Te Waihora Mahinga Kai: a compilation of data and summary of existing research on freshwater fishes in Te Waihora

Prepared for the Whakaora Te Waihora Partners

September 2013

Authors/Contributors:
Shannan Crow
Marty Bonnett

For any information regarding this report please contact:

Shannan Crow
Scientist
Freshwater Ecology Group
+64-3-343 7868
shannan.crow@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street
Riccarton
Christchurch 8011
PO Box 8602, Riccarton
Christchurch 8440
New Zealand

Phone +64-3-348 8987
Fax +64-3-348 5548

NIWA Client Report No:	CHC2013-097
Report date:	September 2013
NIWA Project:	ENC13509

Contents

Tables

Figures

Reviewed by

Dr Dave Rowe

Approved for release by

Dr Helen Rouse

Executive summary

Te Waihora (Lake Ellesmere) is a taonga to Ngai Tahu, providing them with a valuable source of mahinga kai. Te Waihora is also nationally significant because of the customary and commercial fisheries supported by this lake. The value of the lake has resulted in many research projects being carried out on fishes, but these studies have collected and stored data in different ways. A synthesis of these data and results into a single resource would outline the current state of research knowledge for the fishes in the lake.

The aims of the present study were: 1. synthesise published and unpublished data on mahinga kai fishes in Te Waihora, and 2. present these results alongside information from other reports and publications. This summary of existing knowledge on mahinga kai species only relates to published and unpublished scientific research in the lake and does not cover the customary knowledge held by Ngai Tahu.

The commercial eel fishery is focussed on shortfin eels (longfin eels are not harvested), and is unique in that commercial fishers harvest migrating shortfin males. Reserve areas extend for a radius of 1.2 km around the mouth of the Irwell, Selwyn, LII and Halswell Rivers, and Harts Creek. These reserves are beneficial for eel populations, particularly for inshore areas where eel movement is limited and individuals are more likely to remain within the protected area.

Te Waihora also supports a significant, but highly variable flatfish (patiki) fishery. Annual catches vary from about 3 tonnes to more than 200 tonnes. This variability in the flatfish catch is likely to be caused by inter-annual differences in recruitment associated with flatfish spawning success or the lake not being open to the sea. The yellow-eyed mullet fishery is highly variable and small.

Other migratory fish species (e.g. common bullies, inanga and smelt) in the lake are less dependent on lake openings, because they can form localised self-sustaining land-locked populations. However, common bullies are a key prey species for other fish present, and inanga contribute to whitebait fisheries. The proportion of the total population that is sustained by land-locked spawning is not well understood, but this will be explored during an upcoming research project being done under the Fisheries Management and Enhancement Project.

While mechanical lake opening can enhance fish migration, water level reductions during openings can reduce fish habitat. High lake levels are generally beneficial for fishes, but low lake levels may lead to several detrimental environmental changes such as increased turbidity and reduce littoral habitat.

Inshore lake habitats are important to many of the fish species in Te Waihora and these are influenced by changes in quality and quantity of water entering the lake. The water quality and quantity of the tributaries has declined over the past decade as a consequence of low flows and intensification of land use and, the size of the ephemeral zone in the Selwyn River is increasing at an average of 0.6 km year^{-1}. This report has consolidated data of fishes in Te Waihora, established a fish database and provided an initial summary of fish. Key information gaps for future research have been identified and linked to the Fisheries Management and Enhancement Project addressing these knowledge gaps within the Whakaora Te Waihora Program.

1 Introduction

Te Waihora (Lake Ellesmere) is a taonga to Ngai Tahu (Figure 1-1), providing a major source of mahinga kai and mana (Te Runanga of Ngai Tahu and Department of Conservation 2005). Te Waihora covers an area of approximately 20 000 ha and is highly turbid (Secchi depths < 0.2 m; Glova and Sagar 2000) with the shallow lake being dominated by soft substrates. As part of the Ngai Tahu Settlement Act, the Crown vested the bed of the lake with Ngai Tahu. The lake is nationally significant because it supports a customary and commercial fishery. It contributes about a quarter of the national commercial eel catch and supports a significant flatfish/flounder (patiki) fishery.

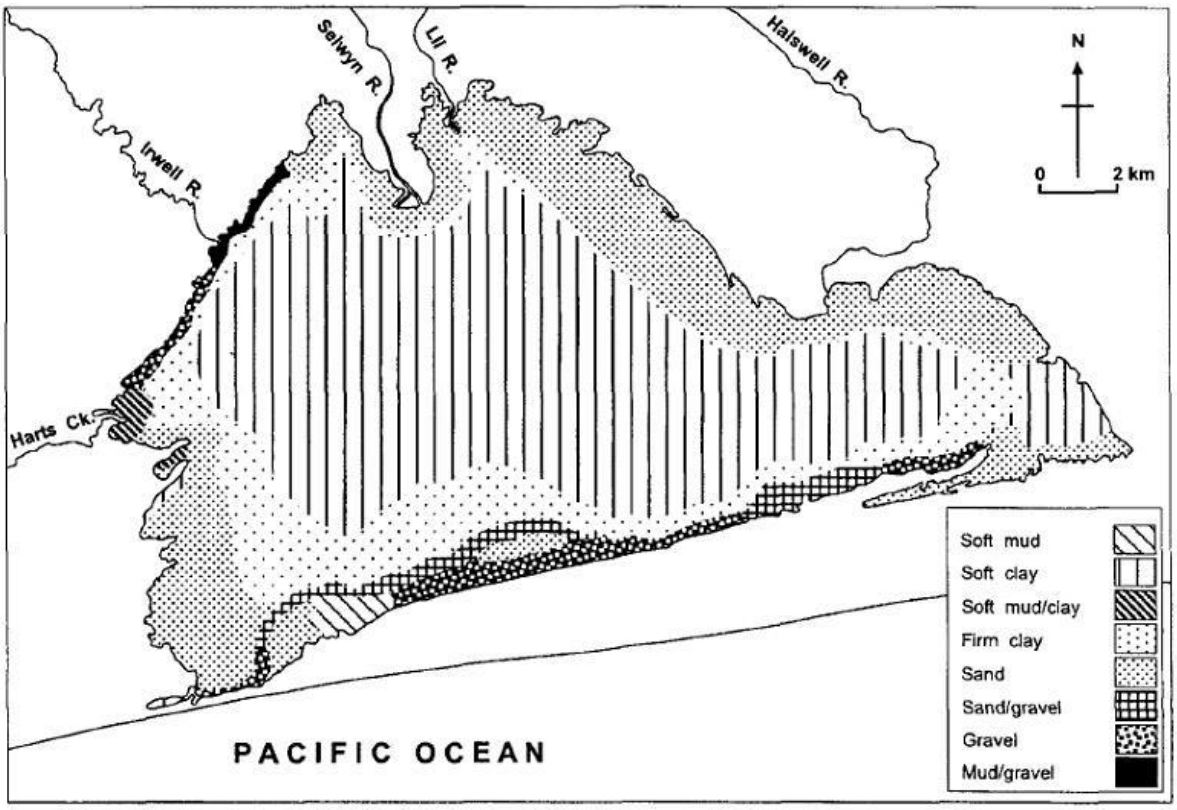

Figure 1-1: Outline of the major tributaries and habitat types present in Te Waihora. From Glova and Sagar (2000)

Fishes and fisheries of Te Waihora have been investigated by many different researchers through the years with much of this research focused on eels (tuna) and flatfish (patiki). Subsequently, a multitude of data have been recorded for these species, but the information has been stored in many different formats and files, which are not available in a single location. Synthesising these data into a single resource would establish a database, allow existing fish knowledge to be summarised, allow analysis to detect any trends in fish population over time and identify information gaps that need to be addressed. The consolidated datasets could then be used to monitor the success future management initiatives in Te Waihora.

The objectives of the present study were: 1. synthesise published and unpublished data on mahinga kai fishes in Te Waihora, and 2. present these results alongside information from other key reports and publications. Specifically, the first objective aimed to consolidate the available datasets on fishes and fisheries collected from Te Waihora and its tributaries into coherent and usable datasets for future use. Consolidation of the existing data is a continuing task as new work is completed, but this synthesised dataset could be used as a template for recording fish and fisheries data from Te Waihora in the future. The second objective aimed to generate new results from these integrated datasets and utilise these findings and previously published research to summarise of the current scientific knowledge of size, abundance, catch, growth and recruitment of the key mahinga kai species: eels (tuna), flatfish (patiki) and mullet (aua), inanga, and smelt. Current knowledge of bullies was also summarised because Ngai Tahu view this fish as a key prey species that help maintain the abundances of tuna and patiki. This summary of existing knowledge on mahinga kai species only relates to published and unpublished scientific research completed in the lake and does not cover the customary knowledge held by Ngai Tahu.

This report is the first task of the Fisheries Management and Enhancement Project within the Whakaora Te Waihora Research Program funded by the Whakaora Te Waihora Partners (Environment Canterbury and the Te Waihora Management Board). Where appropriate, this report identifies areas that require further research and any links to projects within the Fisheries Management and Enhancement Project that will be addressing these knowledge gaps.

2 Methods

Three datasets were assimilated from existing published and unpublished resources: one dataset of individual fish measurements (e.g. lengths, weights), one dataset of commercial catch data and one dataset of standardised fish abundances. The exact data contained within each of these datasets are covered individually in the following sections.

2.1 Dataset of individual fish measurements

The first dataset of individual fish measurements was generated from university theses (e.g. Todd 1974; Ryan 1978), journal articles (e.g. Glova and Sagar 2000; Jellyman 2011), and reports (e.g. Hardy 1989; Jellyman 2011). Electronic and paper records were used to compile data from 50,000 fishes caught between 1961 and 2010. This table was stored in a Microsoft Excel spreadsheet, with each row containing the following information for each fish recorded:

1. **Catchment**. Describes the location of the record; i.e. “Lake Ellesmere”, or a tributary of the lake (e.g. “Harts Creek”).
2. **Location**. Describes a more specific location for the record, if known, (e.g. “Timberyard Point”).
3. **Date**. Date of fish capture (day/month/year).
4. **Year and Month** if the full date was not available**.**
5. **Fishing method**. Describes the method used to catch the fish for this record, (e.g. “fyke net”).
6. **Species**. Species of fish recorded.
7. **Length**. Length of fish in millimetres.
8. **Weight**. Weight of fish measured in grams if known. Some weights were also estimated from a standard length-weight relationship by the original authors which have also been included
9. **Sex**. Sex of fish if known.
10. **Age.** Age of fish, in years, if known.

Information for all of these columns were not available for all fish. These gaps are indicated by blank cells in the datasheet (see Table 2-1 for an example of the excel format).

Table 2-1: Example of the fields in the database of individual fish measurements.

Catchment	Location	Date	Year	Month	Fishing method	Species	Length (mm)	Weight (g)	Sex	Age (years)
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	569	330	female	23
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	458	160	female	15
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	589	372	female	22
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	537	312	female	17
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	690	762	female	20
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	629	480	female	19
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	604	465	female	21
Lake Ellesmere	Kaitorete Spit	15/03/1974	1974	3	fyke net	shortfin eel	540	298	female	16

2.2 Dataset of annual commercial catch

Annual commercial catch data for Te Waihora were sourced from records held by the Ministry for Primary Industries? (MPI) and compiled into a single Microsoft Excel table. This contained data on the total annual commercial catches in tonnes for eels, flatfishes and yellowed mullet. Data for annual catch in Te Waihora are held by MPI and stored by fishing year (February 1 to January 31), but for clarity, results in tables and figures were presented as calendar year. Inaccuracies may exist in this dataset because of errors in coding by the catch recorders. For example, there are some catch landing records of grey mullet (*Mugil cephalus*), but this species has not been recorded elsewhere and are possibly yelloweye mullet that have been miscoded. Raw commercial catch data are available in Appendix A.

2.3 Dataset of fish abundance

The dataset outlined in 2.1 was used to generate information of fish abundance. Each entry in this dataset contained data on the numbers of each species caught from a single net/trawl, date, location, method and area fished. These data were then used to calculate numbers of fish caught/net/night or numbers of fish/m^2. These measures of catch-per-unit-effort (CPUE) provide an index of abundance specific to each sampling method used. Assuming that CPUE is directly related to population size (and is not influenced by other factors), then it provides a valid way of detecting changes in relative abundance over time.

2.4 Analysis

Datasets outlined in sections 2.1 to 2.3 were used to generate various plots of length-frequencies and abundances for different species which are presented along with published plots in Section 4 summarising research information available of each mahinga kai species.

Generalised Linear Models (GLM) were used to examine trends over time in shortfin eel length, condition and growth rate. These GLM were carried out on 8,618 shortfins from the dataset in Section 2.1, because these were the only individuals that contained data for all variables. GLM could not be carried out on any other species because there were insufficient data. Data on growth rates in freshwater were calculated for all shortfins by estimating the mean yearly length increases in freshwater (mm/year). This calculation was completed by subtracting the mean length at entry to freshwater of 60 mm from the total length of the fish and then dividing by the fish's age.

GLM were carried out between each of the three responses (length, condition and growth rate) and year, but this relationship was standardised for differences in the ages and sexes sampled between years. This standardisation was required because the data available for each year had differing proportions of fish ages and sexes present, which could confound the relationship between the responses and year. We used the standardised GLM approach outlined in Vignaux (1994), to control for the effects of these confounding variables and to present a standardised index (unitless) of the relationship between each of the responses and year. The variation explained by year and the two standardising variables were recorded for each GLM.

3 Overview of individual fish measurements

The dataset of individual fish measurements contained information from a total of 50,604 fishes and 12 species (Table 3-1). Most of these records were from shortfin eels (n=42,112), with common bullies being the second most abundant fish (n=3,102), followed by longfin eels (n=1,198), yellowbelly flounder (n=1,108) and black flounder (n=1,026). All remaining fishes had fewer than 1000 entries. Not all entries contained information for all fields, but 8,618 entries were available for shortfins where data were entered for all fields. This was the largest complete dataset for a single species.

Table 3-1: Numbers of individual fish lengths by species.

Common name	No. of records
Black flounder	1026
Common bully	3102
Common smelt	929
Goldfish	76
Inanga	46
Longfin eel	1198
Shortfin eel	42112
Sand flounder	615
Sprat	62
Unidentified eel	123
Yellowbelly flounder	1108
Yelloweye mullet	207
Total	50604

4 Summary of available information on mahinga kai in Te Waihora

The following sections summarise the existing information available for each mahinga kai species and present previously published information alongside new results generated using the datasets outlined in the methods section.

4.1 Fish species of Te Waihora

Te Waihora catchment contains a diverse range of fishes with a total of 46 species recorded from the lake and its major tributary the Selwyn River (Table 4-1). Lists of the species recorded from the lake have been provided in Ryan (1974), Hardy (1989), Taylor (1996), and Jellyman and Smith (2008), but the latter is the most comprehensive and is reprinted in Table 4-1. Of the 46 species recorded from Te Waihora, 26 are freshwater/esturine fishes while the remaining are marine species. Of the freshwater species not resident in Te Waihora, many are in transit from the sea to riverine habitats. Hence the lake provides an important migration corridor for many species. Most long-term resident fish species in the lake are tolerant of varying levels of salinity (euryhaline) (i.e. eels, flatfish, smelt, inanga, common bullies). While most flounder species and mullet are abundant, the remaining marine species are only occasionally present during periods of extended lake opening. In 1997 catfish were recorded once around the Halswell area, but have never been recorded since.

Species abundance in the lake is dominated by six orseven species depending on the time of the year. Many of the 46 fish listed in Table 4-1 are recorded only as “present” or “often found”, but six species were recorded as abundant by Jellyman (2012). These abundant species were shortfin eels, yellow belly flounder, black flounder, sand flounder, yelloweye mullet and common bullies. Glova and Sagar (2000) also report these six fishes and common smelt as being the most abundant of the 13 species caught from around Te Waihora with fine-mesh fyke nets in 1995 (Table 4-2). Catches reported from Jellyman (2012) collected in 2008 with seine nets and otter trawls found that common bullies were the numerically dominant species in the lake, comprising > 90 % of total fish abundance. Also despite their small size compared to species like eels, common bullies made up about 44% of the fish biomass (total weight) in the lake (Jellyman 2012).

Table 4-1: Fish species recorded from Te Waihora. Y = a diadromous species Y[1] indicates can be voluntarily non-diadromous, Y[2] indicates usually non-diadromous but can also have sea-run stocks * = recorded, ** = often found, *** = common. (From Jellyman and Smith, 2008).

Common name	Scientific name	Diadromous	Te Waihora	Selwyn catchment
Freshwater/estuarine species				
Yelloweye mullet	*Aldrichetta forsteri*	Y	***	*
Shortfin eel	*Anguilla australis*	Y	***	***
Longfin eel	*Anguilla dieffenbachii*	Y	**	**
Goldfish	*Carassius auratus*		**	*
Torrentfish	*Cheimarrichthys fosteri*	Y	*	*
Giant kokopu	*Galaxias argenteus*	Y	*	
Koaro	*Galaxias brevipinnis*	Y	*	
Banded kokopu	*Galaxias fasciatus*	Y	*	
Inanga	*Galaxias maculatus*	Y	**	*
Canterbury galaxias	*Galaxias vulgaris*			**
Lamprey	*Geotria australis*	Y	*	*
Upland bully	*Gobiomorphus breviceps*			***
Common bully	*Gobiomorphus cotidianus*	Y [1]	***	**
Giant bully	*Gobiomorphus gobioides*	Y	*	*
Estuarine triplefin	*Grahamina sp.*	Y	*	
Canterbury mudfish	*Neochanna burrowsius*			*
Common smelt	*Retropinna retropinna*	Y[1]	**	*
Black flounder	*Rhombosolea retiaria*	Y	***	
Koura	*Paranephrops spp.*			*
Perch	*Perca fluviatilis*		*	*
Brook char	*Salvelinus fontinalis*			*
Brown trout	*Salmo trutta*	Y[2]	*	**
Rudd	*Scardinius erythrophthalmus*		*	
Catfish	*Ameiurus nebulosus*		*	
Tench	*Tinca tinca*		*	
Chinook salmon	*Oncorhynchus tshawytscha*	Y	*	
Marine species				
Kahawai	*Arripis trutta*		*	
Yellowbelly flounder	*Rhombosolea leporina*		***	
Sand flounder	*Rhombosolea plebeia*		***	
Greenback flounder	*Rhombosolea tapirina*		*	
Common sole	*Peltorhamphus novaezelandiae*		*	
Sprat	*Sprattus antipodum*		*	
Hake	*Merluccius australis*		*	
Sand stargazer	*Crapatalus novaezelandiae*		*	
Estuarine stargazer	*Leptoscopus macropygus*		*	
Sand eel	*Gonorynchus gonorynchus*		*	
Red cod	*Pseudophycis bachus*		*	
Basking shark	*Cetorhinus maximus*		*	
Rig	*Mustelus antarcticus*		*	
Elephant fish	*Callorhynchus milli*		*	
Spiny dogfish	*Squalus acanthias*		*	
Skate	*Raja nasuta*		*	
Globefish	*Contusus richei*		*	
Spotty	*Pseudolabrus celidotus*		*	
Warehou	*Seriolella brama*		*	
Red gurnard	*Chelidonichthys kumu*		*	

Table 4-2: Total numbers and length ranges of the fish species sampled in Te Waihora during January-March 1995, using fine-meshed fyke nets. (TL = total length; FL = fork length; - = not measured.) * = subsamples measured. (From Glova and Sagar 2000).

