Managing mahinga kai prey: Variation in common bully abundance and spawning habitat availability in Te Waihora

Prepared for Whakaora Te Waihora Partners

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Executive summary

Te Waihora (Lake Ellesmere) is of exceptional significance to Ngāi Tahu as a tribal taonga, providing a major source of mahinga kai and mana. The lake is considered nationally significant for both customary and commercial fisheries of tuna (eels) and pātiki (flounder). These fish enter the lake as juveniles and rely on having abundant prey resources in the lake for growth and maturation. The key prey fish for tuna and pātiki is common bully (*Gobiomorphus cotidianus*), so ensuring bullies remain abundant in the lake is crucial for maintaining adequate stocks of mahinga kai. The objectives of this work were to assess the status of the common bully stock in Te Waihora and determine how best to sample populations of this prey fish. The type of lake-bed material coupled with the current state of the lake (e.g., no macrophyte beds) may mean that that common bully stocks in the lake are limited by the availability of spawning substrate. This research also examined spawning substrate preferences to better understand how lake-level variation may influence the availability of spawning substrate for common bully.

To quantify changes in common bully stocks we examined catch data from the last 20 years that was collected with three methods: beach seine netting, near-shore benthic tows (hand pulled) and off-shore beam trawls (boat towed). Data collected during field work for the Whakaora Te Waihora (WTW) programme from 2013 – 2015 was compared with previous datasets from these three methods. Population estimates and size distribution data were analysed to determine which method yielded the most reliable data for monitoring changes in common bully populations. To complement field survey data, experimental work was used to examine common bully spawning habitat preferences. A controlled laboratory experiment was used to observe whether common bully would spawn on lake-bed material or use various artificial spawning substrates. Spatial GIS analyses were also used to assess how lake-level variation might impact on the availability of different lake-bed materials that may be used by common bully for spawning.

Common bully survey data suggested that there had been no major change in abundance over the last 20 years; the common bully population for the lake is coarsely estimated at approximately 50 million fish. Analyses showed that seine net sampling collected a wide size range of common bully compared to other techniques and is the method recommended for future, cost-effective population monitoring. Laboratory experiments showed that common bullies would not spawn on the soft lake mud that dominates the majority of the lake bed. Spawning was only observed on firm surfaces – both artificial substrates (drain pipe and rubber car tyre) and the aquaria glass walls – and the onset of spawning occurred within hours of the bullies being placed in the aquaria despite the potential stress of capture, transport and handling. Our results, coupled with our knowledge regarding the current state of the lake (e.g., no macrophyte beds), suggests that common bully in the lake are strongly limited by the availability of spawning substrate. This was corroborated by GIS analyses of the lake bed material which showed that potential spawning substrate on the lake bottom was very limited and that its availability is strongly influenced by lake-level variation.

Improving the availability of spawning habitat for common bully will require management intervention. The most successful technique for Te Waihora is likely to be constructed rock reefs and whilst the installation of rock reefs would be an expensive solution to increase spawning substrate availability, such structures could serve multiple purposes (e.g., provide co-benefits such as shelter structures for macrophyte re-establishment, reducing lake shore erosion, habitat for various aquatic species) improving its cost effectiveness. In the absence of any lake management intervention, it will be critical that the lower reaches of tributaries flowing into Te Waihora are protected as these areas are likely to be vital to maintaining fish stocks in the lake.

1 Introduction

Te Waihora (Lake Ellesmere) is of exceptional significance to Ngāi Tahu as a tribal taonga, providing a major source of mahinga kai and mana (Te Runanga o Ngāi Tahu and Department of Conservation 2005). The lake is considered nationally significant for both customary and commercial fisheries, contributing about a quarter of New Zealand's commercial eel catch and supporting a significant flatfish fishery. Both tuna (shortfin and longfin eels) and pātiki (flounder) enter the lake as juvenile fish and rely on having abundant prey resources in the lake for growth and maturation; the key prey fish for both these mahinga kai species is common bully (*Gobiomorphus cotidianus*) (Kelly & Jellyman 2007). Therefore, ensuring common bully remain abundant in the lake is crucial for maintaining adequate stocks of tuna and pātiki.

The effective management of mahinga kai fisheries within the lake is currently hindered by some critical knowledge gaps although this is starting to be addressed by Investigation brief D5 'Fish restocking/recruitment including a review of fisheries management' in the Whakaora Te Waihora (WTW) programme. To date, investigation brief D5 has collated existing fisheries data for Te Waihora (Crow & Bonnett 2013), examined recruitment patterns for a range of mahinga kai species (Jellyman & Crow 2015) and investigated the tuna population within the Horomaka Kōhanga area (Jellyman et al. 2016). The brief D5 has four primary research-based objectives, these are:

1. Identify the factors limiting mahinga kai recruitment. Specifically, the recruitment of yellowbelly flounder, shortfin eels and longfin eels will be monitored around lake openings using seine and fyke nets. Data will be used to generate relationships between mahinga kai recruitment and season, lake opening regime and species abundance. Identification of recruitment periods for these species will assist in the development of lake opening regimes.

2. Monitor the growth, sizes and relative abundance of key mahinga kai species. Specifically catch rates, condition, growth rates and length and weight distributions of shortfin eels will be monitored throughout the lake by fyke netting. The results will be used to compare the productivity of the shortfin eel fishery in different areas of the lake, evaluate the effectiveness of the establishment of the Horomaka Kōhanga area and identify factors that may influence survival, growth and maturation of mahinga kai species.

3. Identify and evaluate the effectiveness of in-lake and wider catchment interventions aimed at providing protected or enhanced environments for mahinga kai species and their prey. Specifically, the effectiveness of enhancing in-lake spawning habitat for non-diadromous populations of prey species (bullies and īnanga) will be determined through assessing īnanga spawning habitat availability and quantifying the extent of non-diadromous populations of these species. In addition, the effects of macrophyte re-establishment on mahinga kai habitat and prey availability will be assessed by monitoring colonisation of re-established macrophyte beds by mahinga kai species and fish and invertebrate prey. Enclosure experiments will also be used to determine the effects of macrophyte re-establishment on fish biomass, size and survival.

4. Determine the effectiveness of the establishment and enhancement of Kōhanga areas in protecting mahinga kai species. Specifically population estimates of shortfin eels in the Horomaka Kōhanga reserve will be developed through mark-recapture and used as a

baseline to monitor future changes in abundance resulting from the establishment of the reserve. Additionally, the movements of individual eels in and out of the reserve will be monitored through radio-telemetry. Telemetry data and population estimates will be used to calculate the number of eels within the Kōhanga reserve whose daily movements out of the protected area put them at risk of capture by commercial fishery operations.

This report is focussed on the availability of the key prey fish – common bully – for two important mahinga kai species in Te Waihora. This research report forms part of the third objective focussed on providing or enhancing mahinga kai species and their prey. Whilst this report is not a 'contract deliverable', the extent of work conducted on this topic warranted an additional report.

1.1 Common bully ecology

Common bully are widely distributed throughout New Zealand and although they have been found substantial distances inland (since they can form landlocked populations), they are generally most abundant close to the coast. Coastal-dwelling common bully typically have a diadromous life-cycle, where newly hatched larvae migrate out to sea, then re-enter fresh water in spring at 15–20 mm total length before maturing through to adults. They are particularly common in lowland and coastal lakes, such as Te Waihora, where they grow to an average length of 70–80 mm (McDowall 1990). Common bullies are opportunistic carnivores with diets mainly consisting of Chironomidae (midges), Ephemeroptera (mayflies) and Trichoptera (caddisfly larvae), although molluscs, fish eggs and small fish may form a major part of the diet at certain times of the year. Common bullies are benthic predators and in Te Waihora they move into shallower waters during summer months where they tend to compete with small eels for midge larvae before the eels grow large enough to prey on bullies (Jellyman & Todd 1998). Common bully can mature at age one and live for four to five years (McDowall 2000) meaning they likely spawn multiple times during their life.

1.2 Common bully stocks in Te Waihora

Te Waihora is a large but very shallow coastal lake with a maximum depth of just over 2 m (under typical lake levels). These unique characteristics (i.e., depth and proximity to the coast) means that compared to other lakes, it is conceivable that all of the lake bed potentially provides bully habitat. Thus, common bullies are highly abundant and widely distributed in Te Waihora and its tributaries (Glova & Sagar 2000; Kelly & Jellyman 2007). This species has been described either as diadromous (McDowall 1990) or facultatively amphidromous (Closs et al. 2003), and may migrate between marine and freshwater environments as part of its life-cycle. Non-diadromous stocks readily become established in "landlocked" freshwater environments, and as access between the sea and Te Waihora is intermittent, it is possible that both diadromous and non-diadromous forms exist in the lake.

Common bully are a critical component of the freshwater food web in Te Waihora as they support higher trophic levels (e.g., shortfin eel, flatfish species, herons, shags and gulls) and are the primary prey source for shortfin eels larger than 400 mm (Kelly & Jellyman 2007). A self-sustaining common bully population in Te Waihora is critical to ensuring that the cultural and commercial values of the lake are maintained. In recent years concerns have been raised, by commercial fisherman in particular, about the potential reduction in common bully abundance in the lake (C.Smith, pers. comm. to S.K

Crow). If reductions have occurred, several reasons could explain a decline in common bully numbers such as a reduction in lake or habitat quality, a lack of lake openings during their primary recruitment period, decreasing availability of spawning habitat or an increase in predator numbers. If common bully populations are declining it could have major implications for the food web of Te Waihora because bullies are fed on by large fish and bird species; in particular, shortfin eels, herons and shags (Sagar et al. 2004). As the primary prey source for large shortfin eels, a decline in common bully abundance could also result in slower growth rates and/or fewer predatory fish being supported in the lake.

