The abundance and movement of tuna (*Anguilla australis*) in the Horomaka Kōhanga, 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 for Ngāi Tahu Whānui. One of the most highly valued mahinga kai resources gathered from Te Waihora is fish, particularly tuna (shortfin eels). However, numerous changes in the wider Te Waihora catchment, and to the lake itself, has meant that the health of the lake and the fisheries resources it supports have declined since the arrival of European settlers. One of the most recent mahinga kai management initiatives instigated by Ngāi Tahu Whānui for Te Waihora has been the creation of kōhanga areas where no commercial fishing can take place. By far the largest kōhanga is the Horomaka kōhanga (i.e., at the Banks Peninsula end of the lake) and although commercial fishing is not allowed inside the kōhanga, fish are capable of moving in and out so Ngāi Tahu are interested to know the status of the current tuna resource and what level of protection from commercial fishing the kōhanga might provide for tuna. Thus, estimating tuna population size and examining tuna movement into and out of the kōhanga were the primary objectives of the work. There were also two supplementary objectives that examined spatial variation in abundance from around the kōhanga and how the eel population changed with water depth throughout the kōhanga.

A mark-recapture study was used to examine shortfin eel movement and abundance in the eastern part of Te Waihora from October 2015 to April 2016, primarily focussed within the Horomaka kōhanga area. The study was conducted during a period of very stable lake levels (average lake level 0.75m), with no lake opening events. Fyke nets were used to catch eels and we tagged 4,071 eels sized ≥400mm from late October to mid-December. Eel catches, measured as catch-per-unit-effort (CPUE), increased significantly over the seven-week tagging period as the water temperature became warmer; CPUE in December was more than double what it had been in late-October at the start of tagging work. Compared to a survey conducted by NIWA in 1995 before the Horomaka kōhanga was established, eel numbers and biomass have more than doubled which is consistent with the rest of the lake. Within the Horomaka kōhanga large shortfin eels (>600mm) are most abundant in shallower waters (<1m depth) while smaller eels tended to dominate catches in the deeper water. A combination of declining CPUE abundance and eel length with increasing lake depth resulted in CPUE weight (kg/net/night) declining ten-fold over the range of depths sampled (0.4 to 2.2m).

Shortfin eel population size was estimated in mid-December 2015 based on a randomised recapture methodology using fyke nets set throughout the kōhanga. We estimated the population size (±S.E.) of shortfin eels ≥400mm in the Horomaka kōhanga to be 75,161 (± 9,501). Since shortfin eel tag retention was 99.5%, no adjustment for tag loss was made in our estimate of population size. Based on the population size estimate and our length-frequency data, it is estimated that the weight of shortfin eels >400mm in the Horomaka kōhanga is 29.09 tonnes (± 3.67 tonnes).

Tuna movement was examined using data from the recapture of 207 tagged eels by NIWA and a further 211 tagged eels caught by commercial fishers (analysis of commercial recaptures was limited because recapture location could only be assigned to a general area). Nearly 40% of eels recaptured by NIWA were caught within 11–20 days of tagging although there were eels caught in April 2016 that had been at large for 140 days. NIWA recapture data showed 63% of tagged eels were recorded within 2000m of their release location although extensive movements were possible as one tagged eel captured by a commercial fisher showed the eel had moved over 20km to the outlet of the lake within 16 days (i.e., 1269m per day).

Eel movement out of the kōhanga was examined in March/April 2016 with 60 fyke nets set up to 5km either side of the Horomaka kōhanga boundary. There were 52 tagged eels recaptured during the survey and 83% (43 tagged eels) of the recaptures were within the Horomaka kōhanga. Whilst sampling effort was standardised inside and outside the kōhanga, 1651 shortfin eels were caught inside the kōhanga compared to 1196 eels outside; regardless of whether inside or outside the kōhanga two-thirds of the eels caught were 400mm or larger.

The establishment of the Horomaka kōhanga has had a positive influence on the abundance of shortfin eels available for customary and recreational fisheries (i.e., nearly 30 tonnes of shortfin eels ≥400mm). The largest tuna were most common in the shallower parts of the kōhanga, which is also where the highest catch rates (i.e., CPUE) were found. These shallow near-shore areas with high catch rates may be valuable to customary and recreational fishers who do not have access to a boat. Whilst 17% of the eels were estimated to be moving out of the Horomaka kōhanga during the four months of the tagging study, the customary eel resource located within the kōhanga will only decline if a similar percentage of eels do not move back into the area, which was not assessed as part of this work. However, under different lake conditions (e.g., lower lake levels and warmer water temperatures), there could be a substantial reduction in near-shore habitat area within the Horomaka kōhanga. The reduced habitat could force eels to move or forage over a wider area, increasing their susceptibility to capture by commercial fishers. Future work undertaken during a time of lower lake levels would be needed to assess this and determine if the results from our single season movement survey are reflective of other years.

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 for Ngāi Tahu Whānui (Te Runanga o Ngāi Tahu and Department of Conservation 2005). The original name for the lake – Te Kete Ika a Rākaihautū – translates to 'The Fish Basket of Rākaihautū' exemplifying the bountiful resources that the lake provided. The lake is the largest in Canterbury (by area) and is considered nationally significant for both customary and commercial fisheries, contributing about a quarter of New Zealand's commercial tuna (shortfin eel) catch.

Ika (fish) are one of the most valued mahinga kai resources in Te Waihora, particularly tuna and pātiki (flounder). Unfortunately, numerous landuse changes in the Te Waihora catchment since the arrival of European settlers have caused a decline in the health of the lake and the fisheries resources it supports (Jellyman et al. 2015). The fisheries component of the Whakaora Te Waihora (WTW) programme has been examining the current status of the fisheries resource, for example, recruitment (Jellyman & Crow 2015), productivity (Crow & Jellyman in press) and the availability of prey species (Jellyman et al. press). There are many factors that have contributed, or are contributing, to the current state of the mahinga kai fisheries resource but there are also a number of management initiatives that have been introduced as an attempt to halt further declines and potentially improve the lake fisheries.

One of the most significant mahinga kai management initiatives has been the creation of the customary and recreational fishing areas (kōhanga) in 2005 as part of Joint Management Plan (JMP) between the Crown and Iwi for Te Waihora (TWJMP 2005). Whilst some areas of Te Waihora have been closed to commercial fishing since 1986 under the Fisheries Regulations (South East Area Commercial Fishing)[1], the establishment of the Horomaka kōhanga at the eastern end of the lake reserved more than 25km² of the lake for customary and recreational use only (Figure 1-1). Whilst commercial fishing is not allowed inside the kōhanga, fish are able to freely move in and out and could be captured by commercial fisherman outside the Horomaka kōhanga. Ngāi Tahu would like to better understand what level of protection from commercial fishing the kōhanga actually provides for fish. To manage the current resource effectively, Ngāi Tahu need to know the approximate size of the fisheries resource regularly using the Horomaka kōhanga.

[1] Including any river or stream that flows into Te Waihora; areas of Te Waihora within a 1.2 kilometre radius of the mouths of the Irwell River/Waiwhio, Selwyn River/Waikirikiri, Halswell River/Huritini, Harts Creek/Waitatari, LII River/Ararira and within the waters of Te Korua, near Taumutu.

Figure 1-1: The location of the Horomaka kōhanga (established in 2005) an area of Te Waihora that is reserved for customary and recreational use. The rectangle in the upper panel indicates the area which is shown in more detail in the lower panel. Some of the areas not included in the kōhanga are dry at certain times of the year, as shown below in Figure 1-2.

Figure 1-2: Satellite image of the eastern end of Te Waihora (10 April 2013). It is apparent that much of the area not included in the green shading of the kōhanga (Figure 1-1) is actually very shallow so can be dry during certain times of the year.

1.1 Study objectives

In the Whakaora Te Waihora (WTW) programme, Investigation brief D5 is responsible for 'Fish restocking/recruitment including a review of fisheries management'. This brief has four primary research-based objectives, and this report addresses the fourth research objective which was:

- 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/kōhanga. 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.

To deliver on this research objective we developed four complementary project objectives. The first two objectives were critical to addressing the primary research outcome, whereas the third and fourth objectives were supplementary. The four project objectives were:

1. Estimate tuna population size within the Horomaka kōhanga area;

2. Examine tuna movements within (and outside of) the Horomaka kōhanga area;
3. Identify differences in relative eel abundance within the Horomaka kōhanga area;
4. Quantify changes to eel populations at different lake depths within the Horomaka kōhanga area.

The initial proposal to WTW had identified radio-telemetry as the method to be used for investigating these project objectives. However, a combination of low lake levels and sediment accumulation in the Halswell River canal meant that it was not possible to launch boats into the Horomaka kōhanga area to undertake radio-tracking of eels during the first two years of the WTW programme. After the ongoing delays to the project due to low lake levels, we revised the tagging approach in consultation with the WTW Partners and explored two alternative approaches. Firstly, we investigated the use of acoustic tags in combination with an acoustic receiver array throughout the kōhanga area [i.e., a tagged eel(s) swims around and the tag is emitting a beep which is picked up by receivers positioned around the area]. However, the advice from the acoustic equipment manufacturers (VEMCO) was that the tag detection range/distance would probably be relatively poor in a shallow, soft-bottom, highly turbid lake (i.e., all of these factors impede the movement of sound waves through water and decrease the distance that tagged eels could be detected over) and they did not recommend using this type of equipment in Te Waihora. Secondly, we explored the use of simple external tags. This had the disadvantage of returning less information on fine-scale daily and weekly movements of eels within the kōhanga, but had a number of advantages for collecting information on the number of eels exiting the kōhanga (because tags would be visible to commercial, customary and recreational eel fishers) and would give a much better estimate of population size.

2 Methods

To address the project objectives outlined above, a mark-recapture study on shortfin eels was conducted in the eastern part of Te Waihora from October 2015 to April 2016, primarily focussed within the Horomaka kōhanga area (Figure 1-1).

2.1 Environmental information

Environmental data were provided by Environment Canterbury (ECan) and collected by NIWA staff. Water temperature data were collected during each sampling trip by NIWA staff and obtained from the mid-lake (maintained by ECan) water quality data recorder. This data recorder measures temperature (± 0.1 °C) every 15 minutes at various depths ranging from 0.2m to 2.7m elevation (0.2 m is near the lake bed whereas 2.7m is surface water temperature). The present study used data recorded from the 1.7m elevation. Water temperature data were averaged across each 24 hour period (0000–2400 hours) and reported as mean daily water temperature.

Lake level data from the Taumutu water level recorder were used to examine variation in water levels (m) during the study. Lake level data were recorded every 15 minutes to the nearest millimetre. There is another water level recorder closer to the study area, but as the purpose of these data were only to show general trends in lake variation, rather than relate survey data to incremental changes in water level, they were not examined. Lake level data were averaged across each 24 hour period (0000–2400 hours) and reported as mean daily lake level.

Wind speed and direction data were also obtained from Taumutu (the only location around the lake where it is recorded). Wind data were recorded every 15 minutes with wind speed measured to the nearest 0.1 m/s (later converted to km/h) and wind direction to the nearest azimuth degree. Wind speed (speed and azimuth both included) data were averaged across each 24 hour period (0000–2400 hours) and reported as mean daily wind speed but maximum wind speed for each day was also calculated. Wind direction data were matched with maximum wind speed direction data.

2.2 Initial tagging of shortfin eels

A fleet of up to 20 fyke nets were used to capture shortfin eels for tagging from throughout parts of the Horomaka kōhanga from October – November 2015. Nets were set at sites that could be accessed primarily by a powered boat, but we did include several shallow water sites to ensure the fringes of the kōhanga were sampled. For logistical reasons, the shallow water sites were limited to an area within 100m of the shallowest point the boat could access (see Figure 2-2 for the fyke net locations). Unbaited coarse-mesh fyke nets (12mm stretched mesh, with a 6m single leader and no escapement tubes) were used with nets typically set perpendicular to the shore (with the opening of the net facing the shore) with both ends of the net staked (or secured with a Danforth anchor on either end in deeper water) into the lake bed so they did not move in the wind. At each site, water temperature (accuracy: ±0.1 °C) and depth (accuracy: ±0.1m) were recorded; note depth measures were combined with existing lake bathymetry data to produce Figure 2-1 so that the location of where nets were set could be visualised relative to the changes in lake depth.

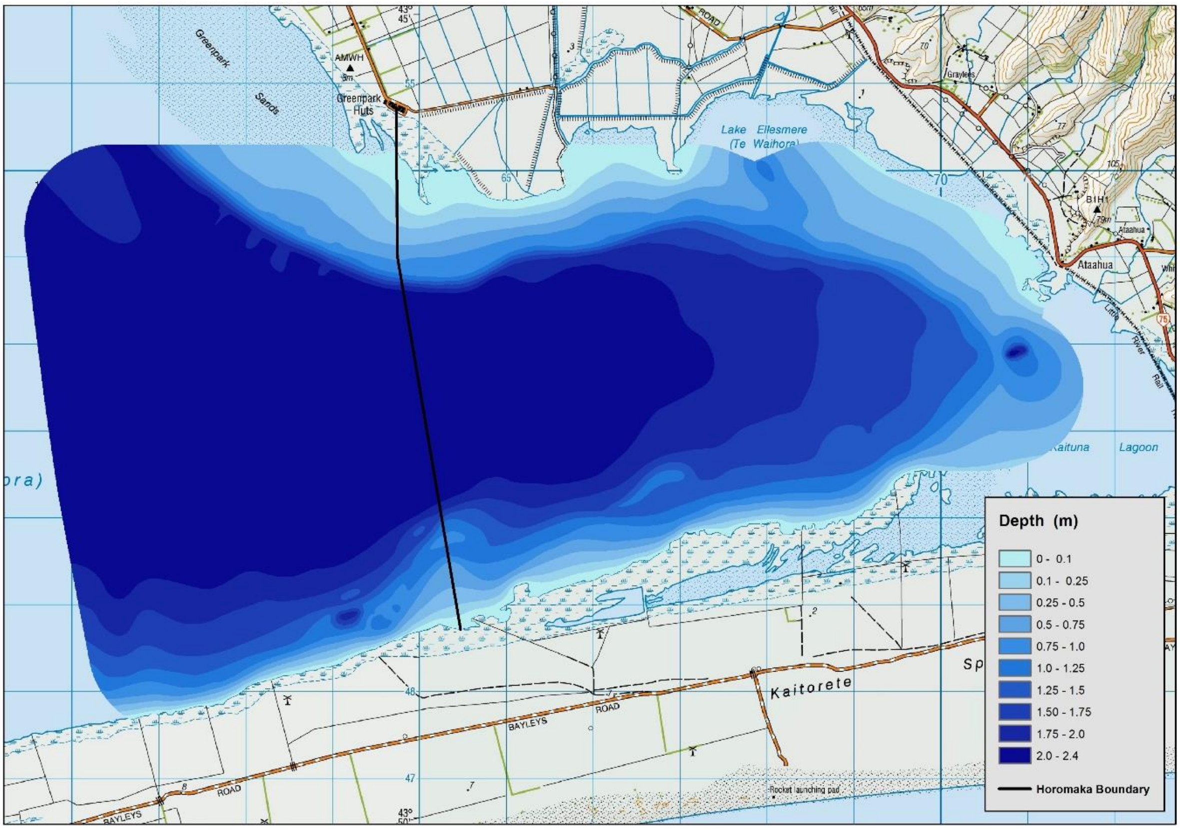

Figure 2-1: Variation in lake depth throughout the study area. The black line across the lake indicates the Horomaka kōhanga boundary.

After the first two tagging trips, where the nets had been left to fish overnight, only an average of 10 fish per net were being caught and it was only possible to access c. 13–15 nets a day[2] by boat. Based on that level of catch-per-unit-effort (CPUE) it was not logistically or financially feasible to retrieve and tag 1500 eels each day because the catch rates were too low (our pre-determined minimum number of fish for a statistically robust study). However, it was apparent that we were limited by the number of sites we could access in a day far more than the number of eels we could tag in a day (i.e., we could tag far more eels in a day if more were being caught). Therefore, we decided to leave nets set for three nights; the concern with leaving nets set for longer time periods was that the eels may get injured and/or die. However, this approach was successful with the number of eels being caught per trip increasing from less than 100 to 309–805 (see Figure 2-3), and importantly, no eel deaths in nets were recorded during any trip[3].

[2] From late October to December, the wind would regularly strengthen throughout the day so by early afternoon (c. 2 pm) boating often became unsafe (and of course the issues of staff and animal welfare when inserting sharp tagging needles into eels).

[3] Whilst no eel or flounder deaths were recorded during the study, yelloweye mullet had a relatively high mortality rate in nets. However, mullet mortality rates seemed to be unrelated to the number of nights nets were set.

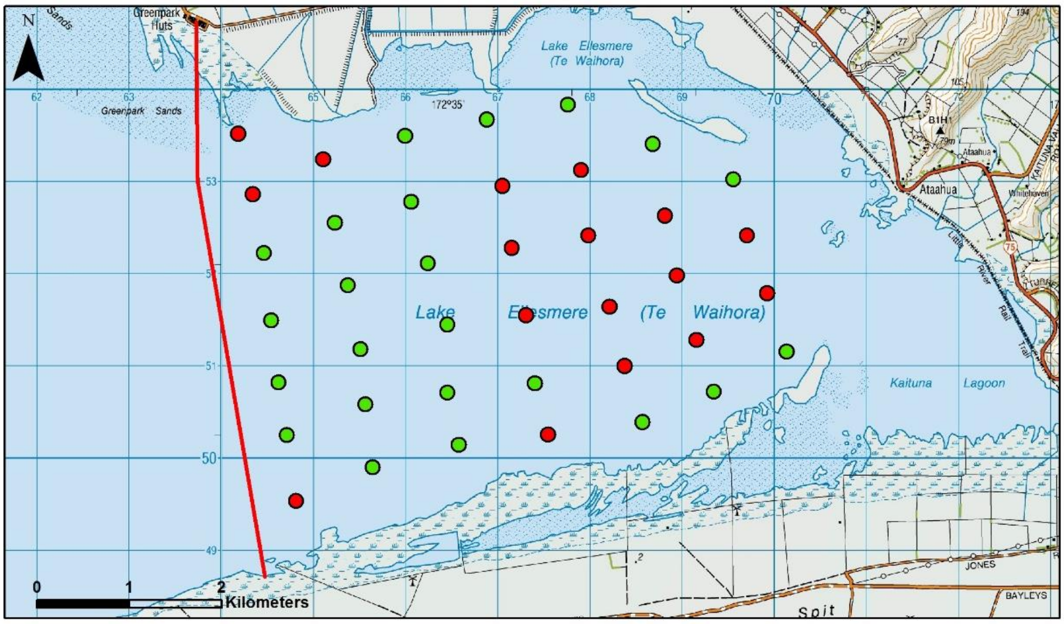

Figure 2-2: The locations (green circles) where fyke nets were set in the Horomaka kōhanga for the initial shortfin tagging work. Green circles indicate locations where nets were set. The red circles were locations where nets were planned to be set but for which nearby catch data suggested would likely have lower catch rates. The red line indicates the boundary of the kōhanga. Note, tagged eels were released throughout the 'boating' grid so that tagged eel release locations were not strongly biased towards eel capture locations.