Species	N	Length (mm)
common bully	157106*	11-135 (TL)
common smelt	5576*	21-93 (FL)
inanga	3564*	60-134 (FL)
shortfin eel	2171*	62-830 (TL)
black flounder	726	15-310(TL)
yellowbelly flounder	486	15-320 (TL)
sand flounder	285	30-325 (TL)
sprat	87	59-105 (FL)
longfin eel	8	-
yelloweye mullet	5	155-292 (FL)
brown trout	3	220-281 (FL)
goldfish	3	73-240 (FL)
torrentfish	1	45 (TL)

Table 4-3: Numbers of fish caught in seine hauls at Fisherman's Point, Taumutu and by otter trawl at Timberyard Point, 2005-08. (Jellyman 2012, NIWA unpublished data).

Species	Seine		Trawl	
	Number	%	Number	%
common bully	45855	76.83	6129	90.69
common smelt	12859	21.55	78	1.15
sprat	448	0.75	1	0.01
yellow belly flounder	217	0.36	239	3.54
shortfin eel	78	0.13	211	3.12
black flounder	63	0.11	33	0.49
inanga	56	0.09		
sand flounder	47	0.08	26	0.38
goldfish	42	0.07	37	0.55
whitebait	11	0.02		
torrentfish	3	0.01		
stargazer	2	0.00		
brown trout	1	0.00		
yellow eye mullet	1	0.00	4	0.06
Total	59683	100.00	6758	100.00

4.2 Freshwater eels (tuna)

Two species of freshwater eel are found in Te Waihora and its tributaries; the shortfin eel (shortfins) and the longfin eel (longfins). Shortfins are found all around New Zealand and in eastern Australia, Tasmania, and New Caledonia. Longfins are endemic (i.e. unique to this country), and are found only on the three main islands of New Zealand and in the Chatham Islands. Both species are diadromous, with adults moving out of freshwater near the end of their lives to spawn at sea. Juveniles arrive in New Zealand inshore waters as glass eels from about July to December (Jellyman 1977), but the main months for glass eel migration into Canterbury freshwaters is September-October for shortfins, and August-September for longfins. The eel population of Te Waihora was dominated by shortfins in results of Glova and Sagar (2000), with shortfins being c. 270 fold more abundant than longfins. Recent investigations of eel populations in the tributaries of Te Waihora indicate that these areas are dominated by longfins (Jellyman and Graynoth 2010).

There has been growing concern for the longfin eel populations in recent years by Māori, the New Zealand Conservation Authority, environmental scientists and local government representatives. In March 2013, a petition calling for a moratorium on commercial fishing of longfin eels was presented to Parliament. A recent investigation into the status and management of the longfin eel (Parliamentary Commissioner for the Environment 2013) recommended that the commercial catch of longfin eels should be suspended until stocks are shown to have recovered, and that the Minister of Conservation should direct his officials to increase the protection for longfin eels and other threatened migratory fishes. Longfin eels are also classified as “declining” by the Department of Conservation (DoC) (Allibone et al. 2010). In light of these concerns, longfins in Te Waihora are now voluntarily released by commercial fishers.

4.2.1 Eel size

Jellyman (2012) suggested that there has been little change in shortfin length over the past 30 years. A standardised GLM analysis of shortfin length over years using the dataset in section 2.1 supports Jellyman (2012), by showing that the standardised relationship between length and year did not change throughout the time series (Figure 4-1). This GLM explained 74.4% of the total variation with, year explaining 17% of the variation while the addition of age and then sex increased the total variation explained to 65% and 74% respectively (Table 4-4).

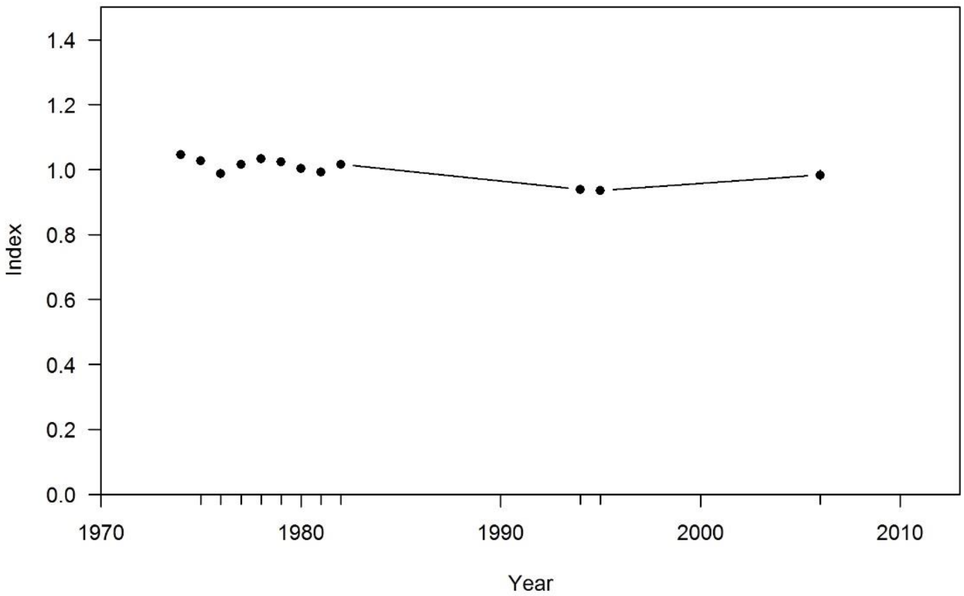

Figure 4-1: Standardised relationship between shortfin length and years using the dataset of individual fish measurements. Note that standard errors for each year were covered by the circles. The index axis is a unitless measure that shows the relative standardised lengths between years.

Because there is little inter-annual variation in the size of eels, the data for each year can be combined. The overall, Length-frequency distributions of eels show a peak in the abundance of size classes around 400 mm for both species, but this is much more pronounced for shortfins (Figure 4-2). While shortfin catches are clearly dominated by fish around 400-420 mm and show a steep decline above these lengths, longfin catches have higher relative abundances of the larger size categories from 500-800 mm.

Standardised GLM of shortfin condition over years showed some variation between years, but there was no increasing or decreasing trend over decadal time scales (Figure 4-3). This GLM explained a total of 71% of the variation with year explaining 20% while the addition of age and sex to the GLM increased the variation explained to 62% and 71% respectively (Table 4-4).

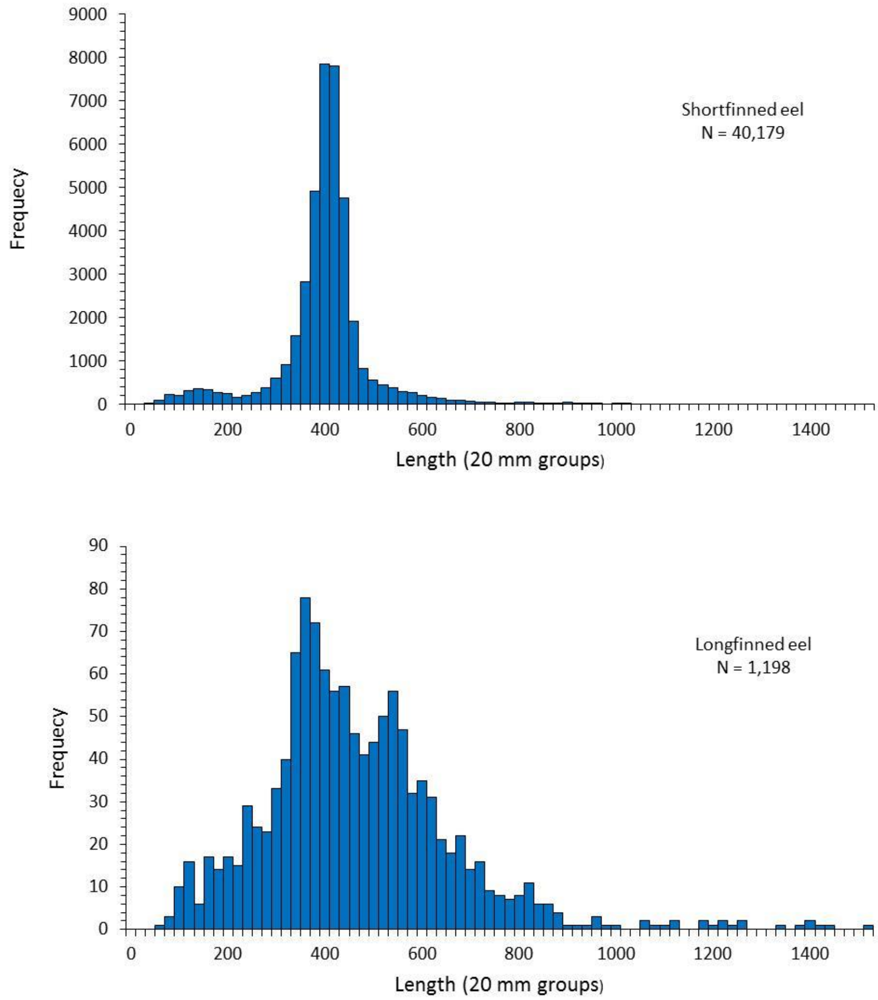

Figure 4-2: Length frequencies (20 mm size groups) of shortfins (upper) and longfins (lower) caught by in Te Waihora and its tributaries from 1974 to present. Plots were generated using the dataset outlined in Section 2.1.

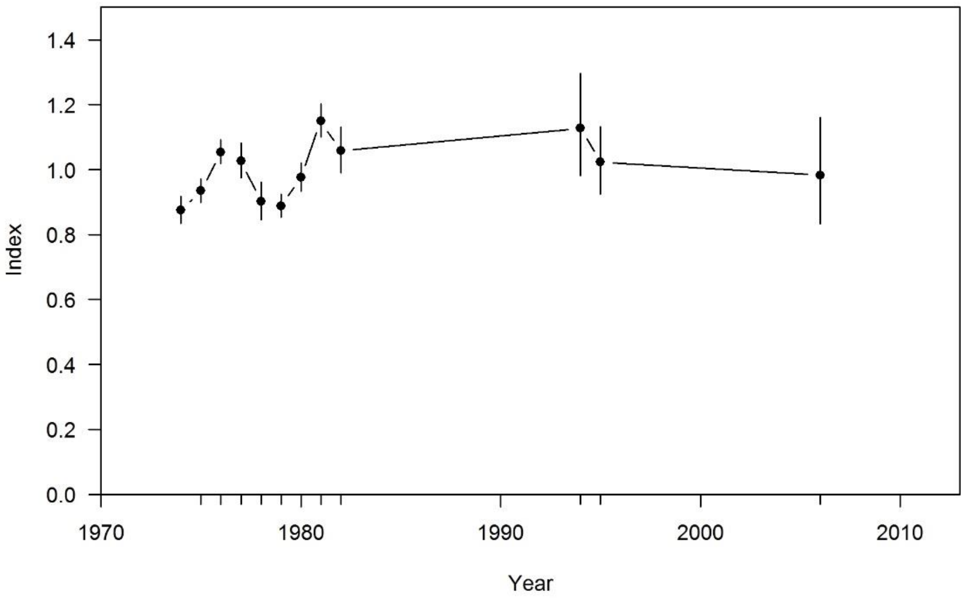

Figure 4-3: Standardised relationship between shortfin condition and years using the dataset of individual fish measurements. The index axis is a unitless measure that shows the relative standardised condition [length (mm)/weight (g)] between years.

Table 4-4: Total variation in shortfin length, condition and growth explained by year and with the addition of each standardising variable (age and sex) in the GLM analyses.

Response	Predictors	R^2
Length	Year	0.17
(mm)	Age	0.65
	Sex	0.74
Condition	Year	0.20
(K)	Age	0.62
	Sex	0.71
Growth	Year	0.04
(mm/yr)	Age	0.56
	Sex	0.64

Based on migrant males catches from the 1970's-1990's, there has been concern that the size of male migrant eels has declined (Jellyman and Todd 1998), with the weight of shortfin male migrants reducing from 200 g to 120 g. This reduction in weight of migrant males may be caused by fish reaching maturity at a smaller size or because of some unknown environmental changes in the lake (Jellyman and Todd 1998). Length-frequency distributions of migrating shortfin males from 1970's-2000's suggest that fishes in the last decade are slightly larger than fish from the 1990's, but are still not as large as fish from the 1980s and 1970 (Figure 4-4). In contrast to shortfin male migrants, the length of female shortfins declined from the 1940's to the late 1970's, but have increased markedly from about 600 mm to 900 mm (Jellyman 2001). This increase has been attributed to changes in diet with larger eels preying on the plentiful bullies in the lake, and female eels adopting a size-maximising strategy that results in significantly increased fecundity (Jellyman 2001).

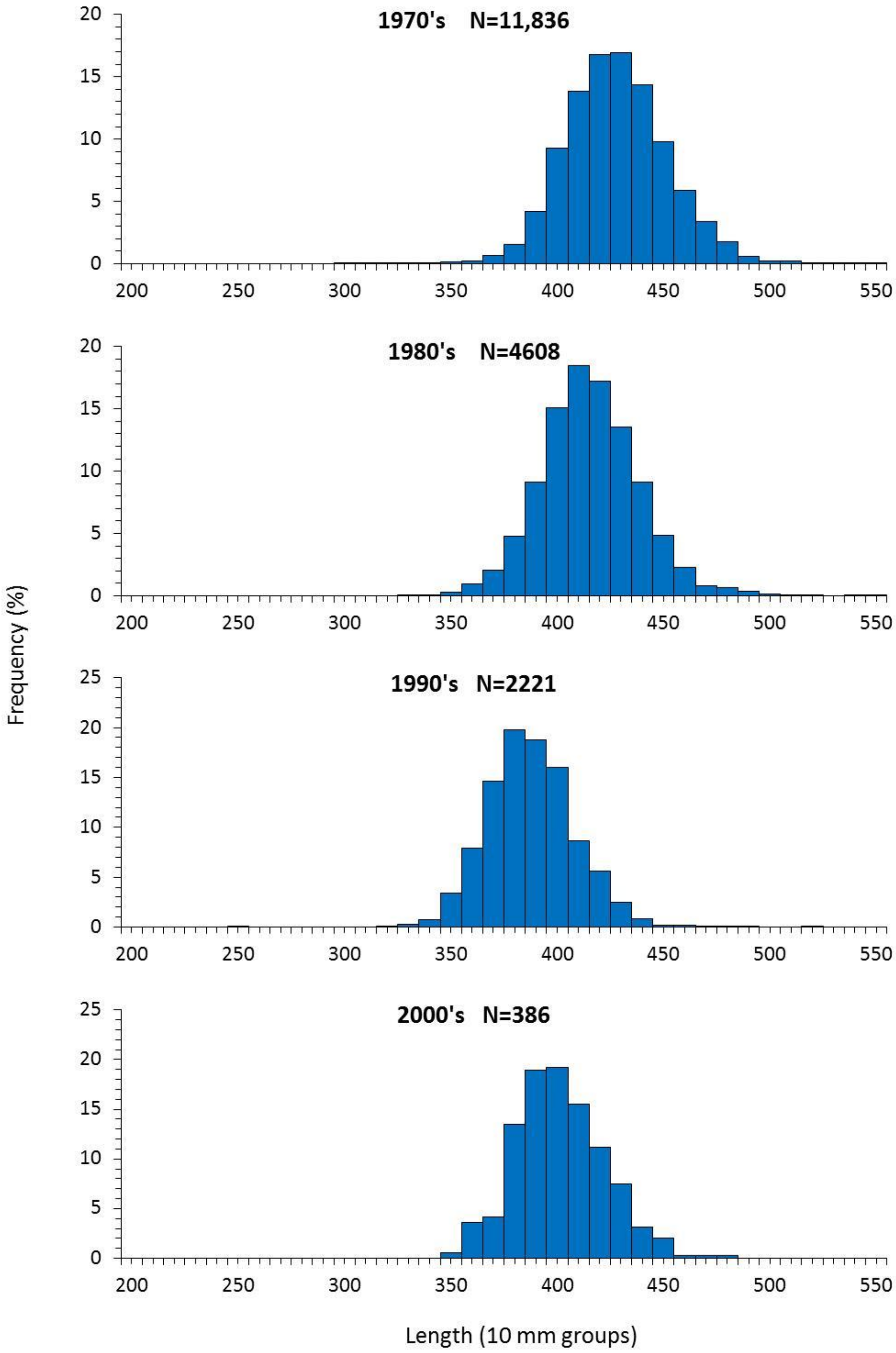

Figure 4-4: Size distribution of male migrant shortfin eels in the last four decades. Data for 2000 was generated from the dataset in Section 2.1.

4.2.2 Eel growth

Growth rates for shortfins in Te Waihora (as determined from total length increases while in freshwater and ageing from otoliths) are typically 25 - 35 mm/year, but once eels reach about 300 mm their diet may include fish, and growth rates may double (Jellyman 2001, Kelly and Jellyman 2007). Growth rates of longfins are slower than shortfins, averaging around 25-30 mm/year Jellyman (2012).

There has been an increase in mean growth rates of feeding (i.e. pre-migrant) shortfins recorded from studies published between the 1970's and 2000's (Jellyman and Smith 2008). Mean annual growth increments increased from 24 mm/year in 1974 to 39 mm/year in 2007 (a 63% increase). The growth rate of migrating males does not appear to have changed much over the years, but the mean growth rate of migratory females has increased from an average of 26 mm/year in 1972-1980 to 47 mm/year in 1998. This may be the result of there being fewer larger eels and/or more common bullies in the lake (Jellyman and Todd 1998).

Table 4-5: Mean annual growth increment (mm/year) for feeding and migrating eels from Te Waihora for various years (From Jellyman 2012). * = Beentjes and Chisnall 1998; ** = sample from Harts Creek reserve; Jellyman and Graynoth 2010; *** = sample from tributaries, Jellyman and Graynoth (2010).

Species	Status	Year	Number aged	Growth (mm/year)	SE
Shortfin	Feeding	1974	230	24.0	0.3
		1975	1208	25.6	0.2
		1994	265	31.2	0.6
		1996/97*	116	35.3	0.5
		2007	65	38.9	1.0
		2010***	20	34.2	1.3
	Migrant males	1975-82	2389	25.1	0.1
		2006	39	26.4	0.6
	Migrant females	1972-80	181	25.8	
		1998	50	47.3	
Longfin	Feeding	1974	215	24.9	0.4
		1975	81	25.3	0.6
		1994	8	32.4	4.2
		2007**	13	25.2	2.3
		2010***	18	31.7	2.3

A standardised GLM of shortfin growth using the dataset in Section 2.1 showed that the standardised relationship between growth and year did not change throughout the time series (Figure 4-5). Year only explained 4% of the variation while the addition of age and then sex increased the variation explained to 56% and 64% respectively (Table 4-4). The contrasting growth rate results between Figure 4-5 and Table 4-5 suggests that differences between years shown in Table 4-5 may be generated by different proportions of the sexes and ages in the catches between years.