1.2.1 Availability of spawning habitat for common bully

Of the many factors that could be influencing common bully populations, the availability of spawning habitat can be partially investigated without major expense. Rowe & Graynoth (2002) stated that bullies in lakes generally deposit eggs on hard substrates such as rocks, wood, old weed stalks and mussel shells, mainly in the littoral zones of lakes; although specific data were not presented. Spawning substrates for common bullies in lakes has received little research but in rivers they include firm substrates and aquatic weeds such as *Lagarosiphon* (McDowall 1990). Coffey (1983) highlighted the adaptability of common bullies when spawning, showing that they are capable of using many different hard substrates such as plastic plant pots, aquatic plants and metal structures. It is possible that spawning substrate in Te Waihora is limited because there are only a few areas of firm substrate around the lake margins and no longer any significant macrophyte beds[1]. The lake is often manually opened to the ocean during spring and summer months which can result in lower lake levels during (or after) the period when bullies spawn (McDowall 1990). If low lake levels prevent bullies from accessing their spawning substrates around the lake margins then the population may be forced to spawn on poor substrate or excessive spawning may occur on the limited available substrate compromising egg survival. There has been extensive research into the importance of the eel populations in the lake (Ryan 1984; Jellyman et al. 1996; Jellyman 2001; Kelly & Jellyman 2007), but there is a lack of research on their prey populations and whether their spawning habitat may be limiting.

1.3 Study objectives

To assess whether common bully populations were decreasing in Te Waihora two data sets were compared to assess different sampling techniques. Based on these findings, we also suggest a standardised method for sampling lake common bully populations that may also benefit future state and trends monitoring.

From discussions with commercial fishers, the primary objective of this study was to test whether there was any evidence of a decline in common bully numbers in the lake (*Objective 1*). To address this objective several fish sampling methods were compared to establish which method was the most suitable for making inferences about the status of the stock (*Objective 2*). Common bully stocks may be limited by the availability of spawning substrate in the lake so a third objective was to conduct an experiment to examine spawning substrate preference (*Objective 3*). Finally, the implications of lake-level variation on the availability of potential common bully spawning substrate was investigated using GIS mapping (*Objective 4*).

[1] Note there is a WTW project attempting to address this very issue in the lake.

2 Methods

2.1 Sampling common bully populations

To examine the changes of common bully abundance between sites and over time (*Objective 1*), the present study used two methods of fish sampling. Seine netting and benthic tow sampling were used because previous data generated using these methods were readily available and they are a simple and cost effective way to address the aims of the study (*Objective 2*). Other sampling methods such as underwater observation, fyke nets, electro-fishing and beam trawls were not considered due to lake characteristics, time taken and personnel needed (although previous data from boat-mounted beam trawl surveys is later presented for comparative purposes). Lake transect sampling has previously shown that populations of common bullies are generally found in the littoral regions of the lake (Glova & Sagar 2000), so sampling was conducted around the lake margins.

Common bully were sampled at nine locations around the lake with beach seine netting (Figure 2-1). The seine net used was 21 m x 3 m net (mesh size 4 mm) and sampling was conducted during the day by dragging the net towards the shore. When the shoreline was reached, researchers on either end of the net dragged it up the shore until the pursed part of the net containing the fish was out of the water. The net was then hauled onto the shore where the fish were transferred into buckets of water containing a weak solution of anaesthetic (Aqui-S). The area fished varied between sites so a laser range-finder was used by a person standing on the shoreline to determine the distance offshore that the net would cover during the seine drag. Area fished at each site was then calculated by multiplying the distance fished by the net width. Fishes were identified, their length measured and then released close to the sampling site.

A benthic (tow) sled was also used to quantitatively sample common bully populations at seven locations near the lake shoreline (see Figure 2-1). The sled had an aluminium frame 1.45 m long by 0.6 m wide with the bottom covered by 2 mm thick plastic to allow the sled to easily move over the surface of the lake with minimal drag. The front edge of the plastic sheeting was upturned 30 mm to prevent accumulation of mud and prevent the sled digging into the substrate. A 1.3 m long net (250 µm mesh) was attached directly behind the aluminium mouth which had a rectangular opening 0.54 m wide and 0.16 m high that tapered down to a smaller bag at the back of the net. At each sampling site (see Figure 2-1) the sled was towed along 5–10 transects. The sled was towed parallel to the shoreline and the distance of the tow depended on the length of rope attached to the sled (either 7 or 12 m). The sled was towed by hand at a steady rate and at the end of each tow the sled was upended with the net mouth foremost to prevent any fish escaping from the mouth of the net. This moved the fish down to the rear of the net where they were collected and then transferred into a bucket of water and anaesthetic. These fish were then identified, measured and released after all tows had been completed. Tows were performed in daylight at selected locations around the lake and no tows were conducted within 500 m of any tributary inflow. At each site the shore features were recorded or measured. This included beach width, height of bank and abundance of macrophytes. Habitat information was also recorded for each tow: distance from shore, water depth and percentage substrate composition (e.g., mud, gravel, sand).

Two data sets were collected for fish population analysis. Seine net data from 2005–2008 and 2013–2015 and benthic tow data from 2007–2008 and 2014–2015. These data were used to test whether bully populations have declined over this time frame. Beam trawl data from 1994–2000 were included for comparative purposes because the density data from this method also allowed a population estimate to be made. To account for differences in sampling area between sites, fish catches were converted to density values (no. of fish/m^2). The total population of the lake was then calculated using the lake area (197.8 km^2) and density. The coarse estimate for total common bully numbers in the lake assumed that the population was uniformly distributed across the lake because sufficient data on spatial variability were not available (i.e., multiple lake transects in different parts of the lake has not been done).

Figure 2-1: Locations of common bully sampling sites around Te Waihora. Red circles are seine net only sites, blue diamonds are benthic tow only sites and green squares are sites where both sampling methods were used. Beam trawls were done in various parts of the lake from 1994-2000 but sampling transects are not shown.

2.1.1 Data analysis

To examine *Objective 1*, a three-way analysis of variance (ANOVA) was used to determine whether there were significant differences between common bully densities across months, years and sampling methods (benthic tow or seine net). Summary data from beam trawl surveys conducted in 1994–2000 are shown for comparative purposes, but the raw data was not available for use in analyses. If there were multiple seine or benthic tow sampling events during a particular month, common bully density was averaged so that only a single density value per month was used in the analysis. Seine and benthic tow data were only included in the statistical analysis if both were available for a particular month. All analyses were completed using the software package R v3.2 (R Development Core Team 2015).

2.2 Substrate spawning experiment

To examine the spawning habitat preference of common bully (*Objective 3*), a controlled laboratory experiment (NIWA, Christchurch) was used to observe spawning substrate use. The experiment used five glass tanks (950 mm × 500 mm × 320 mm), which were split in half with a clear acrylic divider and filled with approximately 120 L of fresh water (Figure 2-2). The tanks were connected on a flow-through system with the inflow and outflows covered with mesh to prevent common bully moving between tanks or tank compartments. The 10 equal-sized tank compartments were filled with lake sediment (a mixture of mud/clay) taken from Te Waihora at Te Kōrua. Each tank compartment was connected to an airline to ensure the water was sufficiently oxygenated. To examine spawning substrate preferences, rectangular drain pipe (200 mm × 110 mm) and sections of rubber car tyre (300 mm × 180 mm with 2 mm tread) were placed in selected tank compartments (see Figure 2-3); tank compartments were too small for an intact tyre so two sections of tyre were placed into each tank. Both of these substrates were known to have previously been used by common bully in other New Zealand lakes (Coffey 1983). Tyres were specifically chosen as it was noted by Golder Associates (2012) that common bullies used old tyres and wooden posts as spawning sites in Te Waihora. Of the 10 tank compartments, three had plastic drainpipe added, three had tyre sections and four had no additional substrate added (i.e., control compartments).