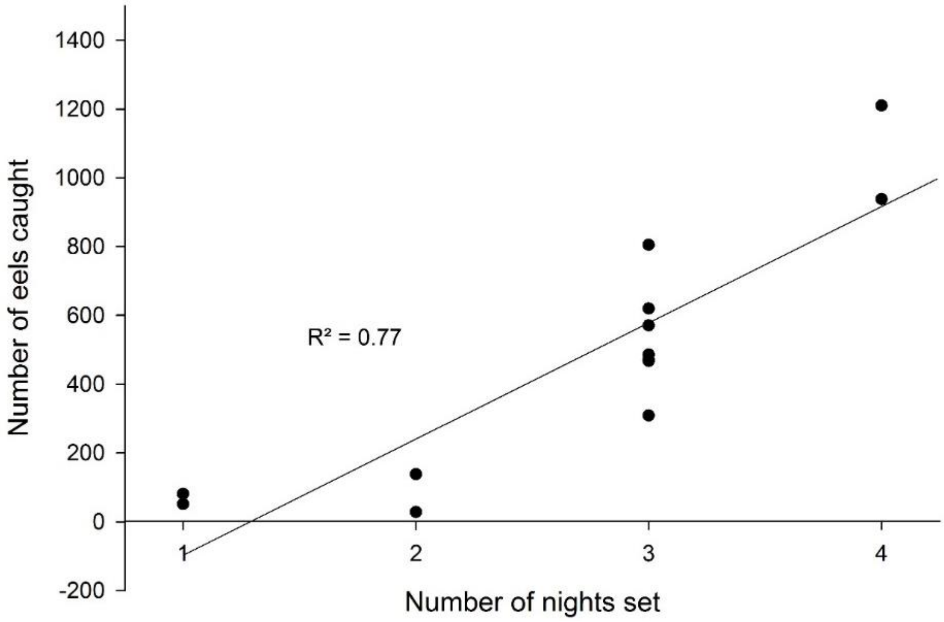

Figure 2-3: The relationship between the number of eels caught and the number of nights each fyke net stayed set before processing. Nets were only left for four nights when weather conditions resulted in unsafe boating conditions and therefore net collection had to be delayed.

For each fyke net, all eels were counted and the total weight of the eel catch was recorded (accuracy: ±10 g) once all bycatch species were counted and removed. All eels were then anaesthetised using a natural clove-oil-based fish anaesthetic (AQUI-S©)[4] and measured for total length (mm). Leaving nets for multiple nights meant there was a large number of eels captured, but only shortfin eels ≥400mm were tagged[5]. This lower size limit for tagging shortfin eels was based on the research of Jellyman & Graynoth (2005) who found that the probability of reliably capturing eels decreased markedly when they were smaller than 400mm (for fyke nets with 12mm stretched mesh).

For the majority of shortfin eels >400mm, two external Floy tags (also called T-bar or streamer tags) were inserted into the dorso-lateral muscle mass either side of the dorsal fin (see Figure 2-4), as per Jellyman et al. (1996). The practice of double tagging eels was done to quantify the rate of tag loss, which is an important variable to account for when estimating population size and had not been previously examined by Jellyman et al. (1996). Once eels had recovered from being anaesthetised, they were released back into the lake at a distance of at least 500m from the capture site to reduce the likelihood of them being caught in the same net during subsequent trips. The release location of all eels was recorded using GPS.

All the external tags contained the name 'NIWA', a contact phone number and a unique tag number (e.g., No. 6944) (Figure 2-5). As tagged eels could potentially be captured by a range of people fishing in the lake, we placed signs at the primary access points to the Horomaka kōhanga and asked anyone who caught a tagged eel to contact NIWA (see Appendix A); all commercial fishers and eel processing plants were informed of the study and asked to return any information on tagged fish that were found in their nets or processing plants.

[4] AQUI-S © was the anaesthetic used for all catch processing because it is the only fish anaesthetic registered under the Agricultural Compounds and Veterinary Medicine (ACVM) Act 1997. It also contains biodegradable ingredients. This anaesthetic was chosen to ensure that any tuna captured by Ngāi Tahu or recreational fishers (or commercial fishers for eels caught outside of the kōhanga) would be safe for consumption and that fish returned to the water would be unsafe for future consumption should they be captured during any customary harvests

[5] Ngāi Tahu had expressed concern about including longfin eels in the WTW work so any longfin eels that were captured in nets were immediately released untagged.

Figure 2-4: The location where Floy tags were inserted into shortfin eels. Top picture is a close-up of the tagging locations shown in the bottom picture

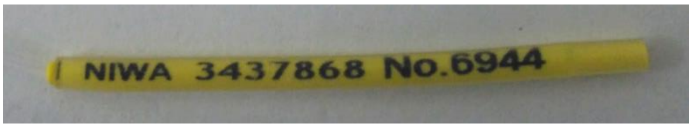

Figure 2-5: The information shown on a typical Floy tag that was used in the project.

2.3 Recapture of shortfin eels to estimate population size

To estimate population size within the Horomaka kōhanga, a fyke-netting survey was used to recapture tagged eels from 10 – 15 December 2015. A spatially stratified sampling regime was used to ensure unbiased sampling effort throughout the kōhanga area during the recapture survey. The kōhanga area was divided into 1km² grid cells; for simplicity we used the 1km² grid cells from the topographic map of Lake Ellesmere/Te Waihora (Figure 2-6). For the grid cell to be used for sampling, c. 50% or more of the cell had to be covered in water (as opposed to shoreline/land) on the topographic map and it needed to be accessible by boat (i.e., the majority of the grid cell had a depth >0.5m). There were 28 grid cells that met these two criteria. Within each cell, the location of where the fyke net would be placed was randomised; having randomised net locations for recapturing eels was critical to producing an unbiased population estimate. Nets were set for four nights, 15 nets were set on December 10 and retrieved on the 14 and 12 nets were set on December 11 and retrieved on the 15. Strong winds/large waves meant it was not possible to safely set the final net on the second day so 27 of the 28 initial grid cells had nets set (i.e., one site was never sampled, see red circle in Figure 2-6).

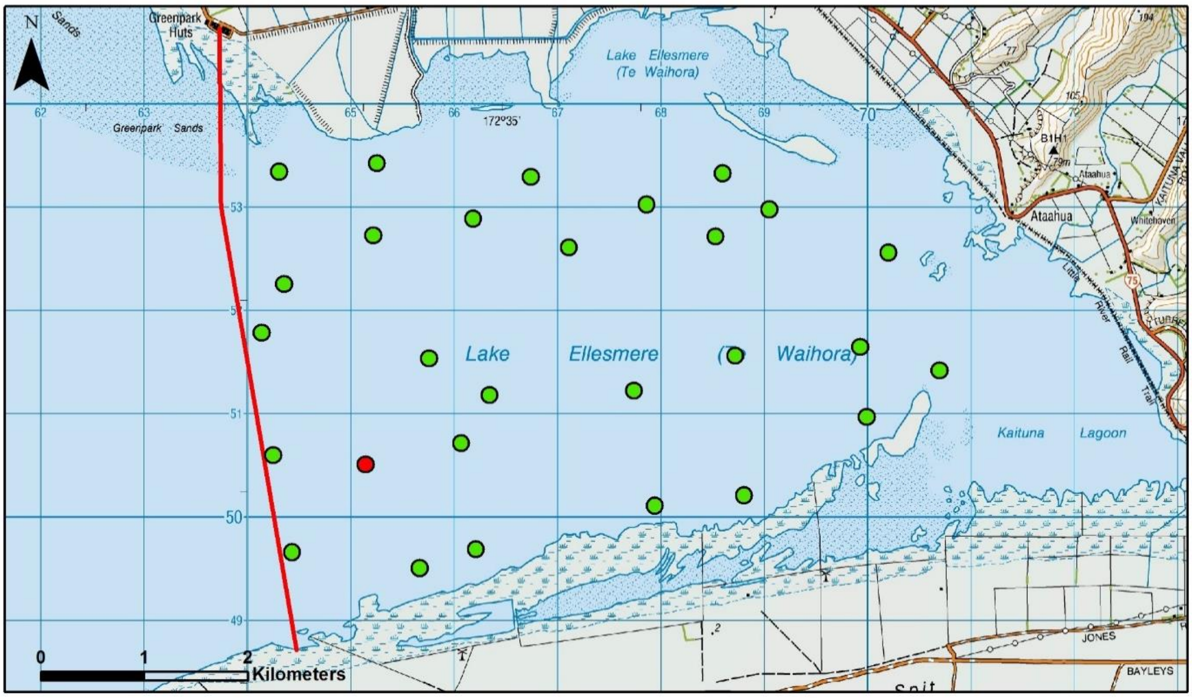

Figure 2-6: The locations of fyke nets used to recapture tagged eels for the population estimate objective. Green circles indicate locations where nets were set and the red circle the location where the net could not be safely set. The red line indicates the boundary of the kōhanga.

Nets were processed following the same procedure as the initial tagging, with bycatch species counted and all eels weighed (in bulk) and then individually counted. The tag numbers of any recaptured eels were also recorded and they were measured for total length. We continued to tag untagged eels during this survey to increase the number of tagged eels for examining eel movement within (and outside of) the Horomaka kōhanga area (See Section 2.4). All eels >400mm caught on December 14 were double tagged. On December 15, eels were initially double tagged, but when the number of tags started to run low, eels were single tagged until all tags were used.

2.4 Tuna movements within (and outside of) the Horomaka kōhanga area

To examine the movement of eels within and outside the Horomaka kōhanga we sampled six transects between 14 March and 1 April 2016. Transects were setup with the kōhanga boundary as the mid-point of each transect line (Figure 2-7). For each transect, there were five nets inside and five nets outside the kōhanga with equidistant spacing between each net. As we had 20 fyke nets available, only two transect lines could be fished simultaneously. The particular sequence of transect sampling was based on logistical feasibility rather than trying to use a partially paired design to control for any spatial differences in lake conditions during the survey.

Nets were processed differently for this work compared to the initial mark-recapture study because no additional tagging was needed and the length of the eels being captured was not required. For each net, the bycatch species were identified and counted and then the weight and abundance of shortfin eels in each net was recorded. All tagged fish had their tags read and their length measured. The remaining eels in the catch were counted and classified as either <400mm or greater than

400mm; with the exception of tagged eels, the only eels that were individually measured were those close to 400mm to ensure correct size-class classification. For recapture work, it was critical to count the number of untagged eels that were (and were not) of 'tagging size' (>400mm).

Information on tuna movements from NIWA recapture work was supplemented with recapture data from commercial fishers. Tags that were collected by eel processing plants were returned to NIWA. Because commercial eel fishers clear all their nets without checking for tagged eels the precise location of where tagged eels were captured is not known (although the general area that the fishing was conducted is known based on discussions with the eel fishers themselves). Commercial eel fishers also have minimum size limits imposed (c. 470mm minimum size) so do not capture the full size range of eels we tagged. Thus, commercially caught tagged eels were analysed separately to the recaptured eels caught by NIWA.

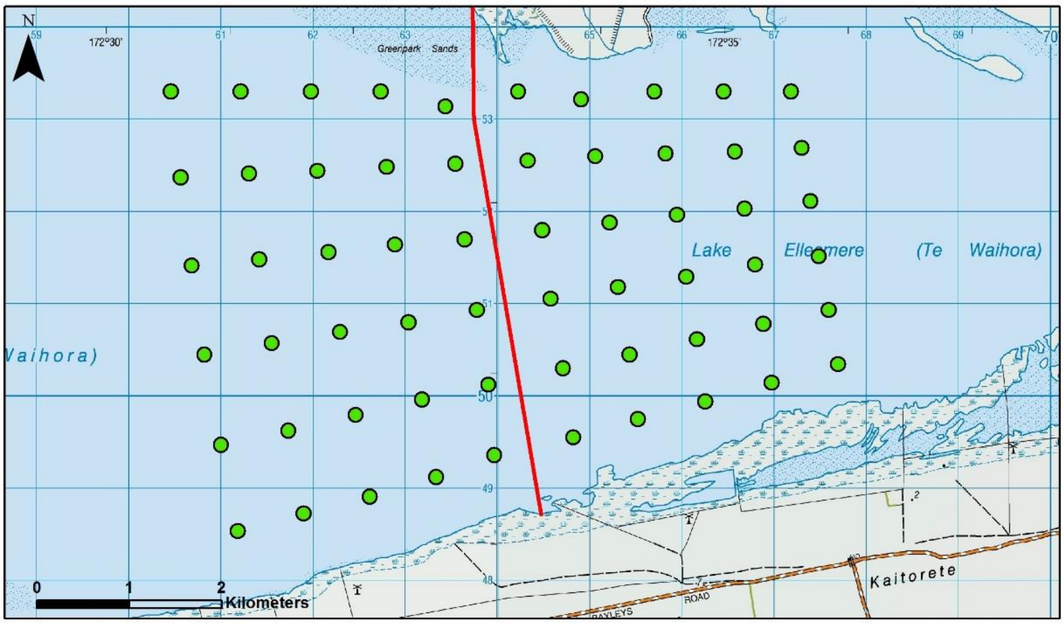

Figure 2-7: The locations where fyke nets (green circles) used to examine shortfin eel movement. The red line indicates the boundary of the kōhanga.

2.5 Data analysis

To estimate the size of the eel population in the Horomaka kōhanga area, a mark-recapture calculation method was used. This method simply assumes that the proportion of marked (i.e., tagged) fish appearing in a random sample provides an estimate of the proportion of marked individuals in the total population. This approach also assumes that there is an equal probability of capturing both tagged and untagged fish. To estimate eel population size in the Horomaka kōhanga the following values needed to be known:

m = total number of tagged eels in the population;

c = number of eels in the sample (i.e., how many tagged and untagged eels >400mm were caught when conducting the survey to estimate population size);

r = number of tagged eels recaptured in the sample;

$\hat{N}$ = estimate of the total number of fish in the population.

The estimation formula is:

$$\hat{N} = \frac{mc}{r}$$

The standard error of the population estimate, designated by S.E.($\hat{N}$), is estimated by the formula:

$$S.E.(\hat{N}) = \hat{N}\sqrt{\frac{(\hat{N} - m)(\hat{N} - c)}{mc\,(\hat{N} - 1)}}$$

To extrapolate the population estimate that was obtained to a total weight of eels in the Horomaka kōhanga, a length-weight regression was applied to the length-frequency distribution for shortfin eels caught in the kōhanga. The length-weight equation used was:

$$W = aL^b$$

where:

W = is whole body weight in grams;

L = length in mm;

a = is the intercept value;

b = the slope value.

Data generated from a previous WTW report (Crow & Jellyman in press) were used to produce the following length-weight regression for shortfin eels in Te Waihora (range = 264-860mm, n = 100, R^2 = 0.95):

$$W = 6.668 \times 10^{-7}\, L^{3.176}$$

This relationship gave nearly identical length-weight predictions to the national relationship published for shortfin eels (Jellyman et al. 2013).

Spatial mapping of depth and CPUE was conducted in ARC GIS. The CPUE results from survey work were used to produce interpolated maps for the survey area. Spatial restrictions were imposed on the GIS interpolation so that CPUE predictions could only be modelled up to 1km from an actual netting location where CPUE data had been collected.

2.5.1 Tuna movement analysis

Two data sets were available for movement analysis. These were the randomised recapture data used for the population estimate (Section 2.3) and recapture data from the six netting transects used to assess movement into and out of the Horomaka kōhanga (Section 2.4). Both of these datasets were pooled and then used to calculate three movement metrics: linear distance moved, distance moved per day, and days at large.

The spatial arrangement of nets and the size of the kōhanga resulted in more nets being set in close proximity to release points than far away from release points. This means that we would expect to catch more fish in close proximity to the release points simply because there was more fishing effort. For example, if an eel was tagged at the edge of the Horomaka kōhanga, it could potentially move a maximum distance of 9000m across the longest axis of the kōhanga. But, if an eel was released in the centre of the kōhanga it could only move a maximum of c. 5000m in either direction. Thus, if eel movement was random, eels would have a higher likelihood of encountering nets at a small or medium distance away (e.g., less than 5000m) compared to encountering nets further away (e.g., greater than 7000m) because only a few eels would have been tagged in a location that permitted them to move to a net(s) located at larger distances away from their release location. To account for this spatial variation in capture probability, a spatial matrix was used to display how fishing effort (number of nets) varied across distance categories. This index of fishing effort was then graphically displayed on all graphs of the three movement metrics. This index of fishing effort could then be used to compare actual catch against fishing effort for each distance category.

2.5.2 Comparisons with previous datasets

We compared catch and movement data in the present study with three published datasets collected from Te Waihora: Jellyman & Chisnall (1996), Jellyman et al. (1996), and Glova & Sagar (2000).

Jellyman & Chisnall (1996) examined the habitat preferences of shortfin eels in Te Waihora using beam trawl data. The beam trawl is a piece of sampling equipment towed behind a boat and is attached to 2m wide net that is tapered throughout the 4m length to a cod-end; a "tickler" chain on the front of the trawl disturbs fish on, or in, the substrate. The beam trawl method is most suitable for providing an estimate of the full size range of eels present when employing only a single fishing method. For beam trawl catch processing, Jellyman & Chisnall (1996) separated eels into two size groups (<300mm or >300mm) and their CPUE measure was the number of eels per five minute tow. Their study examined eel data against lake depth and distance offshore and the present study has replicated their data figures using our 2015-16 data. The study of Jellyman & Chisnall (1996) was conducted at 14 sites around the lake, but measured an additional 17 sites along a north-south transect from the Selwyn River mouth to Kaitorete Spit. Therefore, the figure presented in the results (Figure 3-9) is from 31 sites in Te Waihora of which only two sites were inside the Horomaka kōhanga area.

Jellyman et al. (1996) initiated a tagging study in the late 1970’s to examine eel movement in Te Waihora. That study tagged and released eels in two locations between December 1977 and February 1978; LII Bay (4968 eels tagged) and the lake centre (4987 eels tagged) (Figure 2-8). Eel recapture data was provided by 23 commercial fishers, from 1978 to 1982, who were eel fishing in Te Waihora at the time. However, the precise recapture area of tagged eels was usually difficult to determine from the notes of eel fishers and because tagged eels were often not seen until later transfer at a fisher’s depot.