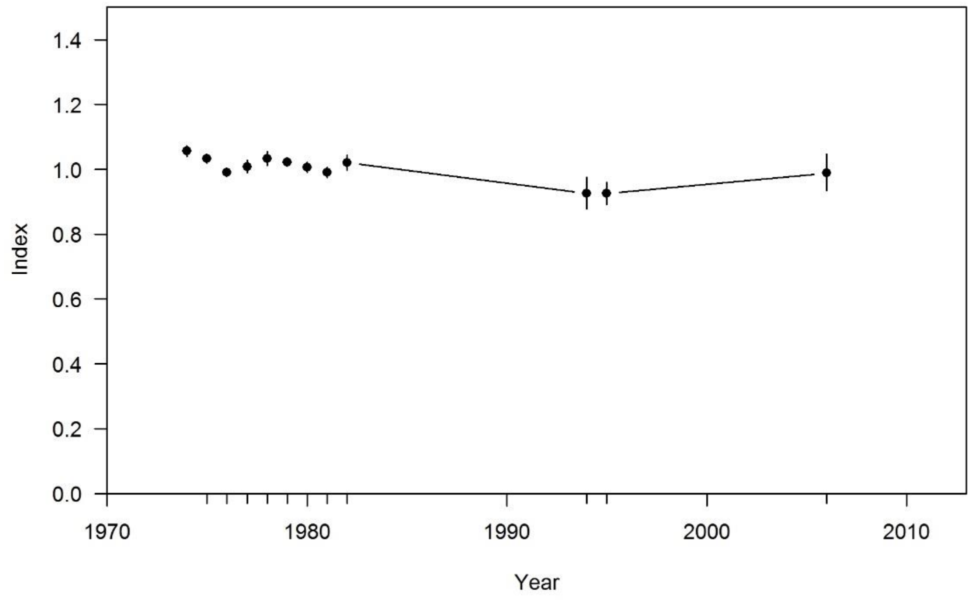

Figure 4-5: Standardised relationship between shortfin growth and years using the dataset of individual fish measurements. The index axis is a unitless measure that shows the relative standardised growth between years.

4.2.3 Eel recruitment

Glass eels moving from the sea into Te Waihora are sensitive to light and are most likely to migrate during darkness (Jellyman 1977; Jellyman 2012; Jellyman and Lambert 2003). Typically any recruitment commences around sunset and peak runs occur within 1-2 h after sunset. Glass eels are not strong swimmers and few will enter the lake immediately after the lake opens to the sea, because the outgoing flow of water may reach velocities of more than 2.0 m/s (Taylor 1996). As the lake level drops, the outgoing flow eases and the migrating glass eels will take advantage of any incoming tide to passively transport them into the lake by a process known as selective tidal transport. Glass eel recruitment will be highest during the twice-monthly spring tide periods, but the new-moon spring tide is likely to transport more fish because it is associated with little or no moonlight (Jellyman and Lambert 2003). When flows reverse during the outgoing tide phase, glass eels are thought to burrow into the substrates and await the next incoming tide to transport them further upstream. Most of the shortfin glass eels will remain in the lake, where they can utilise small interstitial spaces in the fine substrates as cover (Jellyman et al. 2003). Longfin glass eels will mostly move through the lake to the flowing water in tributaries, and will probably migrate successively upstream each spring and summer (Jellyman 1977, Martin et al. 2006) as they colonise further and further upstream.

The main features of glass eel recruitment in Te Waihora were summarised by Jellyman (2012) as follows:

- The recruitment season in Canterbury can extend from August to November, but the main period for shortfins is September and October, while the main period for longfins is August-September.

- Glass eels at sea will be attracted to the outflow of the lake.
- Most glass eels will arrive in “pulses” associated with spring tides, especially the spring tide of the new moon phase.
- Recruitment will mainly take place at night.
- Some recruitment is likely to take place as the initial outflow recedes and some glass eels can move along the shallow edges of the flow. However, most of the recruitment will occur when the flow recedes to the point where actual tidal movement commences, with a discernible flood tide phase providing inward passage for glass eels.
- Large outflows will attract more glass eels than small outflows. A preferred opening duration would be > 4 weeks as that would ensure that recruitment could occur on at least one new moon spring tide (whereas 3 weeks would ensure a spring tide but not necessarily a new moon spring tide).

4.2.4 Eel habitat and foraging

To obtain quantitative samples of glass eels, Jellyman and Chisnall (1999) used a fine meshed beam trawl to sample small eels at varying distances off shore and from differing habitat types. Effective sampling in shallow waters (0 – 0.3 m depth) was not possible, meaning residence in such areas is uncertain. However, shallow areas are subject to considerable wave energy (Jellyman et al. 2009) and periodic dewatering, suggesting that long-term residence in such areas would seem hazardous, and thus it is considered unlikely that small eels would be resident in such inshore littoral zones. Most of the small eels caught were in reasonably shallow water, mainly from 0.6 – 1.2 m depth (Figure 4-6) although eels ≥ 300 mm showed no particular association with depth. Smaller eels (<300 mm) were predominantly caught closer to the shore, often within 100 m (Figure 4-7) whereas similar numbers of larger eels were caught at all distances from the shore. More juvenile eels were also caught in areas with gravel/mud substrate (Figure 4-8). Larger eels were predominantly caught on sand, although habitat differences for this size group were not significant. This study of habitat use, however, did not account for habitat availability in the lake. Subsequently, a habitat preference study (i.e. proportion of habitat used/proportion of available habitat) may identify depths or substrates preferentially used by eels.

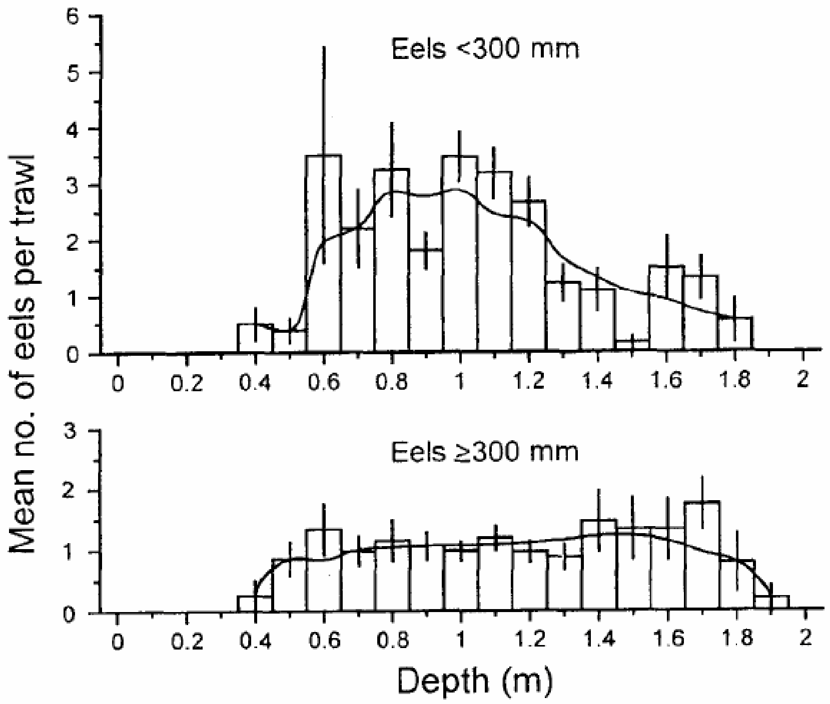

Figure 4-6: The mean number of juvenile shortfin eels caught per trawl at various depths off Timberyard Point, Te Waihora. Vertical lines are ± 1 SE, and a 5-point moving average has been fitted to show trends. From Jellyman and Chisnall (1999).

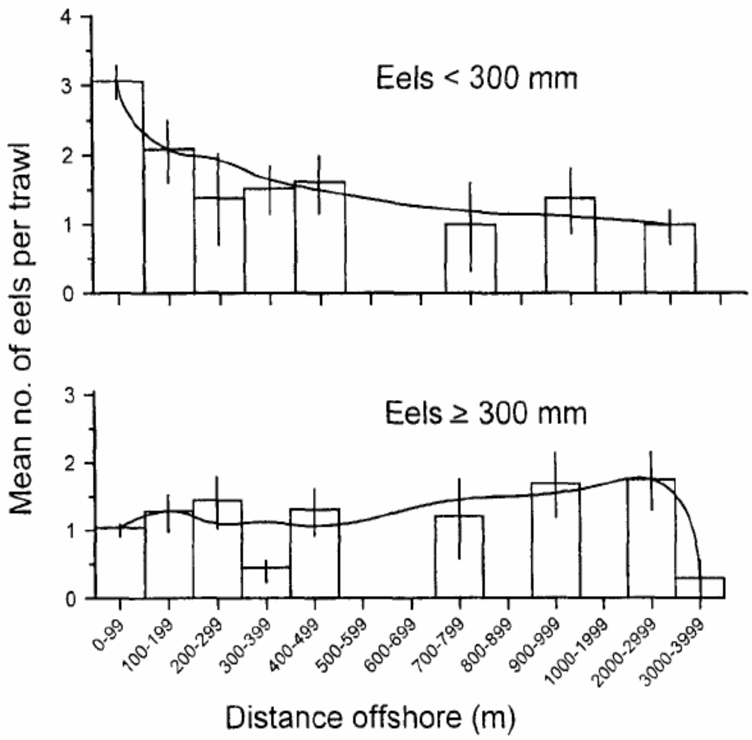

Figure 4-7: The mean number of juvenile shortfin eels caught per trawl at various distances offshore off Timberyard Point, Te Waihora. Vertical lines are ± 1 SE, and a 5-point moving average has been fitted to show trends. From Jellyman and Chisnall (1999).

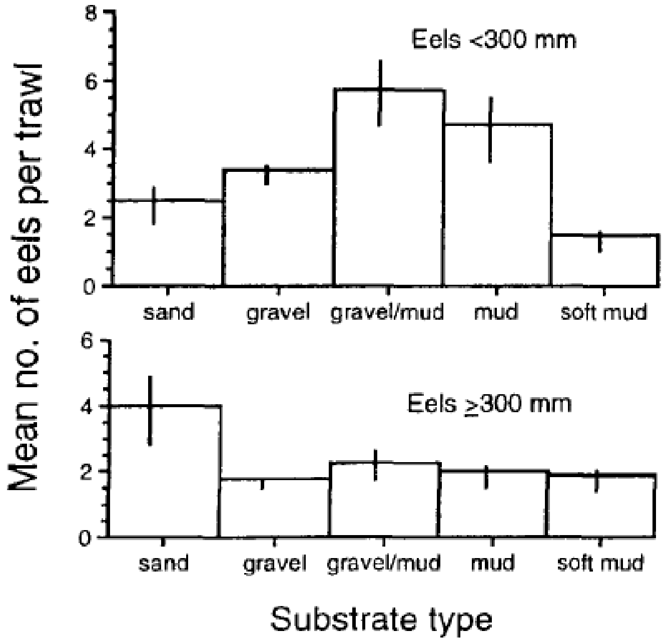

Figure 4-8: The mean of juvenile shortfin eels caught per trawl caught on various substrates. Vertical lines are ± 1 SE. From Jellyman and Chisnall (1999).

In contrast to the smaller (<300 mm) eels, large eels are more mobile and spend considerable amounts of time foraging above the substrates (Glova and Jellyman 2000). They are readily captured by fyke nets set along shorelines. The extensive fyke-netting surveys by Glova and Sagar (2000) showed that shortfin eels were abundant and widespread in the lake, but tended to be more concentrated around river mouths and the lake outlet (the latter being mainly shortfin males congregating prior to their seaward migration). These areas with higher shortfin biomass may be associated with bully abundance as Glova and Sagar (2000) noted that "high eel biomass coincided with high abundance of bullies". Similarly, eels were not particularly abundant in Kaituna Lagoon, or on the extensive sandy beds of Greenpark Sands and the large bays on the western side of the lake, all of which had relatively low densities of bullies (Glova and Sagar 2000).

Shortfins feed primarily on aquatic invertebrates, but they are opportunist scavengers and will forage along newly inundated shorelines during high water levels (Jellyman 1989). Feeding eels move with the wind, possibly taking advantage of wind-derived currents (Jellyman and Smith 2008). Feeding shortfins are inactive in Te Waihora at water temperature < 12ºC (Jellyman et al. 1996), which corresponds to May until September inclusive (Environment Canterbury data for Timberyard Point), but once temperatures exceed this the eels increase feeding activity, especially in spring and early summer.

Larger eels in Te Waihora tend to forage within a restricted area Jellyman (2012). Jellyman et al. (1996) reported a study from December 1977 and February 1978 which tagged 4,968 and 4,987 eels respectively and released all fish at LII Bay and the centre of the lake. From these, there were 1982 recaptures (excluding 780 multiple recaptures where the same eels was caught on more than one occasion) recorded by commercial fishers over the following five years. Main results (Figure 4-9) showed that eels were mainly recaptured close to their release site, but some fish did move extensively. A short-term sonic tagging study also found that movement of eels was limited (Jellyman et al. 1996), particularly in areas around the lake margins. Jellyman et al. (1996) reported that while eels tagged in the centre of the lake ranged from 3.3 to 10.8 km from the original tagging location, eels tagged at inshore sites generally remained within 1-2 km of the release site.

Figure 4-9: First recapture locations and numbers for (a) eels tagged in the centre of lake and (b) at LII Bay (north side of the lake). Sizes of the recapture circles are proportional to the number of eels recaptured. (From Jellyman et a. 1996).

4.2.5 Reserve areas for eels

The limited movement of eels (Jellyman et al. 1996), suggests that reserve areas could be an effective means of protecting a portion of the population. Reserve areas may be particularly beneficial if they are established around lake margins where movement is more restricted than in the centre of the lake (Jellyman et al. 1996). Reserves around lake mouths or in areas with high bully abundance will improve eel numbers further because eels favour these conditions (Glova and Sagar 2000). Presently reserve areas extend for a radius of 1.2 km around the mouth of the Irwell, Selwyn, LII and Halswell Rivers, and Harts Creek, and there is a more extensive kohanga area (recreational and customary use area) being established around the Kaituna River (marked as JMP-Joint Management Plan in Figure 4-10).

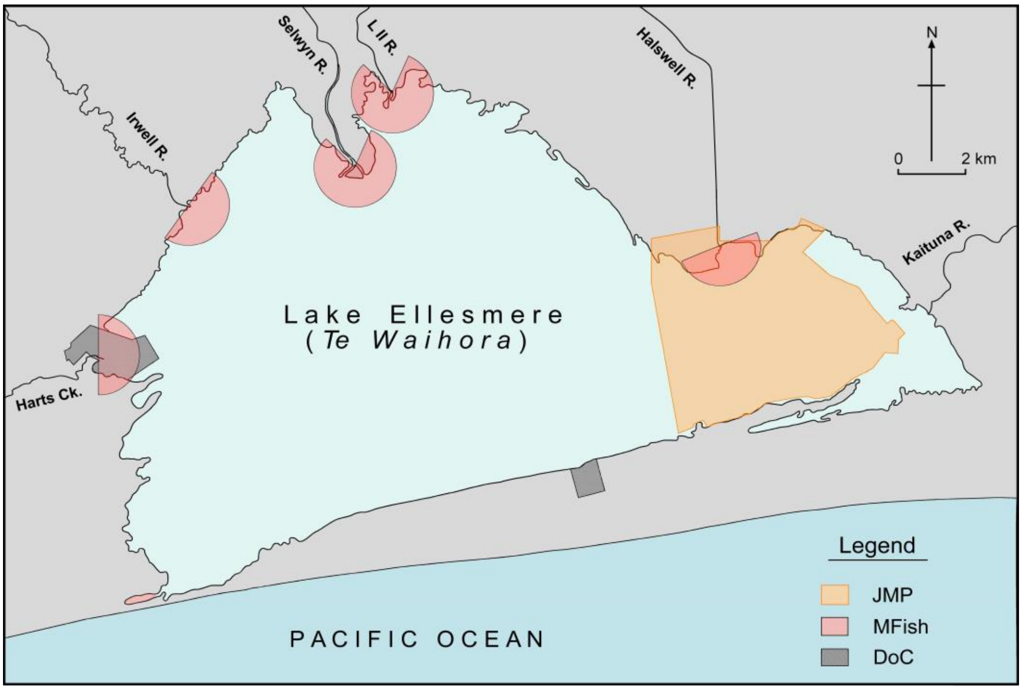

Figure 4-10:Areas closed, or proposed, to commercial eel fishing in Te Waihora. The exact boundaries around the JMP area may have changed since this report was published in 2010 (from Jellyman and Graynoth 2010).

The value of reserve areas can be seen in Figure 4-11 where fyke net catches are compared between the reserve area at Harts Creek and the commercially fished area at Timberyard Point, a distance of < 3.0 km away. The Harts Creek sample (n = 318 eels) contained 37 (12%) longfins, whereas the Timberyard Point sample (n = 150 eels) contained none. These differences, however, could be associated with different habitat availability between the sites. The size differences in eels from both locations is also marked, with few shortfins from Timberyard Point exceeding 550 mm (360 g), and very few exceeding 700 mm (800 g), whereas both these size groups were well represented in the Harts Creek sample. The mean length of shortfin eels from Harts Creek (mean length = 691 mm, SE 40.0mm) was significantly larger than shortfin eels from Timberyard Point (mean length = 469 mm, SE 7.7 mm) (ANOVA, F = 118.4, p = <0.001).

Shortfin eels have always dominated eel stocks in the lake, but the proportion of longfins has declined with time from 4.3% in 1974-82 to 0.5% in 1997-98 (Jellyman and Smith 2008). More recent surveys highlighted the significance of longfin eel populations in lake tributaries and identified the potential for these areas to act as reserves aiming to maintain spawning stocks of female eels, especially longfins (Jellyman and Graynoth 2010).