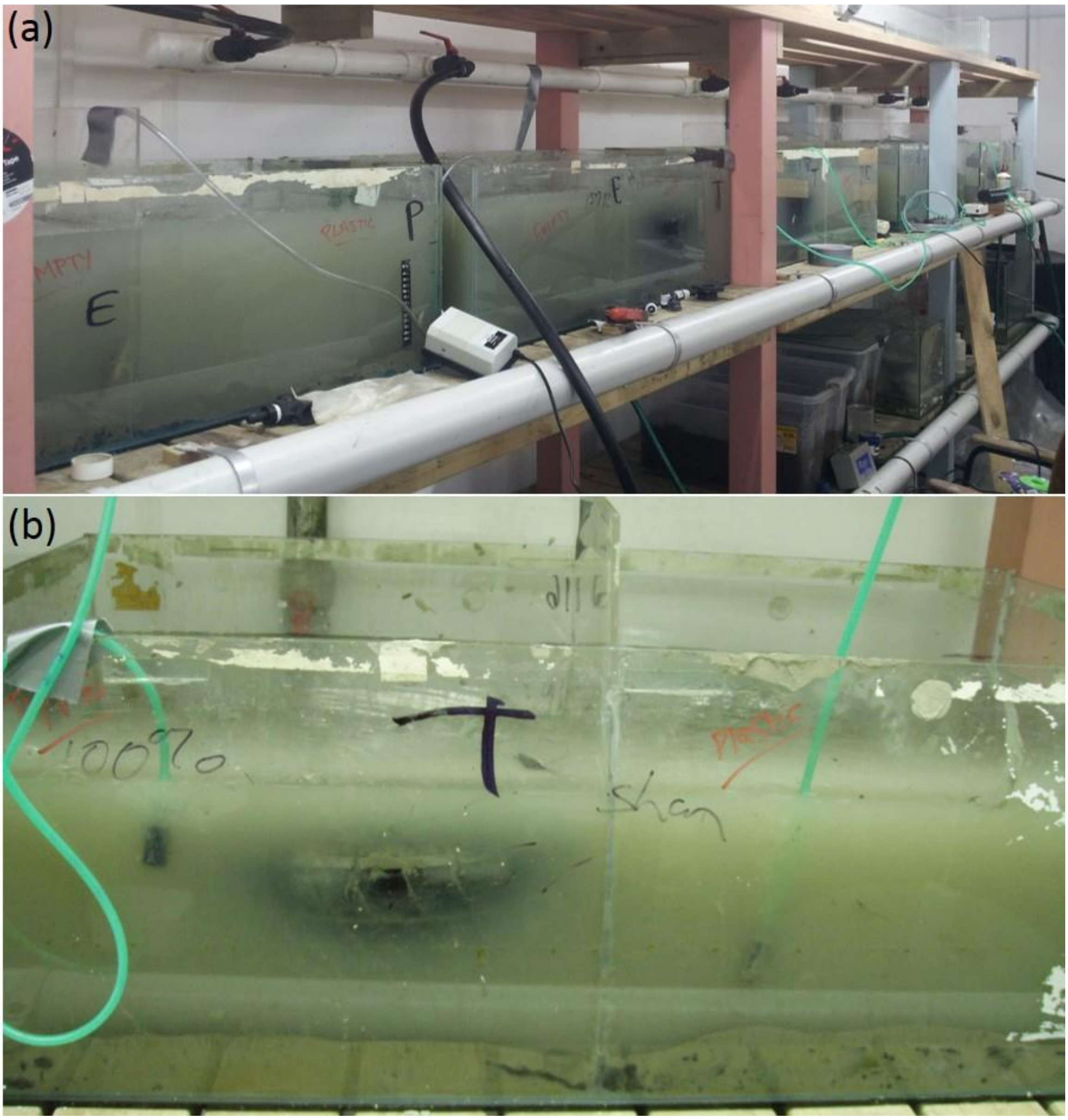

Figure 2-2: The experimental tank setup used for the common bully substrate spawning experiment. All five tanks used are shown in (a). During the initial experimental setup portable bubblers were used [as seen in (a)] but these were replaced by a permanent airline supplied by a compressor for the experiment. Each of the five tanks were split into two treatments by an acrylic divider extending above the top of each tank (b); each divider contained a large mesh section that allowed water to be exchanged between each side. In (b) the layer of lake sediment and the clarity of lake water can also be seen.

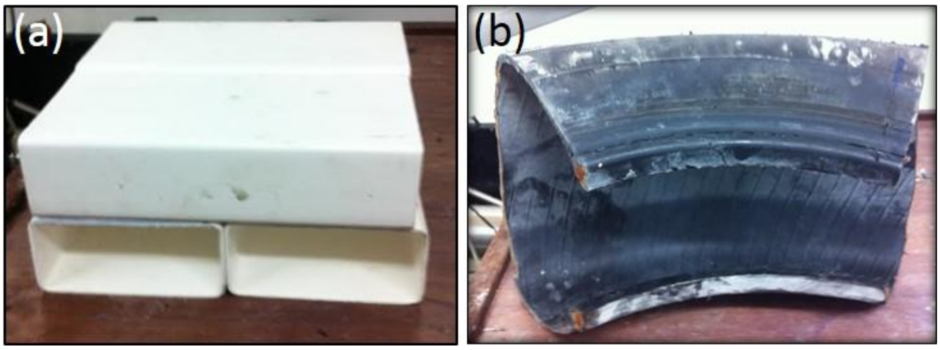

Figure 2-3: The artificial substrates that were placed into some of the experimental tanks. Rectangular drain pipe (a) and sections of a car tyre (b) were provided as possible spawning substrates.

Common bully (66–97 mm) used in the experiment were captured from Timber Yard Point with a seine net. Following capture, fish were selected for the experiment if they were larger than 60 mm and their abdominal cavity appeared swollen (i.e., potentially gravid). Fish were transported in aerated containers back to the laboratory where they were temporarily transferred into 40 L aquaria containing untreated artesian bore water. These aquaria (i.e., holding tanks) were in a temperature-controlled room (19 °C), with a 12 h light: 12 h dark photoperiod. Fish were given several hours to acclimate before seven fish were added to each tank compartment. Fish were separated to ensure a similar size distribution of fish were placed in each tank, but determining gender was difficult whilst alive (as we did not want to anaesthetise fish prior to the experiment) so they were not separated based on sex. The fish were monitored twice daily to check for evidence of spawning. All fishes were fed 3·6 g of commercial frozen *Glycera* spp. (bloodworms) each afternoon. After 14 days the experiment was concluded and all fish were preserved in isopropyl alcohol (IPA) for determination of sex in the laboratory. Female gonads were removed in the laboratory, dried and weighed to assess whether fish from tanks that had spawned could be clearly identified based on gonad weight.

2.3 Spawning substrate availability in Te Waihora – GIS analysis

To create and overlay substrate and water depth maps for Te Waihora, ArcMap 10.2.1 was used (see Appendix A). This approach was similar to Rowe et al. (2002) who used GIS to map spawning areas of smelt in Lake Taupō. The present study overlaid substrate and bathymetry layers to determine availability of potential spawning sites at different lake levels (*Objective 4*). To examine how spawning may have changed or been affected in the lake, both the historic distribution of macrophyte beds in the lake (Hughes et al. 1974) and substrate composition (Glova & Sagar 2000) were digitised. The images were geo-referenced using the New Zealand Transverse Mercator (NZTM) co-ordinates. The bathymetry map for Te Waihora was surveyed in 1989 (Irwin & Main 1989) at a lake height of 0.8 m. However, the first bathymetry contour is at a depth of 0.8 m (i.e., lake level of 0.0 m) so the existing contours of the lake were used to interpolate the lake bathymetry between a depth of 0.8 m and the shoreline (i.e., depth of 0 m). Digitized polylines were then used to represent specified lake level contours to create polygons to depict areas for substrate comparisons at multiple lake levels. Area was calculated for different attributes using the geometry tool in ArcMap. Large rocks, macrophytes and large woody debris are likely to be the preferred lake spawning substrates but given the general absence of all three in the lake (although maimai, duck shooting shelters, are present around the lake), the most available natural hard substratum for common bully is likely to be gravel-based substrates.

It is not known whether or not common bullies in the lake historically used macrophytes as a spawning substrate when they were abundant. However, even if macrophytes themselves were not used it is likely that their stabilising effect on the lake bed would have meant that macrophytes, either directly or indirectly, resulted in greater spawning habitat availability than presently available. Whilst a change in the distribution of macrophyte beds will not be responsible for recent claims of declines in bully abundance, it is worthwhile to map their historic presence for comparative purposes with the contemporary lake substrate map.

3 Results

3.1 Common bully survey work in Te Waihora

Estimates of common bully density were compared for different methods to examine whether there was any evidence of a recent decline in abundance (*Objective 1*). There was a five-fold difference in the area sampled between the current beach seine and previous beam trawl methods, but mean bully density was relatively consistent for both methods and thus the estimated size of the common bully population similarly varied by only c. 10% (Table 3-1). Given the 20-year span of the data and the different locations around the lake that were sampled by these two methods, having such a narrow common bully density range (0.236 to 0.266 m^2) is remarkable.

Common bully data were also collected by a third and less conventional method, a benthic tow. In contrast to beach seine and beam trawl data, benthic tow sampling showed a major difference in common bully density between surveys in 2007–2008 and 2014–2015 (Table 3-1). The area fished between sampling periods was similar (i.e., less than a 4% difference) but there was a 98% decrease in the number of common bully caught; density was 1.17 fish/m^2 in 2007–2008 compared to 0.024 fish/m^2 in 2014–2015 (Table 3-1).

Table 3-1: A comparison of common bully population size estimates based on different fish sampling methods conducted at various times. Population size estimates are simply the mean density value multiplied by the total lake area (see Section 2.1.1) for comparative purposes only.

Method	Period sampled	No. of trawls/ tows/hauls	Area sampled (m^2)	No. of common bullies	Mean density (no./m^2)	Estimated population
Beach seine	2005-2008	137	158,106	41,855	0.265	52,601,000
Beach seine	2013-2015	101	52,026	12,263	0.236	46,835,000
Beam trawl	1994-2000	549	274,500	73,078	0.266	52,898,000
Benthic tow	2007-2008	179	1,157	1,354	1.170	232,532,000
Benthic tow	2014-2015	119	1,114	27	0.024	4,816,000

Detailed beam trawl data were not available, so to assess the most suitable method for sampling common bullies in the lake (*Objective 2*), beach seine netting and benthic tow sampling were compared. There was a significant difference in common bully density estimates from the two methods ($P = 0.02$; Table 3-2) as well as a significant difference for the 'Method × Year' interaction ($P = 0.01$; Table 3-2) indicating that the sampling method used produced different density estimates between years. Visual examination of these data showed bully density estimates from benthic tow sampling were consistently higher during sampling in 2007-08 compared to 2014-15 and density peaks tended to occur between March and May (Figure 3-1). It was also apparent that seine net data were far less variable between sampling dates (Figure 3-1).

Table 3-2: Table of three-way ANOVA results comparing bully density caught by either beach seine netting or benthic tow sampling over time.