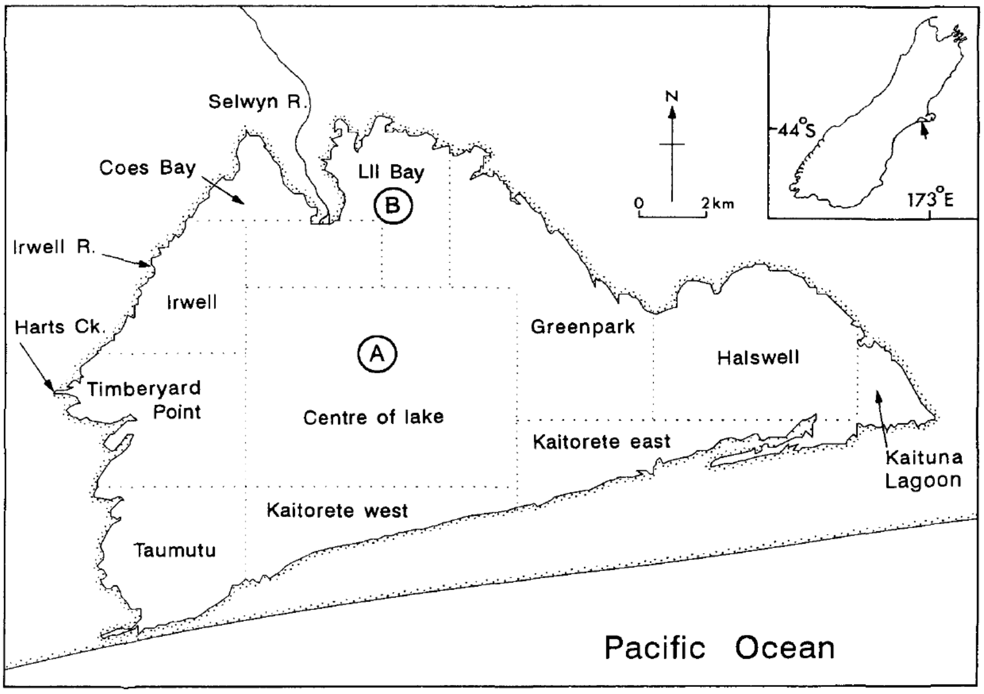

Figure 2-8: Map of Te Waihora showing the two tagging locations used by Jellyman et al. (1996).

Glova & Sagar (2000) investigated spatial patterns in shortfin eel abundance around Te Waihora between 23 January and 3 March 1995. They set three fine-meshed fyke nets at various locations around the lake to examine differences in eel numbers and biomass (see Figure 2-9). The study had 11 sampling sites that were in a similar location to those from the present study so were able to be used for a comparison of variation in CPUE between 1995 and 2015-16.

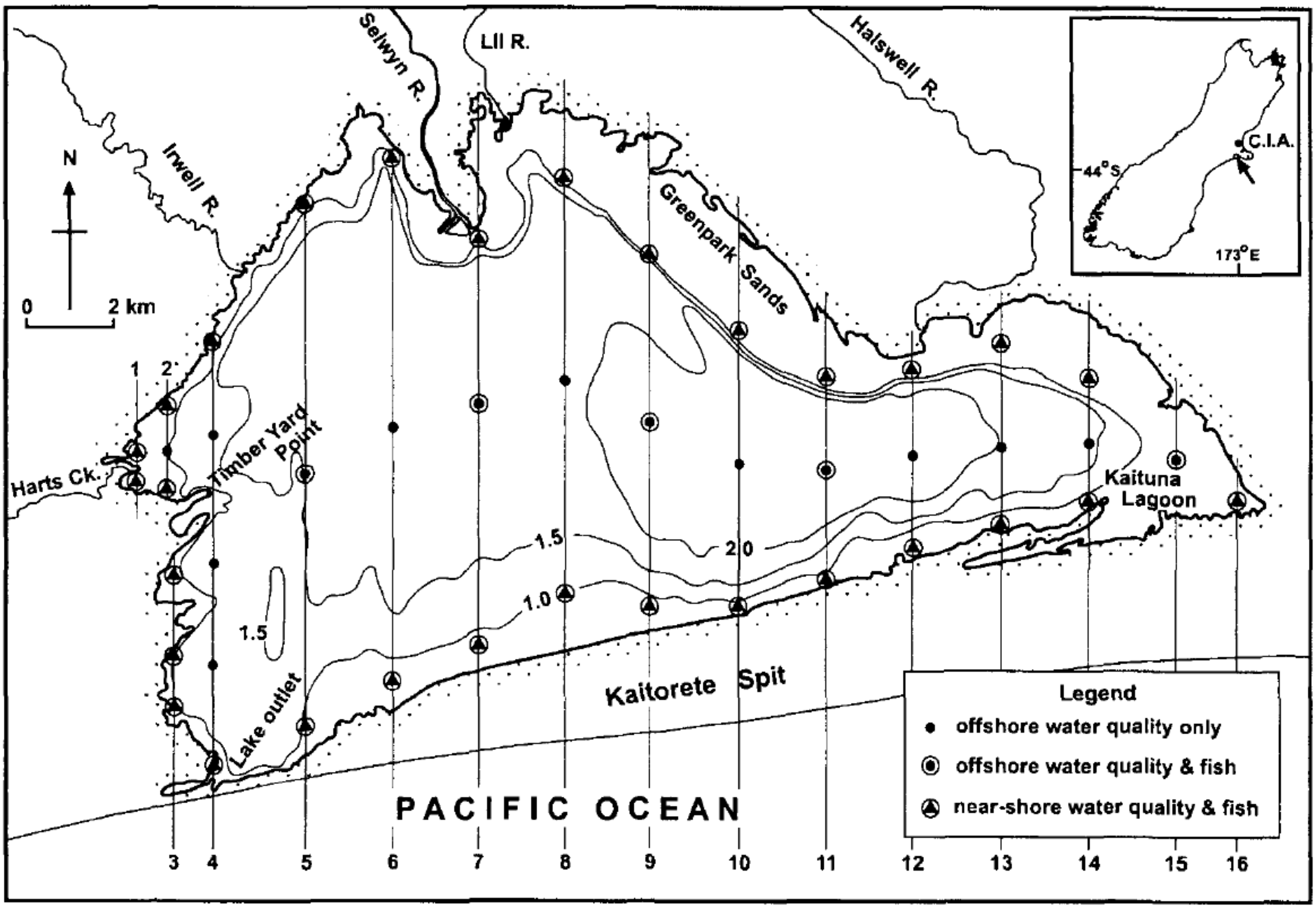

Figure 2-9: The fyke netting locations around Te Waihora sampled by Glova & Sagar (2000).

3 Results

3.1 Summary of environmental information in Te Waihora during the study

Examination of lake-level data over a 12-month period showed that the study was conducted during a period of very stable lake levels (Figure 3-1). The average (±SE) daily lake level during the study was 0.746 (±0.004)m, with notable peaks and troughs in lake level associated with strong wind conditions (i.e., wind fetch effects) (Figure 3-2). The lake was never open to the sea during the study period.

Water temperature in the lake increased steadily from winter into early summer and water temperature was increasing during the tagging phase of the study (Figure 3-1). The average water temperature during the December 2015 population estimation work (15.2°C) was similar to the temperature during the March 2016 movement work (15.8°C).

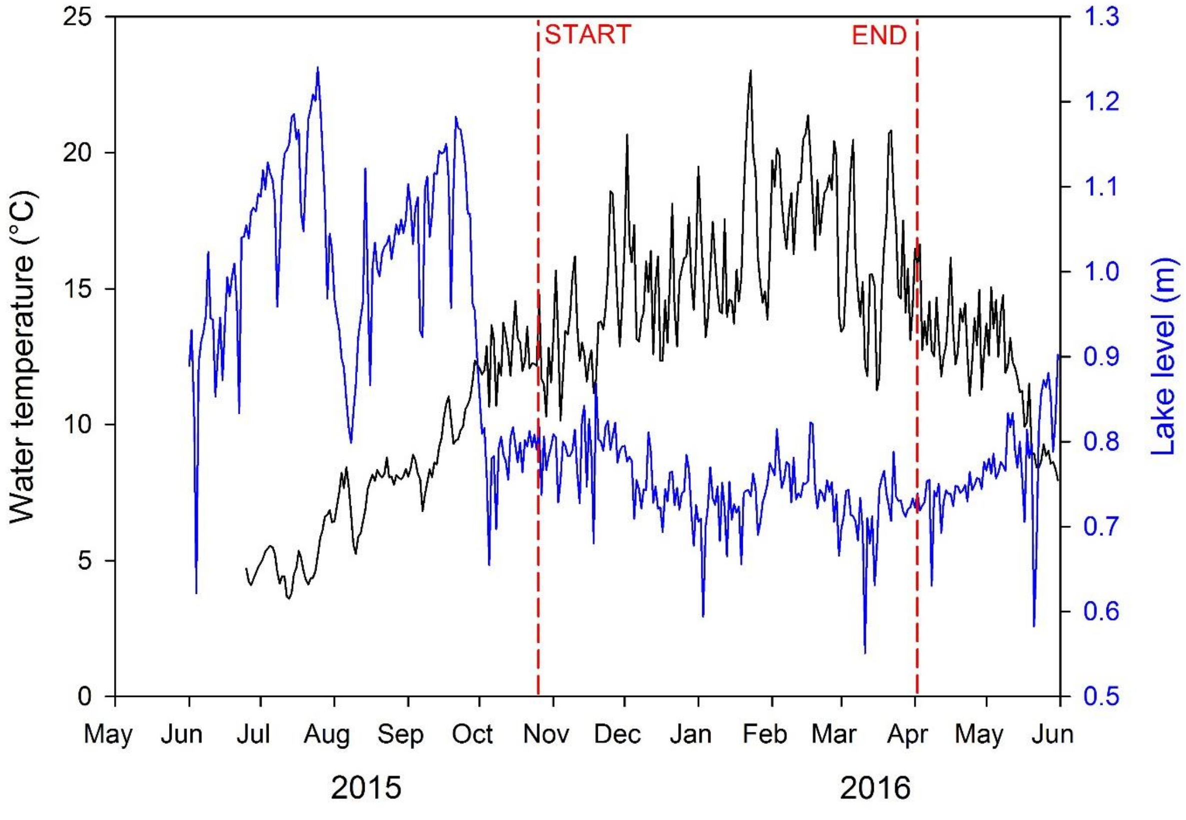

Figure 3-1: Variation in water temperature (°C) and lake level (m) in Te Waihora from mid-2015 to mid-2016. Water temperature data were taken from mid-water column (ECan mid-lake recorder, elevation 1.7m) and lake-level data are from ECan's water level recorder at Taumutu. Major changes in water level may relate to either strong wind effects or successful lake opening events (lake openings take far longer for water level to increase after the sudden change). The red dashed line identifies the study period. Data source: ECan.

Wind data showed that Te Waihora was a windy location, given that the average daily wind speed is seldom less than 10km/h (Figure 3-2). Strong winds exceeding 75km/h were regularly recorded at the lake throughout the year, although temporal variability in wind speed was reduced during the study period (Figure 3-2). Compared to the winter and spring months prior to the tagging work beginning, there were fewer instances of maximum wind speed exceeding 75km/h during the study. However, the fastest wind speed recorded over the 12-month period examined – 113km/h – was recorded during the tagging study period (Figure 3-2). Strong wind events (i.e., >75km/h) were associated with wind events from particular directions. Of the eight strong wind events recorded during the study period, four were from southerly or southwest storms and the other four were from 'norwesters'.

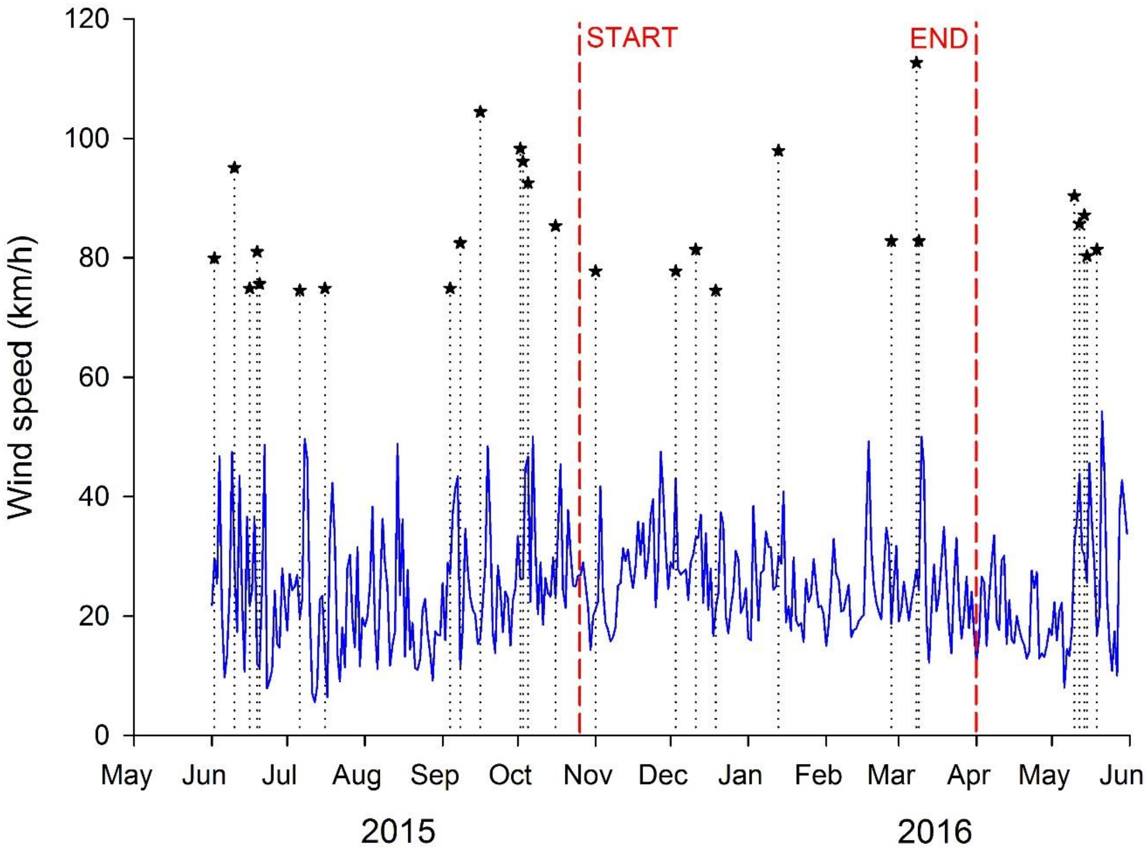

Figure 3-2: Variation in mean daily wind speed (km/h) at Te Waihora from mid-2015 to mid-2016. Star symbols denote any day where the maximum wind speed exceeded 75km/h. The red dashed line identifies the study period. Data source: ECan.

3.2 Variation in relative tuna abundance

Eel tagging was conducted from October to December 2015 and mean daily water temperature increased by 3.4 °C during this period. Eel CPUE increased significantly over this period as the water temperature became warmer; CPUE in December was more than double what it had been in late-October at the start of tagging work (Figure 3-3). Variation in CPUE was also examined in relation to other environmental parameters but none had significant effects on catch rates. There were three strong wind events (i.e., winds exceeding 75km/h) during the study and two of these occurred when we had nets set. CPUE did not appear to change markedly in response to strong winds in this study, but too few replicates were available to draw any conclusions about wind effects on catch rates.

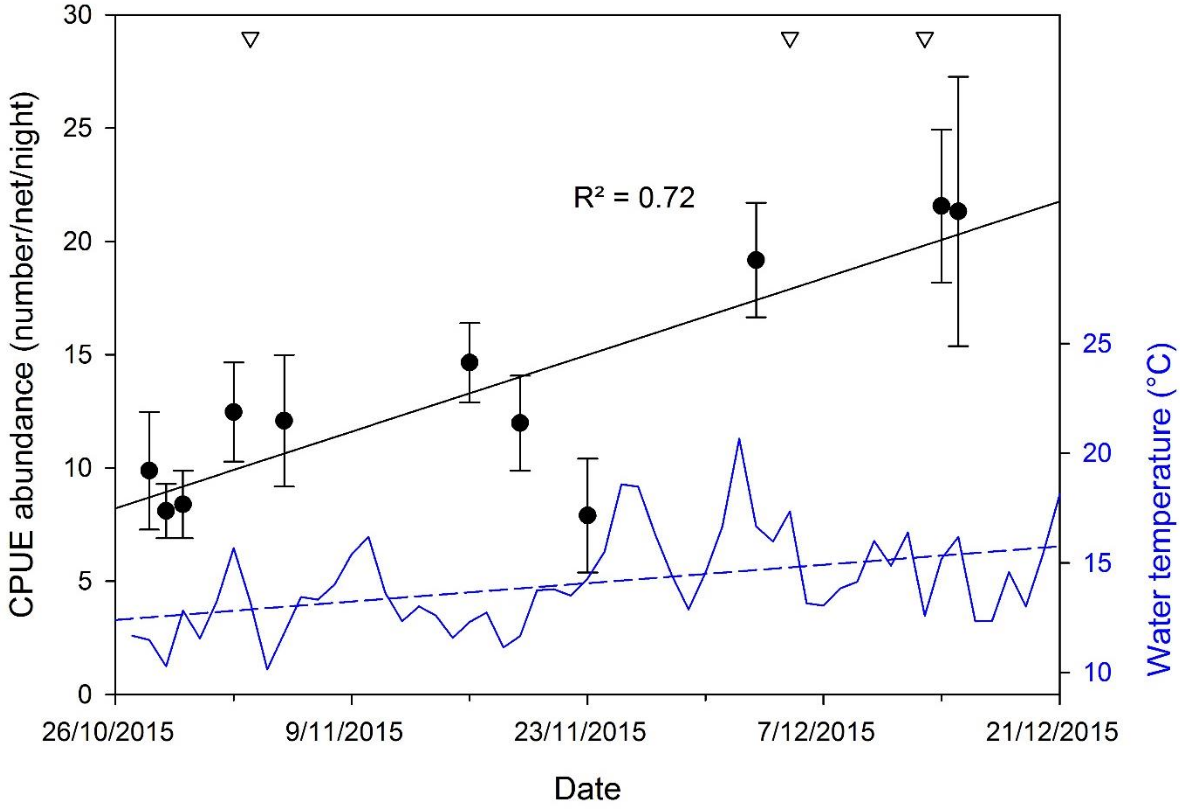

Figure 3-3: The relationship between mean daily water temperature and eel CPUE (±SE) during the initial tagging work. The triangle symbols show major wind events (>75km/h) during the tagging period. The blue dashed line is a linear regression line fitted to the water temperature data; the line is dashed only to distinguish it from the raw data line.

CPUE abundance was more consistent from mid-December 2015 through to April 2016 when the water temperature was consistently 15°C or higher (Figure 3-1). Thus, only CPUE data – both abundance and weight – from the population estimation and tuna movement work were used to examine variation in CPUE across depth (because these CPUE data did not appear to be strongly influenced by water temperature). CPUE abundance showed a trend of higher eel abundance in the shallower lake waters compared to the deeper waters (Figure 3-4). Across all sites (i.e., both inside and outside the Horomaka kōhanga), the lowest CPUE abundance tended to occur in the deeper areas of the Horomaka kōhanga (Figure 3-4).

There were subtle differences in the relative abundance of CPUE weight and CPUE abundance throughout the kōhanga. Outside of the Horomaka kōhanga, various areas had been modelled as having moderate eel abundance but these same areas typically had reduced CPUE weight estimates (Figure 3-5). In contrast, sampling sites inside the Horomaka kōhanga were modelled as having low CPUE abundance but more moderate CPUE weight estimates (Figure 3-5). This suggested the average weight of eels inside the Horomaka kōhanga was heavier compared to eels outside of the area.