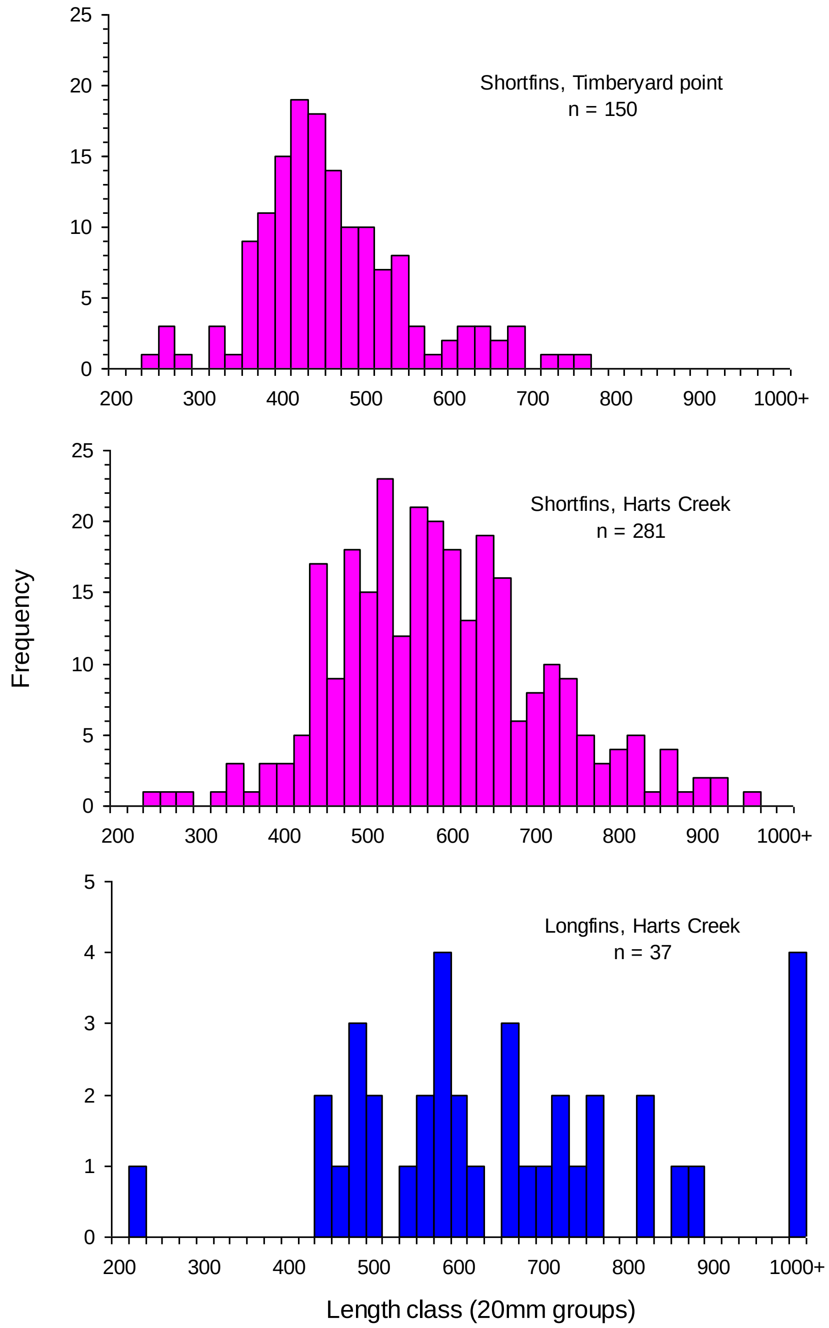

Figure 4-11:Sizes and species of eels caught at Timberyard Point, and within the Harts Creek reserve, March 2007. From Jellyman (2012).

4.2.6 The role of tributaries

A survey of the main tributaries entering the lake (Jellyman and Graynoth 2010) used electric fishing and baited or unbaited fyke nets to obtain data on species proportions, densities and sizes of resident eels. Overall results found an almost equal representation of both species from electric fishing (Table 4-6), with the numbers of longfins exceeding those of shortfins at 6 of the 9 sites. From fyke netting data, 61% of all eels caught were shortfins, although this was because of high numbers of shortfins at the lower river sites of Harts Creek and the Selwyn Huts (86% shortfin). If these sites were removed from the database, the total catch was dominated by longfins (80%).

Table 4-6: The numbers of each eel species and species composition of all eels sampled in tributaries of Te Waihora. Number in brackets = number measured. From Jellyman (2012).

			Number			Percentage	
Method	Catchment	Site	Shortfin	Longfin	Total	Shortfin	Longfin
Electric fishing	Boggy Creek		65	7	72	90	10
	Hanmer Road Drain		63	17	80	79	21
	Harts Creek	Birdlings Brook	43	44	87	49	51
		Halcombe Creek	7	33	40	18	83
		Lower Harts Creek	69	162	231	30	70
	Irwell	Lower Irwell	131	3	134	98	2
	Selwyn	Chamberlains Road	7	15	22	32	68
		Mid Selwyn	5	20	25	20	80
		Coes Ford	27	50	77	35	65
	Total		**417**	**351**	**768**	**54**	**46**
Fyke netting	Halswell	Various	59	148	207	29	71
	Harts Creek	Mid	0	35	35	0	100
		Lower	314 (209)	87	401 (296)	78	22
	LII	various	13	108	121	11	89
	Selwyn	Selwyn Huts	401 (178)	33 (22)	434	92 (89)	8
	Total		**787 (459)**	**411 (400)**	**1198 (859)**	**66**	**34**
	Grand total		**1204**	**762**	**1966**	**61**	**39**

Of particular interest was the proportion of small eels (< 300 mm) caught in these tributaries (Table 4-7).The table shows that almost 50% of shortfins were < 200 mm, compared with only ~17% of longfins. Lower Harts Creek had the highest proportion of its catch composed of small longfins (< 300 mm), 55%, compared with Birdlings Brook at 23%, Hanmer Road Drain at 12% and Coes Ford at 26%. Comparable data for shortfins < 300 mm were: Harts Creek 55%, Birdlings Brook 91%, Hanmer Road Drain 70%, Irwell 53%, Coes Ford 74%.

Table 4-7: The percentage of electric fished small eels of both species sampled in tributaries of Te Waihora. From Jellyman (2012).

	0-99 mm	100-199 mm	200-299 mm	Total (0-299 mm)	Total ≥ 300 mm
Shortfins	1.4	47.0	25.4	**73.8**	**26.2**
Longfins	0.9	16.0	21.1	**38.0**	**62.0**

Overall this survey confirmed the importance of tributaries as refuge areas for longfins and small eels <300 mm. There was a relatively small proportion of small longfins, but this is consistent with patterns elsewhere on the South Island east coast (Jellyman 2012). Jellyman and Graynoth (2010) estimated that ~ 540 migrating female longfins would be produced each year from the tributaries, about 2% of the estimated annual national spawning total. Given that these tributaries cannot be commercially fished, Jellyman and Graynoth (2010) concluded that the reserve status of tributaries was essential for:

- Providing an effective means of retaining commercially unfished portions of the population.
- As longfin eels prefer running water, reserves within tributaries or at the mouths of tributaries provide important refuges for this species.
- Lower reaches of tributaries can provide important refugia if the lake becomes prone to multiple stressor events like a combination of high water temperatures and significant algal blooms, with a consequent reduction in dissolved oxygen.
- A critical factor in managing eel stocks is maximising the number of females that escape to sea to spawn each year. The Te Waihora tributaries could potentially provide ~ 2% of the annual New Zealand spawning production of longfin female eels, and hence their continued protection in these areas is of particular importance. Habitat and water quality improvement would also enhance this situation.

4.2.7 Seaward migration of spawning eels

Each summer and spring, migrating (heke) eels begin congregating in the vicinity of Taumutu, prior to their attempts to leave the lake on their seaward spawning migration. Arrival times of eels at Taumutu vary according to species and sex, with males preceding females for both species, and shortfins preceding longfins. It seems that relatively short residence in the brackish water allows rapid transition to their saltwater migration because fish will emigrate from the lake immediately if it is opened. Earliest observations on this emigration in Te Waihora are those of Hobbs (1947) who recorded timing of arrivals, sizes of eels, and estimated a population size of 977,000 shortfin females from results of a small mark-recapture trial. Shortfins dominated the early season (March – April) but had virtually disappeared by June when the lake was opened. Hobbs also noted the presence of migrant eels in poor condition, and presumed these were unsuccessful migrants from the previous year.

In a more extensive study, Todd (1981) recorded the numbers of migratory eels caught per month by fyke netting at Taumutu. A summary of these data indicates that February – March are the main months for shortfin males (Table 4-8), with March – April for shortfin females. For longfins, April and May were the main months for males, with May – June for females.

Table 4-8: The percentage of migratory shortfin and longfin eels of both sexes, caught from Te Waihora 1975-79.

	Feb	Mar	Apr	May	Jun	Total no.
Shortfin male	30.1	67.6	1.9	0.5	0	10426
Shortfin female	6.4	66.1	21.8	5.7	6.4	422
Longfin male		4.7	44.2	44.2	7.0	43
Longfin female		0.4	13.1	70.5	15.9	251

Todd (1981) noted that during the early part of the season (late January), 76% of the catch was feeding eels, but the proportion of these declined and at the peak of the migrant season feeding eels comprised only 1.5% of the catch. The arrival period for longfin is shorter than that for shortfin (Todd 1981) with the migratory activity being associated with environmental conditions. Todd (1981) found that most catches during the new moon phase exceeded those during the full moon period; although local fishers claimed that the best catches were made during fresh to moderate winds, normally from the northwest, Todd (1981) found no association with wind direction and/or strength. Commercial fishers have observed that migrating eels are very sensitive to moonlight and also to wind, and that a northeast wind will move them to Taumutu in large quantities. Should a strong southerly produce waves that overtop the spit, then eels become very active and may even wriggle across the bar to reach the sea.

Reviews of the sex proportions of migratory eels, and the size of male and female shortfins (Jellyman and Todd 1998; Jellyman 2001) found that the sex ratio of shortfins has changed from being dominated by females to males, with males becoming smaller and females larger. Earlier research by Hobbs (1947) estimated about 500 t of shortfin females present at migration, compared with 2-3 t in 1996 (Jellyman and Todd 1998). Today the commercial eel fishery targets shortfin males during the eel migration periods, and females are voluntarily released by fishers, often directly to sea, although some are still harvested for customary purposes.

4.2.8 Eel fishery

The commercial eel fishery in Te Waihora commenced in the early 1970's, and peaked in the late 1970's (Figure 4-12) when it accounting for almost half of the total New Zealand eel catch. However, concerns over the sustainability of these catches led the lake to be declared a controlled fishery in December 1978. The initial total allowable catch (TAC) for the 17 fishers on the lake was set at 256 tonnes (not including migratory eels), and was then reduced to 136.5 tonnes in 1986 and distributed among 11 fishers. The minimum allowable size of eels from Te Waihora was initially set at 150 g, but this was progressively increased to align with the national minimum size of 220 g. In 2000, the commercial catch of eels in the South Island were incorporated into the Quota Management System (QMS), and the TAC for Te Waihora was reviewed and allocations made for customary and recreational use (customary = 31.26 tonnes, recreational = 3.13 tonnes). There are presently five commercial eel fishers on the lake, and the annual Total Allowable Commercial Catch (TACC) of 121.93 tonnes is reached most years (Jellyman and Smith 2008). By agreement, longfin eels are not commercially harvested.

Part of the commercial catch targets migratory shortfin males that are smaller than the minimum commercial size of 220 g, but without access to these fish the commercial fishery would be reliant on fishing for female shortfins. This is not a desirable situation (Jellyman and Todd 1998), and in 1996 commercial fishers were granted a concession to harvest migrating shortfin males at Taumutu prior to their seaward migration in late February – March. Unlike anywhere else in New Zealand, the fishing year for the Te Waihora eel fishery commences on 1 February to allow fishers access to this migration. They then catch the unfilled portion of their quota later in the same year or in January of the following year. Of the TACC of 122 tonnes, fishers often take as much as 90–100 tonnes of shortfin males (Jellyman and Smith 2008). Assuming an average weight of 116 g (Beentjes 1999), then 100 tonnes equates to approximately 862,000 eels.

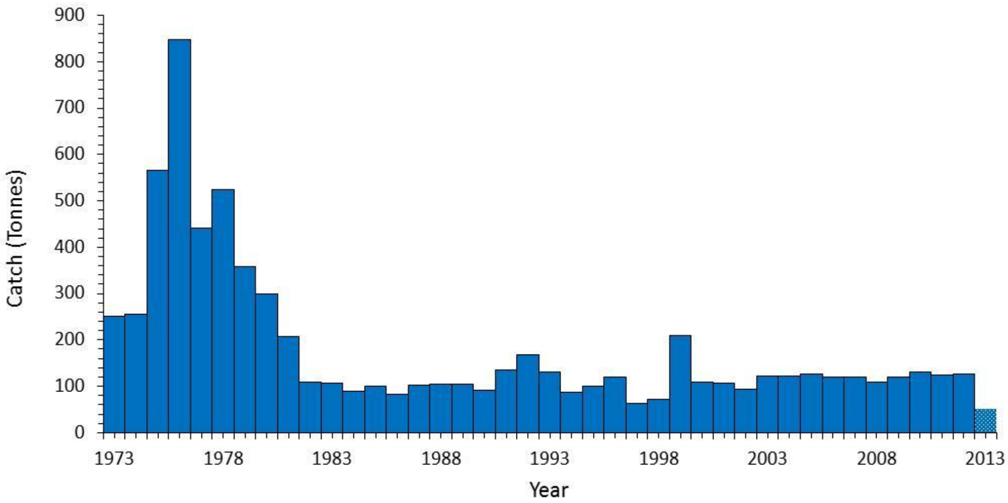

Figure 4-12:Annual commercial catch of eels from Te Waihora. Note that the 2013 fishing year is still in progress. Data from MPI (Appendix A).

The fishery for migratory (silver) eels from Te Waihora is unique in New Zealand, and elsewhere there are “gentlemen’s agreements” or policy (e.g. South Island Eel Industry Association 2009), to not take migrant eels which are normally released by fishers as a conservation measure.

Measures of the standardised CPUE of the fisherman for the years 1991 to 2006 show a small, but steady increase from 2002 to 2006 (Figure 4-13), indicative (for shortfins) of a productive fishery. Fishing methods used by the fisherman have changed between years, but they have remained the same during the increase observed from 2002-2006.

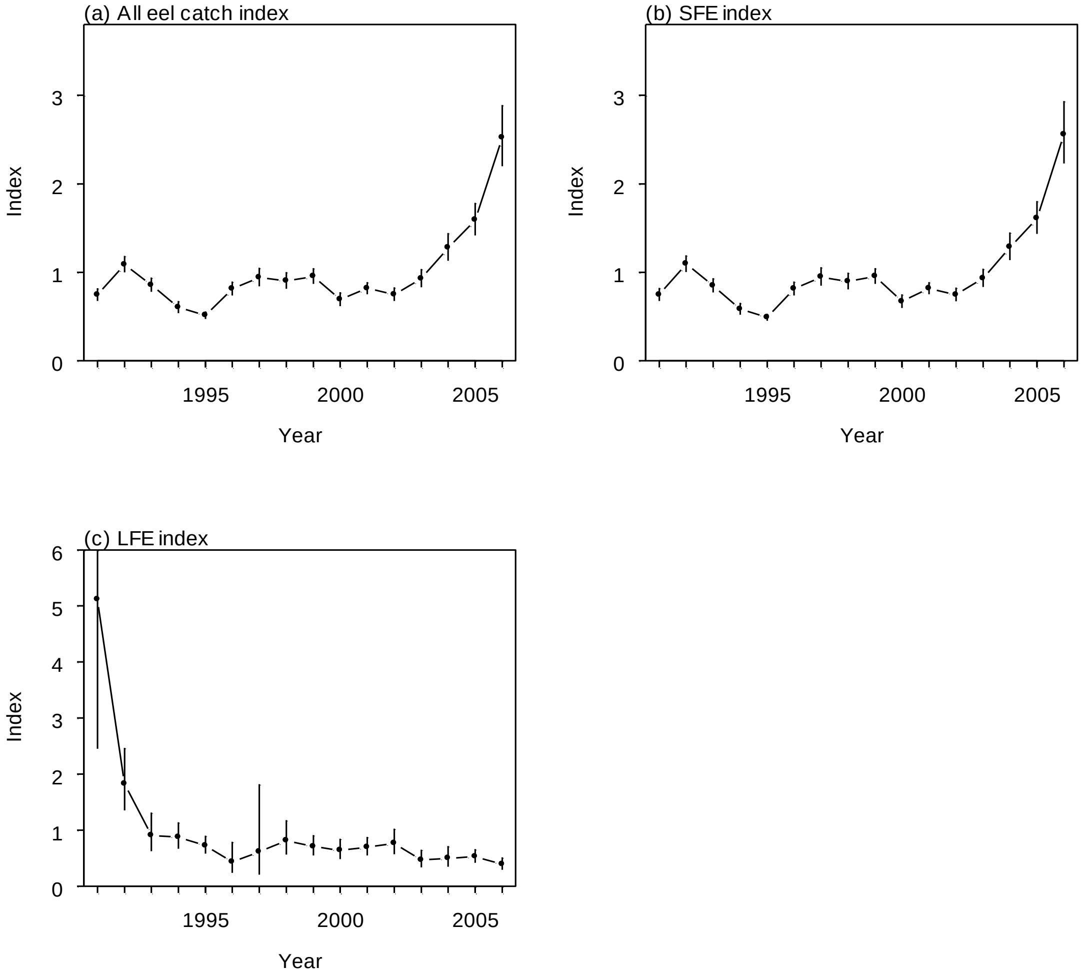

Figure 4-13:The catch-per-unit-effort (CPUE) trends for Te Waihora eels. Note that the All eel catch index (top left) is almost identical to that for SFE index (shortfin eels, top right) indicating that longfins make a negligible contribution to the fishery. (From Jellyman 2012; data from Beentjes and Dunn 2008).

4.3 Flatfish (patiki)

The flatfish population in Te Waihora is dominated by three main species - black flounder, yellowbelly flounder, and sand flounder (also called dabs, three corners, and whites). Occasionally small quantities of greenback flounder are recorded; juvenile common sole frequently enter the lake, but do not survive to enter the fishery. The abundance and catch of flatfish varies greatly from year to year, as does the proportion of the three main species in the catch.