Factor	df	SS	MS	F value	P value
Method	1	2.39	2.39	6.20	**0.02**
Year	1	0.17	0.17	0.45	0.51
Month	1	0.15	0.15	0.39	0.54
Method × Year	1	2.60	2.60	6.74	**0.01**
Method × Month	1	0.74	0.74	1.92	0.17
Year × Month	1	0.00	0.00	0.00	0.99
Method × Year × Month	1	0.35	0.35	0.90	0.35
Residuals	35	13.47	0.38		

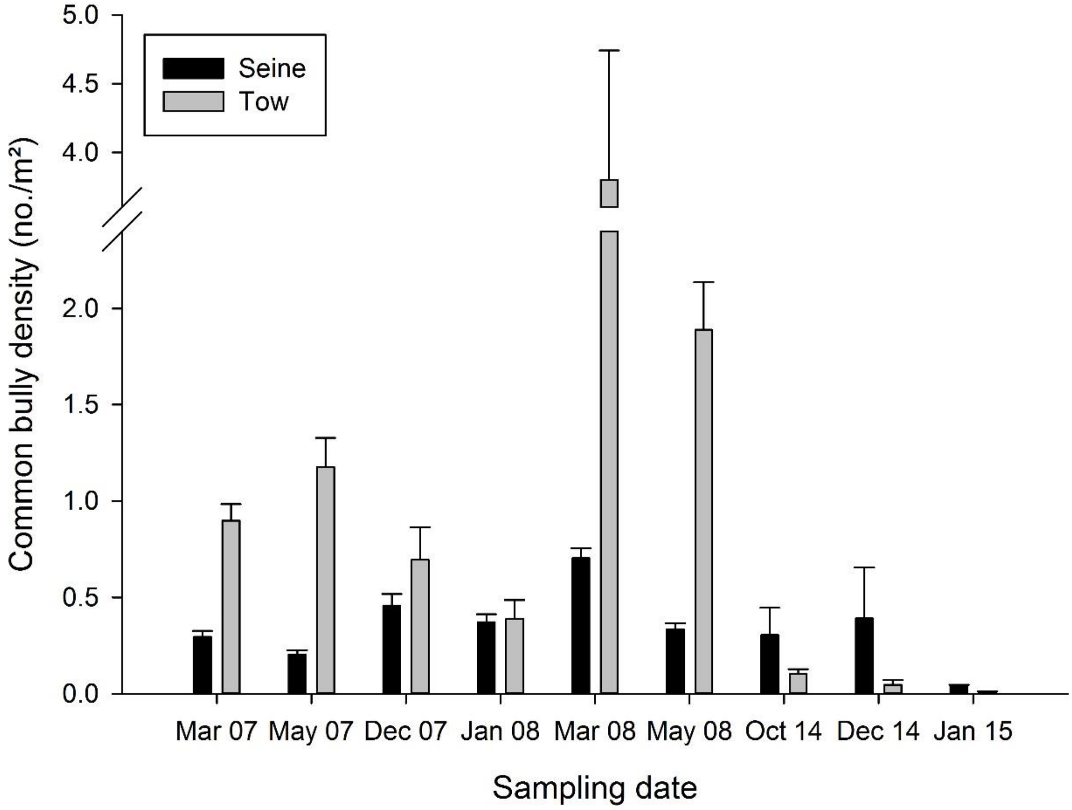

Figure 3-1: A comparison of common bully density across sampling dates for which both beach seine and benthic tow sampling was conducted. Note, there is a break in the y-axis from density values 2.0–4.0 for visual clarity.

A kernel density comparison clearly showed the size bias produced by different methods when sampling common bully populations. The benthic tow data caught a high proportion of small common bully, with the highest density of fish caught being approximately 30 mm in length (Figure 3-2). In contrast, the beam trawl caught very few small common bully but was strongly size selective for larger bullies, with a density peak around 80 mm. The kernel density plot for seine net data had a markedly wider base compared to the other two methods indicating the method was sampling a wider range of common bully size classes (Figure 3-2).

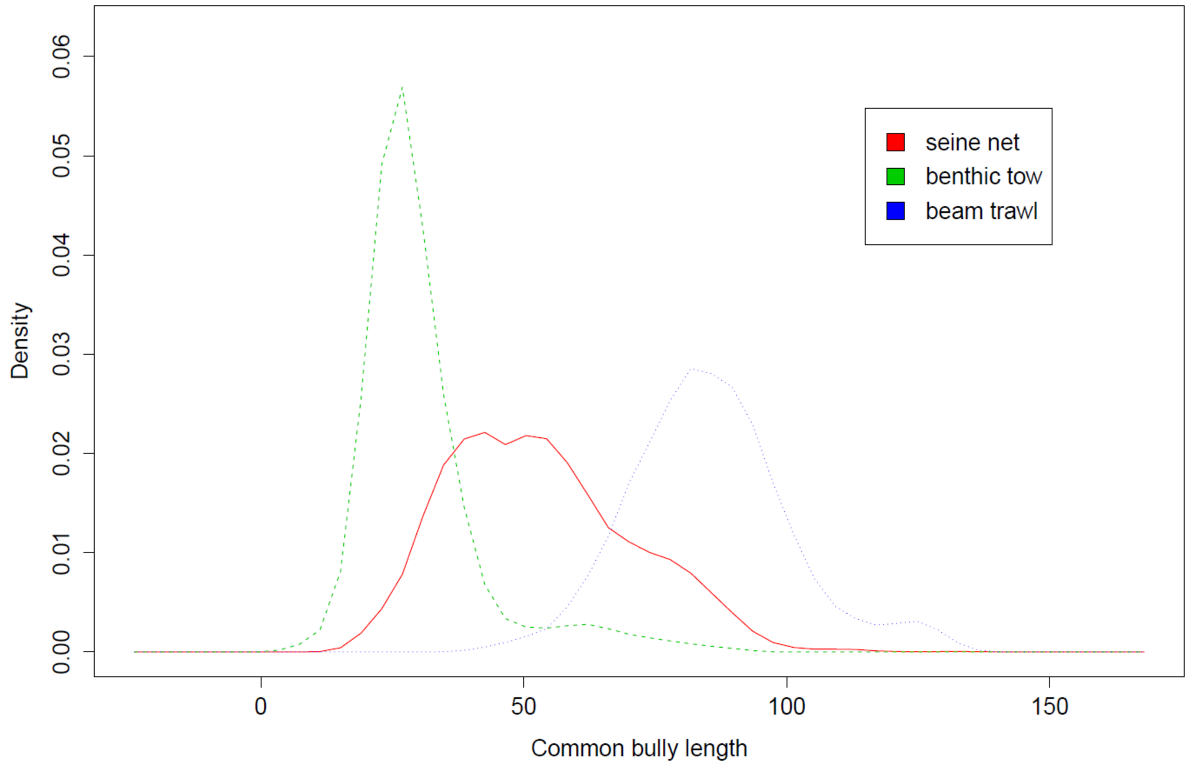

Figure 3-2: Common bully length as a function of kernel density for three different sampling methods.

3.1.1 Variation in common bully populations over time (seine data)

To examine variation in common bully populations through time, seine data were used because this method was effective for sampling a wider range of common bully sizes (Figure 3-2). From 2005 to 2015 there was nine-fold variation in common bully density; however, there was no significant difference between the mean common bully abundance in the 2005–2008 compared to seine net sampling in 2013–2015 (One-way ANOVA: $F_{1,34}$ = 1.26, P = 0.27). Note: 2015 is excluded from this statement because of markedly smaller sample size relative to the other years (Figure 3-3a).

The months with the highest common bully density were also the most variable (Figure 3-3b). There were two distinct peaks in common bully density in February and November (Figure 3-3b). Density was lowest during winter months but then increased markedly through spring (Figure 3-3b). This increase in density from winter to spring was paralleled by an increase in mean length over this time period (Figure 3-4).