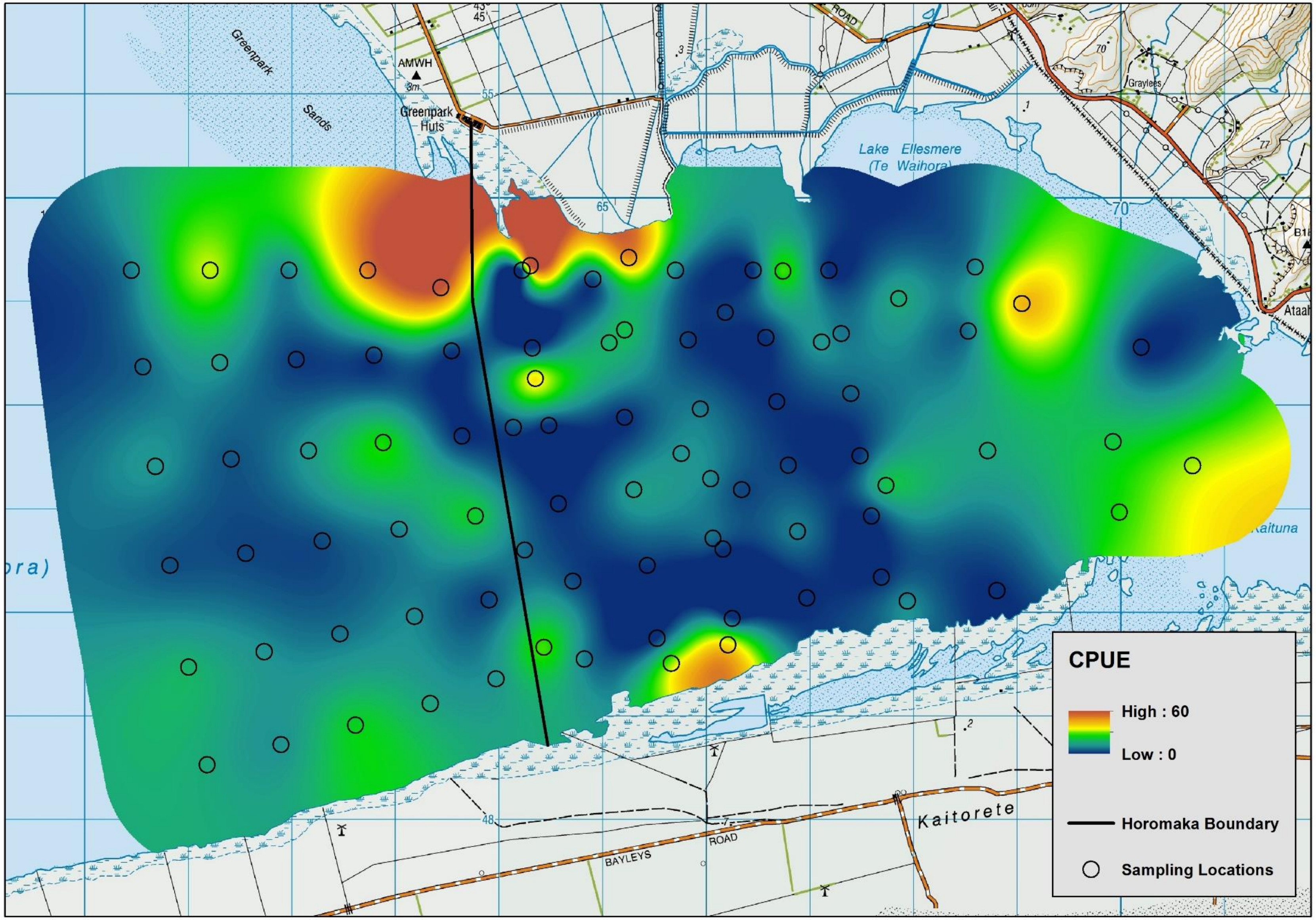

Figure 3-4: Variation in the CPUE abundance (numbers/net/night) of shortfin eels throughout the study area as modelled by GIS using linear interpolation. The black line across the lake indicates the Horomaka kōhanga boundary. Transparent circles show the location of fyke netting data used to construct the abundance model.

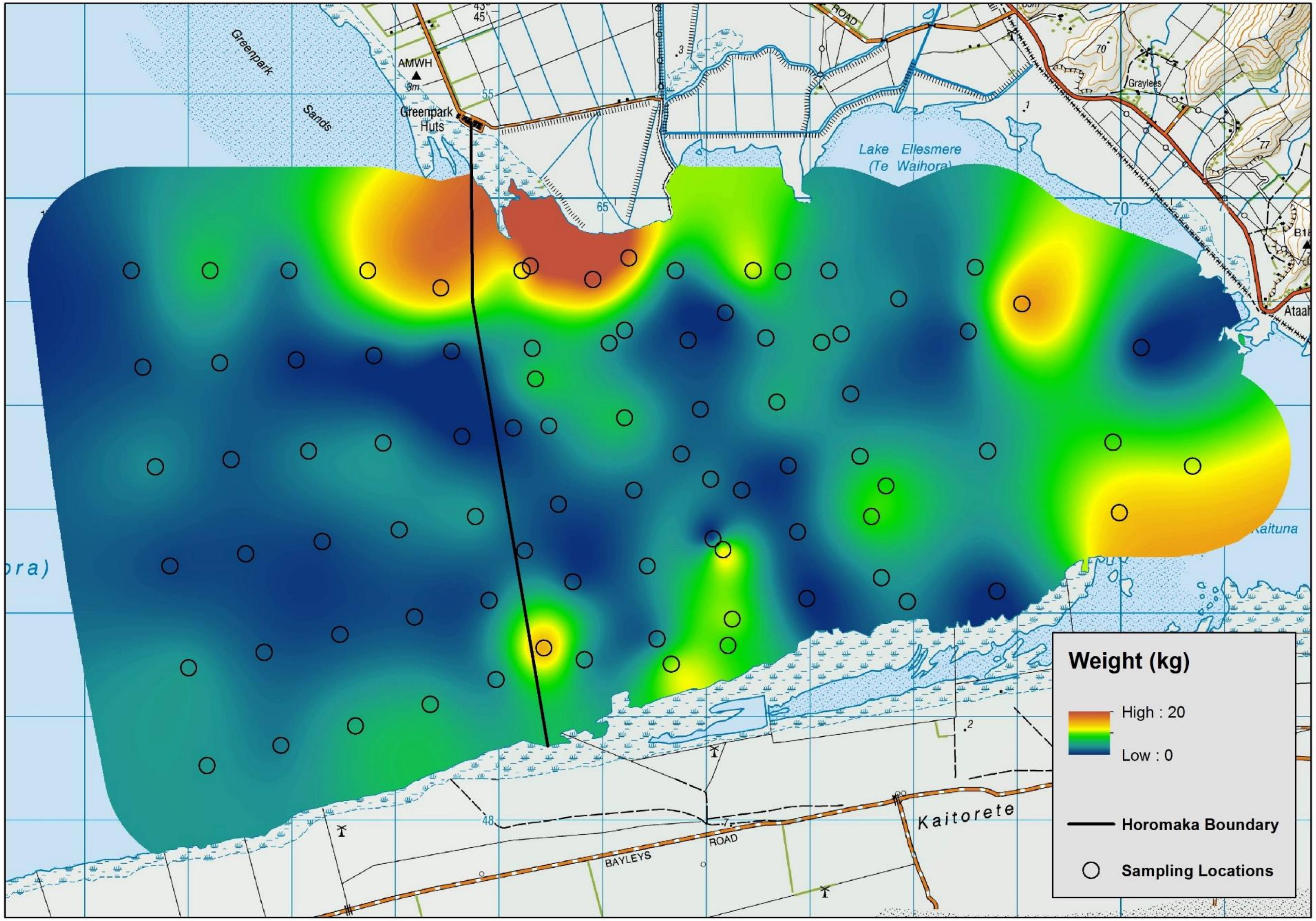

Figure 3-5: Variation in the CPUE weight (kg/net/night) of shortfin eels throughout the study area as modelled by GIS using linear interpolation. The black line across the lake indicates the Horomaka kōhanga boundary. Transparent circles show the location of fyke netting data used to construct the weight model.

3.2.1 Comparisons between shortfin eel relative abundance data and previous surveys

The CPUE data from the present study were compared to that of Glova & Sagar (2000). This study sampled eel CPUE within the Horomaka kōhanga area 20 years prior to our study when commercial fishing was permitted. We attempted to keep the height of the bars similar between the two studies (Figure 3-6) for comparison, but this required us to halve the height of our scale bar. The differences in the scale bars suggest that shortfin eel CPUE abundance in the Horomaka kōhanga during the present study was more than double what it had been 20 years ago.

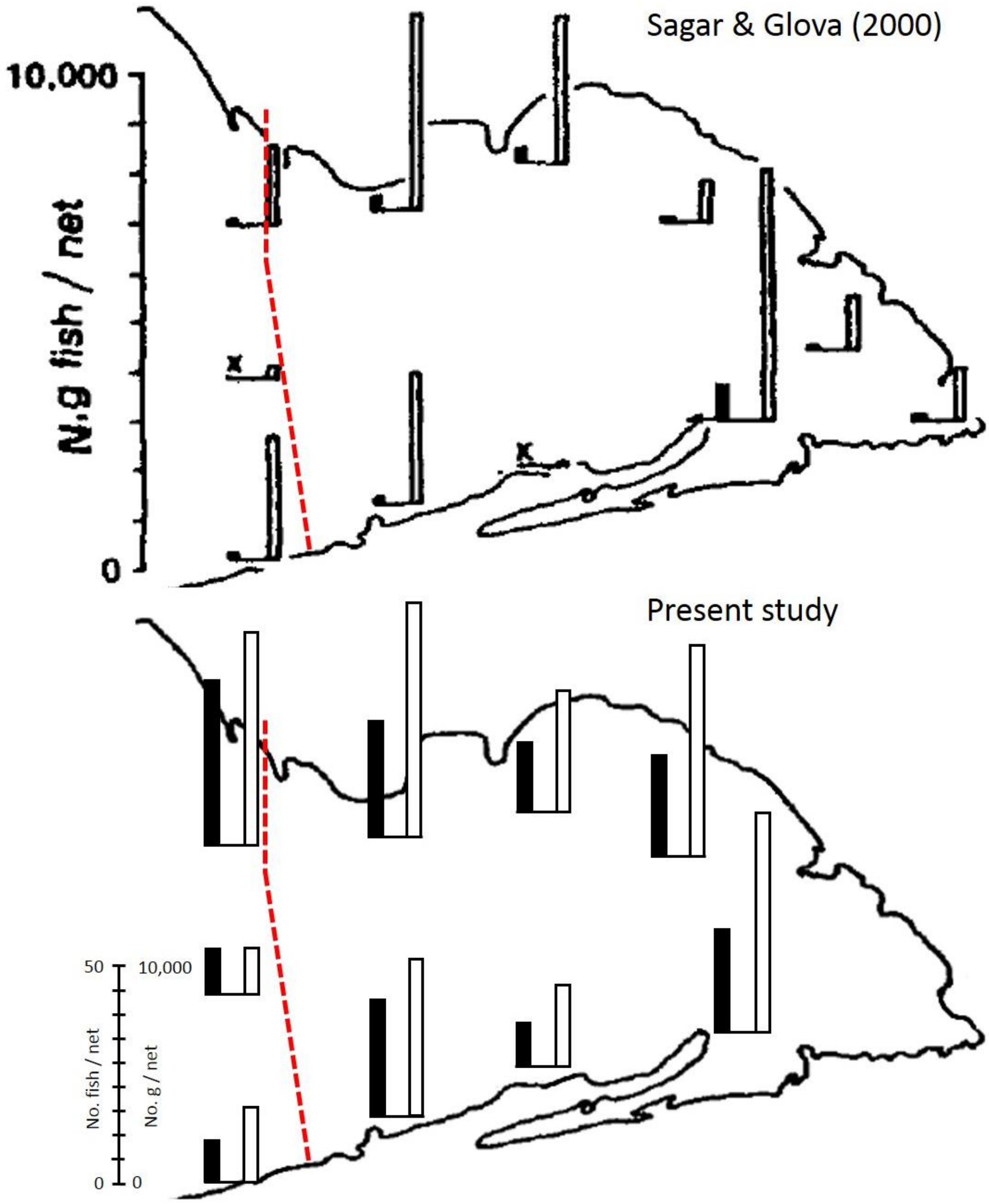

Figure 3-6: A comparison between the present study and Glova & Sagar (2000) of mean number (solid bars) and weight (open bars) of shortfin eels. Comparisons are based on three fyke net hauls at each location. The sampling by Glova & Sagar (2000) was conducted in January-March 1995. The red dashed line indicates the boundary of the Horomaka kōhanga.

3.3 Tuna size distribution with depth

To examine the influence of lake depth on eel abundance, netting data from 2015 were used (note, the 2016 movement data could not be used because individual eel lengths were not measured). Fyke nets were set in water that ranged in depth from 0.4 to 2.2m with an average of 11.6 fyke nets set at each lake depth (based on 0.1m depth increments). The only lake depth where no nets were set was 1.3m. Variation in lake depth within the Horomaka kōhanga is shown in Figure 2-1 and the depth of our sampling sites relative to the distance from the lake edge is shown in Appendix B.

A comparison of length-frequency distributions for three depth categories was made and showed that larger shortfin eels were more abundant in shallower waters (<1m) and that smaller eels dominated the deeper water of the Horomaka kōhanga (Figure 3-7). Whilst large and small eels occurred at all depths sampled, for depths <1m, 40% of the catch was comprised of eels >600mm. In contrast, for depths between 1.7 and 2.2m, eels greater than 600mm made up only 13% of the catch (Figure 3-7). Linear regression analysis showed that the average length of shortfin eels significantly declined with increasing lake depth ($F_{1,17}$ = 8.70, P = 0.009; R^2 = 0.35) (Figure 3-8a).

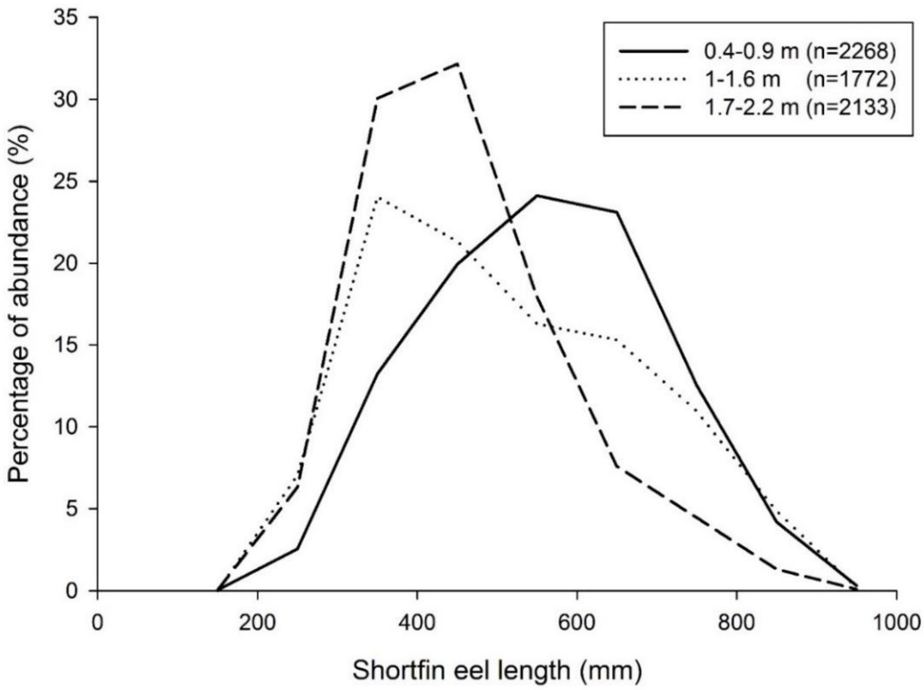

Figure 3-7: Comparison of shortfin eel length-frequency distributions for different depth ranges. Each depth range was comprised of data from six depths (note for the 1–1.6m range, there were no data for 1.3m). Plotted lines are based on data for 100mm size bins, with data plotted for the mid-point of each size bin.

In addition to the relationship between water depth and eel length, both measures of eel CPUE also varied in response to changes in depth. There was a significant decline in CPUE abundance (number/net/night) in relation to increasing depth; mean CPUE declined from 31.3 to 5.4 eels/net/night across the depth range we sampled ($F_{1,17}$ = 10.40, P = 0.005; R^2 = 0.39) (Figure 3-8b). The combination of declining CPUE abundance and eel length with increasing lake depth resulted in

CPUE weight (kg/net/night) declining ten-fold over the range of depths sampled ($F_{1,17}$ = 41.18, $P < 0.001$; R^2 = 0.72) (Figure 3-8c).

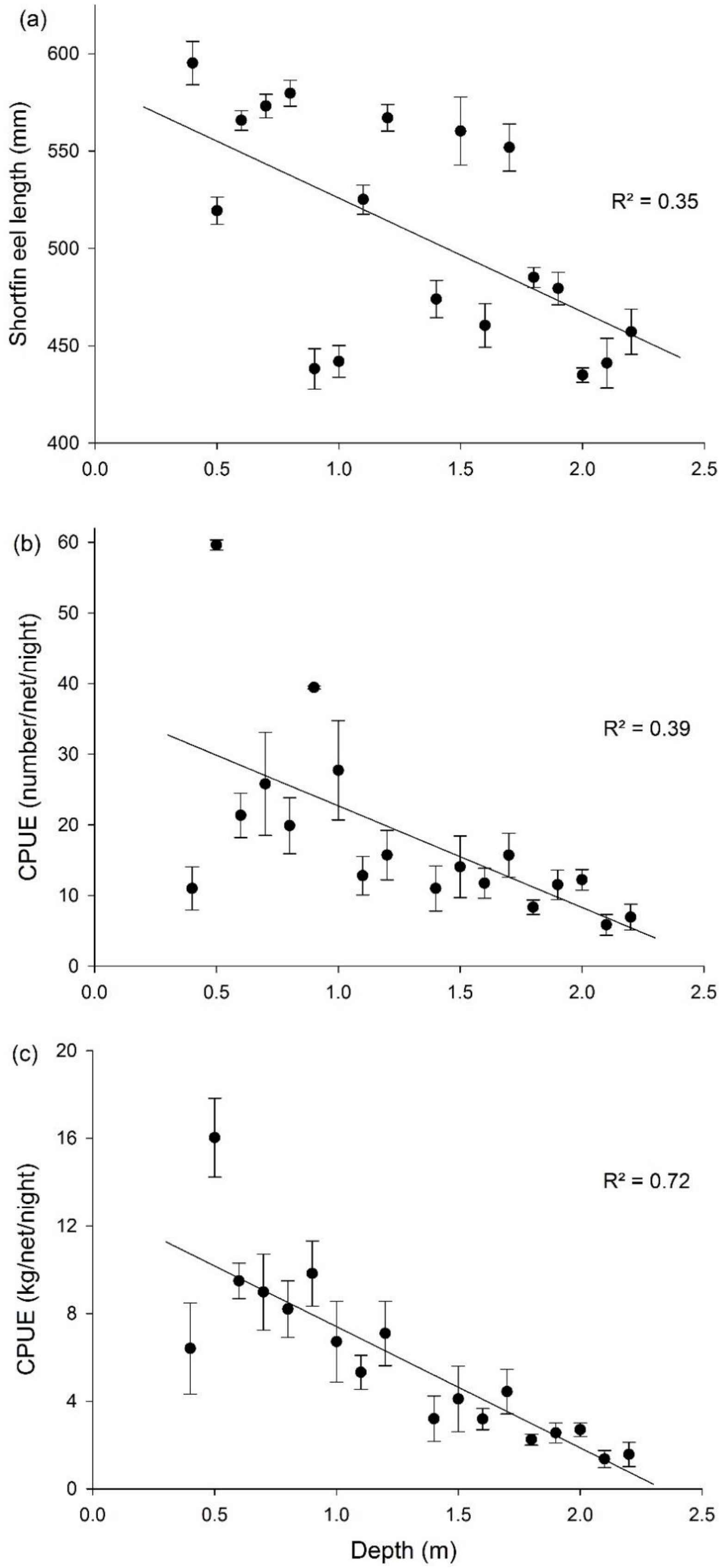

Figure 3-8: Variation in mean (±SE) length (a), CPUE abundance (b) and CPUE weight (c) of shortfin eels with changing lake depth (m). All figures are fitted with statistically significant linear regressions.