4.3.1 Size

Black flounder length data from the dataset assembled in section 2.1 showed that this population is dominated by small fish <50 mm, with a small proportion of larger individuals present (Figure 4-14). Sand and yellowbelly flounder show a bimodal peak in size distributions around 40 mm and 230 mm, which is likely to represent different year classes

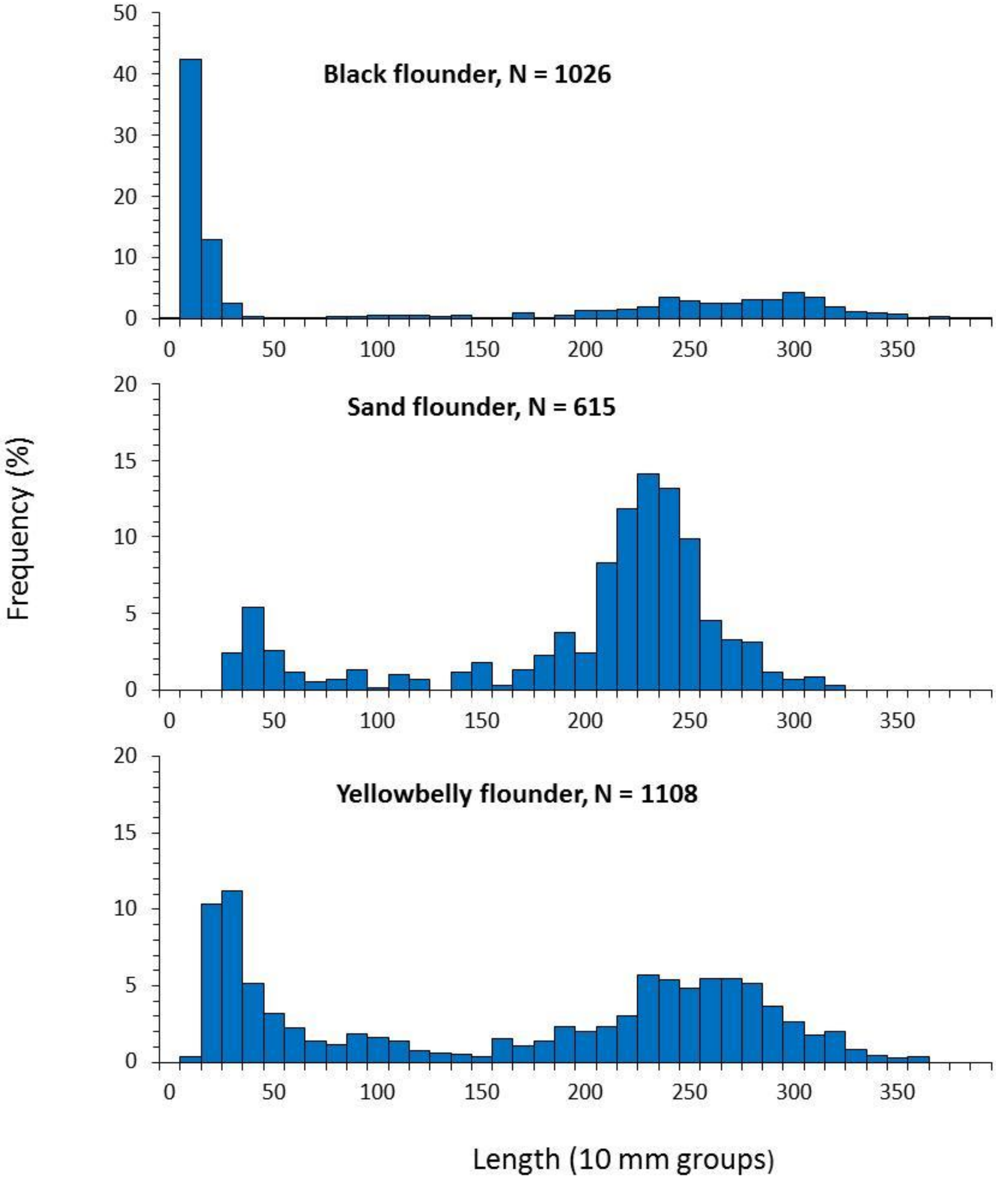

Figure 4-14:Length distribution of black, sand, and yellowbelly flounder from Te Waihora.

4.3.2 Flatfish recruitment

The main species of flatfish in Te Waihora do not spawn in the lake, and populations in the lake depend on recruitment of juveniles from the sea when the lake is open. Some adult fish may also move into the lake when it is open, but probably not in great numbers. Maturing adult flounders migrate out of the lake during lake openings in winter and spawn at sea (Jellyman 2012). Adult yellowbelly and sand flounders often have pronounced ovaries throughout long periods of the year, indicating prolonged breeding seasons, while black flounder appear to mature more rapidly, with nearly mature fish congregating at Taumutu in July and August.

Flatfish spawning in the sea occurs over many months and juvenile flatfish may recruit into the lake over 4-6 months (Table 4-9); but only if the lake is open. The monthly length-frequency distributions for black, sand, and yellowbelly flounders is illustrated in Figure 4-15, Figure 4-16 and Figure 4-17 respectively, which show that recruitment (indicated by occurrence of smallest fish) of each species peaks at slightly different times of the year. Black flounder recruitment peaks in November while both sand flounder and yellowbelly flounder recruitment appears to peak in August. These plots, however, were generated using data from different studies across years and missing catches of juvenile fishes during some months will reflect a lack of sampling rather than a lack of recruitment.

Table 4-9: Timing of black (*Rhombosolea retiaria*), sand (*R. plebia*) and yellowbelly (*R. leporina*) flounder spawning and recruitment recorded as either "Spawning" (occurrence of ripe fish or larvae) or "Recruitment" (arrival of juveniles into shallow marine areas of estuaries/lakes). From Jellyman (2012).

Species	Location	Spawning	Recruitment	Author(s)
Black flounders	Te Waihora		Dec	Jellyman 2011
	Te Waihora		Oct - Dec	Taylor & Graynoth 1995
	Waimakariri lagoon		Oct – Nov/Dec	Eldon & Kelly 1985
	Rakaia River lagoon		Nov - Dec	Eldon & Greager 1983
	Turakina River	July		Stevens 1993
	New Zealand	Winter		McDowall 2000
Sand flounders	Te Waihora		Sept - Dec	Jellyman 2011
	Ahuriri Lagoon		July – Dec	Kilner & Akroyd 1978
	Hauraki Gulf	Jun – Nov		Colman 1973
	Otago Coast	Jul – Feb	June – Jan.	Roper & Jillett 1981
	Kaikoura	Jan – Oct		Hickford & Schiel 2003
	Canterbury Bight	Jun – Dec		Mundy 1968
	New Zealand	Sep – Dec		Ayling & Cox 1982
	New Zealand	Winter and spring		Paul 2000
Yellowbelly flounders	Te Waihora		Nov-Dec	Jellyman 2011
	Waimakariri lagoon		Mar – Aug	Eldon & Kelly 1985
	Ahuriri Lagoon		July – Dec	Kilner & Akroyd 1978
	Hauraki Gulf	Sep - Nov		Colman 1973
	New Zealand	Winter and spring		Paul 2000

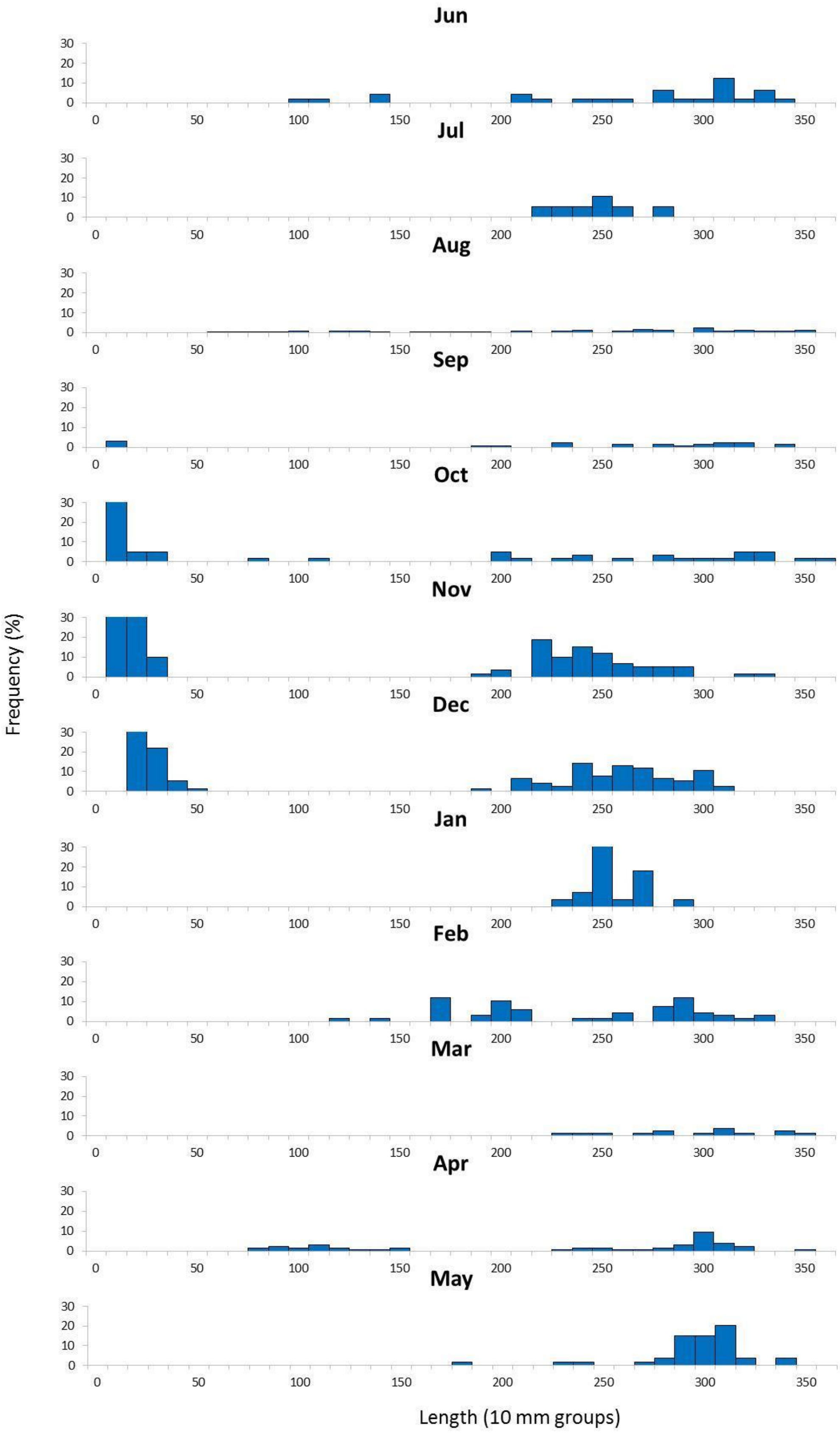

Figure 4-15:Monthly length frequency of black flounder in Te Waihora. Plots generated from the dataset outlined in section 2.1.

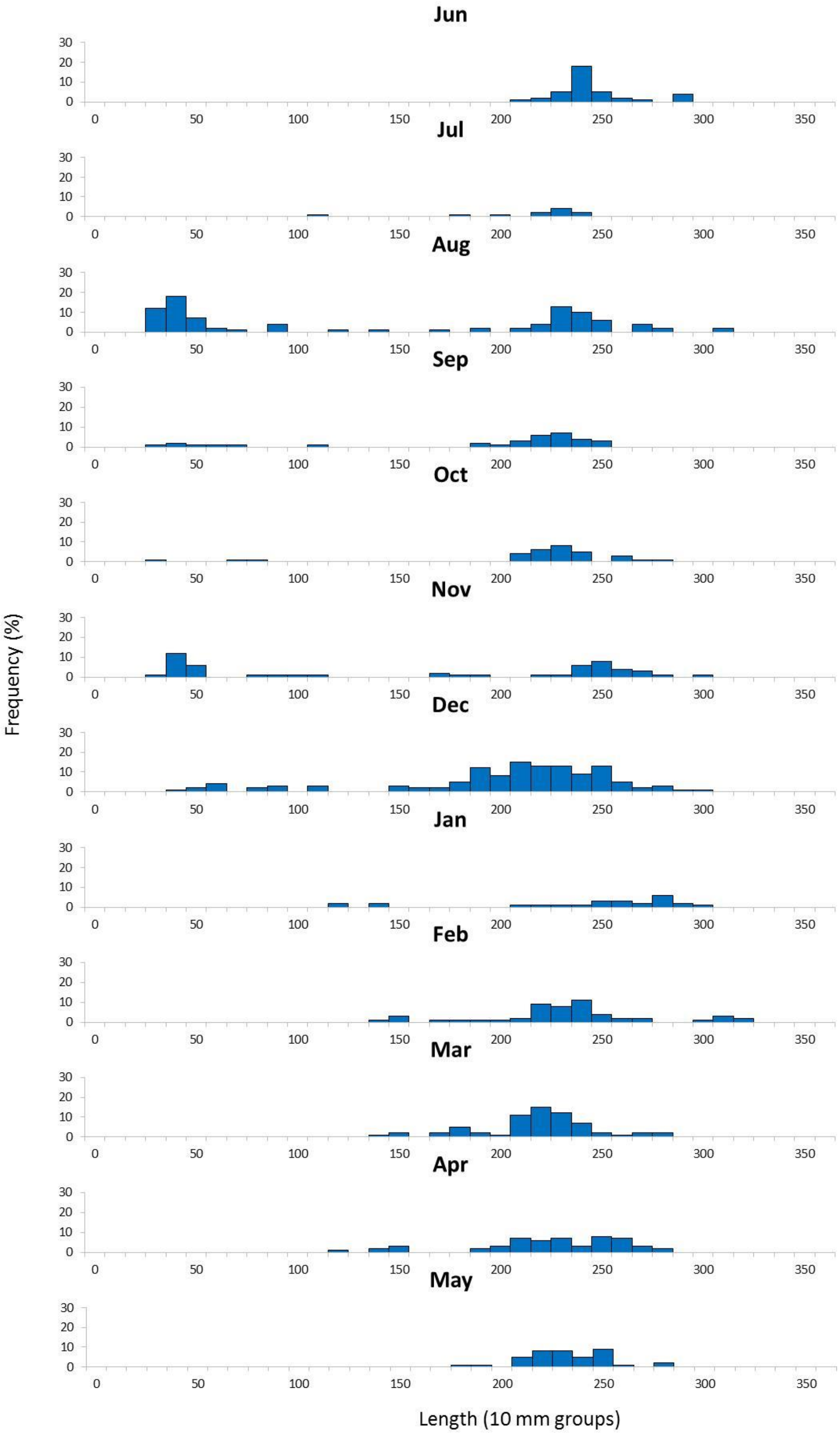

Figure 4-16:Monthly length frequency of sand flounder in Te Waihora.

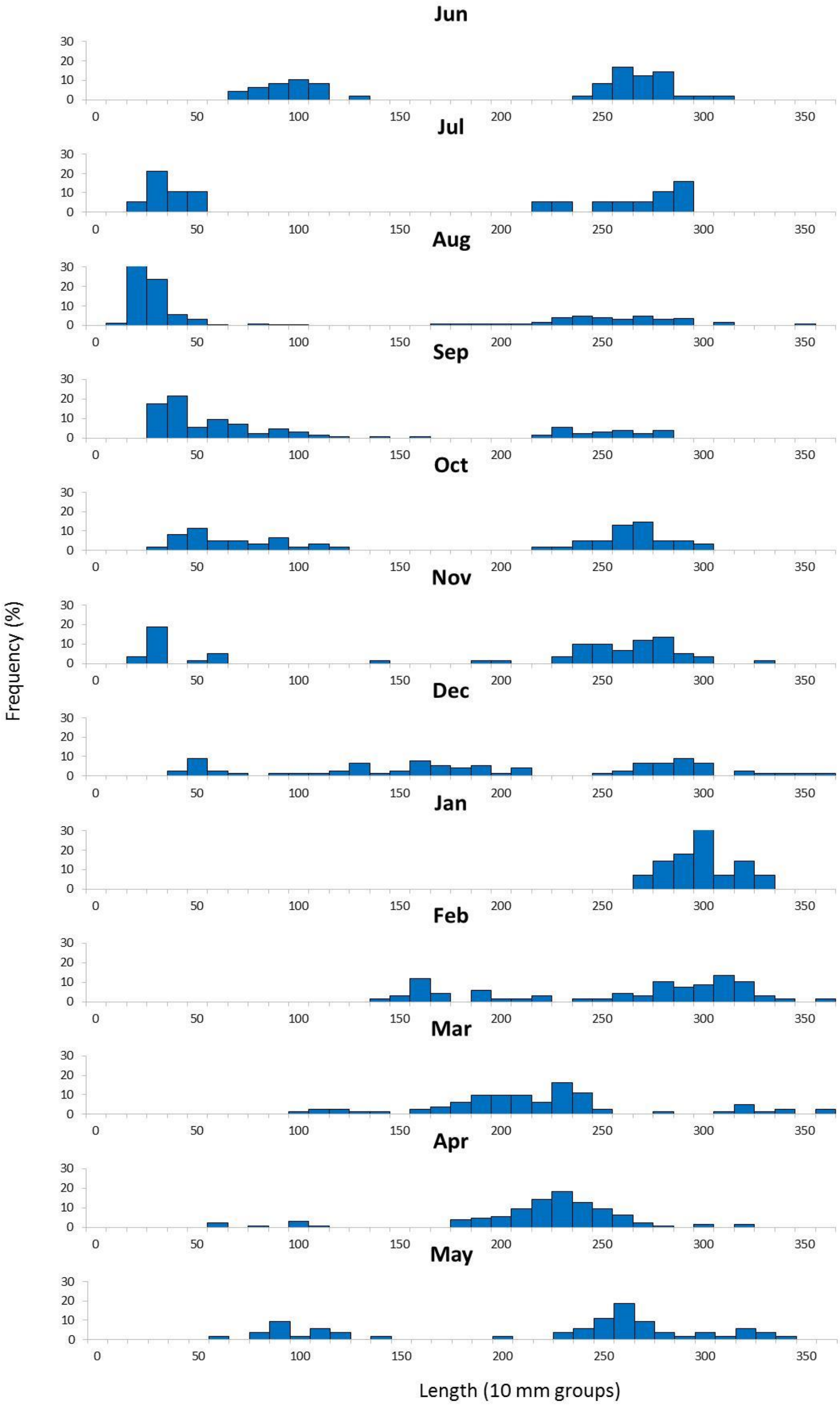

Figure 4-17:Monthly length frequency of yellowbelly flounder in Te Waihora.

Taylor and Graynoth (1995) studied native fish immigration into the lake during 1994, when the lake was open for extended periods between July and October, and their results plus the review by Jellyman (2012) and Figure 4-15, Figure 4-16 and Figure 4-17, have been used to summarise the recruitment of the three main flatfish species into Te Waihora as follows:

- Juvenile yellowbelly flounders are the earliest species to arrive in the lake with some arriving in July, but peaking in August and September. Recruitment may continue until November or December.
- Juvenile sand flounders were next to arrive, and appeared to have the shortest recruitment period from the study by Taylor and Graynoth (1995), with most arriving in the lake during August. Other studies suggest that recruitment may occur over a much longer period.
- Juvenile black flounders arrived later, mostly during October and November.

Overall, the timing of recruitment of flatfish into the lake is not completely understood, as it is based mainly on sampling in one year (1994) when the lake was open for extended periods, but not after October. Better information on monthly recruitment of flounder is being collected over the next two years under the Fisheries Management and Enhancement Project which will help address this knowledge gap. Each year the timing and duration of lake openings will greatly influence the numbers and species composition of flatfish recruiting into the lake. The timing and success of spawning will also influence catches.