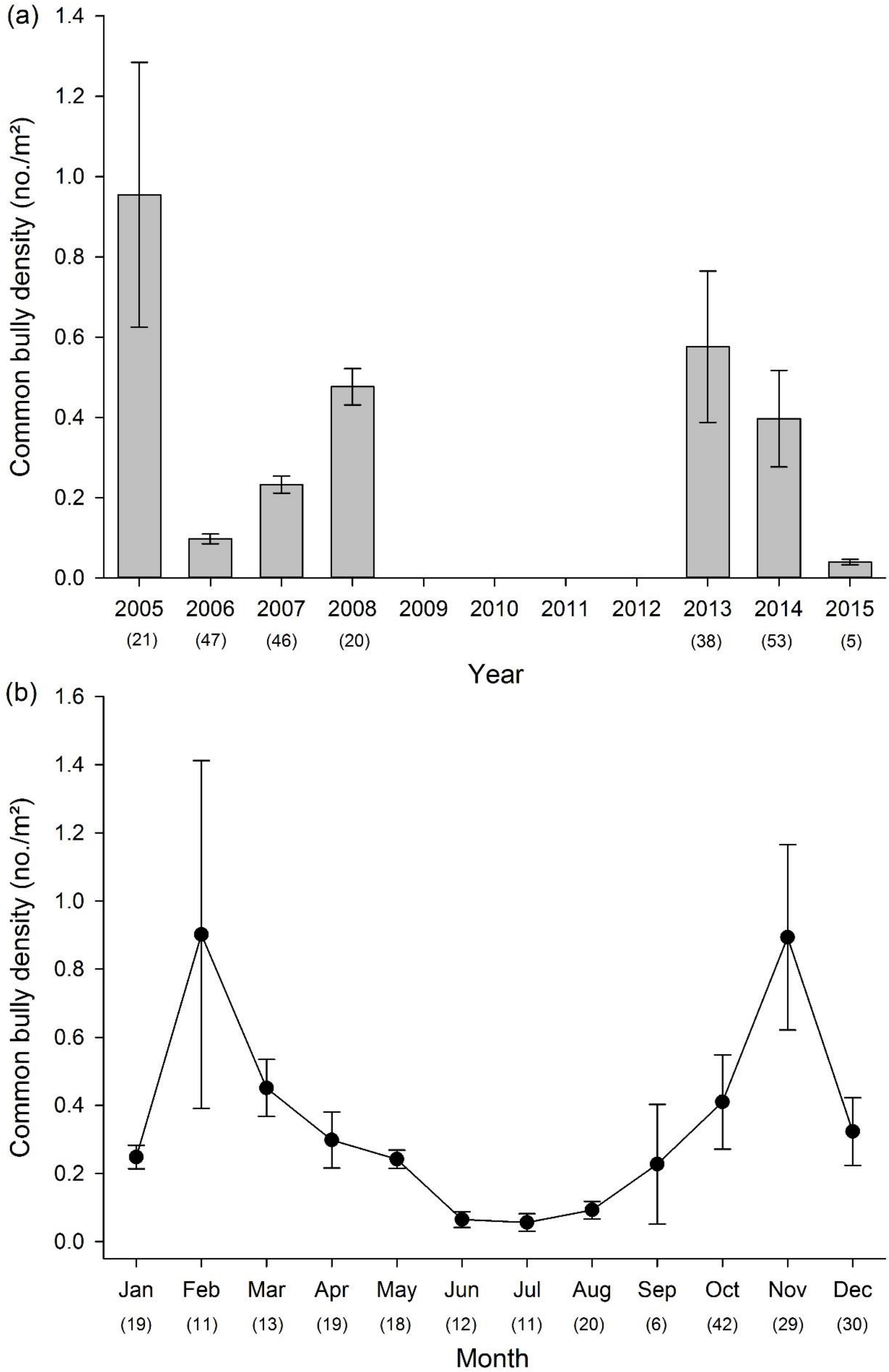

Figure 3-3: Variation (±SE) in common bully density over different years (a) and months (b) based on seine netting data. The number of seine hauls (sample size) are provided in parentheses. Note in (a), the year 2015 only contains data up to mid-February.

Common bully length was examined to assess whether there had been mean changes in length over time. Between the two seine-netting datasets there were 3,565 bullies measured for length (1,358 in 2005–2008 and 2,207 in 2013–2015) and the mean length in 2005–2008 was 53.7 mm compared to 53.1 mm in 2013–2015. There was no statistically significant change in common bully length between the two datasets (One-way ANOVA: $F_{1,3563} = 0.95$, P = 0.33) and this result did not change when accounting for potential differences in sampling month between the two datasets (Two-way ANOVA: dataset × month interaction, $F_{1,3561} = 1.49$, P = 0.22).

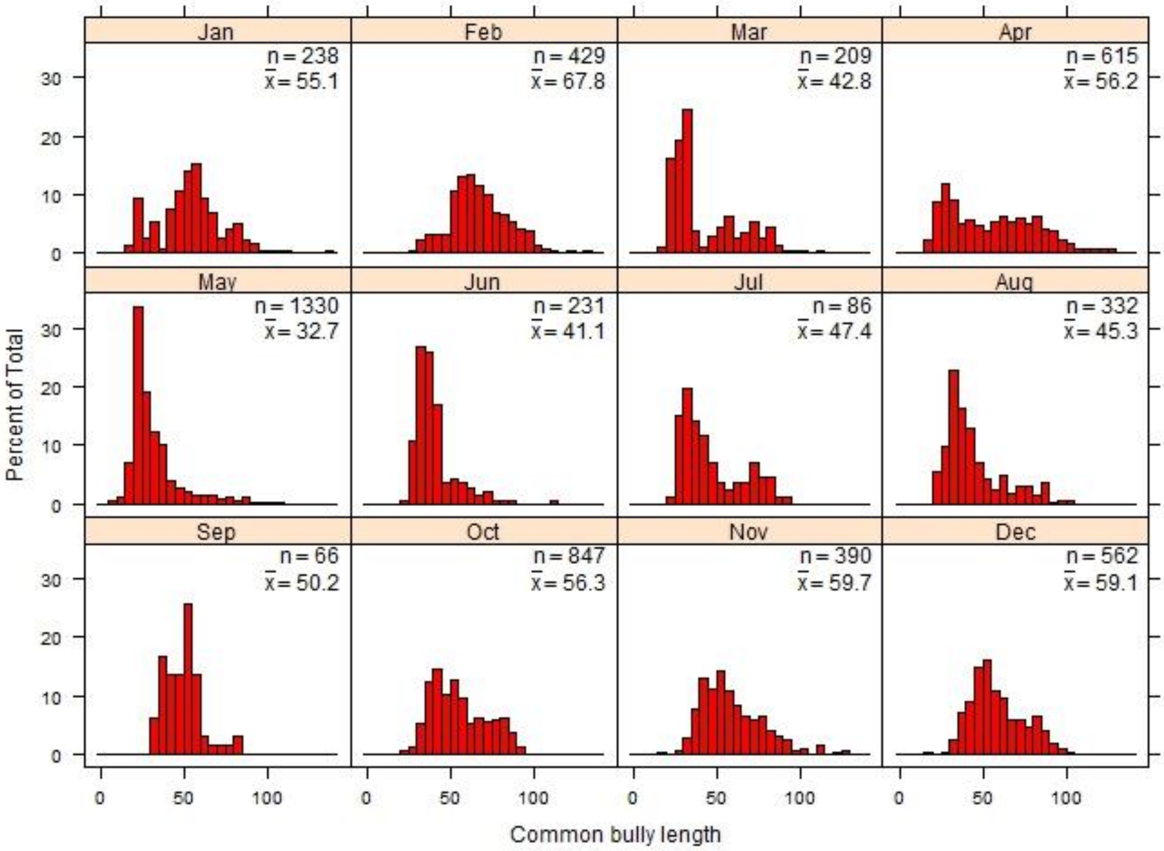

Figure 3-4: Changes in the length-frequency distribution of common bully in Te Waihora for each month of the year.

3.2 Spawning experiment

The type of spawning substrate used or required by common bully was investigated in a controlled laboratory experiment (*Objective 3*). Spawning was first noted in the tanks within 12 hours of the experiment commencing; researchers watched multiple bullies spawning on the glass of a tank when first checked the following morning (see Figure 3-5a). At the conclusion of the experiment it was apparent that common bully had spawned on the glass on the side of the tanks more often than on the artificial spawning substrates provided, although spawning did occur on artificial substrates (see Figure 3-5b, Table 3-3). Common bullies in the 10 replicate tanks also had access to mud substrate, but no spawning on this lake-bed material was apparent (Table 3-3). Because bullies spawned on the glass surfaces of the aquaria, it prevented any statistical analysis of spawning frequency between treatments.

Common bully were not sexed prior to the experiment, but the sex ratio (determined after bullies were euthanized) was strongly biased in favour of females. In total, 30% of common bully in the tanks were male and 70% were female but this sex ratio had no detectable influence on whether or not spawning occurred during the experiment. Larger females contain bigger gonads (Figure 3-6) which could influence their spawning behaviour, however, in this experiment the body length of females did not vary significantly between replicates (One-way ANOVA: $F_{9,38}$ = 1.61, P = 0.15). It was not possible to tell whether or not an individual female fish had spawned basely solely on gonad weight (Figure 3-6).

Figure 3-5: Evidence of common bully spawning on both the glass of the experimental aquaria (a) and tyre substrate (b). In (a) two female common bully (circled in red) were laying eggs on the glass sides of the aquaria within hours of the experiment starting. Another bully on the bottom of the tank is also visible in (a).

Table 3-3: Results of the common bully spawning experiment for different artificial substrates. NA = not applicable.

Treatment	Rep no.	Sex ratio (Male : Female)	Spawning observed	Spawning on mud	Spawning on artificial substrate
Control	1	1 : 6	×	×	NA
Control	2	2 : 5	✓	×	NA
Control	3	1 : 6	✓	×	NA
Control	4	2 : 5	×	×	NA
Plastic	1	1 : 6	✓	×	×
Plastic	2	1 : 6	✓	×	×
Plastic	3	5 : 2	×	×	×
Tyre	1	1 : 6	✓	×	✓
Tyre	2	2 : 5	×	×	×
Tyre	3	5 : 2	✓	×	✓
Total		**21 : 49**	**6/10**	**0/10**	**2/6**

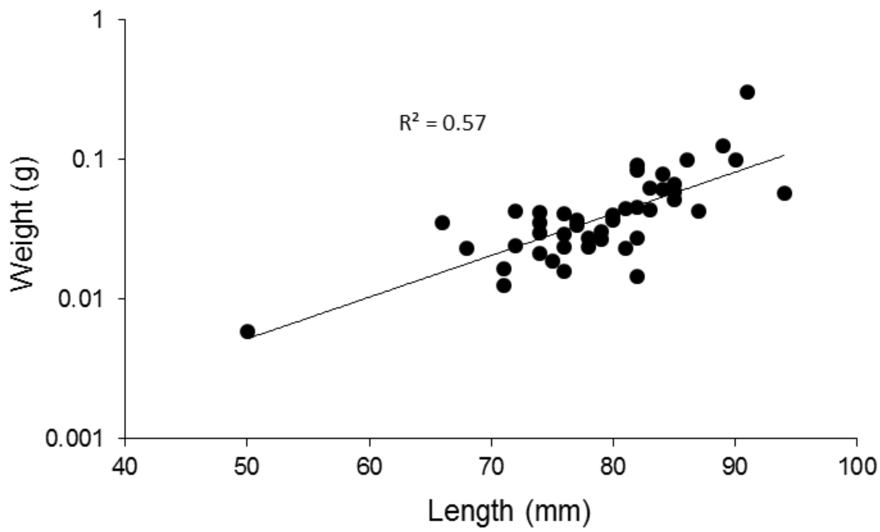

Figure 3-6: Relationship between female common bully length (mm) and gonad dry weight (g). Note: measurements taken at the conclusion of the experiment.