3.3.1 Comparison with previous data on shortfin eel distribution with varying depth

There were no equivalent fyke-net data from Te Waihora to compare the depth-related findings of this study with but Jellyman & Chisnall (1996) did examine the relationship between eel size and lake depth using beam trawl data. As noted in Section 2.5.2, only two of the 31 sites from the earlier study were within the Horomaka kōhanga area and the beam trawl method used a much smaller mesh size for sampling compared to the fyke nets used in the present study. Thus, the representation of different size classes in both datasets will differ.

Jellyman & Chisnall (1996) caught 1,029 small eels (<300mm) using the beam trawl method and found that the highest density of small eels were caught at 0.6-1.2m (Figure 3-9). Shortfin eels >300mm showed less distinct depth preferences except that their numbers declined at depths <0.6m and >1.7m. Only 208 small eels (<300mm) were caught using fyke nets in the present study but there was a distinct preference shown for depths around 1m (Figure 3-9). Whilst Jellyman & Chisnall (1996) found no major pattern for large eels, the present study showed their abundance declined with increasing depth (Figure 3-9).

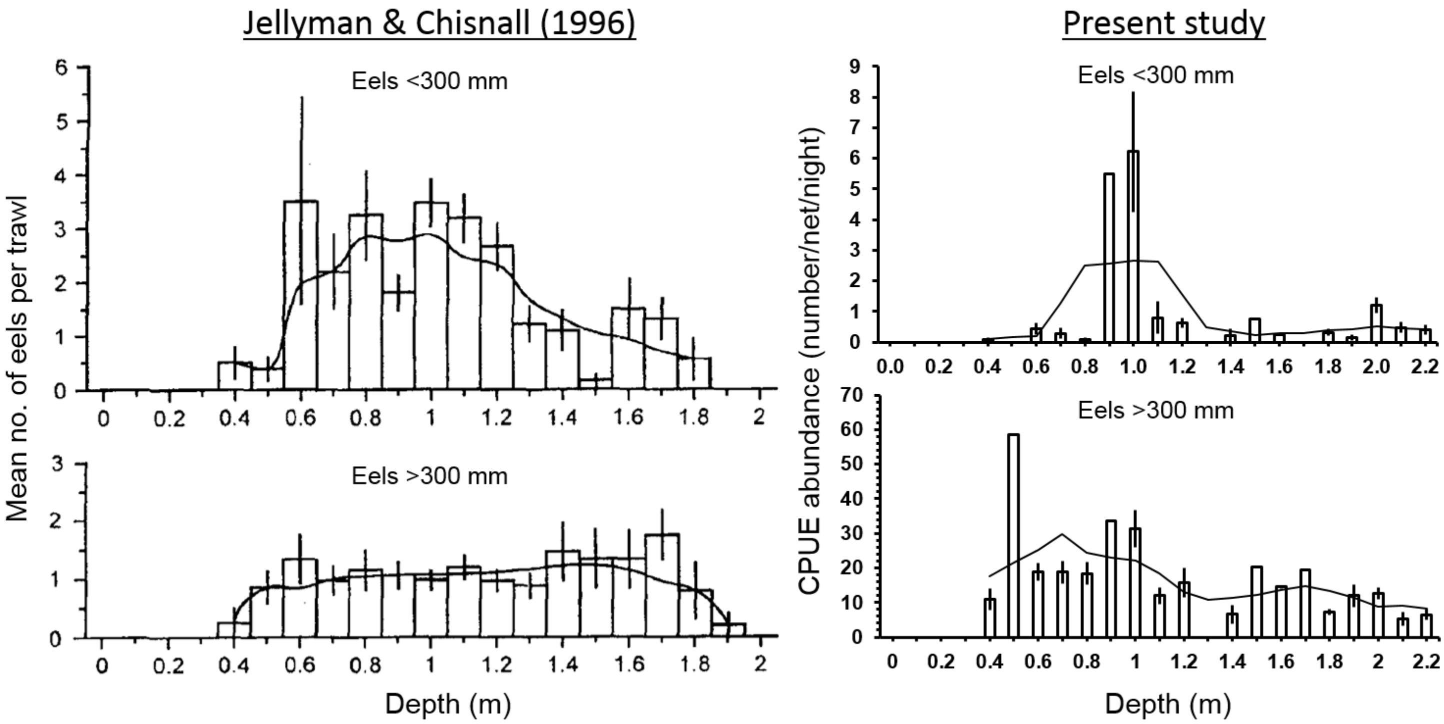

Figure 3-9: Mean (±SE) abundance of shortfin eels caught per trawl from 1994-1996 at various depths (left) compared to the fyke netting survey in 2015 (right). The line shows a 5-point moving average trend. As it is not known how Jellyman & Chisnall (1996) calculated the 5-point moving average trend value at the ends of the depth range, the present study calculated this by extrapolation of neighbouring values.

For eels >300mm, Jellyman & Chisnall (1996) found no association between CPUE and distance offshore although they did record their lowest CPUE at their furthest distance offshore (Figure 3-10). The present study also found no relationship between CPUE and distance offshore (Figure 3-10). Whilst Jellyman & Chisnall (1996) found that for eels <300mm CPUE declined with increasing distance offshore, the present study found no such relationship (Figure 3-10).

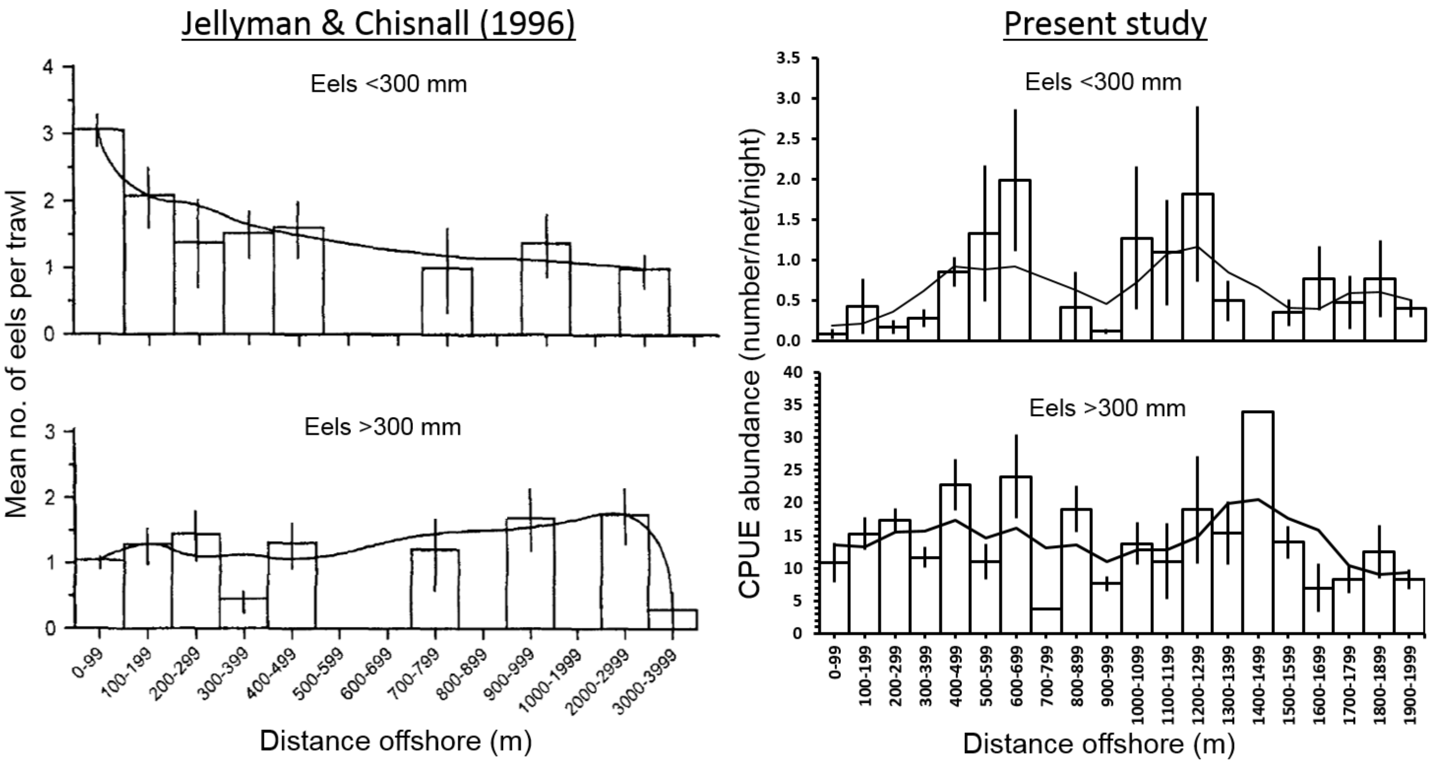

Figure 3-10: Mean (±SE) abundance of shortfin eels caught per trawl from 1994-1996 at different distances offshore (left) compared to the fyke netting survey in 2015 (right). The line shows a 5-point moving average trend. As it is not known how Jellyman & Chisnall (1996) calculated the 5-point moving average trend value at the ends of the depth range, the present study calculated this by extrapolation of neighbouring values. Note, Jellyman & Chisnall (1996) presented their data in 100m bins so our data are also presented using the same distance breaks. Jellyman & Chisnall (1996) had no data between 1000 – 1999m but as we did our data are presented for this distance range in 100m bins.

3.4 Tuna population size

A total of 9,014 eels were caught by NIWA staff during the study. Many of these eels were not tagged (e.g., eels were <400mm) or did not have their length measured (e.g., any untagged eel during the 2016 movement study) but the species was recorded when counting all captured fish. Shortfin eels comprised 99.4% (8,960 total number) of the total eel catch with only seven eels noted as male migrants[6].

3.4.1 Tuna tag retention

There were 4,071 shortfin eels tagged during the project and of these, 3,825 (94%) were double tagged; note, single tagging was only performed when it was clear that we would run out of tags for the number of eels captured on the last day of tagging. Investigating short-term tag retention/loss was important for estimating population size because if a major proportion of the eels were losing their tags whilst in the lake then this would need to be accounted for in the eel population estimate. Tags returned from commercial processing plants were not used in this part of the analysis because the capture, holding and transport of eels may have increased tag loss relative to NIWA's capture and

[6] Migrant were identified based on external morpholgical features mentioned in Todd (1981a)

release within and just outside of the Horomaka kōhanga. NIWA had 215 eel recaptures, of which 11 recaptures were of single-tagged eels. Recaptured single-tagged eels comprised 5.1% of all recaptures which was very similar to the percentage of the entire population that was single tagged (i.e., 6%). Of the 204 recaptures of double-tagged eels, only one eel was caught with a tag missing. Since shortfin eel tag retention was 99.5%, no adjustment for tag loss was made in our estimate of shortfin eel population size.

3.4.2 Calculating shortfin eel population size

Shortfin eel population size was estimated based on the randomised recapture methodology outlined in Section 2.3. The mark-recapture statistical method (see Section 2.5) estimated the population size (±S.E.) of shortfin eels ≥400mm in the Horomaka kōhanga in December 2015 to be 75,161 (± 9,501). The standard error on this population size estimate was 12.6%.

Sufficient data were collected during the tuna movement work (April 2016) from inside the kōhanga to make another population estimate. Whilst the methodology was not as robust compared to the December 2015 survey (because the whole kōhanga area was not sampled as the focus of this work was on examining tuna movement differences), the estimated population size inside the Horomaka kōhanga was 108,034 (± 16,065). Whilst the December 2015 survey is the more robust population size estimate, having a secondary population estimate that is not two- or three-fold different gives greater confidence that our December 2015 survey produced a realistic estimate.

To determine the weight of eels (>400mm) in the Horomaka kōhanga, a length-weight regression was applied to the length-frequency data (Figure 3-11). Based on the population size estimate and the length-frequency data, it is estimated that the weight of shortfin eels >400mm in the Horomaka kōhanga is 29.09 tonnes (± 3.67 tonnes). The mesh size used for our fyke nets introduces a sampling bias which means it is not valid to calculate the weight of eels <400mm.

This approach can be extrapolated to estimate the weight of eels (>400mm) for the whole lake. Such an estimate is based on calculating the area of the Horomaka kōhanga, for the average lake level during our survey work (0.746m), relative to the total lake surface area. At a lake level of 0.746m, the Horomaka kōhanga comprises 11.62% of the total lake surface area (187.23km^2 based on the lake level-lake surface area calculation of Measures et al. 2014). This suggests there is approximately 647,000 eels (>400mm) weighing approximately 250 tonnes. Such a major extrapolation makes a number of assumptions, such as eel abundance in the Horomaka kōhanga is representative of the entire lake; this is almost certainly an invalid assumption given eel abundance is highest closest to the lake opening (see Crow & Jellyman in press) and that commercial fishing happens outside the Horomaka kōhanga. While this estimate is not entirely robust given the assumptions that must be made when scaling up the data, as stock estimates for the lake (or any New Zealand lake) are seldom able to be calculated, we considered it worthwhile to report this estimate.

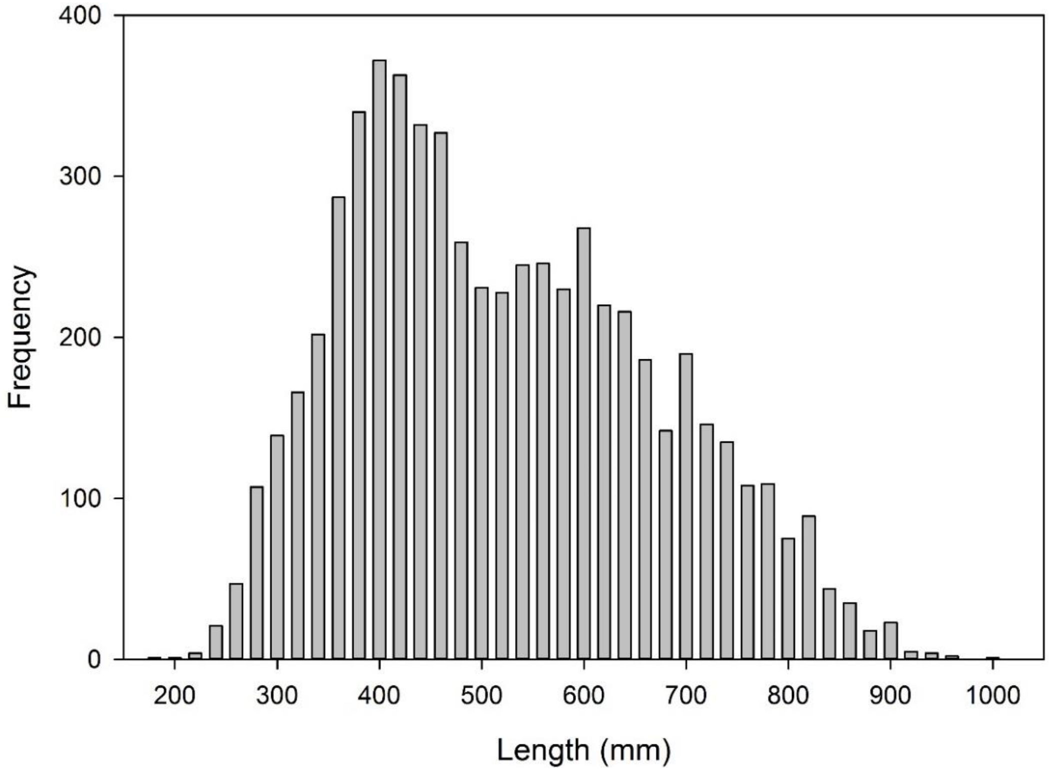

Figure 3-11: The length-frequency distribution of shortfin eels caught within the Horomaka kōhanga. Note, data includes all eels caught during sampling work from October to December 2015 but does not include data from the recapture work in March/April 2016 when individual lengths were not measured.

3.5 Tuna movements within (and outside of) the Horomaka kōhanga

Over 200 tagged eels were recaptured during the study. Approximately half of these tagged eels were caught during the initial tagging phase of the project. There were 59 tagged eels caught during the December 2015 population estimation work (when all nets were set inside the Horomaka kōhanga) and four months later, 52 tagged eels were recaptured during the movement study.

3.5.1 Movements of tuna

Recaptured eels were caught throughout the study period on every sampling occasion from the first day after they were tagged to the last day of sampling in April 2016. Based on the timing of our sampling design, the highest likelihood of capturing tagged eels should have been within 10 days of tagging because nets were often reset soon after eels were tagged (see Figure 3-12a). However, nearly 40% of recaptured eels were caught 11–20 days after tagging which was three times higher than would be expected than if these fish were caught in proportion to when we were sampling (Figure 3-12a). After the 11–20 day period, progressively fewer eels were generally being caught within increasing days at large although tagged eels were consistently being caught between 90 and 140 days after tagging (Figure 3-12a). Note, no sampling was conducted between January and early March so it was not possible to capture eels between 51 and 90 days at large (Figure 3-12a).