4.3.3 Movement and growth of adult flounders

Flounders move with the wind during all stages of their lifecycle (Jellyman and Smith 2008). Mature black flounders arrive at Taumutu in July and August during northeast winds, whereas they move away during a southerly wind. Movements of tagged flounders within the lake showed no obvious pattern (Gorman 1960), with some moving from Taumutu to Halswell within 10 days, while others showed no overall movement 3 weeks after liberation. Six were recaptured at sea, of which one black flounder was caught off Nugget Point, Otago, a distance of 320 km achieved in 175 days.

Growth rates are rapid with most fish reaching the minimum commercial size (250 mm) within two years. Yellowbelly flounders achieve minimal maturity in the lake, while black flounders become nearly fully ripe by June/July and nearly mature fish congregate at Taumutu in July and August. Sand flounders appear to have two peaks in reproductive maturity during December/January and again during May–July (Jellyman 2011). The seaward migration of sexually maturing flounders is not well documented, but is apparent by their absence after an opening. Although there is some local belief that flounders could spawn in the lake, this is not supported by observation or science. None of the species achieve full ripeness in the lake, and if spawning did occur, we would not expect the extreme fluctuations seen in the annual catches of juveniles.

Unlike eels that have a stricter seasonal migration, maturing flounders will exit the lake during late summer, autumn and early winter, but it is likely that they will show a preference for later (May - July). If spawning flounders are unable to leave the lake, their gonads will regress and they will spend a further year in the lake.

4.3.4 The flatfish fishery

In Te Waihora the commercial catch of flatfish (all species combined) varies drastically from year to year, as do the proportions of the three main species in the catch. Annual variation in catches of flatfish can be seen from the commercial catches of flatfish over the past 60 years (Figure 4-18), which shows that flounder catches in adjacent years can vary more than 10 fold. There has been an active commercial flatfish fishery in the lake since the late 1890's (Singleton 2007), and the variability of catch reflects flatfish abundance rather than fishing effort. Most commercial flatfish fishers in the lake also fish for eels, and observing the number and size of the bycatch of juvenile flatfish enables them to predict the strength of upcoming cohorts of flatfish and prepare accordingly (Jellyman 2012).

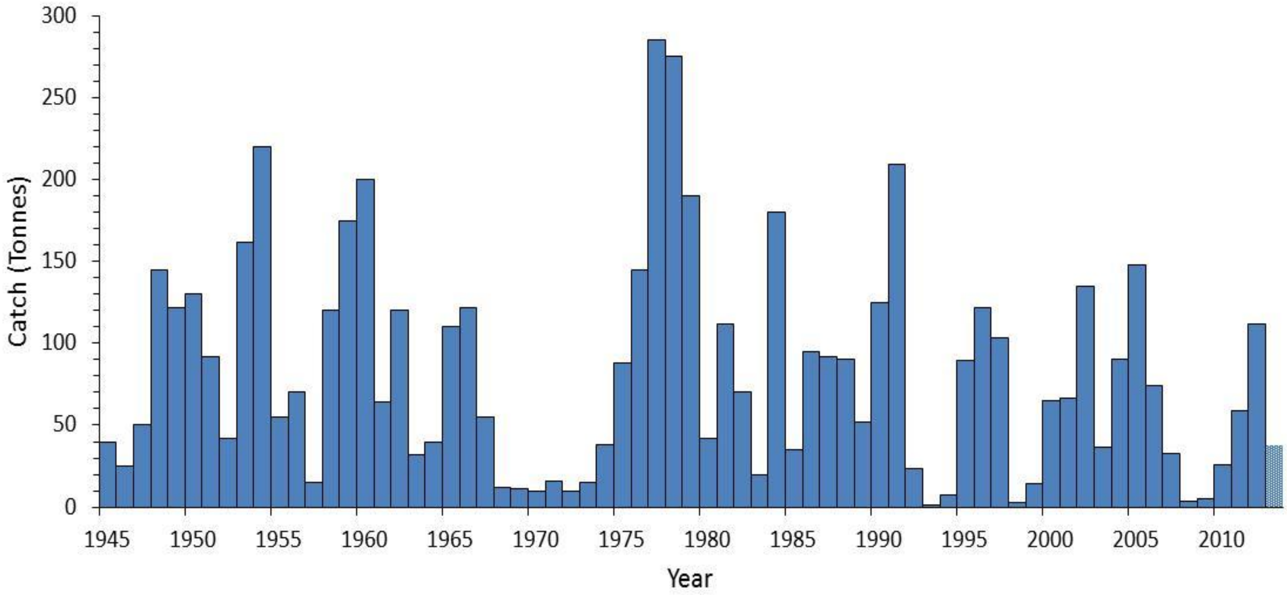

Figure 4-18:Annual commercial flatfish catches from Te Waihora, 1945 to 2013. Note that 2013 figures are incomplete at time of writing.

A plot of the commercial fishery returns from 1990-2013 by species (Figure 4-19), shows that black flounders provide the bulk of the catch (633 tonnes, 43%) over the past 23 years, followed by sand flounders (216 tonnes,15%) and yellowbelly flounders (181 tonnes, 12%). Unspecified flatfish catches (where species of flatfish landed was not recorded, or the fish caught were not the three main species) accounted for a total of 432 tonnes (30%). While these are the proportions derived from fishers' estimates, a previous review suggested that the high proportions of sand flounder is unlikely and is probably associated with coding errors leading to an over-representation of this species (Jellyman and Smith 2008).

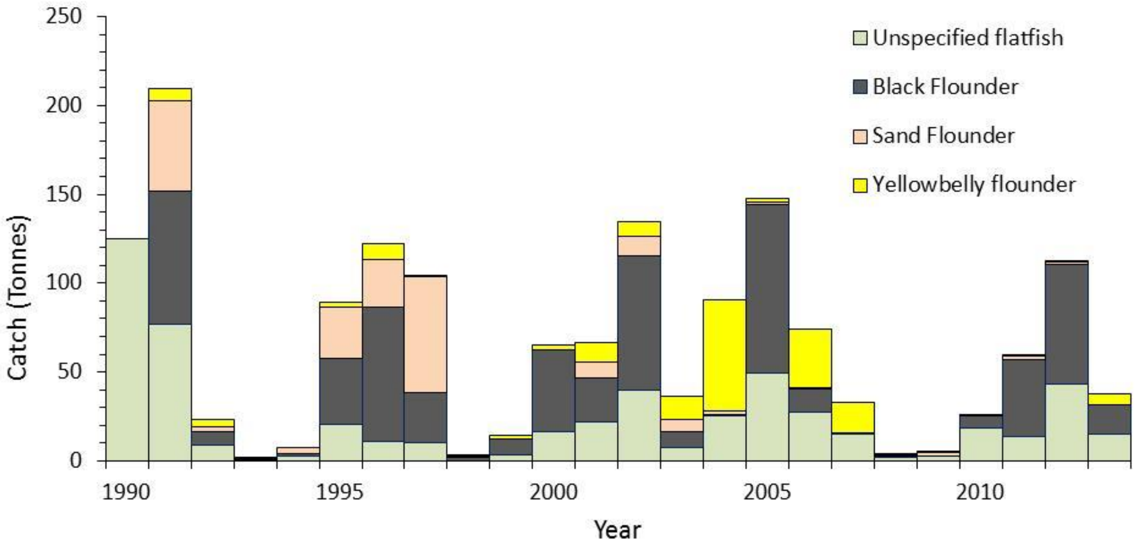

Figure 4-19:The species proportions of flatfish reported from the Te Waihora commercial fishery 1990-2013. Note that 2013 figures are incomplete at time of writing.

4.3.5 Aquaculture potential of flatfish

The annual variability of flatfish catch from Te Waihora is almost certainly associated with the annual variation in recruitment of juveniles. One way of potentially counteracting the fluctuations in the lake's flatfish stocks may be supplementing recruitment with an aquaculture program of one or more of the main flatfish species. While there has been considerable research on aquaculture of flatfish species elsewhere in the world, e.g. the aquaculture of turbot and sole in the United Kingdom and Europe (Person-Le Ruyot 1990), this has been focused on sea water aquaculture. It is not known if the feasibility of using aquaculture of flatfish to supplement recruitment in Te Waihora has ever been fully investigated. In a review of the aquaculture potential of New Zealand freshwater species (McDowall 1995), it was noted that the black flounder is closely related to the greenback flounder (*Rhombosolea tapirina*), for which there had been some experimental aquaculture work undertaken in Tasmania. It was concluded that aquaculture of this species could be achieved in a technical sense. Although there was little information on the economics of flatfish aquaculture, it would probably be viable only if the product obtained a high market value (Hart 1994). Supplementing recruitment is likely to help support the commercial fishery from the lake, which may not be the desired outcome if the management objective is to ensure higher abundances of fish are available for customary and recreational catches. Overall, there is probably little potential for aquaculture of flatfish species in the lake, because the cost of setting up and developing new techniques may not be warranted given the intermittent need for enhanced recruitment.

4.4 Yelloweye mullet (aua)

Although yelloweye mullet are a marine species, they are able to tolerate a range of salinities and are frequently found in estuaries and low gradient rivers. Usually, yelloweye mullet move upstream into rivers on incoming tides to feed on algae and small invertebrates (McDowall 1990). They are common in Te Waihora and support a commercial fishery, with some fish recorded up to almost 40 mm in length (Figure 4-20). Spawning occurs at sea, probably in two separate periods; McDowall (1990) suggested early summer and autumn, and Webb (1973) reported ripe females being recorded from the Avon - Heathcote estuary from June–July and November–February. For both sexes, first maturity was reached at 220 – 230 mm.

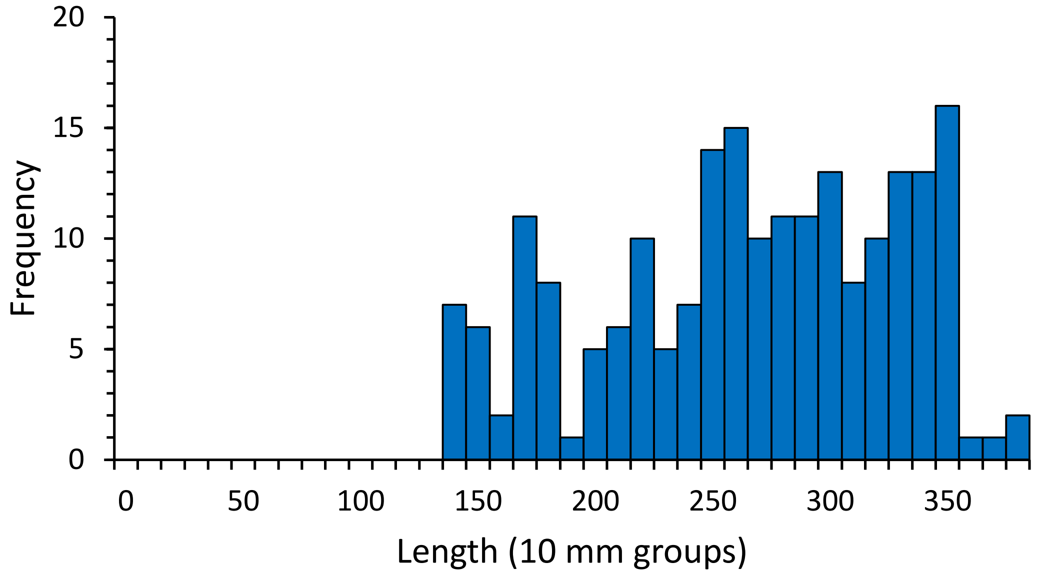

Figure 4-20:Length frequency of yelloweye mullet taken by gill-netting from Te Waihora, 1961.

4.4.1 Commercial Fishery

The commercial fishery in Te Waihora fluctuates with both recruitment of fish from the sea, and also with market demands (Jellyman 2012). In an early review of the mullet fishery of the lake, Gorman (1960) noted that the catches peaked in midwinter with a lesser peak in summer. While this winter fishery was partly because eels were less active (and eels frequently attacked mullet caught in the gill nets), it was also because mullet are affected by cold water temperatures which results in them forming schools and becoming more accessible to fishers (Jellyman and Smith 2008).

Catches of mullet in Te Waihora, and at other locations around Canterbury, from various studies show marked seasonal variability (Jellyman 2012). Fyke nets set at Taumutu gave peak catches from May to July and in December (Hardy 1989), but few mullet were caught at Timberyard Point during this time. In contrast, seasonal seine net catches from September 2005 to May 2008 in Te Waihora captured no mullet from 60,000 fishes (NIWA unpublished data). Low proportions (0.05% of catch abundance) of mullet were caught in a study of fish recruitment by Taylor and Graynoth (1995) with most fish being caught during July, September and October. Similarly, 66% of the mullet recorded by Webb (1972) in the Avon-Heathcote estuary were caught between September and December. In a seasonal study of fish entering the Rakaia Lagoon, Eldon and Greager (1980) found that mullet were present from September to June, but large numbers from only January to April. In a seasonal study of the Waimakariri Lagoon, Eldon and Kelly (1985) recorded juvenile mullet (< 60 mm) during February and March.

Based on the above findings of monthly variability in mullet abundance, recruitment of juvenile mullet into Te Waihora is likely to occur mostly from December to February. As movement into brackish and freshwater is not obligatory for this species, it is quite likely that recruitment of larger fish could occur at almost any month of the year. Emigration of ripening adults (fish > 220 mm) will probably take place from April to June. Fish are known to move in and out of estuaries on a tidal cycle, suggesting that it is possible for emigration of immature fish to occur frequently throughout the year.

In a review of the mullet fishery (Jellyman 2012) made the following conclusions:

- The annual catch of mullet from Te Waihora averages 5.8 tonnes, with a maximum of 22 tonnes observed in 1992 (Figure 4-21).
- The fishery is essentially a winter one, with about 66% of the catch taken between June and August inclusive.
- Catches from the lake will reflect favourable opening times for entry of juveniles and pre-spawning adults, usually in spring or early summer.
- Catches also reflect market demand. At present, the demand is relatively small and the yield from the fishery could be easily increased if required.

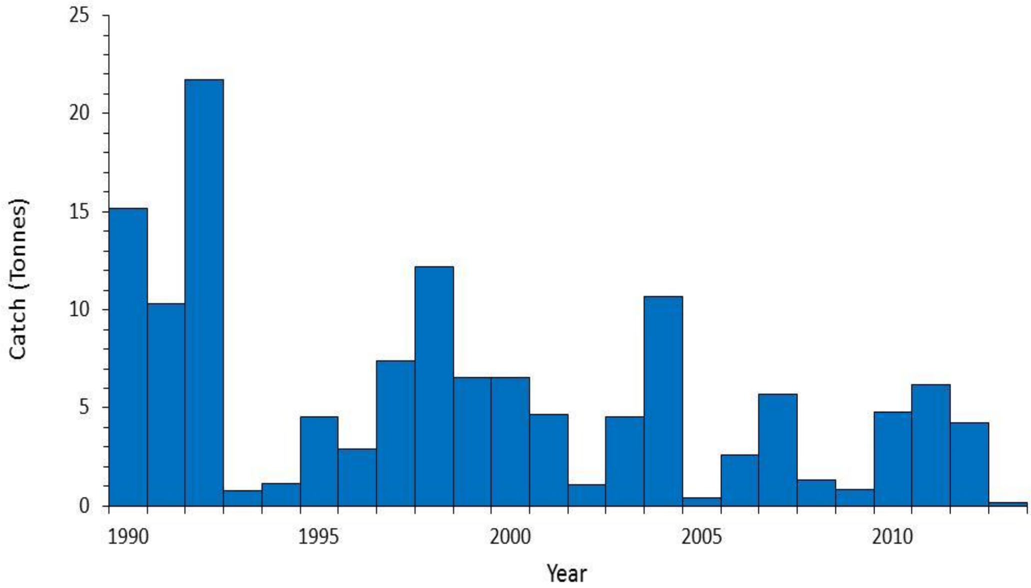

Figure 4-21:Annual commercial mullet catches from Te Waihora, 1990 to 2013. Note that 2013 figures are incomplete at time of writing. Data from MPI (Appendix A).

4.5 Inanga

Inanga are the most common of New Zealand's five whitebait species, and are frequently found in coastal waters and estuaries (McDowall 1990). They are commonly encountered in Te Waihora, and were the third most abundant fish species caught by Glova and Sagar (2000) (Table 4-2). Inanga are diadromous, but some non-diadromous (landlocked) stocks also exist in the North Island (McDowall 2010). It is highly likely that both diadromous and non-diadromous forms of inanga coexist in Te Waihora (Jellyman 2012).

In their study of fish communities in the lake, Glova and Sagar (2000) found that inanga were distributed around the lake margin, particularly along the western side of the lake. No inanga were caught at offshore sites, and it has been suggested that wind would displace these fish to the lee shore by wind-driven currents (Taylor 1996). It was hypothesised that such pelagic species could become displaced by winds, but experience with frequent winds may lead fish to occupy the specific sheltered embayments along the lake margins (Jellyman 2012).

Jellyman (2012) reported that gravid male and female inanga were present near Taumutu from mid-February to mid-April, but by the end of May fish were spent. Spawning is known to take place in Waikekewai Creek (Taylor 1996; Taylor et al. 1992), and spawning here was recorded during early May 1989 (Taylor et al. 1992). This spawning took place a few days after new moon, even though the lake was closed at this time. The spawning area was destroyed in May 1990 when a digger was used to dredge the area (Figure 4-22).

Inanga eggs are laid at the base of vegetation on the banks of inlet steams (or the lake edge) when water levels are high and when eggs are exposed to the air during dropping water levels. Eggs survive as long as the relative humidity is high, hence it is important to have overhead shade and low canopy plants to retain moisture for the several weeks between eggs being laid and hatching. Most inanga spawn at one year of age, although some will delay maturation until their second year, or occasionally their third year (McDowall 1990); spent fish die after spawning.When the lake is open during the whitebait season (August to November), good catches can be collected at Taumutu, and to a lesser extent, at the mouths of the Irwell, Selwyn and Halswell Rivers within a few days of the lake opening (Taylor 1996). Within the slow flowing tributaries, whitebait are known to migrate as far as 4-5 km upstream.

In summary, important areas for this species are the sheltered embayments along the eastern shoreline, especially those with vegetated shorelines as inanga will take advantage of the shelter provided by such areas, especially raupo, during times of strong wind. Reeds and rushes will also provide refuge from predatory birds and fish (eels and trout). Waikekewai Creek is the only known spawning area, and as spawning is normally associated with the salt-wedge (interface of salt and fresh water in riverine habitats), spawning here is more likely than at sites more distant from Taumutu. The lower reaches of the main tributaries may also provide significant habitat for rearing juvenile and adult inanga.