3.3 Spawning substrate availability in Te Waihora – GIS analysis

To examine the implications of lake-level variation on the availability of potential common bully spawning substrate (*Objective 4*), GIS mapping was used to plot historical lake conditions. The distribution of macrophytes in the lake prior to 1960 were mapped based on the depiction by Hughes et al. (1974). The total area of macrophyte beds, a possible spawning substrate for common bully, was 40.5 km^2. This equated to 14% of the total lake area at that time (which was a lake area of approximately 300 km^2), but there are no macrophyte beds in the lake at present[2]. The outline of Te Waihora on the present day topographic map is for a lake water level of 0.8 m resulting in a lake area of only c. 191 km^2. This difference in lake area between pre-1960 and the current topographic map is explained by more intensive lake-level management (through artificial control of the lake level) at present resulting in a smaller littoral 'varial' zone around the lake (i.e., the area that re-wets and dries through time). A more 'swampy' boundary historically means that the lake edge would have been less defined which is likely why what was described as 'macrophytes' by Hughes et al. (1974) appears outside of the lake margins along Kaitorete Spit in Figure 3-7.

The dominant lake-bed substrate in Te Waihora is currently soft clay which comprises approximately 52% of the lake bed (see Figure 3-8). Common bully prefer to spawn on firm rather than soft surfaces so it is reasonable to assume that only substrate types with a gravel component (i.e., mud/gravel, sand/gravel, gravel) are likely to be used for spawning. At a lake level of 0.8 m, only 6.5% of the lake-bed is composed of these three substrate types. As the lake level decreases, the availability of different substrate types are disproportionately lost. For example, when the lake level decreases from 0.8 to 0.6 m, only 7% of sand/gravel habitat is lost, but more than 30% of the gravel habitat is lost (Figure 3-9).

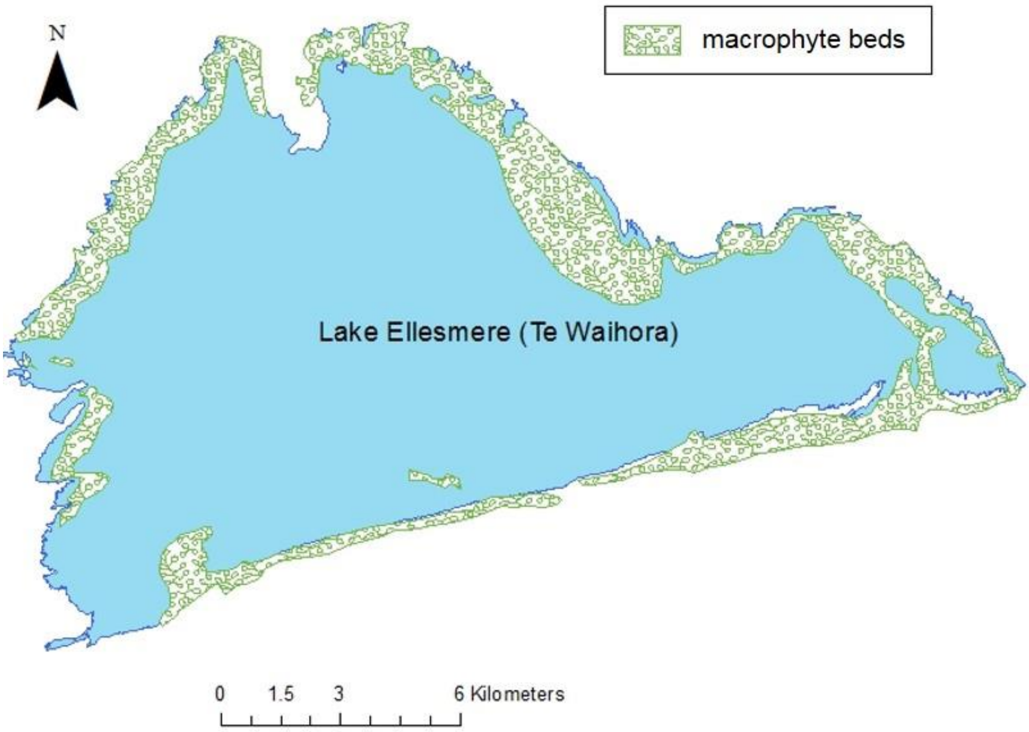

Figure 3-7: The distribution of aquatic macrophytes around Te Waihora in 1960. This mapping is based on the macrophyte distribution as depicted by Hughes et al. (1974). Note the macrophyte beds extend outside the current lake margins along Kaitorete Spit, likely because of the way that 'macrophytes' were previously defined (i.e., including areas of swamp around the lake) rather than an error in distribution mapping.

[2] Although there is a WTW project attempting to re-introduce macrophytes in several parts of the lake.

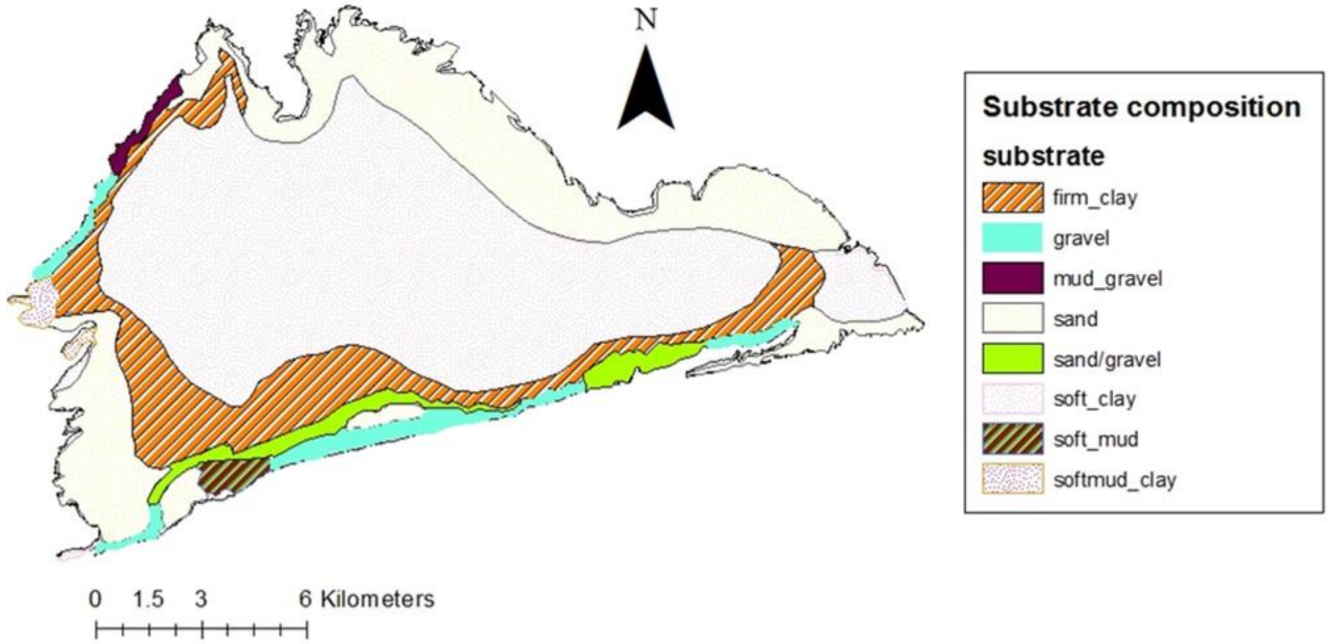

Figure 3-8: The composition of lake-bed substrates in Te Waihora.

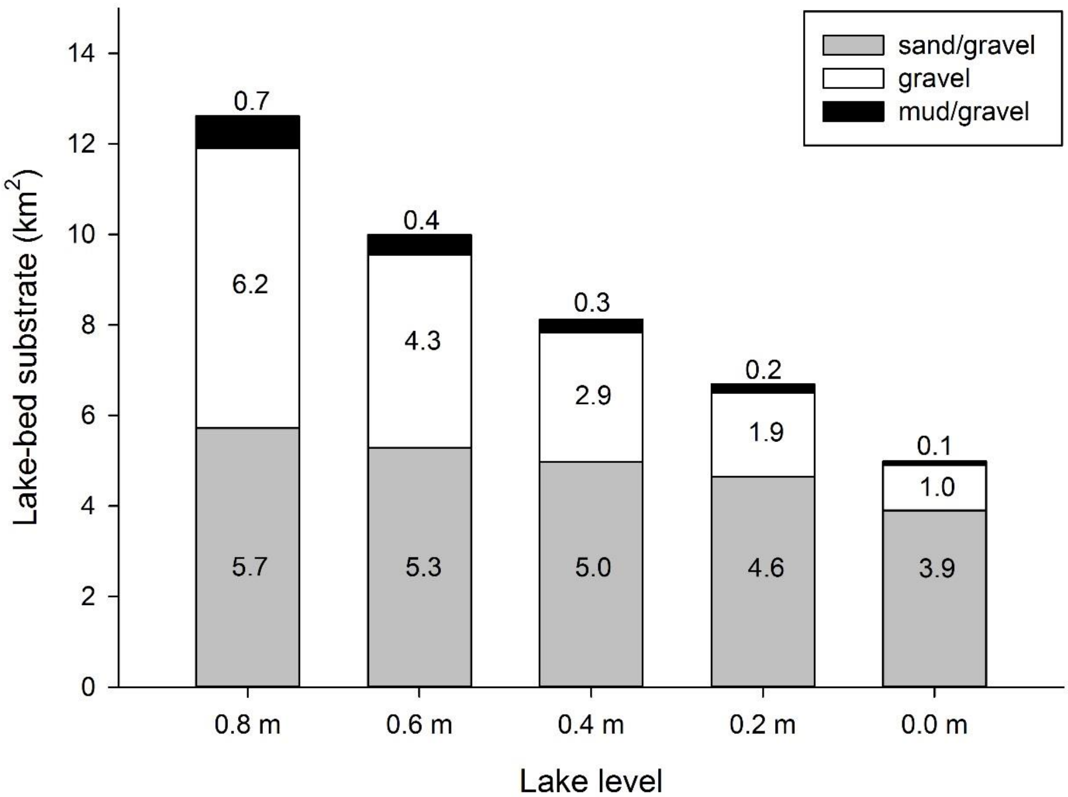

Figure 3-9: Change in the area of different potential common bully spawning substrates at different lake levels.