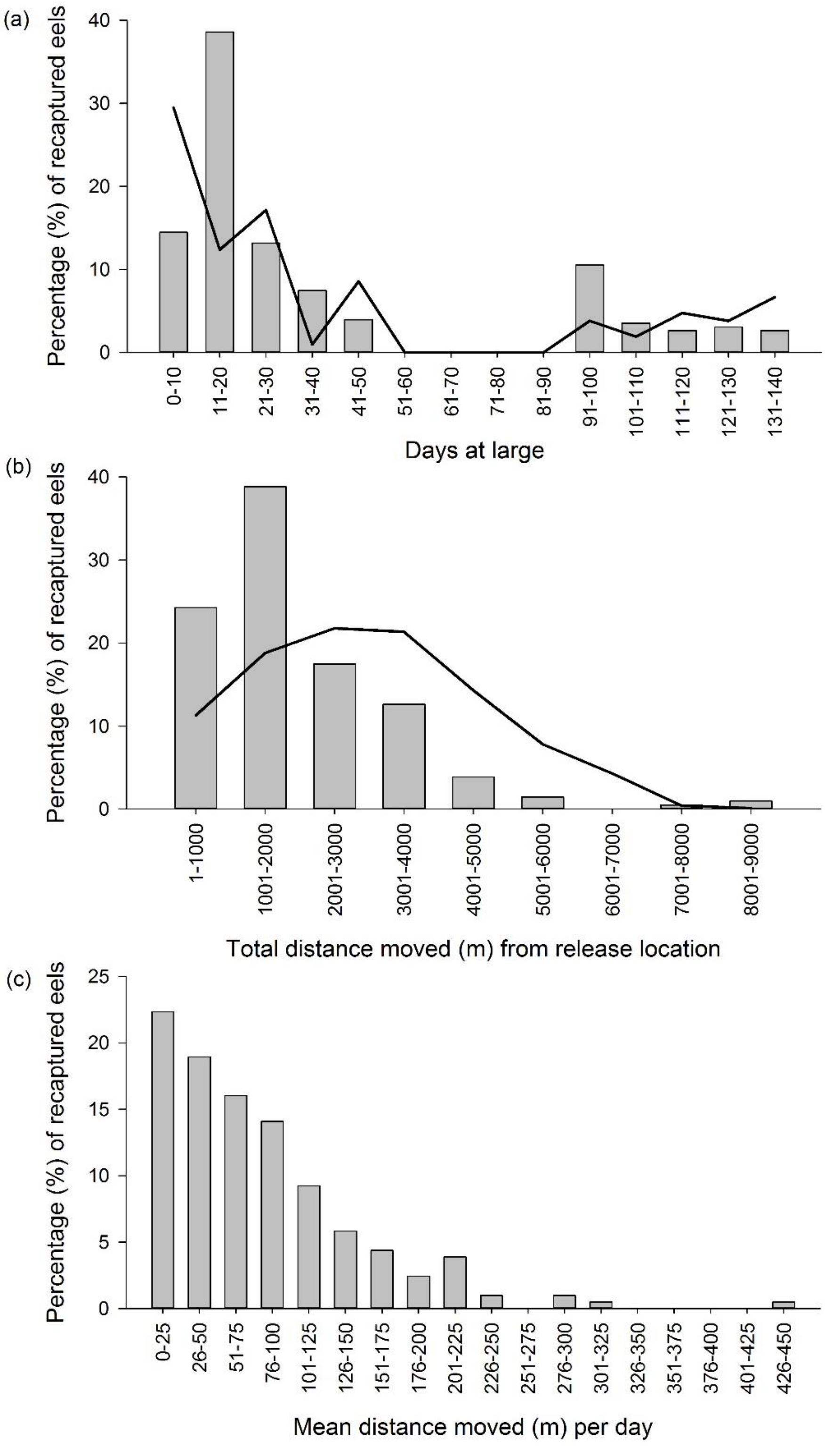

Figure 3-12: The percentage of eels recaptured by NIWA compared to days at large (a), distance moved from release location (b) and estimated mean daily movement (c). Note, in (a) the line indicates the likelihood (%) of randomly capturing a tagged eel based on the temporal distribution of our sampling effort. The line on (b) indicates the likelihood (%) of encountering a net based on the spatial distribution of our sampling effort. The approach for calculating these lines is explained in Section 2.5.1.

The spatial arrangement of the fyke nets in December 2015 and March 2016 indicated that if eel movement was random then 30% of eels should have been recorded within 2000m of their release location (Figure 3-12b). However, NIWA recapture data found that 63% of tagged eels were recorded within 2000m of their release location. Most nets (43%) were located within 2001–4000m of the release location and 30% of eels were recaptured within this distance range (Figure 3-12b). Only 7% of tagged eels were recorded more than 4000m from their release location and 27% of nets were set more than 4000m from the release location (Figure 3-12b).

The percentage of recaptured eels declined exponentially as the mean distance moved by eels increased ($R^2 = 0.87$, $P < 0.001$) (Figure 3-12c). Based on the calculation method for 'mean distance moved' (see Section 2.5.1), 71% of eels were moving less than 100m per day, although one eel was recorded as having moved 448m per day (i.e., 2,690m in 6 days). Whilst this was the most eel movement from calculations based on NIWA recapture data, the most extensive daily movement recorded during the study was from a recaptured eel caught by a commercial fisher. A 584mm shortfin eel tagged inside the Horomaka kōhanga was recaptured 16 days after tagging by a commercial fisher next to the outlet of Te Waihora. The eel had moved 1,26m per day to travel just over 20km to reach the location where it was captured; this eel was subsequently released by the commercial fisher upon noticing it was a NIWA tagged eel.

All NIWA recapture data were used to examine whether the distance travelled between release and recapture location was related to eel length. As shown in Figure 3-13, there was no relationship between the distance an eel moved and its body length; both small and large shortfin eels were estimated to have moved both negligible and moderate distances from their initial release location. There was a positive relationship between the number of days at large and total distance moved from the release location by tagged eels ($F_{1,205} = 28.46$, $P < 0.001$; $R^2 = 0.12$) (Figure 3-14); eels moved further from the release location as the number of days at large increased. It was also apparent that the total distance that had been moved by tagged eels after 90 days at large was far more variable than the distance moved by eels within 50 days of tagging (Figure 3-14).

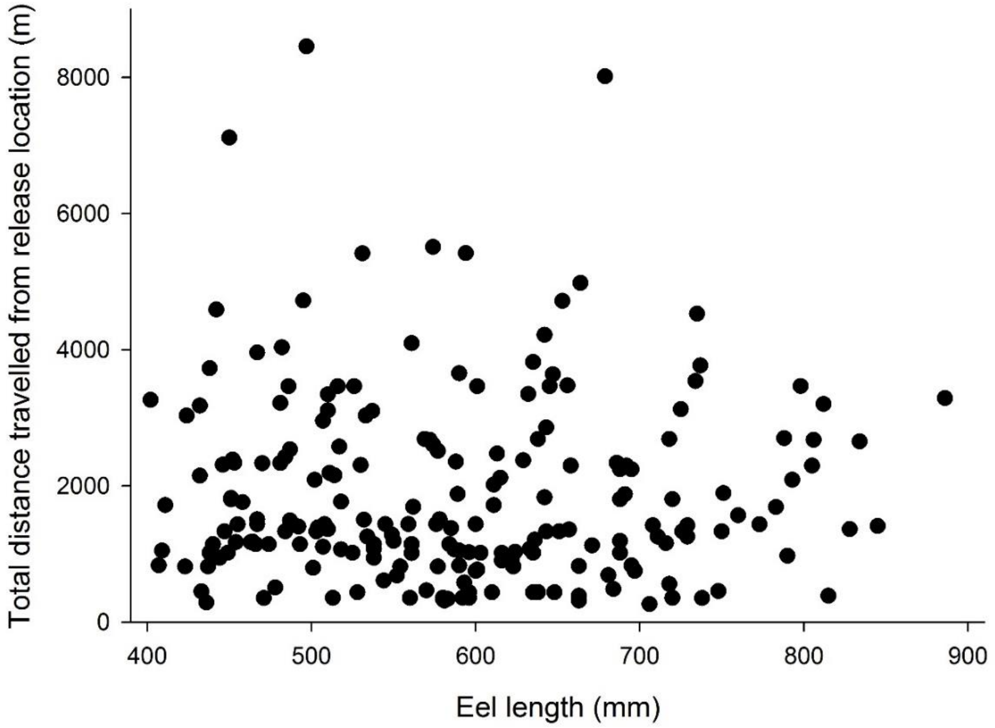

Figure 3-13: The relationship between eel length (mm) and distance travelled (m) for eels recaptured by NIWA.

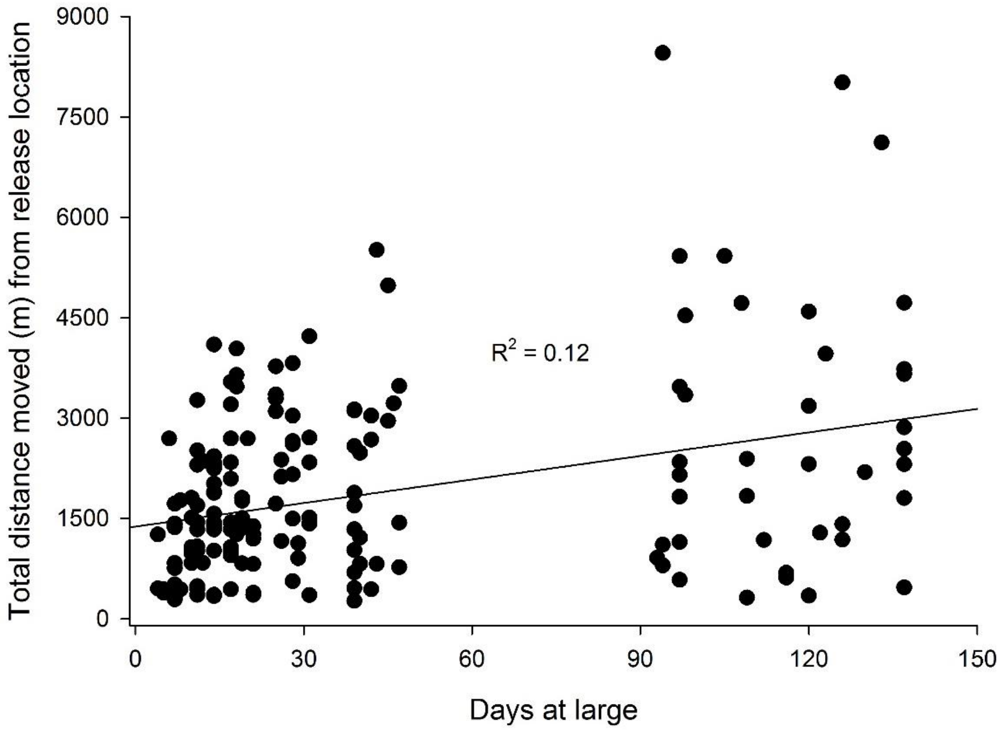

Figure 3-14: The relationship between days at large and distance moved (m) for tagged eels. These data include recaptured eels from throughout the study captured by NIWA but does not include any data from commercial eel fishers.

3.5.2 Tuna movement outside of the Horomaka kōhanga

There were 52 tagged eels recaptured during the study of movement patterns across the Horomaka kōhanga boundary. Of these tagged eels, 43 (83%) were caught inside the Horomaka kōhanga. For the nine shortfin eels captured outside the Horomaka kōhanga, there was no discernible spatial pattern between where an eel was released inside the kōhanga and where it was captured outside the kōhanga (Figure 3-15). There was also no pattern in the size of tagged eels caught outside the Horomaka kōhanga. It was not possible to examine the size distribution of all eels (tagged and untagged) inside and outside of the Horomaka kōhanga because the length of untagged eels was not measured during the March/April movement work. However, it was apparent that there was no relationship between the length of eels that were recaptured outside the kōhanga and the distance they had moved (which parallels the findings for all recaptured eels, see Figure 3-13).

The average (±S.E.) CPUE weight of shortfin eels in nets inside the Horomaka kōhanga was 5.1 (±0.8) kg/net/night which was higher than the average CPUE weight of 3.1 (±0.6) kg/net/night for nets set outside of the kōhanga (Figure 3-16). However, this difference was not statistically significant ($F_{1,57}$ = 3.34, P = 0.07).

Shortfin eel CPUE abundance showed a similar pattern to CPUE weight. The average (±S.E.) CPUE abundance inside the Horomaka kōhanga was 19.0 (±3.4) eels/net/night was higher than the CPUE abundance outside of the kōhanga which was 13.3 (±2.5) eels/net/night (Figure 3-16). This difference was not statistically significant ($F_{1,57}$ = 1.83, P = 0.18). However, in total, there were 1,651 shortfin eels caught inside the Horomaka kōhanga of which 66% were 400mm or larger. The percentage of eels ≥400mm outside the Horomaka kōhanga was highly comparable to inside the kōhanga, with 65% of the 1,196 eels in this size range. Thus, the percentage of eels 400mm or larger inside and outside the kōhanga were very similar but there were far fewer eels of this size outside the Horomaka kōhanga.

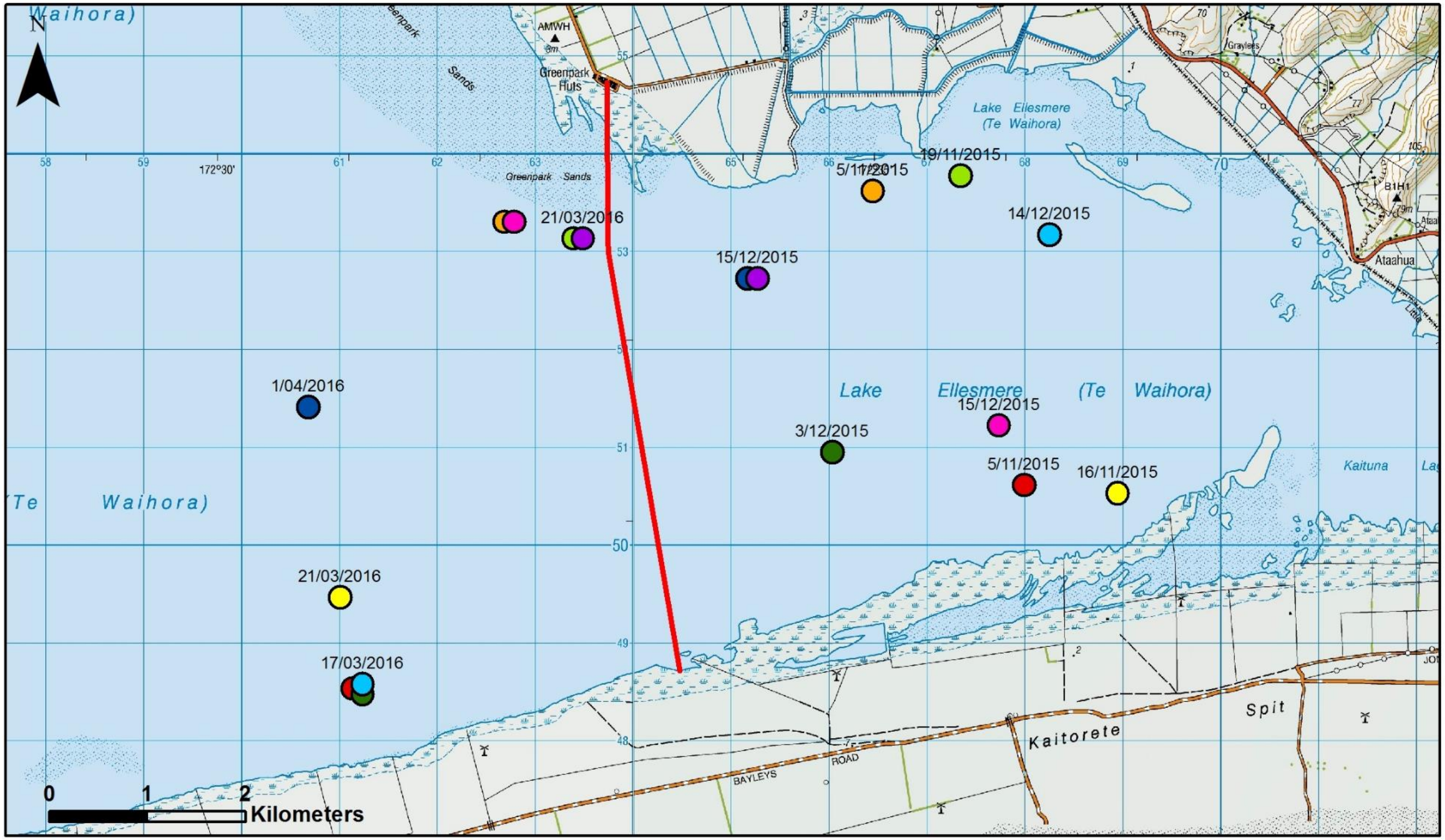

Figure 3-15: The location and tagging date of the nine eels that were caught outside of the Horomaka kōhanga by NIWA. Each different coloured circle inside the Horomaka kōhanga has a corresponding circle outside the Horomaka kōhanga. Overlapping circles indicate sites where multiple eels were tagged or recaptured. The red line indicates the kōhanga boundary.

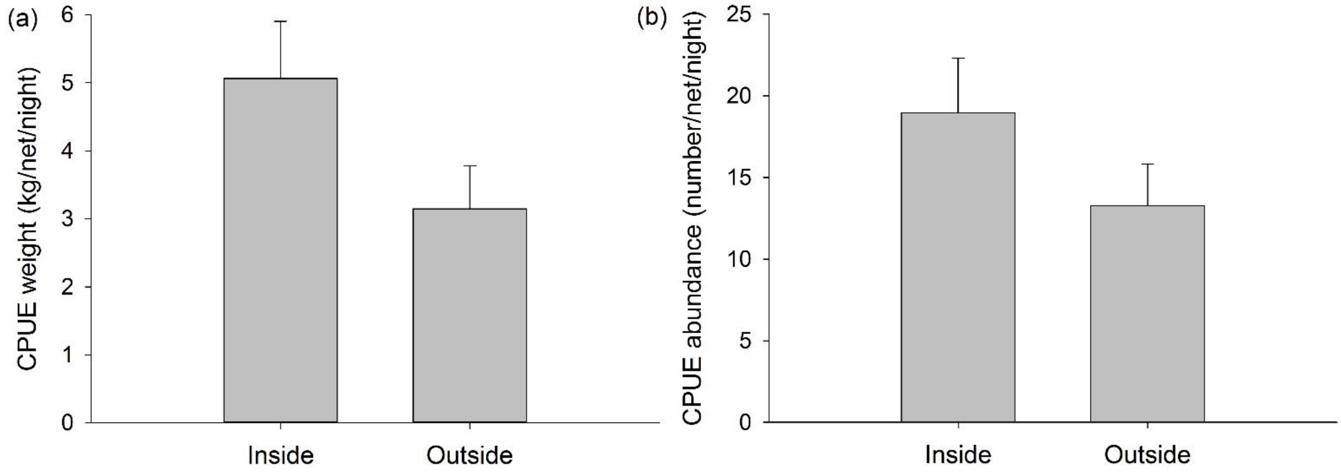

Figure 3-16: Comparison of CPUE weight (a) and abundance (b) inside and outside the Horomaka kōhanga.

3.5.3 Length-frequency distributions of tagged and recaptured eels (by NIWA and commercial fishers)

There were notable differences between the length-frequency distributions of the initial tagged eel population compared to the length distribution of tagged eels that were recaptured by NIWA and commercial fisherman (Figure 3-17). The length distribution of tagged eels recaptured by NIWA showed that eels <550mm were under-represented compared to the total tagged population, but at lengths >550mm, eels were recaptured in a proportion similar to that of the tagged population (Figure 3-17, Figure 3-18). With the exception of one eel, shortfin eels <520mm were absent from the tagged eels caught by commercial fishers. This is to be expected because there is a minimum size limit for commercially caught shortfin eels of 220g so commercial fishers have nets with escapement tubes for smaller eels (NIWA nets do not have these fitted). Crow & Jellyman (in press) estimated that a minimum size limit of 220 g corresponded to a length of approximately 470mm for shortfin eels in Te Waihora; the tagged eels being caught by commercial fishers were 50mm above this size.

Commercial fishers (or more typically the eel processing plants) returned tags for 211 eels to NIWA[7]. This equated to 5.2% of all tagged eels being caught by commercial fishers outside the Horomaka kōhanga over a four-month period from December to March (i.e., the period when NIWA received tag returns). Of the commercially caught eels, 73% were captured in the eastern half of the lake (excluding the kōhanga) and the remaining 27% in the south-west corner of the lake. Thus, a total of 3.8% of all tagged eels were caught by commercial fishers in the eastern half (just outside the kōhanga boundary) of the lake where fishing is permitted.

[7] This may be an underestimate because It is not known whether or all tagged eels that were caught by commercial fishers were returned given that it was at the discretion of the processing plants to remove and returned the tags to NIWA.