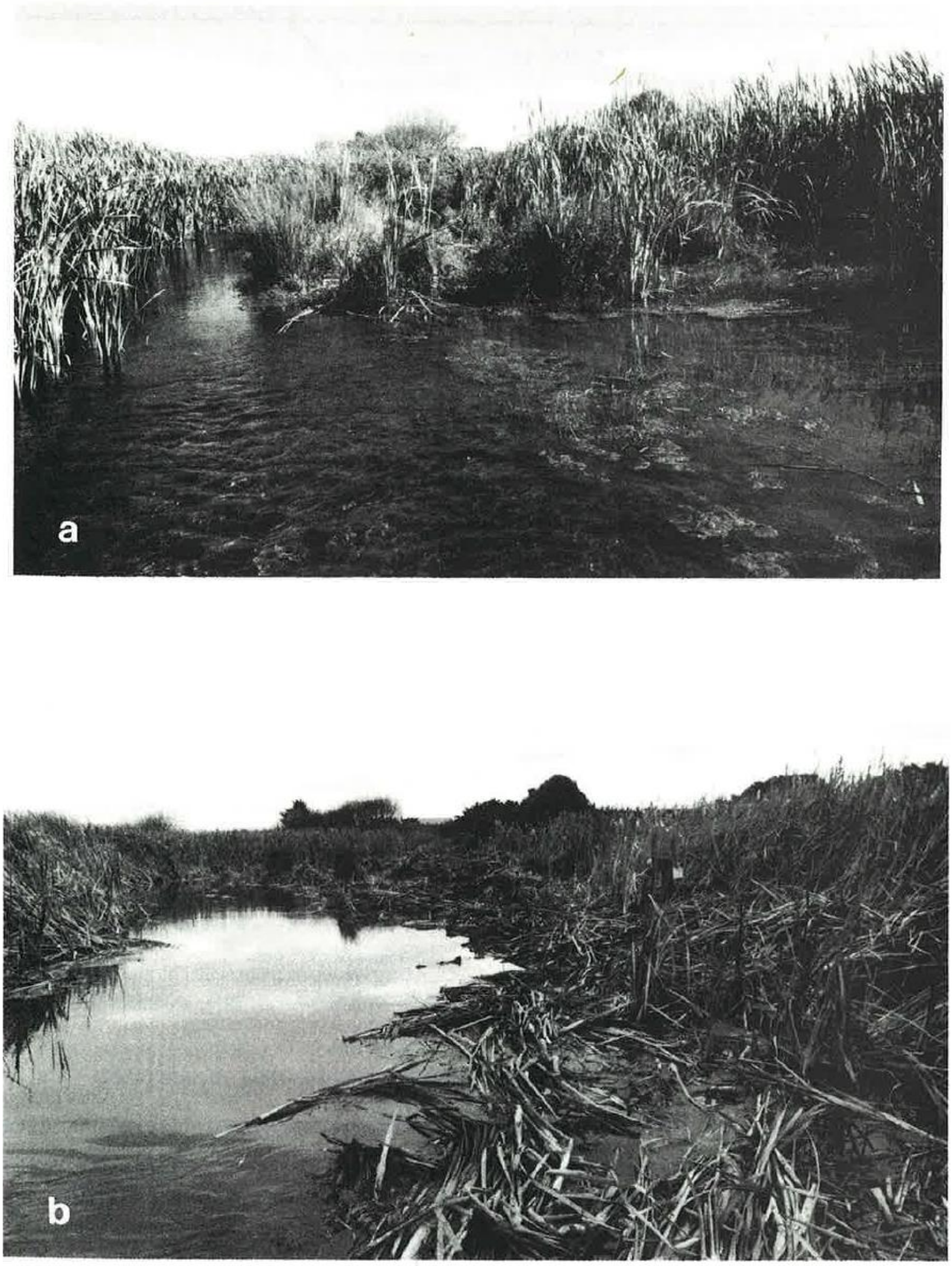

Figure 4-22: Inanga spawning area around Waikekewai Creek before (a) and after (b) being cleared by a mechanical digger in 1990. (NIWA unpublished data).

4.6 Common bullies

Common bullies dominate the fish community of the lake, comprising 92% of the abundance and 44% of the biomass (Glova and Sagar 2000). Similarly, common bullies accounted for 93.4% of the fish abundance in trawl catches reported by Graynoth and Jellyman (2002). Chisnall and West (1996) found that catches of common bullies in Te Waihora were twice those recorded from Lake Waahi in the Waikato (1544 fish/night cf. 784 fish/night). There is some suggestion that numbers of bullies in Te Waihora have increased over time (Jellyman and Todd 1998), possibly associated with a loss of macrophytes.

Common bullies measured in Te Waihora range in size from < 10 mm long to adults of 136 mm. The size range of bullies varies with distance offshore; bullies caught by trawl (100-4000 m offshore) are larger than from seines (0-100 m offshore). However, there is little variation in bully length with water depth. Sampling by a hand-towed benthic sled (NIWA unpubl. data), showed that small bullies (< 40 mm) were found in water as shallow as 10 cm, and occurred throughout the depth range. (Figure 4-23).

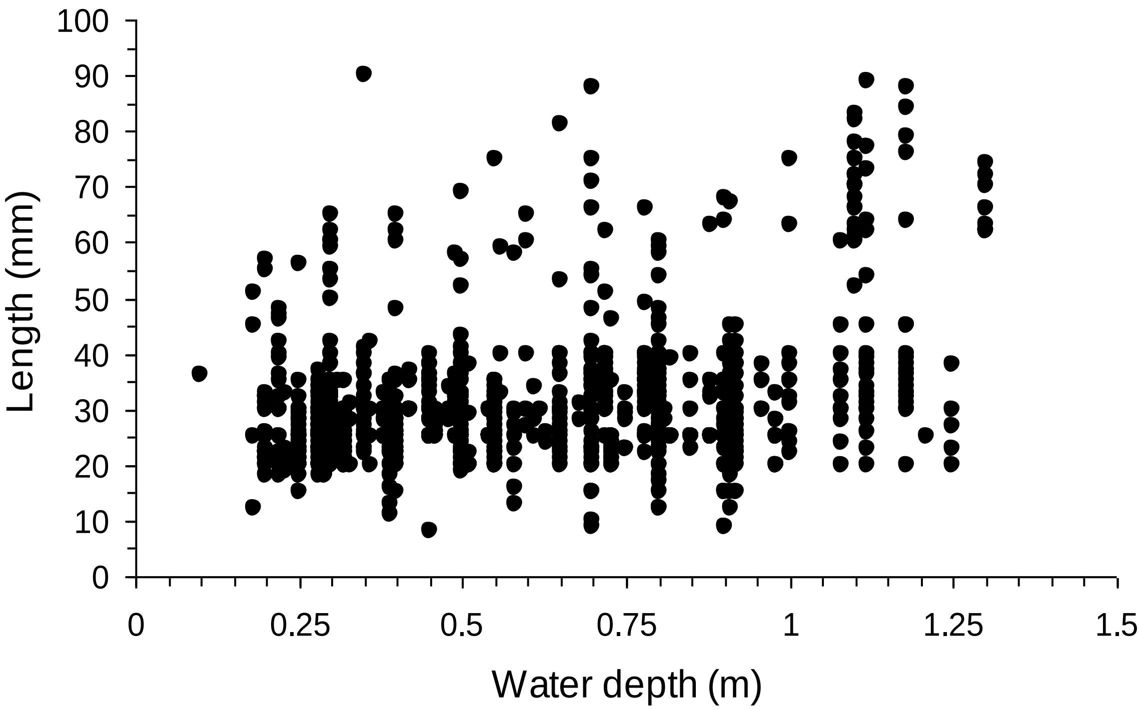

Figure 4-23:Length of common bullies caught in benthic sled tows at different depths from around Te Waihora. (NIWA unpublished data).

Common bullies can form both diadromous and non-diadromous populations which can coexist. Bullies spawn in spring and summer (McDowall 1990), and in diadromous populations, the newly hatched larvae are swept out to sea and return to fresh water as juveniles 15-20 mm long in autumn. In non-diadromous populations, the entire life-cycle occurs within fresh water and larvae do not go to sea. Larval bullies are pelagic (i.e. they occur in the water column), and those originating from non-diadromous stock will live in the water column of the lake until they reach 15-20 mm in length, at which stage they will move to the shallow littoral areas and commence benthic (bottom) living.

Landlocked populations of common bullies occur when access to the sea is blocked; typically this is in inland lakes that are beyond the normal distance of recruitment from the sea. For example, landlocked common bullies occur in Lakes Hawea, Pukaki, Wanaka, Ruataniwha, and Tekapo (all > 100 km inland) (McDowall 1990). Hydro lakes can also have non-diadromous populations because the fish are unable to surmount the dam and enter the lake (e.g. Lake Waitaki). Land locking can also occur if larval fish are unable to find their way out of a lake, usually in large lakes with a relatively small or intermittent outflow (McDowall 2010), as is the case with Te Waihora. The migratory status of common bullies in Te Waihora has not been determined, but it is presumed that the majority of fish are non-diadromous. Upcoming work in the Fisheries Management and Enhancement Project aims to address this knowledge gap. Reasons that the majority of the population are likely to be non-diadromous have been suggested by Jellyman (2012):

- Voluntary landlocking of common bullies is common and can occur in large lakes with small (or infrequently opened) outlets like Te Waihora and Lake Wairarapa.
- There is a strong representation of a range of size classes in the lake, even when the lake has been closed during spring and summer, the period of recruitment.
- Larval bullies have been caught in the centre of the lake (Taylor and Graynoth 1995).

Bullies provide a very important "food chain link" between invertebrates and predatory fishes in the lake (Kelly and Jellyman 2007). While bullies would always have been an important component in the diet of eels, there is some evidence that shortfins become piscivorous (fish eaters) at a smaller size (> 400 mm, Kelly and Jellyman 2007) than formerly thought (> 500 mm, Ryan 1978). Acceleration in growth rates of shortfins in Te Waihora at lengths between 380 – 660 mm has been attributed to eels becoming piscivorous (Jellyman 2001). Although primarily an invertebrate feeder, flounders are also known to occasionally feed on bullies (NIWA unpubl. data). Bullies also form an important component of the diets in herons, cormorants, gulls and terns (Sagar et al. 2004).

4.7 Common smelt

Two species of smelt occur in the Canterbury region – Stokell's smelt (*Stokellia anisodon*) and common smelt (*Retropinna retopinna*). Stokell's smelt is present in large rivers like the Waimakariri, Rakaia, Ashburton, Rangitata and Waitaki, but is uncommon or absent from smaller rivers like the Ashley, Opihi, Waihao, and Paerora (Bonnett 1992, McDowall 2010). McDowall (2010) suggested that periodic mouth closure of these smaller rivers might be a reason for the absence of this species. The same situation may apply in Te Waihora because this species has not been recorded from the lake (Bonnett 1992).

In contrast to Stokell's smelt, common smelt are frequently encountered in Te Waihora. Like common bullies, both diadromous and non-diadromous types are likely to co-exist in Te Waihora and in other lowland lakes, e.g Lake Waahi (Northcote and Ward 1985), Lakes Wairarapa, Wairewa, and possibly Waituna Lagoon (McDowall 2010). The two differ in vertebral counts with diadromous forms in Te Waihora having a vertebral count of 56 whereas the non-diadromous ("landlocked") form has about 61 vertebrae (McDowall 1990). There are also some more subtle differences between the two forms in characters like eye size, head length and the number of gill rakers.

Spawning of smelt occurs in fresh water, but this has not been observed in Te Waihora. Spawning is likely to take place on shallow, sandy beaches or in slack water around river and stream mouths (McDowall 1990), at depths of 0.5 – 2.5 m (Rowe et al. 2002). Spawning can occur over a prolonged period in summer and autumn (McDowall 1990), and larval migrations in the lower Waikato River indicated a small spring spawning, followed by a much larger summer - autumn (March – June) spawning (Meredith et al. 1989).

Larval smelt are planktonic and are frequently encountered in large shoals in some lakes. They remain a shoaling species throughout their lives, feeding on plankton, especially mysids in Te Waihora. Most will mature, spawn and die within a single year (Ward and Boubée 1996).

4.7.1 Abundance and size

From the fish community survey of Glova and Sagar (2000), smelt comprised 3% of the numbers (and 2% of the biomass) of fish they caught (Table 4-2). Similarly, smelt comprised 3.5% of the trawl caught fish recorded by Graynoth and Jellyman (2002). However, from shore-based seine fishing (NIWA unpubl. data), the proportion of smelt was much greater, being 21.6% of all fish caught (Table 4-3). Such variation will largely reflect the fishing methods and locations because they predominantly occur along western shorelines and are sparse offshore (Glova and Sagar 2000). Smelt are also a shoaling fish, and thus numbers can fluctuate considerably, depending on the likelihood of encountering a school.

Size distributions of 929 common smelt collected from Te Waihora ranged from 36 to 135 mm in length (NIWA, unpubl. data), but were mostly between about 60 and 85 mm (Figure 4-24). From the length distribution of samples caught in January 2007, two year classes can be seen: juveniles of about 35 to 45 mm in length and adults about 60 to 85 mm in length (Figure 4-25). At entry into fresh water from the sea, juvenile smelt of diadromous origin can be as small as 45 – 60 mm, but are usually 70 – 90 mm (McDowall 1990). This indicates that the smaller fish in the January sample would be smelt of non-diadromous (i.e. landlocked) origin.

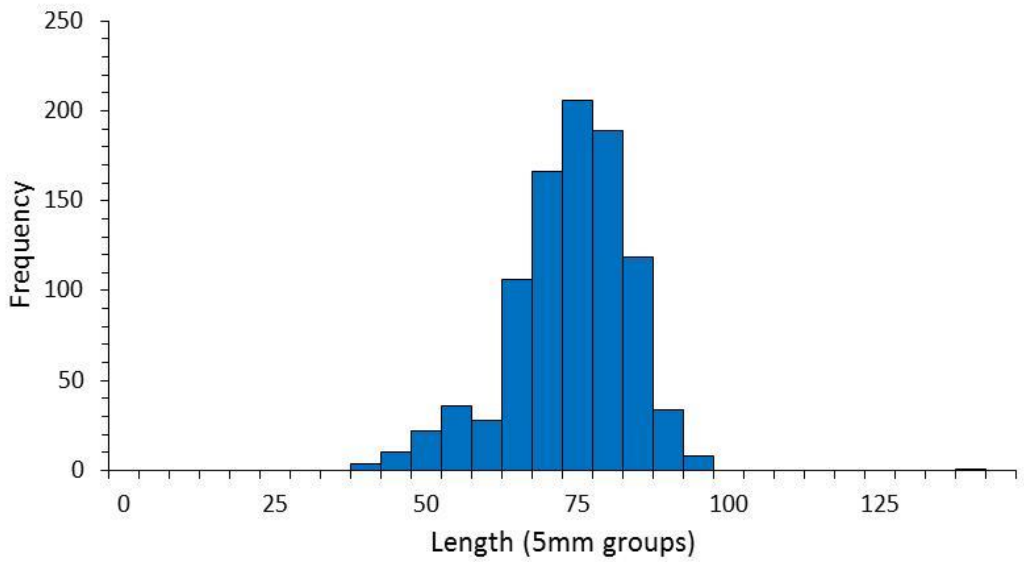

Figure 4-24:Length of common smelt from Te Waihora.

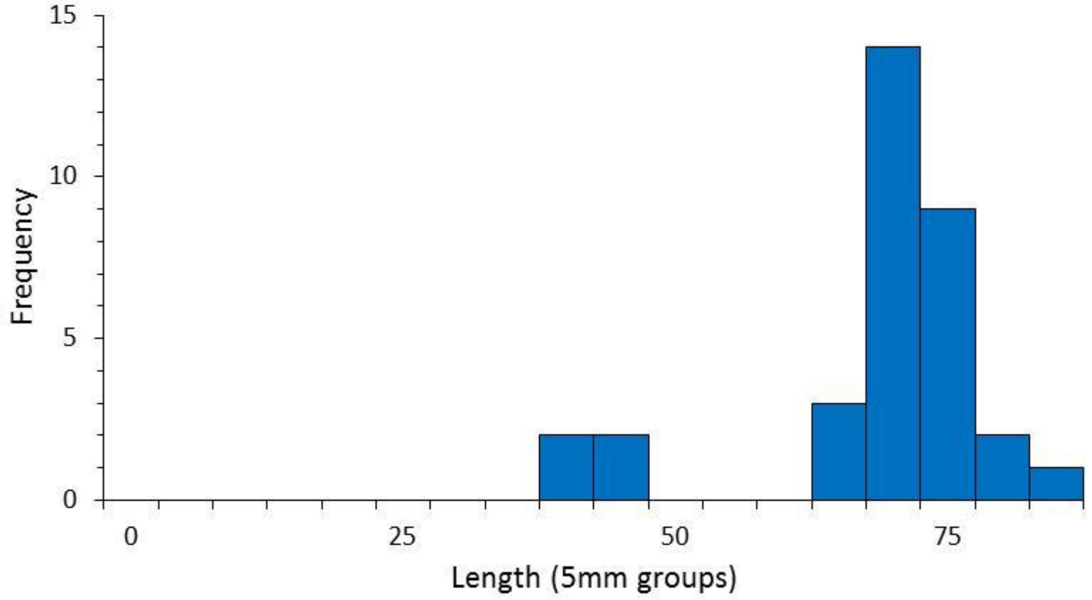

Figure 4-25:Length of common smelt from Te Waihora in January 2007.

5 Summary and discussion

Te Waihora is a large, productive lake that supports a high level of biodiversity and mahinga kai values. It also supports significant commercial fisheries for eels, flatfish, and mullet. There has been a commercial eel fishery in Te Waihora for almost 40 years; catches were initially very substantial (e.g. 847 tonnes in 1976) but soon began to decline, and the lake has been a controlled fishery since 1978. With the entry of South Island eels into the Quota Management System (QMS) in 2000, the total allowable catch (TAC) was reviewed and allocations made for customary and recreational use (customary = 31.26 tonnes, recreational = 3.13 tonnes). Measures of the CPUE in the fishery have shown steady increase in recent years, indicative of a productive fishery (Jellyman 2012). Little is known about factors driving eel growth, but upcoming work in the Whakaora Te Waihora Research Program aims to quantify factors responsible for growth and identify high productivity areas of the lake.

Longfin eels are not commercially harvested from Te Waihora, and the commercial fishery is unique because fisherman target migrating shortfin males. The fishing year for the Te Waihora eel fishery commences on 1 February to allow fishers access to the migration of male shortfins; the unfilled portion of fishers' quota may be caught later in the same year or in January of the following year.

Reserve areas are an effective means of safeguarding a portion of the eel populations. Reserves may be particularly effective for inshore areas because eel movement is more limited in these areas compared to the middle of the lake. Presently, reserve areas extend for a radius of 1.2 km around the mouth of the Irwell, Selwyn, LII and Halswell Rivers, and Harts Creek. The larger kohanga area (recreational and customary use area) around Kaituna Lagoon is also likely to be an important reserve area for freshwater fishes. Upcoming work in the Fisheries Management and Enhancement Project aims to quantify the proportion of eels within this reserve that may be temporarily exposed to commercial fishing when they move outside the reserve during foraging movements. This study will also generate data on fish abundance that could be used as a baseline dataset for measuring future changes in eel population sizes.