4 Discussion

4.1 Sampling and estimating common bully populations

Examination of common bully abundance data, collected using conventional sampling methods (i.e., seine netting and beam trawling), indicated that mean population densities have been relatively stable over time (*Objective 1*). The similarity between the coarse population estimates using these two methods was remarkable given the estimated population from seine netting samples the littoral regions of the lake whereas beam trawling samples lake transects over a range of depths. This could suggest that the shallow bathymetry of Te Waihora results in bully densities being relatively evenly distributed throughout the lake. Whilst an alternative sampling technique in the form of a benthic tow was also used to assess changes in the population over time, this method was largely exploratory and showed a strong size bias for small bullies. The benthic tow method showed a major decline in bully abundance over time, but numbers of juvenile fish can show major variability because of recruitment differences between years, so this should not be considered representative of the lake common bully population. Based on the available population data it is concluded that there has not been a detectable change in abundance of adult common bullies in Te Waihora in recent years. Moreover, as mean common bully length has not changed through time, the biomass of common bullies will not have been altered.

A comparative analysis on the combined temporal dataset for seine and benthic tow data indicated that common bully density did not vary significantly between months for either sampling method. This was somewhat surprising given it is likely that large numbers of small bullies, either from ocean recruitment or possibly from non-diadromous sources, would be entering the lake at certain times of the year. Whilst sampling methods would be unlikely to capture small 'fresh' recruits, a density pulse might still be expected to be seen in the dataset. However, the dataset only included months when information was available for both sampling methods so the lack of a clear recruitment pulse in the density data may be because of data gaps in the combined dataset.

Of the methods used during this study, beach seine netting was considered to be the most effective method for sampling common bully populations in the lake (*Objective 2*). This method sampled the widest range of size classes of common bullies and has the advantage of using relatively low cost equipment (compared to a beam trawl which is towed behind a boat). The size range sampled by seine netting was not replicated by either beam trawl or benthic tow sampling which were both highly size-selective. The beam trawl mainly captured larger bullies and likely under-represented smaller bullies in the catch data. However, it is not known whether the beam trawl sampling is actually size selective or whether small common bully are just largely absent in the off-shore waters primarily sampled by this method (also beam trawls are typically undertaken during spring and summer when smaller fish are less common than in winter, see Figure 3-4). For the benthic tow there is no ambiguity as it is the method that is size selective. Seine netting in the same areas of the lake as benthic tow sampling shows there is a range of size classes present but the larger size classes are very poorly represented in benthic tow catches. Whilst seine net sampling is recommended to monitor common bully population in the future, the methodology has been considered to be more efficient at sampling mid-water species (e.g., common smelt) compared to benthic species such as common bully (Pierce et al. 1990; Portt et al. 2006). Differences in capture efficiency for these different types of fishes are typically attributed to benthic fishes being caught less readily because they are able to escape underneath the lead-line as the seine net is dragged through the water. However, this is considered far less of an issue when sampling in Te Waihora because most of the lake-bed habitat typically seine netted is muddybottomed (as opposed to rocky-bottomed where less of a 'seal' is created along the lead-line). Thus, escapement rates under the lead-line should be relatively low since the line is effectively being dragged underneath the lake-bed surface and capturing the benthic fish on top of this surface.

4.2 Common bully spawning in Te Waihora

4.2.1 Spawning on artificial substrates

The spawning substrate experiment showed that common bullies have a strong preference for spawning on large, firm surfaces (e.g., glass, tyres) and will not spawn on lake-bed mud (*Objective 3*). Previous observations of common bully spawning have noted it occurs beneath, or on the sides or top of some firm, flat surfaces and that bullies may actively remove sediment to expose firm surfaces for spawning (Coffey 1983; McDowall 1990). One of our artificial spawning substrates, plastic drain pipe, was not spawned on. However, in plastic drain pipe treatments bully spawning occurred on the glass rather on (or in) the drain pipe. As bully spawning tended to cover an area of c. 10 x 15 cm (although it is not known if this was typically from one or several individuals), the plastic pipe may have been too restrictive for bully spawning hence the glass was preferentially used.

It is important to note that the sex ratio of fish used in each replicate was not the same, however all replicates contained female bullies and the sex ratio had no detectable effect on whether spawning occurred or not. The most surprising finding of the experiment was how quickly common bully started to spawn. Typically the stress associated with the capture, transport and handling of fish would be expected to delay a behaviour such as egg laying/spawning, but large numbers of eggs had already been deposited on the glass of tanks within the first 12 hours of the experiment (i.e., within 18 hours of being captured). Multiple bullies were observed spawning on the glass this quickly and in different tanks; the fine suspended lake sediment in the water meant it was not possible to observe whether artificial treatment substrates, such as tyres, had been spawned on until the end of the 14-day experiment. Given the speed at which several female bullies in different replicates started laying eggs, once provided with a firm surface, it seems highly likely that common bully in the lake are limited by the availability of spawning substrate.

4.2.2 Availability on spawning substrate in Te Waihora

Potential lake-bed spawning substrates for common bully (e.g., substrates with a gravel component) make up only a small proportion of Te Waihora because the lake bed is largely composed of soft clay and sand. Substrate layers containing some gravel are mainly found around the edge of the lake so their availability is strongly influenced by lake level (*Objective 4*). The most likely lake-bed spawning substrate is gravel and its availability reduces by 30% when the lake level drops from 0.8 to 0.6 m. It was assumed that any substrate layer with some gravel component could be 'potential' spawning habitat, and therefore was modelled, but whether or not these layers are all used by common bully for spawning is unknown. Prior to the Wahine storm in 1968, macrophyte growth in Te Waihora had been described as 'spectacular and luxuriant' (Jellyman et al. 2009) and given the additional habitat diversity this would have provided it is reasonable to assume that the lake supported a much larger population of common bully; this contention is supported by anecdotal fisheries information that the fishery supported many more eels than are captured today which would require more prey fish such as bullies to support (assuming there are sufficient invertebrate prey to sustain more fish). Gerbeaux (1993) and Jellyman et al. (2009) proposed that attempts be made to re-establish macrophytes in the lake and there is currently a WTW project that is doing this. The re-establishment of macrophytes would provide further spawning substrate for bullies to lay eggs on. If large macrophytes beds returned then lake-bed sediments would start to stabilise reducing sedimentation of eggs and enabling greater spawning to occur on suitable lake substrates. At present, large numbers of common bully have also been observed to move up into tributary streams, presumably in search of suitable spawning substrates (Jellyman 2012). Such a movement is probably because eggs deposited along the lake shore are likely to be subject to desiccation due to the regular and unpredictable fluctuations in lake levels both from wind-fetch effects and manual lake openings. However, flows in tributary streams are likely to be more stable and therefore favourable for egg survival; therefore, the lower reaches of tributaries may be disproportionately important to bully spawning success given the current state of Te Waihora (Golder Associates 2012).

4.2.3 Further spawning work

Further research is required to corroborate the results of the preliminary experimental work which suggests bullies in the lake could be limited by the availability of spawning habitat. With larger rocky substrate very limited in the lake, bully spawning sites may be rather opportunistic as indicated by anecdotal reports of common bully spawning on maimais and car tyres around parts of the lake (i.e., from old attempts to minimise lake shore erosion). However, as part of efforts to improve the aesthetics and safety of the lake, 700 old maimais and 1000 car tyres from around the Halswell River mouth have been removed by North Canterbury Fish & Game over the last 15 years. Whilst these clean-up efforts are to be applauded, an unintended consequence has likely been the removal of common bully spawning sites in the lake. In other lakes around the world, the addition of large woody debris (LWD) is often used to create habitat complexity and spawning sites for different aquatic organisms, however, such additions in shallow lakes such as Te Waihora can create boating hazards; much of the woody debris present in the lake seems to get moved around in the strong winds/waves (P. Jellyman, pers. obs.) and covered by fine sediment, so its usefulness as a firm spawning substrate for bullies given the current state of Te Waihora may be limited. Bassett (1994) reviewed over 4000 artificial fish habitats in US lakes to determine the best technique for creating artificial habitats. Items such as tyres were placed in lakes but were not widely used due to unpleasant aesthetics in clear water lakes although the addition of different LWD (e.g., half logs, stumps, log cribs and brush piles) was often used in deeper lakes. These options are not very suitable for Te Waihora and the review found that tyres and LWD didn’t markedly increase lake-wide fish production. The most successful technique was to construct rock reefs and spawning boxes, both of which could be trialled in Te Waihora. Whilst the installation of rock reefs would be an expensive solution to help address the issue of spawning substrate availability, such structures could serve multiple purposes (e.g., shelter structures for macrophyte re-establishment, reducing lake shore erosion, habitat for aquatic species) improving its cost effectiveness. In the absence of any lake management intervention, it will be critical that the lower reaches of the tributaries flowing into Te Waihora are protected as these areas are likely to be vital to maintaining fish stocks in the lake.

5 Acknowledgements

We thank Julian Sykes who assisted with the GIS analyses contained in this report. Don Jellyman, Marty Bonnett, Julian Sykes and Greg Kelly collected the majority of Te Waihora common bully data prior to 2010 used in this report.