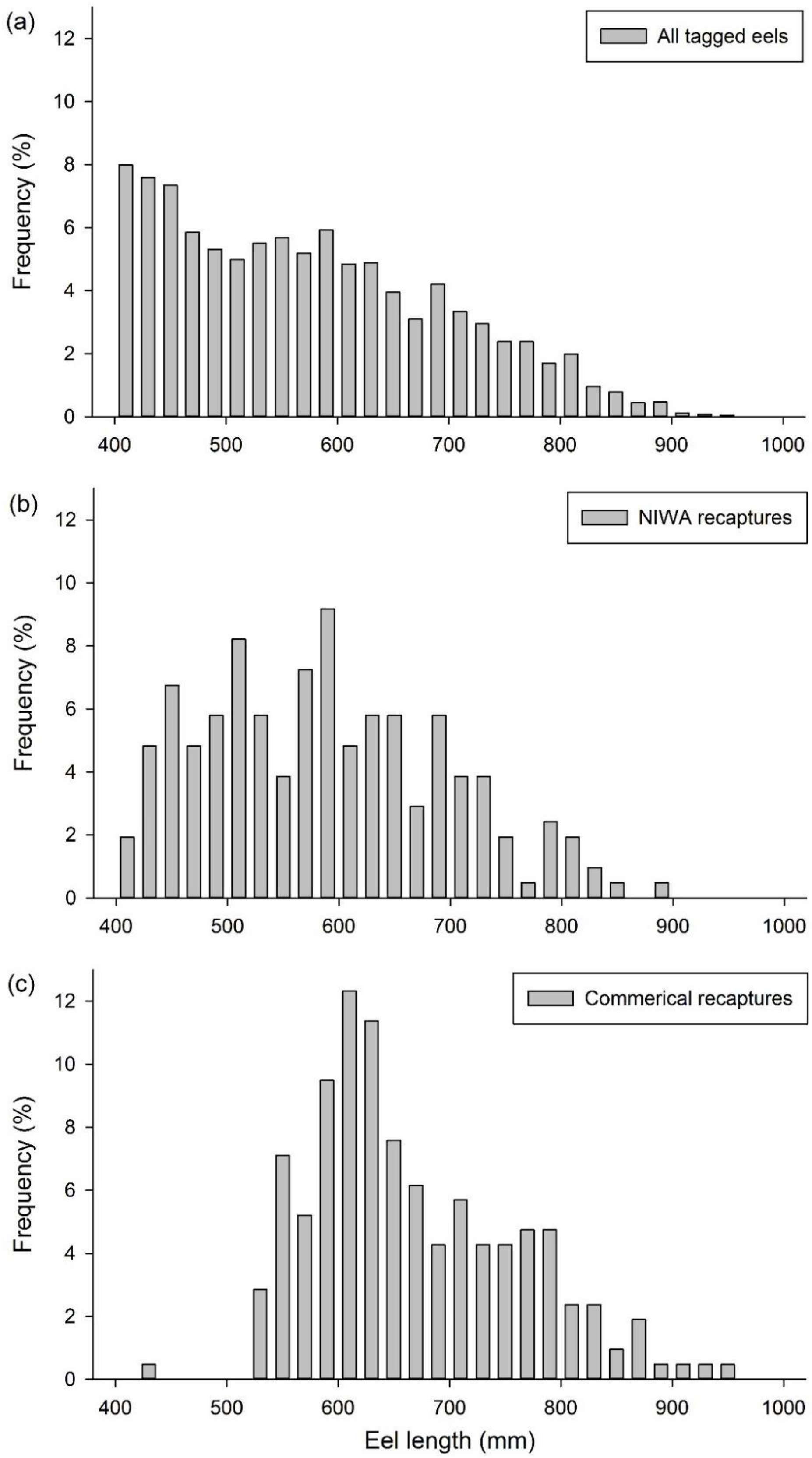

Figure 3-17: The length-frequency distribution for all tagged shortfin eels (a) compared to the eels recaptured by NIWA (b) and commercial fishers (c). Note, for the 'all tagged' dataset, n = 4,071; for the NIWA recaptured dataset, n = 207; for the commercial recapture dataset, n = 211.

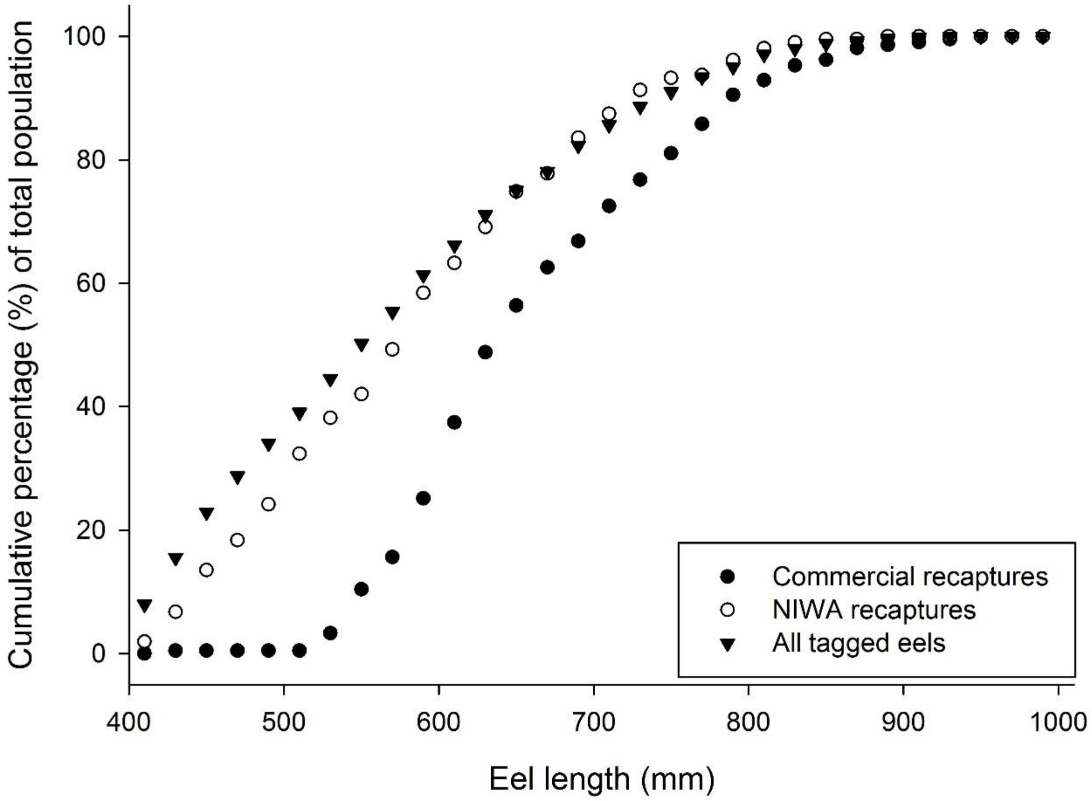

Figure 3-18: A comparison of how the cumulative percentage of eels changed with increasing body length. This figure is a different way of illustrating the data shown in Figure 3-17.

4 Discussion

The primary focus of this work was to determine the effectiveness of the Horomaka kōhanga in protecting mahinga kai species, specifically shortfin eels. The two main project objectives focussed on estimating the size of the eel resource in the Horomaka kōhanga and examining how regularly eels may be moving out of this protected area. The method used to address these objectives was to externally tag over 4,000 eels that were 400mm or larger. This approach was successful in addressing the main objectives and also allowed two supplementary objectives to be investigated about spatial variation in eel abundance within the Horomaka kōhanga, as well as the effect of lake depth (and other environmental factors) on eel abundance during the months sampled.

4.1 The influence of environmental factors on eels in the Horomaka kōhanga

The original methodology proposed to address the WTW Horomaka kōhanga fisheries work required extensive boating which caused delays because of the low lake levels observed during the first two years of the project. The success of this eel tagging project justified decisions to delay the start of the project because of the increased spatial coverage and number of eels that were able to be tagged and recaptured during 2015-16. Rather fortuitously, this study was conducted during a period of very stable lake levels; seldom does the lake level stay so constant over a six-month period. This had a number of advantages for the study. For example, survey results did not need to account for major expansion or contraction in potential eel habitat/feeding area associated with major inflow events or artificial lake openings that might have prompted greater movement by eels.

The variation in lake level did not need to be accounted for in analyses but environmental factors such as wind strength, water temperature and water depth all had the potential to influence eel catch rates. During the study, strong winds were less frequent compared to pre- and post-study periods. Ngāi Tahu eel fishers have told us that strong wind events prior to netting often result in higher catch rates. It is worth noting that of the 54 longfin eels caught, 59% of these eels were caught on 14–15 December when a strong wind event occurred. Combined wind speed and lake level data certainly show how strong winds results in major wind fetch effects causing large volumes of water to move from one part of the lake to the other so it is easy to envisage how this large movement of water could result in increased eel movement and thus greater CPUE for eel fishers. Whilst increased CPUE abundance was recorded after major wind events in this study, higher eel catches at this time were consistent with a trend of increasing water temperature. This study had too few replicates following major wind events to draw any defensible conclusions about the effect of wind strength on eel catch rates. However, given that the variability in CPUE was more consistent once water temperatures stabilised (from December to April), it is likely that water temperature is the major environmental factor determining seasonal variation in eel catch rates in the Horomaka kōhanga. The observed influence of temperature on catch rates in the present study is consistent with the seasonal variation in glass eel catch rates (August & Hicks 2008). Jellyman et al. (1996) found that eel movement largely ceased below a water temperature of 12°C (zero catches occur at 8°C) and our catch data also showed markedly reduced catches in cooler water; note that based on this prior information we did not start the study until the lake temperature had exceeded 12°C.

The effect of lake depth on eel length and CPUE was surprising given that previous studies (e.g., Jellyman & Chisnall 1996) had not recorded any such pattern. Larger eels were far more prevalent in shallower depths. In the deepest waters (≥2m), average eel size had declined by more than 10mm.

Jellyman et al. (1995) noted that larger shortfin eels appeared to move inshore during spring, a movement likely linked to their diet which is primarily composed of prey fish[8]. A change in the average size of eels combined with a decrease in the number of eels caught in deeper water meant that there was a 10-fold decline in CPUE weight (kg/net/night) between the shallowest and deepest parts of the Horomaka kōhanga; a finding that may be of particular interest to Ngāi Tahu Whānui who fish within the Horomaka kōhanga. This result was also consistent with catch patterns and fish movement observed by customary fisherman (D. Brown pers. comm.).

4.2 Is the Horomaka kōhanga protecting eels?

To determine whether the Horomaka kōhanga was effective in protecting the shortfin eel resource, we focussed on first quantifying the size of the eel population and second on establishing how readily these fish might be moving outside of the kōhanga (and thus potentially exposing themselves to capture by commercial eel fishers). With over 4,000 shortfin eels tagged within the Horomaka kōhanga, and negligible tag loss recorded during the study, we calculated the population of eels 400mm or larger to be just over 75,000 individuals. This equated to 29 tonnes of shortfin eel in the Horomaka kōhanga; note, the population size of eels smaller than 400mm could not be calculated as they were too small to reliably catch in our sampling equipment. This constitutes a major fisheries resource that is available for customary and recreational fishers. Comparisons with previous CPUE data (i.e., Glova & Sagar 2000) suggest eel abundance in this part of the lake has more than doubled since 1995 when the area was accessible to commercial fishers. This increase in catch rate appears to be occurring throughout the entire lake, based on a three-fold increase in commercial eel catch rates (Beentjes & Dunn 2014) (See Crow & Jellyman in press for detailed discussion).

With the size of the eel resource in the Horomaka kōhanga now quantified, the question of eel movement becomes more pertinent because the kōhanga may offer little protection if the majority of the eels are readily utilising feeding and/or refuge habitats outside of the boundary. Commercial fishers set nets very close to the kōhanga boundary (P. Jellyman, pers. obs.) so eels that stray past the boundary markedly increase their chance of being captured relative to the occasional customary fishing pressure we observed inside the kōhanga. The combined results from all of the eel recapture work showed short-term widespread movement was relatively limited with almost two-thirds of all recaptured eels caught within 2000m of their release location. Of these recaptured eels, 55% were caught within 20 days of being tagged so the data are strongly reflective of short-term movement patterns for eels. In a study of shortfin eel movement in Te Waihora over several years Jellyman et al. (1996) also found that although eels are capable of periodic extensive movements, eels did not typically move more than a few kilometres. Thus, short-term eel movements may be relatively localised but as we found a trend of eels moving greater distances as the number of days at large increased, it is difficult to determine to what extent eels may stay within the Horomaka kōhanga based solely on these data.

To determine what proportion of eels are moving out of the kōhanga we examined two different datasets. Firstly, we analysed the tag returns of commercial eel fishers. The tag returns they supplied showed that they caught at least 5% of all eels that were tagged, although approximately one-quarter of these eels were captured on the opposite side of the lake. Secondly, we examined data

[8] Prey fish species in Te Waihora tend to be concentrated in shallower waters (NIWA unpubl. data) presumably because this is where the production of their invertebrate prey is highest.

from our movement study eels which showed that 17% of tagged eels (within 5km of the kōhanga boundary) were moving outside of the kōhanga boundary. Based on our population estimate this could indicate that around 13,000 eels may move out of the kōhanga over the period of a few months in summer, but it is important to recognise that this study has not quantified the movement of eels into the kōhanga so cannot conclude whether this movement of eels would actually constitute any sort of population/stock loss from within the Horomaka kōhanga. Further work in this area would be required to address this question. Whilst our study was only conducted over several months, Jellyman et al. (1996) found over several years that only 39% of tagged eels were recaptured from adjacent areas of the lake (an average distance of approximately 5km), so both studies suggest that most eels make localised rather than extensive movements.

This study was done during a period of time when the lake level was very stable (c. 0.75m). During summer periods when the mean lake level is markedly lower than this (e.g., 0.65m), access to a number of the shallow water habitats – where eel abundance was found to be highest – would be considerably reduced. Eel movement, particularly for larger adult eels who are primarily feeding on prey fish species (e.g., common bullies, see Kelly & Jellyman 2007), may be much greater under these conditions if they need to travel greater distances to meet their metabolic requirements (i.e., a shallower lake is typically warmer which would further increase their food/energy demand). Discussions with Ngāi Tahu eel fishers indicate that when the lake is low and the water temperature in the shallower areas gets too high that eels will move into the deeper parts of the lake and become relatively inactive (as indicated by lower catch rates) (D. Brown, pers. comm.).

The establishment of the Horomaka kōhanga has had a positive influence on the abundance of shortfin eels available for customary and recreational fisheries. One of the primary purposes of the Horomaka kōhanga was to provide an area of the lake that was specifically for use by customary and recreational fishers and in doing so achieve some of Ngāi Tahu's fisheries aspirations for the lake. For example, Ngāi Tahu Whānui have a desire to be able to set nets and have high catches of tuna that are of good 'eating size' (i.e., >500mm). As the Horomaka kōhanga is on the opposite side of the lake to the outlet, under current lake conditions it is probably unreasonable to expect tuna catches in the Horomaka kōhanga to have CPUE comparable to highly productive areas of the lake (e.g., Fishermans Point where proximity to the lake outlet means the abundance of prey fish species will almost always be higher). However, if appropriate timed lake openings continue to permit adequate recruitment into the lake then the Horomaka kōhanga should maintain good catch rates for customary fishers, particularly in the shallower areas as long as the lake temperature is not too warm.

Whilst 17% of eels were estimated to be moving out of the Horomaka kōhanga, this will only be depleting the customary eel resource in the kōhanga if a similar percentage are not moving back into the area (note, eel immigration into the kōhanga was not assessed as part of this work). Commercial fishers caught 3.8% of all tagged eels which equates to commercial fishers capturing 22% of the eels that leave the kōhanga within a season (based on the results obtained from the population estimate). Assuming 83% of the eels stay in the kōhanga, and that 78% of the emigrating eels are not captured in the vicinity of the kōhanga, then with presumed immigration, the effect of commercial fishing on eel stocks in the Horomaka kōhanga may not be substantial. However, under different lake conditions (e.g., lower lake levels and warmer water temperatures), there could be a substantial reduction in habitat area in the Horomaka kōhanga (as well as Greenpark Sands, see Figure 4-1) resulting in these eels being concentrated into a smaller area and likely having to move greater distances to satisfy their energy requirements since their food resources will be under greater pressure and metabolic costs to individual eels will be higher. Lower lake conditions could substantially alter eel movement into and out of the Horomaka kōhanga at a time when eel abundance would likely be higher; under these conditions commercial fishers might be far more effective (i.e., markedly increased CPUE) and therefore be having a detectable impact on the eel stocks that would typically have been contained within the Horomaka kōhanga. Future work during a time of lower lake levels would be needed to assess this issue and determine if our survey results from a single season are reflective of other years.

Figure 4-1: Satellite images of Te Waihora at different lake levels. The top image was taken during the initial tagging work in 1st November 2015. The bottom image was from a drier year (2nd January 2014).

4.3 Knowledge gaps and future work

The number of eels less than 400mm in the kōhanga was not assessed during the study because of the practical limitations of reliably sampling and tagging small eels. Despite the limitations of sampling smaller eels using fyke nets with standard 12mm mesh, smaller eels still comprised 28% of the total catch. Fish of this size may be more resident once settled in the Horomaka kōhanga because compared to larger eels, smaller eels tend not to move large distances once they are in suitable habitat (Jellyman et al. 1995). The Horomaka kōhanga will act as nursery ground for many small eels although whether the absence of commercial fishing activity within the kōhanga results in improved abundance of small eels is unknown. Accordingly, this area may be important for male shortfin migrants because they migrate out to the ocean at small sizes (35 to 45cm) after only 14–15 years (Jellyman & Todd 1998). The commercial fishery targets small shortfin migrant males within the Horomaka kōhanga, which means male shortfins located within the kōhanga will be susceptible to commercial harvests during their outgoing migration.

There may have been an effect of the catching/handling/tagging process on eel behaviour in the Horomaka kōhanga. Eel recapture success in the 10 days after tagging was only half of what would have been expected (if eel recapture was proportional to sampling effort) which could suggest that either capture, handling or tagging resulted in a behavioural response where eels may have ceased or reduced their movement for a short time. Whilst we are not aware of previous studies recording short-term movement cessation following Floy tagging of eels, it is interesting to note that Jellyman et al. (1996) recorded the opposite short-term effect when externally attaching large radio tags (66mm long x 16mm diameter secured by monofilament loops onto the back of large eels). Attaching radio tags resulted in an extensive initial movement by eels, after which, movement was relatively localised for the remainder of the study. The two tags are not particularly comparable but it is interesting that the behaviour following tagging was so contrasting (i.e., 'sulking' after insertion of a Floy tag compared to exaggerated 'shake it loose' movement following attachment of a large external tag). Results from both studies suggest that for any future work, movement data for a short time after tagging (e.g., 1 week) may need to be ignored if the purpose of the work is to examine 'typical' movements within a particular area of the lake.

