tutira contained good stocks of adult banded kokopu in its inlet streams, with juveniles being caught in the lake in spring months.

Lake Tutira is more enriched and eutrophic than Lake Opouahi, consequently the abundance of eels and bullies would be expected to be higher in this lake. This was so for the common bully, but overall, the abundance of eels as assessed by mean CPUE was generally lower in Lake Tutira than in Lake Opouahi. The relative scarcity of eels in Tutira despite its higher productivity could reflect overharvesting, but it could also indicate a lack of eel recruitment.

Shortfin eels dominated in Tutira as they do in heavily overharvested and/or stocked lakes. But large longfins were also present and all of the shortfins present were also relatively large, indicating a lack of fishing pressure. Overharvest is therefore not likely here and it is more probable that recruitment is limiting. This is reinforced by the unimodal size distribution of adults and the absence of eels less than 500 mm TL. In small lakes with no connection to the sea and hence no elver recruitment, eel fishers are known to stock elvers in order to return one to two decades later to harvest the crop. Such stocked populations are characterised by a high proportion of shortfins, by a unimodal size distribution of large eels, and by the absence of any juveniles. These are the current characteristics of the eel stock in Lake Tutira and they strongly suggest that it has been stocked sometime in the past 10-20 years.

This situation is at odds with Guthrie-Smith's (1926) descriptions of historic eel fishing in the lake by Maori in the early 1900s. His descriptions of numerous fishing sites on the outlet stream (http://www.teara.govt.nz/en/te-hopu-tuna-eeling/2/4) indicate the presence of a large stock of eels in Lake Tutira and its catchment. Although these eels may have been stocked, this is unlikely and it is much more probable that natural recruitment occurred to the lake. Confirmation of the historic abundance of eels and the current lack of recruitment would indicate that eel recruitment has ceased since the early 1900s as a consequence of some barrier or unsurmountable fall being created in the Mahiaruhe Stream below the lake. There are no dams on the Arapaoanui or Waikoau River that would create such a barrier, and small eels (longfins: TL 95-250, shortfins: TL 87-165 mm) were abundant in the Waikoau River between site 7 and its confluence with the Mahiaruhe Stream (Fig. 3-1). A natural barrier is likely to have formed in the Mahiaruhe Stream since the early 1900s. At present, a 30 m fall occurs in this stream at NZMG 2844601E, 6214173N and this may now act as a barrier to eel migration into Lake Tutira. Tectonic uplift as a consequence of the Napier earthquake in 1931 could have caused such a change in the fall and hence in eel access to Tutira. Alternatively, a culvert under State Highway 2 may now create a barrier to eel passage upstream. If the barrier can be identified, elver passage could be readily restored to Tutira through the provision of climbing media (c.f., Baker & Boubee 2006; Stevenson & Baker 2009). This issue of reduced natural eel recruitment needs to be addressed as the adult eel stock in Lake Tutira will decline in the future and this will compromise future monitoring to determine the effects of weed removal. It will also detract from the potential future status of Lake Tutira as a sanctuary for eels.

If eels cannot access Lake Tutira from the sea, neither can banded kokopu. The juveniles of both species are good climbers capable of ascending near vertical falls, and penetrating to high altitude streams. But such upstream migrations can be blocked by confined overhangs and/or velocity chutes. It is therefore probable that the population of banded kokopu in Lake Tutira will now be landlocked and that today these fish complete their life cycle within the lake and its inlet streams. This is not uncommon and a number of landlocked banded kokopu populations occur in constructed reservoirs throughout New Zealand.

Common bullies

The large increase in bullies in Lake Tutira following weed control was due primarily to juvenile bullies in the 20-30 mm size class. This will be due to a large increase in either the recruitment or survival of juvenile bullies following weed removal. Survival is not expected to increase because weed removal would expose juvenile bullies to greater predation, but weed removal will have exposed logs and other hard objects on the littoral lake bed. These provide spawning habitat for bullies and hence weed removal can be expected to have increased spawning habitat. It therefore appears that weed removal has increased juvenile recruitment through an increase in spawning habitat and that the survival of these fish is then enhanced by an increase in adult habitat and food supply.