6 References

Bassett, C.E. (1994). Use and Evaluation of Fish Habitat Structures in Lakes of the Eastern United States by the USDA Forest Service. *Bulletin of Marine Science* 55: 1137-1148.

Closs, G.P.; Smith, M.; Barry, B.; Markwitz, A. (2003). Non-diadromous recruitment in coastal populations of common bully (*Gobiomorphus cotidianus*). *New Zealand Journal of Marine and Freshwater Research* 37: 301-313.

Coffey, B.T. (1983). Wanted: Deterrent for a bully. *Freshwater Catch NZ* 18: 18-18.

Crow, S.K.; Bonnett, M.L. (2013). Te Waihora Mahinga Kai: a compilation of data and summary of existing research on freshwater fishes in Te Waihora. *NIWA Client Report* CHC2013-097. 61 p.

Gerbeaux, P.J. (1993). Potential for re-establishment of macrophytes in a shallow coastal lagoon in New Zealand. *Journal of Aquatic Plant Management* 31:122–128.

Glova, G.J.; Sagar, P.M. (2000). Summer spatial patterns of the fish community in a large, shallow, turbid coastal lake. *New Zealand Journal of Marine and Freshwater Research* 34: 507-522.

Golder Associates (2012). A review of critical lake opening periods, habitats and locations for fish in the Te Waihora/ Lake Ellesmere catchment. *Prepared for Environment Canterbury*. 23 p.

Hughes, H. R.; McColl, R. H. S.; Rawlence, D.J. (1974). A Review of the Lake and its Catchment. *NZ Department of Scientific and Industrial Research Information Series*, 99.

Irwin, J.; Main, W. (1989). Lake Ellesmere: Bathymetry. New Zealand Oceanographic Institute, Division of Water Sciences, Wellington.

Jellyman, D.J.; Glova, G.J.; Todd, P.R. (1996). Movements of shortfinned eels, *Anguilla australis*, in Lake Ellesmere, New Zealand: results from mark-recapture studies and sonic tracking. *New Zealand Journal of Marine and Freshwater Research* 30: 371-381.

Jellyman, D.J. (2001). The influence of growth rate on the size of migrating female eels in Lake Ellesmere, New Zealand. *Journal of Fish Biology* 58: 725-736.

Jellyman, D.J.; Todd, P.R. (1998). Why are migrating male shortfinned eels (*Anguilla australis*) in Lake Ellesmere, New Zealand, getting smaller but not younger? *Bulletin Français de la Pêche et de la Pisciculture* 349: 141-152.

Jellyman, D.J.; Walsh, J.; de Winton, M.; Sutherland, D. (2009). A review of the potential to re-establish macrophyte beds in Te Waihora (Lake Ellesmere). *Prepared for Environment Canterbury*. CHC2008-142. 49 p.

Jellyman, P.G.; Crow, S.K.; Sinton, A.M.R. (2016). Examining the abundance and movement of tuna (*Anguilla australis*) in the Horomaka Kōhanga, Te Waihora (Lake Ellesmere). *Prepared for Whakaora Te Waihora Partners*. 84 p. December 2016.

Jellyman, D.J. (2012). Fish recruitment into Te Waihora/Lake Ellesmere. A consideration of the requirements of key species. *NIWA Client Report,* CHC2011-094. 75 p.

Jellyman, P.G.; Crow, S.K. (2015). Identifying the factors limiting mahinga kai recruitment. *Prepared for Whakaora Te Waihora Partners*. 84 p. July 2015. CHC2015_078. http://tewaihora.org/wp-content/uploads/2015/11/Mahinga-Kai-recruitment-report-July-2015.pdf

Kelly, D.J.; Jellyman, D.J. (2007). Changes in trophic linkages to shortfin eels (*Anguilla australis)* since collapse of submerged macrophytes in Lake Ellesmere, New Zealand. *Hydrobiologia* 579: 161-173.

McDowall, R.M. (1990). New Zealand freshwater fishes: a natural history and guide. Auckland, Heinemann-Reed. 553 p.

McDowall, R.M. (2000). The Reed Field Guide to New Zealand freshwater fishes. Reed, Auckland. 224 p.

Pierce, C. L.; Rasmussen, J. B.; Leggett, W. C. (1990). Sampling littoral fish with a seine: corrections for variable capture efficiency. *Canadian Journal of Fisheries and Aquatic Sciences* 47: 1004-1010.

Portt, C.B.; Coker, G. A.; Ming, D. L.; Randall, R. G. (2006). A review of fish sampling methods commonly used in Canadian freshwater habitats. Burlington, Ontario**:** Fisheries and Oceans Canada. 51 p.

R Development Core Team (2015). R: A language and environment for statistical computing. Vienna, R Foundation for Statistical Computing.

Rowe, D.K.; Graynoth, E. (2002). Lake Managers' Handbook: Fish in New Zealand Lakes. *Ministry for the Environment*, Wellington, 110 p.

Rowe, D.K.; Shankar, U.; James, M.R.; Waugh, B. (2002). Use of GIS to predict effects of water level on the spawning area for smelt, *Retropinna retropinna*, in Lake Taupo, New Zealand. *Fisheries Management and Ecology* 9*:* 205-216.

Ryan, P. (1984). Diel and seasonal feeding activity of the short-finned eel, *Anguilla australis schmidtii*, in Lake Ellesmere, Canterbury, New Zealand. *Environmental Biology of Fishes* 11: 229-234.

Sagar, P.; Hawes, I.; Stephens, S.; Jellyman, D.J.; Kelly, D. (2004). Lake Ellesmere (Te Waihora): a review of water clarity, and the potential of macrophyte growth, and the benthic invertebrates, fisheries and birds, and their feeding relationships. *NIWA Client Report.* 55 p. CHC2004-068.

Te Runanga o Ngāi Tahu and Department of Conservation. (2005). Te Waihora joint management plan.

Appendix A Lake area at different lake levels

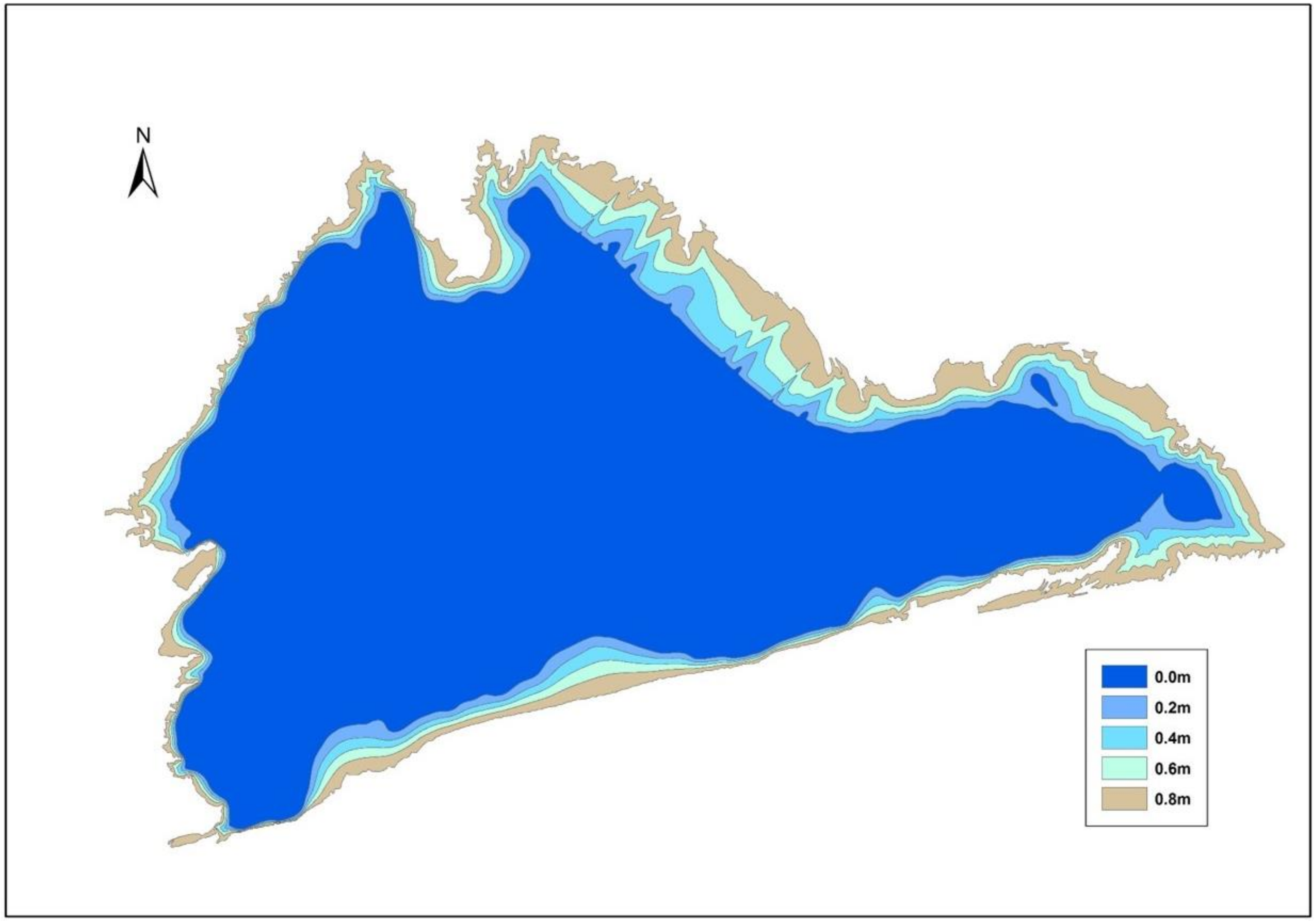

Figure A-1: Variation in total lake area at the different lake levels (0–0.8 m) used in GIS analyses. Note the lake outline shown is for a lake level of 0.8 m