As the level of effectiveness of the Horomaka kōhanga in protecting the customary and recreational fishery resource is of interest to Ngāi Tahu, the frequency of emigration and immigration events by eels into and out of the Horomaka kōhanga warrants further investigation. There is an opportunity to capitalise on the tagging work already done, by carrying out another large scale fyke netting project to examine movement in the tagged fish now 1+ years later. Additional survey work is probably the most cost-effective method for addressing this issue but it may only partly address some concerns. The decision to go with a broad-scale tagging approach to address the objectives proved to be the correct choice for this project. That said, NIWA recently undertook some preliminary acoustic tag testing in Te Waihora (November 2016) to examine whether this method could be used for future eel work in the lake (given advice from the acoustic tag manufacturer was that it may not be a viable approach). The usefulness of this type of tag relates to the distance over which tags can be detected; longer detection distances allow a larger area to be monitored improving the quality of the movement data collected and reducing the overall cost. The factors that reduce detection distance are low water clarity (i.e., high amounts of suspended organic material), soft lake bed sediments and shallow water depth. Our preliminary detection distance trials indicated that the receiving devices (that would be deployed in the lake to continually monitor for tag detections) could detect tags over a distance of 125m (see Appendix C). Thus, they could be used to examine movements in and out of the kōhanga although for full coverage along the boundary line approximately 20 receivers would be needed (assuming reduced detection distance in the shallower water was compensated for by increased detection distance in the deeper water). Whilst this is an option for future consideration, it is important to note that although NIWA has a number of receiving devices, each acoustic tag costs around NZ$500 which lends itself to a much different study design.

Future habitat enhancement work may help encourage tuna to remain within the Horomaka kōhanga. The present study suggests that 17% of the eels within the Horomaka move out of the protection of the reserve within four months. Installing some permanent habitat structures in the reserve may encourage tuna to stay around these structures because they offer some cover that is not available in other areas of the lake. These structures may then encourage tuna to form more localised resident populations and potentially reduce movement out of the reserve. Research would need to be done into what structures would be the most beneficial to install and in what areas and habitat types (i.e., depths, substrate types). Any structures would also need to be marked to ensure they do not pose any boating hazard. Small brush piles are currently being installed in the macrophyte reestablishment area (under the Macrophyte Reestablishment project being managed by Mary de Winton), which may provide an opportunity to monitor fish population changes. A pre-macrophyte fish survey has already been done in this area as part of the D5 programme, which will partially address this question when a follow-up survey is done in the same area after macrophytes have been established. Debris clusters have been used by other iwi in New Zealand as a means of catching small eels at areas such as waterfalls (Downes 1918), which suggests this may be a useful form of habitat enhancement for Ngāi Tahu to pursue. A previous study by Jellyman & Chisnall (1999) used small Manuka debris clusters (Figure 4-2) to successfully sample small eels. The eels entered the debris clusters and congregated in them, which further suggests that habitat enhancement may be a profitable avenue of future research.

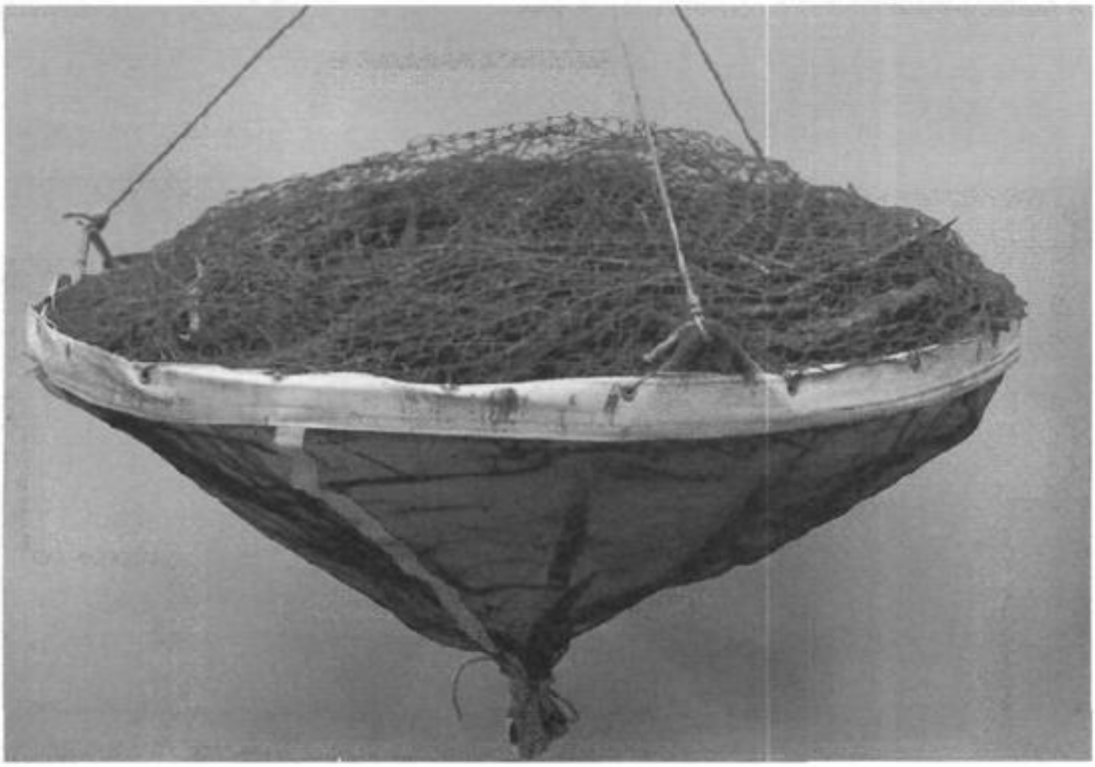

Figure 4-2: Manuka brush collectors used in Te Waihora by Jellyman & Chisnall (1999).

4.4 Summary

The following list is intended to provide Ngāi Tahu with quick access to the main findings of the study without the need to read the main body of the present report.

- Eel catches increased significantly over the seven-week tagging period, which appears to be associated with an increase in water temperature.
- Eel numbers and biomass have more than doubled in the Horomaka Kōhanga over the last 20 years, which is consistent with the rest of the lake.
- Large shortfin eels (>600mm) were most abundant in shallower waters (<1m) and smaller eels tended to dominate catches in the deeper water. A combination of declining CPUE abundance and eel length with increasing lake depth resulted in CPUE weight (kg/net/night) declining ten-fold over the range of depths sampled (0.4 to 2.2m).
- We estimated the population size (±S.E.) of shortfin eels ≥400mm in the Horomaka kōhanga to be 75,161 (± 9,501). Based on the population size estimate and our length-frequency data, it is estimated that the weight of shortfin eels >400mm in the Horomaka kōhanga is 29.09 (± 3.67) tonnes.
- NIWA recapture data showed that most of the tagged eels (63%) were recaptured within 2000m of their release location, suggesting that shortfin eels show some short-term site fidelity. Although extensive movements were possible as one tagged eel

captured by a commercial fisher showed the eel had moved over 20km to the outlet of the lake within 16 days (1,269m per day).

- Eel movement out of the kōhanga was examined in March/April 2016 with 60 fyke nets set up to 5km either side of the Horomaka kōhanga boundary. There were 52 tagged eels recaptured during the survey and 83% (43 tagged eels) of the recaptures were within the Horomaka kōhanga. Whilst sampling effort was standardised inside and outside the kōhanga 1,651 shortfin eels were caught inside the kōhanga compared to 1,196 eels outside; regardless of whether inside or outside the kōhanga two-thirds of the eels caught were 400mm or larger. This showed that catch rates were higher inside compared to immediately outside the Horomaka kōhanga.

- The largest tuna were most common in the shallower parts of the kōhanga, which is also where the highest catch rates (i.e., CPUE) were found. These shallow areas with high catch rates may be valuable to customary and recreational fishers who do not have access to a boat. Whilst 17% of the eels were estimated to be moving out of the Horomaka kōhanga, the customary eel resource in the kōhanga will only decline if a similar percentage of eels do not move back into the area; which was not assessed as part of this work.

5 Acknowledgements

We thank Greg Kelly, Julian Sykes and Don Jellyman for assistance with boating, eel capture and tagging. Valuable discussions were held with Don Brown about changes in the tuna fishery through time when discussing WTW objectives in the lake. Julian Sykes created the CPUE interpolation figures (Figures 3.4, 3.5). Funding for this project was provided by the Whakaora Te Waihora Partners and co-funding was provided by NIWA under Freshwater and Estuaries Programme 6 (Ensuring ecosystem health) (2015/16 SCI) for field work and report preparation.

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Appendix A Signage identifying tagged eels

HAVE YOU CAPTURED AN EEL WITH A YELLOW TAG?

NIWA are conducting scientific research in Te Waihora/Lake Ellesmere and have tagged a number of shortfin eels larger than 400 mm. The tags are about 5 cm long and are shown below.

(Yellow NIWA tags will be numbered 0001 to 8000)

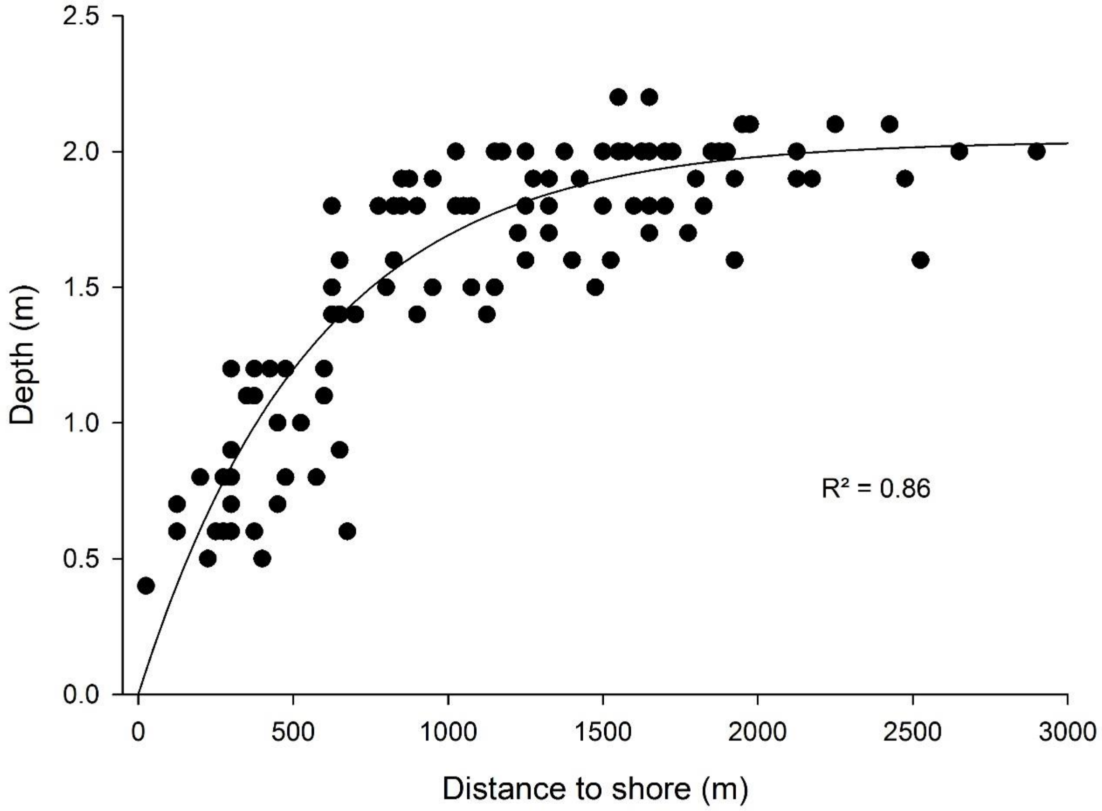
If you capture one of these eels could you please inform Shannan Crow at NIWA Christchurch (03 343 7868). The tags do not affect the eels and tagged eels can still be consumed (although if you are willing to release any tagged eels, after recording the tag numbers, it would be much appreciated).

WHAT TO DO IF YOU CAPTURE A TAGGED EEL?

- Record the tag numbers (it should have 2 tags but could have lost 1 tag)
- Note the approximate location in the lake where it was caught
- Record the date it was caught
- Release eel (if you are happy to do so)
- Ring Shannan @ NIWA (03 343 7868)

Tags should be located towards the front of dorsal (top) fin on either side of fin

Appendix B Relationship between distance to the shore and lake depth within the Horomaka kōhanga



Appendix C Testing of acoustic tag detection range in Te Waihora

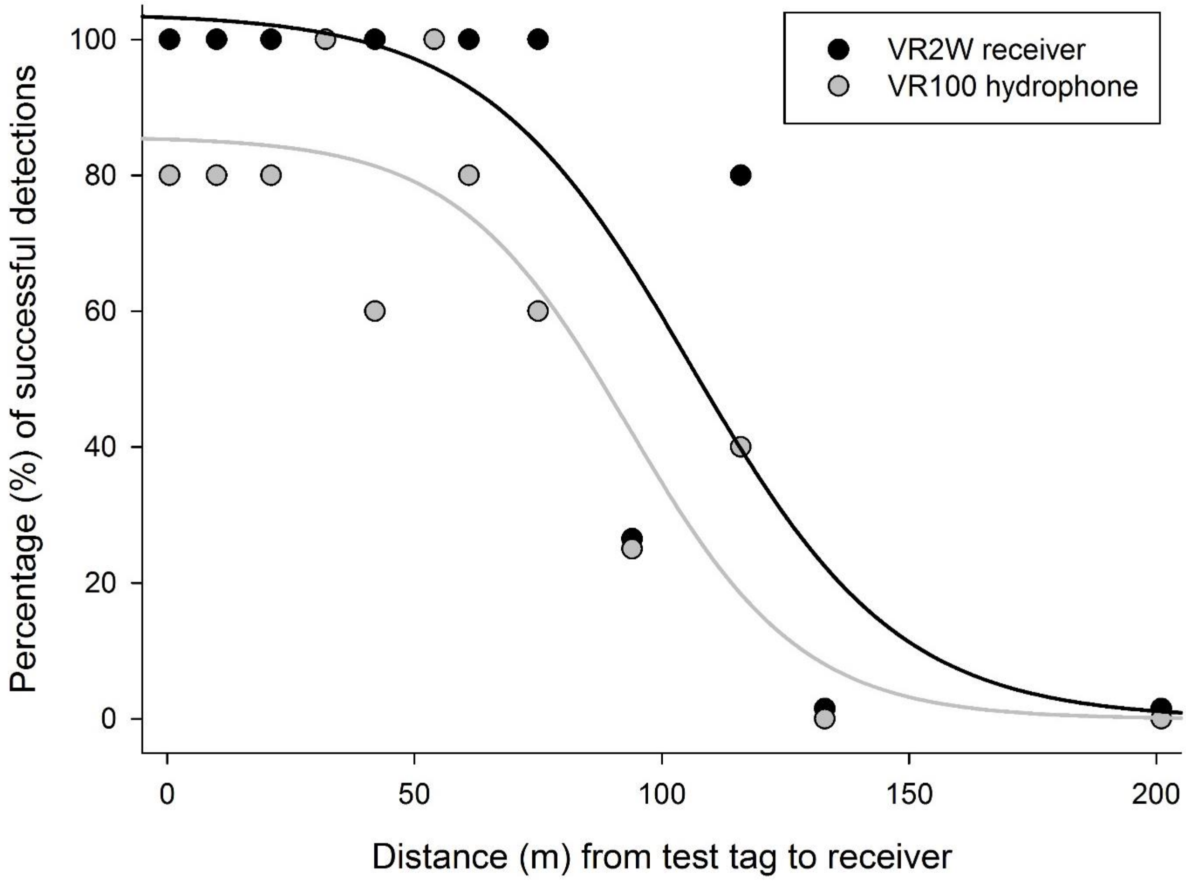
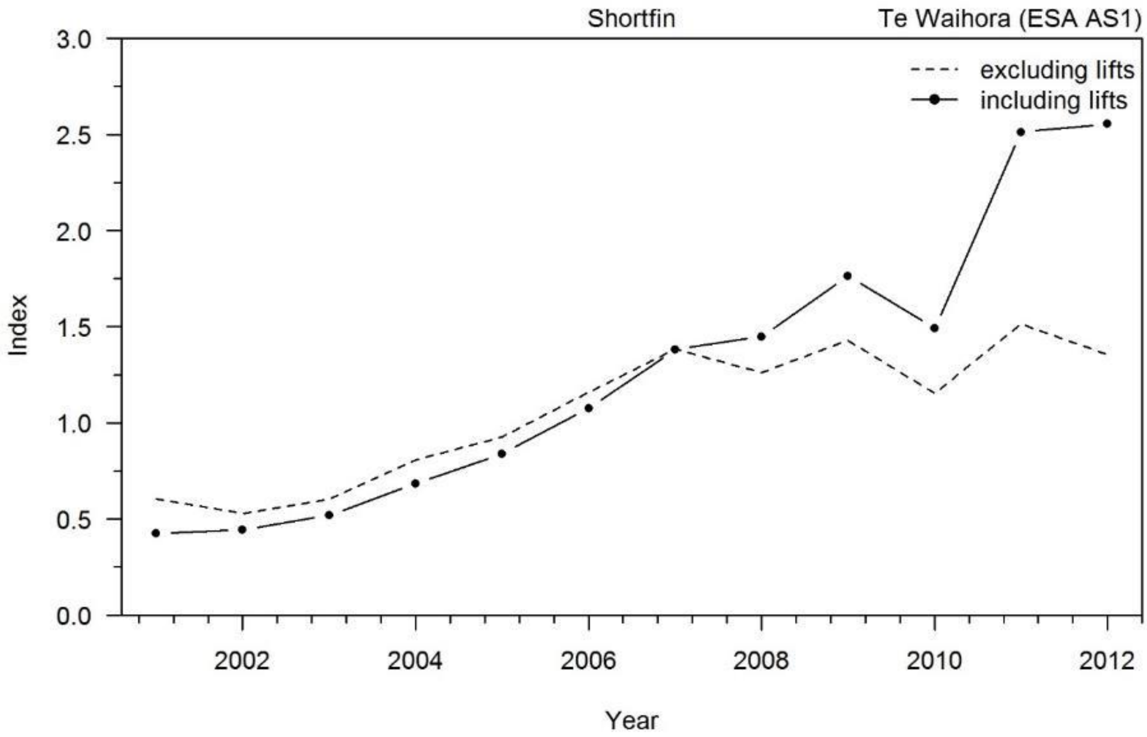


Figure C-1: Testing the detection range (m) of an acoustic tag in Te Waihora using two different detection devices. The tag being tested was a high power V13 tag manufactured by VEMCO. The tag was placed on the bed of the soft-bottomed lake at a depth of 0.7m. The different devices used for tag detection are shown below. The VR100 hydrophone is typically used for real-time detection whereas the VR2W receivers are the devices left in place in the lake for continuous monitoring. The testing was undertaken at Timber Yard Point.

Appendix D Changes in CPUE observed in commercial catch from Te Waihora from 2000–2013 (Beentjes & Dunn 2014)



Standardised CPUE indices for shortfin eels in AS1 (lake) for the years 2001–2012. The base model includes lifts and the sensitivity model excludes lifts. 2001 = 2000–01 fishing year. The index shows a unitless value that represents relative changes in catch rate between years from the lake. These results are only shown for one of the two fishing return areas in Te Waihora called AS1 (see Appendix E), which covers most of the lake.

Google satellite image of Te Waihora. Annotated on the map are eel statistical areas AS1 (lake), AS2 (adult migration area) and the general location of the lake opening. AS1 also includes the lake catchment of Selwyn and Halswell Rivers.