No large bullies (TL > 70 mm) occurred in Lake Opouahi after May 2008 and this is not unexpected as these fish would have died out by 2011. The increased density of bullies in 2011 would then be expected to supress growth such that large bullies become scarce, as in Lake Tutira and other enriched lakes where bully density is high.

6.3 Effects of weed removal by grass carp on native fish

The pre- and post-weed removal surveys of native fish in Lake Tutira and Lake Opouahi have established, once again, that the abundance of common bully has increased as a consequence of weed removal in the littoral zone. This is likely to be due to an increase in spawning habitat, an increase in adult habitat on the lake bed, and an increase in food supply. This change is consistent with other studies on the effects of weed removal on native fish populations in New Zealand lakes (Mitchell 1986; Rowe et al. 1999; Kelly & Jellyman 2007). It indicates that restructuring of the littoral food web from a three dimensional framework of macrophytes, to the two dimensional substrate provided by the lake bed, results in a large increase in common bullies. When the littoral weed beds were present, snails and a diverse range of invertebrates that inhabit such weed beds, would have provided the main food supply for common bullies. After weed removal, chironomid larvae increase in the newly exposed sediment (Mitchell 1986; Kelly & Jellyman 2007) and provide a better and more accessible food source for the common bully. Hard substrates for bully spawning (e.g., logs) also become more accessible when weed cover is removed in the littoral zone and this too may increase the recruitment of bullies. In turn, this small fish, which is a common prey species for piscivorous fish as well as some aquatic birds, increases the food base for top predators in lakes. This changed food web can be expected to persist until such time as grass carp are either removed, or reduced to the point where browsing is too low to prevent native macrophytes from regenerating.

Weed removal was associated with an increase in the size of smelt in Parkinsons Lake (Mitchell 1986) but whether this was due to increased growth or simply to increased use of the littoral zone by large smelt is unknown. Adult smelt utilise the littoral zone of lakes for spawning during spring and summer months, and extensive weed growth in shallow waters can smother this spawning habitat and prevent smelt use of it. Consequently, weed removal may increase the area of smelt spawning habitat and thereby facilitate the entry of large adults into this zone in spring and summer months. This would explain the presence of adult smelt in the littoral zone of Lake Opouahi in November 2008 and 2011, but not in May 2008 or April 2011. In addition, weed removal reduces littoral cover for juvenile smelt and may encourage these fish to move more into open water to avoid predation by trout. Schools of juvenile smelt were observed beneath the jetty in Lake Opouahi in both April and November 2008 but not as frequently as adults. These results and observations indicate that weed removal can affect fish distribution and habitat use within the littoral zone as well as overall fish abundance. Such a change in distribution may explain the increase in shortfin eels in the littoral zone of Lake Opouahi after weed removal, and it may also explain the reduction in minnow trap catches of bullies in Tutira after weed removal.

Lake Opouahi was stocked with rainbow trout in 2008, and trout predation can be expected to reduce juvenile smelt abundance with potential implications for adult smelt abundance. However, smelt populations persist in many New Zealand lakes despite heavy predation from trout and in Lake Opouahi, the smelt population can be expected to stabilise, albeit at a lower density.

Juvenile banded kokopu were present in the littoral zone of Lake Tutira but adults were not caught in the lake, and were only abundant in the inlet streams. This distribution is consistent with the lake being used by larvae and juveniles for rearing and adults using the streams for growth and spawning. This life history pattern mimics that found for diadromous banded kokopu, in which juveniles use the sea for rearing and then migrate into rivers (as whitebait), where adults mainly use the tributary streams for growth and spawning. In lakes, juvenile galaxiids (e.g., dwarf inanga, koaro,) are schooling fish and they feed primarily on zooplankton (principally cladocerans) (Rowe & Chisnall 1996; Rowe et al. 2002). They are therefore more dependent on the limnetic food web than the littoral one. However, juvenile dwarf inanga in northland dune lakes inhabited the littoral zone during the day (to avoid predation) and moved to the limnetic zone to feed at night, whereas adults, which feed on larger littoral invertebrates, exhibited a converse feeding movement also related to avoiding predation (Rowe & Chisnall 1996). The dwarf inanga is therefore more dependent on lake littoral zones than banded kokopu and, as weed removal by grass carp increased its abundance in a eutrophic Northland lake (Rowe et al. 1999), banded kokopu in Lake Tutira are expected to be even less affected by weed removal.