Te Waihora also supports a significant, but highly variable, flatfish fishery. Annual catch of flatfish has ranged from about 3 tonnes to more than 200 tonnes over the years; sometimes a 10-fold difference occurs in consecutive years. In addition to variation in the annual total catch, there is also a great deal of annual variability in the species composition of flatfish caught in the lake. Because adult flatfish do not spawn successfully in the lake, the annual differences in flatfish abundance is most likely to be caused by variability in recruitment of juveniles. Recruitment variability will be caused either as a result of changes in flatfish spawning success at sea, and/or from the lake not being open to the sea for long enough and at the right times for juvenile flatfish to move in. Further information on the monthly timing of flatfish recruitment into Te Waihora is required to assist with lake opening regimes. Better information on monthly recruitment of fishes into the lake is presently being collected under the Fisheries Management and Enhancement Project which will help address this knowledge gap.

Other migratory fish species in the lake are less dependent on lake openings, as land-locked populations may help sustain stocks. The migratory status (i.e. migratory or landlocked) of several species in the lake is not well understood (e.g. common bullies, smelt, inanga) and knowledge is required on this to assess the feasibility of management measures. For example, enhancing spawning habitat within the lake may have limited benefits if population sizes are predominantly dictated by recruitment of diadromous fishes. The proportion of the common bully populations that are diadromous is currently being explored in Fisheries Management and Enhancement Project.

While lake openings can enhance fish migration, water levels reductions during openings can indirectly influence fishes. Jellyman (2012) concluded that high lake levels are generally beneficial for fishes, especially shortfins, because this species will forage over flooded areas for terrestrial invertebrates (Jellyman 1989). Similarly, inanga are expected to forage and seek refuge in flooded margins where they will also feed to some extent on terrestrial food (McDowall 1968). Shortfins and inanga may therefore loose this terrestrial foraging opportunity after the lake is opened and water levels are reduced. Longfins are less responsive to changing water levels, because they predominantly occupy habitats in tributaries. The responses of the smaller species (bullies, smelt, and inanga) to lake level changes will be will be less pronounced because they are strongly associated with sheltered vegetated embayments (Jellyman 2012).

Sustained low lake levels are generally detrimental for most fishes. Reduced lake levels will restrict feeding areas for fish and may lead to elevated water temperatures or increase the likelihood of associated algal blooms. Low water levels during recruitment periods may also restrict opportunities for mouth openings targeted at improving fish recruitment and/or emigration. Shallow lake levels may also result in higher levels of sediment re-suspension, which can reduce feeding opportunities for visual feeders and cause. Furthermore, high sediment levels in the lake could cause reduced respiratory performance (Lake and Hinch 1999) and recruitment of fishes (Boubée et al. 1997).

Falling water levels can be either short-term (hours - wind driven) or long term (days - associated with lake openings). Short-term but rapid drops are generally detrimental to fish, as they may require some compensatory movements to avoid stranding. There is little information on fish stranding, but there are records of Māori harvesting stranded eels (Best 1929). A slow reduction in water levels is likely to have a negligible effect on fish stranding.

The relative importance of the various lake and tributary habitats (Table 5-1) indicates that inshore lake habitats are extremely important for each of the species listed, with the exception of longfin eels where the tributaries are the most valuable habitat. The vegetated margins of the lake are highly important to smelt, but especially to inanga as this species largely resides and spawns in such areas. Bullies are very common inhabitants of both the inshore areas of the lake, and the lower reaches of tributaries.

Table 5-1: The relative importance of generalised habitats to the main fish species of the lake. - = seldom occur; * = minor importance; ***** = major importance. From Jellyman (2012).

Species	Lake- inshore areas	Lake – offshore areas	Vegetated lake margins	Tributaries – lower reaches	Tributaries – upper reaches
Shortfin	*****	**	**	**	-
Longfin	***	*	**	*****	*****
Flatfish	*****	**	**	*	-
Bullies	*****	*	***	*****	*

Smelt	*****	-	****	****	-
Inanga	*****	-	*****	*****	-

Both the quality and quantity of tributary waters are of concern for fish. Water quality of tributaries has shown a general decline over the past decade as a consequence of low flows (Hayward and Ward 2008). Impacts of decreased water quality will be more indirect through aspects like proliferation of aquatic plants (with associated diel shifts in dissolved oxygen and pH), than direct. Of more concern is the marked reductions in surface flow that have accompanied the intensification of landuse of the Te Waihora catchment – for instance, the extent of the ephemeral zone (16 km; Larned et al. 2010) in the Selwyn River is increasing at an average of 0.6 km $year^{-1}$ (Rupp et al. 2008).

6 Acknowledgements

We thank Helen Rouse and Mandy Home who provided useful feedback on this report, and Dave Rowe who reviewed this report. We also acknowledge the efforts of all the people who collected and/or contributed data to this report. Funding for this project was provided by the Whakaora Te Waihora Partners.

7 References

Allibone, R., David, B., Hitchmough, R., Jellyman, D., Ling, N., Ravenscoft, P., Waters, J. (2010) Conservation status of New Zealand freshwater fish, 2009. *New Zealand Journal of Marine and Freshwater Research,* 44*.* 271 – 287.

Ayling, T., Cox, G. J. (1982) *Collins' guide to sea fishes of New Zealand.* Collins, Auckland. 343 p.

Beentjes, M.P. (1999) Size, age, and species composition of commercial eel catches from South Island market sampling, 1997-98. *NIWA Technical Report* 51: 51.

Best, E. (1929) Fishing methods and devices of the Māori. *Dominion Museum Bulletin,* 12: 1-230.

Bonnett, M.L. (1992) Distribution and freshwater residence of Stokell's smelt, *Stokellia anisodon* (Stokell), in the South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 26: 213 - 218.

Boubée, J.A.T., Dean, T.L., West, D.W., Barrier, R.F.G. (1997) Avoidance of suspended sediment by the juvenile migratory stage of six New Zealand native fish species. *New Zealand Journal of Marine and Freshwater Research*, 31: 61-69.

Chisnall, B.L., West, D.W. (1996) Design and trials of a large fine-meshed fyke net for eel capture, and factors affecting size distribution of catches. *New Zealand Journal of Marine and Freshwater Research,* 30: 355-364.

Colman, J.A. (1973) Spawning and fecundity of two flounder species in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 7: 21-43.

Eldon, G.A., Greager, A.J. (1983) Fishes of the Rakaia lagoon. Fisheries Environmental Report. Christchurch, New Zealand Ministry of Agriculture and Fisheries 30. 65 p.

Eldon, G.A., Kelly, G.R. (1985) Fishes of the Waimakariri estuary. Christchurch, New Zealand Ministry of Agriculture and Fisheries. 34 p.

Glova, G.J., Jellyman, D.J. (2000) Size-related differences in diel activity of two species of juvenile eel (*Anguilla*) in a laboratory stream. *Ecology of Freshwater Fish,* 9: 210-218

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

Gorman, T.B.S. (1960) Preliminary report on flatfish: Lake Ellesmere. Special Report, Department of Agriculture and Fisheries, Christchurch, New Zealand. 26. p.

Graynoth, E., Jellyman, D.J. (2002) Growth, survival, and recruitment of juvenile shortfinned eels (*Anguilla australis*) in a large New Zealand coastal lake. *New Zealand Journal of Marine and Freshwater Research,* 36: 25-37.

Hardy, C.J. (1989) Fish habitats, fish, and fisheries of the Ellesmere catchment. *New Zealand Freshwater Fisheries Report,* 104. 152 p.

Hart, P.R. (1994) Tasmanian flounder research – the story so far. *Austasia Aquaculture*, 8(6): 37-39.

Hayward. S., Ward. J.C. (2009) Water quality in the Ellesmere catchment. In: K.F.D. Hughey, K.F.D. & K.J.W. Taylor (Eds). *Te Waihora/Lake Ellesmere – the 2007 State of the Lake and Management Futures Report:* 21-31.

Hickford, M.J.H., Schiel, D.R. (2003) Comparative dispersal of larvae from demersal versus pelagic spawning fishes. *Marine Ecology Progress Series,* 252: 255 - 271.

Hobbs, D.F. (1947) Migrating eels in Lake Ellesmere. *Transactions and Proceedings of the Royal Society of New Zealand,* 77: 228-232.

Jellyman, D.J. (1977) Summer upstream migration of juvenile freshwater eels in New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 11: 61-71.

Jellyman, D.J. (1989) Diet of two species of freshwater eel (*Anguilla* spp.) in Lake Pounui, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 23: 1-10.

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

Jellyman, D.J. (2011) What causes the high interannual variability in the species composition and abundance of flatfish (*Rhombosolea* spp.) in Lake Ellesmere (Te Waihora), Canterbury, New Zealand? *New Zealand Journal of Marine and Freshwater Research,* 45: 575–589.

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, D.J., Chisnall B.L. (1999) Habitat preferences of shortfinned eels (*Anguilla australis*), in two New Zealand lowland lakes. *New Zealand Journal of Marine and Freshwater Research,* 33: 233-248.

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., Graynoth, E. (2010) The importance of tributary streams of Te Waihora/Lake Ellesmere in maintaining populations of longfin eels. *NIWA Client Report*, CHC2010- 087. 68 p.

Jellyman, D.J., Lambert, P. (2003) Factors affecting recruitment of glass eels into the Grey River. *New Zealand. Journal of Fish Biology,* 63: 1067-1079.

Jellyman, D.J., Smith, C. (2008) Native Fish and Fisheries of Te Waihora. In: K.F.D. Hughey K.J.W. Taylor, (Eds.). *Te Waihora/Lake Ellesmere – the 2007 State of the Lake and Management Futures Report*. 41-48.

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 Francais de Pêche et Pisciculture,* 349: 141-152.

Jellyman D.J., Chisnall B.L., Todd P.R. (1995) The status of the eel stocks of Lake Ellesmere. *NIWA Science and Technology Series*, 26: 62.

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.

Kilner, A.R., Akroyd, J.M. (1978) Fish and invertebrate macrofauna of Ahuriri Estuary, Napier. Wellington, *New Zealand Ministry of Agriculture and Fisheries*. 79 p.

Lake, R.G., Hinch, S.G. (1999) Acute effects of suspended sediment angularity on juvenile coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* 56: 862-867.

Larned, S.T., Schmidt, J., Datry, T., Konrad C.P., Dumas J.K., Diettrich, J.C. (2010) Longitudinal river ecohydrology: flow variation down the lengths of alluvial rivers. *Ecohydrology* DOI: 10.1002/eco.126

Martin, M., Boubee, J.A.T, Bowman E., Griffin, D. (2006) Recruitment of freshwater eels: 2004-2005 and 2005-2006. *Research Report for Ministry of Fisheries Research*, Project EEL2004-01. 99 p.

McDowall, R.M. (1968) *Galaxias maculatus* (Jenyns), the New Zealand whitebait. Wellington, New Zealand Ministry of Agriculture and Fisheries. *Fisheries Research Bulletin* 2: 84 p.

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

McDowall, R.M. (1995) Aquaculture potential of non-salmonid fishes and other species in New Zealand fresh waters: an analysis of the prospects and technical issues. *NIWA Science and Technology Series,* no. 20. 49 p.

McDowall, R.M. (2000) *The Reed Field Guide to New Zealand Freshwater Fishes*. Auckland, New Zealand, Reed Books. 224 p.

McDowall, R.M. (2010) *New Zealand Freshwater Fishes. An Historical and Ecological Biogeography*. Springer. 449 p.

Meredith A.S., Empson, P.W., Boubée, J.A.T., Mitchell C. P. (1989) Ichthyoplankton studies on the lower Waikato River. II. Larval distributions at Huntly. *New Zealand Ministry of Agriculture and Fisheries New Zealand Freshwater Fisheries Report*, 109. 58 p.

Mundy, A.R. (1968) *A study of the biology of the sand flounder, Rhombosolea plebia (Richardson) off the Canterbury coast*. Thesis. University of Canterbury. 151 p.

Parliamentary Commission for the Environment. (2013) *On a pathway to extinction?* An investigation into the status and management of the longfin eel. 95 p.

Person-Le Ruyot, J. (1990) Sole and turbot culture. In: G. Barnabe, G. (Ed). *Aquaculture*. Horwood, New York. 2 volumes. 687-734.

Paul, L.J. (2000) *New Zealand fishes. Identification, natural history and fisheries*. Auckland, Reed Books. 253 p.

Roper, D.S., Jillett, J.B. (1981) Seasonal occurrence and distribution of flatfish (Pisces: Pleuronectiformes) in inlets and shallow water along the Otago coast. *New Zealand Journal of Marine and Freshwater Research,* 15: 1-13.

Rupp, D.E., Larned, S.T., Arscott, D.B., Schmidt J. (2008) Reconstruction of a daily flow record along a hydrologically complex alluvial river. *Journal of Hydrology,* 359: 88-104.

Ryan, P.A. (1974) The fish of Lake Ellesmere, Canterbury. *Mauri Ora, 2:* 131-136.

Ryan, P.A. (1978) *The ecology of the short fin eel Anguilla australis schmidtii in Lake Ellesmere, Canterbury*. Unpublished PhD thesis, University of Canterbury, N.Z.

Ryan P.A. (1986) Seasonal and size-related changes in the food of the short-finned eel, *Anguilla australis* in Lake Ellesmere, Canterbury, New Zealand. *Environmental Biology of Fishes,* 15: 47-58.

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,* CHC2004-068. 55 p.

Singleton, G. (2007) *Ellesmere. The jewel in the Canterbury Crown*. Selwyn District Council. 498 p.

Stevens, D.W. (1993) *A comparative study of the otoliths and associated labyrinthine apparatus of the New Zealand flatfish (Order Pleuronectiformes).* M.Sc (Hons) Thesis. Victoria University of Wellington, New Zealand.

Taylor, M.T., Graynoth, E. (1995) Native fish immigration into Lake Ellesmere during 1994. *NIWA Science and Technology Report*, 27: 25.

Taylor K.J.W. (Ed.) (1996) The Natural Resources of Lake Ellesmere (Te Waihora) and its Catchment. Canterbury Regional Council. 322 p.

Taylor, M.J., Buckland, A.R., Kelly, G.R. (1992) South Island inanga spawning surveys, 1988-1990. *New Zealand Freshwater Fisheries Report*, 133: 69 p.

Te Runanga o Ngai Tahu, Department of Conservation. (2005) *Te Waihora joint management plan*. 219 p.

Todd, P.R. (1974) *Studies on the reproductive biology of New Zealand freshwater eels.* Unpublished PhD thesis, Victoria University of Wellington, N.Z.

Todd, P.R. (1980) Size and age of migrating New Zealand freshwater eels (*Anguilla* spp.). *New Zealand Journal of Marine and Freshwater Research,* 14: 283-293.

Todd, P.R. (1981) Timing and periodicity of migrating New Zealand freshwater eels (*Anguilla* spp.). *New Zealand Journal of Marine and Freshwater Research,* 15: 225-235.

Vignaux, M. (1994) Catch per unit effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. New Zealand Fisheries Assessment Research Document. 94/11. 29 p. MAF (Fisheries), Wellington. (Unpublished report held in NIWA library, Wellington.)

Ward, F.J., Boubee, J.A.T. (1996) Effect of age at maturity on life-span and generation time of New Zealand common smelt, *Retropinna retropinna* (Richardson). *Canadian Journal of Fisheries and Aquatic Science,* 53*:* 467 - 473.

Webb, B.F. (1972) Fish populations of the Avon-Heathcote estuary. 1. General ecology; distribution, and length-frequency. *New Zealand Journal of Marine and Freshwater Research,* 6*:* 570 - 601.

Webb, B.F. (1973) Fish populations of the Avon-Heathcote estuary. 2. Breeding and gonad maturity. *New Zealand Journal of Marine and Freshwater Research,* 7: 45 - 66.

Appendix A Commericial catch from Te Waihora

Commercial catch from Te Waihora, in tonnes. Note that records for 2013 are incomplete at date of writing, and that from 1989, year represents "fishing year" in Te Waihora, i.e. 1 February to 31 January.

	Shortfin	Yelloweye	Total	Flatfish : three main species			Flatfish
Year	eel	mullet	Flatfish	black	sand	yellowbelly	unspecified
1945			40				
1946			25				
1947			50				
1948			145				
1949			122				
1950			130				
1951			92				
1952			42				
1953			162				
1954			220				
1955			55				
1956			70				
1957			15				
1958			120				
1959			175				
1960			200				
1961			64				
1962			120				
1963			32				
1964			40				
1965			110				
1966			122				
1967			55				
1968			12				
1969			11				
1970			10				
1971			16				
1972			10				
1973	251		15				
1974	256		38				
1975	566		88				
1976	847		145				
1977	441		285				
1978	524		275				
1979	359		190				
1980	299		42				
1981	208		112				
1982	109		70				
1983	107.5		20				
1984	89.6		180				
1985	99.4		35				

	Shortfin	Yelloweye	Total	Flatfish : three main species			Flatfish
Year	eel	mullet	Flatfish	black	sand	yellowbelly	unspecified
1986	81.6		95				
1987	103.2		92				
1988	103.7		90				
1989	104.5		52				
1990	91.2	15.139	125				
1991	134.5	10.283	209.484	74.75	51.148	6.845	76.741
1992	167.9	21.751	23.146	7.265	3.153	3.898	8.83
1993	130.5	0.789	1.285	0.453	0.298	0.127	0.407
1994	87.6	1.156	7.208	1.582	3.083	0	2.543
1995	99.3	4.533	89.331	37.121	28.576	3.055	20.579
1996	120.4	2.881	121.999	75.015	27.258	8.526	11.2
1997	64	7.3805	103.573	27.824	65.183	0.178	10.388
1998	72	12.1957	2.967	2.13	0.503	0.185	0.149
1999	208.5	6.575	14.6	8.666	0.015	2.361	3.558
2000	107.8	6.566	65.181	46.234	0.224	2.594	16.129
2001	107.4	4.653	66.585	24.778	8.542	11.23	22.035
2002	92.8	1.075	134.464	75.733	11.285	7.788	39.658
2003	121.5	4.532	36.434	8.849	6.626	13.157	7.802
2004	121.9	10.666	90.35	0.954	1.908	62.443	25.045
2005	127.361	0.394	147.641	94.594	1.021	2.292	49.734
2006	120.851	2.624	73.911	13.113	0.383	32.909	27.506
2007	119.815	5.668	32.6828	0.5808	0.578	16.608	14.916
2008	109.477	1.333	3.505	0.299	0.439	0.465	2.302
2009	120.09	0.85	4.8987	0.198	2.1387	0.053	2.509
2010	130.053	4.765	25.5177	6.3883	0.368	0.1364	18.625
2011	125.087	6.168	58.903	43.539	1.805	0.146	13.413
2012	126.956	4.261	111.965	67.22	1.564	0.061	43.12
2013	49.282	0.166	37.771	16.045	0.396	6.095	15.235