Trout are a major predator of galaxiids in lakes and banded kokopu juveniles may (like dwarf inanga) frequent the macrophyte dominated littoral zone by day to avoid predation, and feed on zooplankton in the limnetic zone at night. If so, weed removal could increase the vulnerability of juveniles to predation by trout during the day. However, galaxiid populations persist in many lakes despite heavy predation from trout, and ironically, the stocking of such lakes with smelt, is what has severely reduced or eliminated their populations (Rowe 1993). This may have occurred historically to galaxiids in Lake Opouahi, but there is no proof that galaxiids were present here before the introduction of trout or smelt.

Weed removal in both lakes has had no measurable impact on eel abundance, size or condition to date. The post-weed removal increase in shortfin eels in Opouahi is more likely to represent an increase in foraging in the littoral zone than an increase in overall abundance. However, the abundance of adult eels in both lakes can be expected to decline in the future through natural mortality and/or emigration to the sea to spawn, because recruitment to both lakes is now reduced or absent.

7 Conclusions

Monitoring of the native fish populations in lakes Tutira and Opouahi (Hawke Bay) in 2008 and 2011 has resulted in the characterisation of the fish stocks in these lakes and revealed key aspects of their population dynamics. This information establishes the first baseline survey of the fish fauna in these lakes and provides data on the current status of the native fish populations as they stand at present. Although the historic status of the fish populations is largely unknown, Guthrie-Smith (1926) observed a large number of eel weirs on the Tutira Stream just below the outlet from the lake. These observations indicate that the lake and its inlet streams historically held a large population of eels. This is not so today and information is required from iwi elders (who have access to long-term oral history) and long-term (> 40 years) local residents to provide historic observations within which the current status of the eel stocks and other fish can be better interpreted and framed.

Whereas the native fish populations in Lakes Tutira and Opouahi have not been adversely affected by weed removal to date, monitoring of eels to detect any longer term changes will be compromised if elver recruitment to these lakes is reduced or blocked in coming years. Similarly, the future monitoring of smelt may be compromised by increased stocking of trout into Lake Opouahi. These issues will need to be resolved if monitoring is to continue long-term. In particular, the likely total blockage of elver recruitment into Tutira warrants further investigation, not only because it may compromise future monitoring, but most importantly because it may affect the future of this once regionally significant iwi fishery. As the lake lies within a DOC reserve, the future status of the lake as a ‘sanctuary for eels’ may also be compromised. DOC and local iwi are key stakeholders for the eel stocks in this lake and will both have significant concerns over the future of them.

Similarly, Lake Opouahi lies within a DOC reserve and is another potential sanctuary for eels, particularly longfins, which are deemed to be threatened and in long-term decline (Allibone et al. 2010). It is apparent the elvers can access the outside of the predator proof fence around this lake, but elver entrance to the lake may be temporarily blocked. This may be because of malfunctions in the elver passage facilities, or because elver recruitment is not annual.

8 Recommendations

1. Given, the future implications of failed elver recruitment to Lake Tutira, it is recommended that MAF institute discussions with DOC and local iwi with a view to commissioning an investigation to identify the location and nature of barriers to elver recruitment in the Mahiaruhe Stream and recommend remedial measures including elver stocking should this prove necessary.

2. The problem with elver recruitment past the predator proof fence and over the weir on the Lake Opouahi outlet stream also needs to be resolved and it is recommended that MAF and/or DOC commission an experiment to determine whether elvers stocked immediately below the weir, can pass over it and through the mesh screen or not. If not, actions needed to facilitate elver passage over the weir need to be identified and conveyed to DOC for action by EcoEd Conversation Trust.

3. Given, the absence of any negative effects of weed removal on the native fish populations of Lake Tutira and Lake Opouahi to date, it is recommended that monitoring of native fish by MAF is continued, but on a longer or increasing time scale (e.g., every 3 years instead of 2, increasing to 5 years if there is no further evidence of any adverse effects on native fish).

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