NIWA
Taihoro Nukurangi

Fish recruitment into Te Waihora/Lake Ellesmere. A consideration of the requirements of key species

Prepared for Environment Canterbury

February 2012

Authors/Contributors:
Don Jellyman

For any information regarding this report please contact:
Don Jellyman
Scientist
Freshwater Biology and Fisheries
+64-3-348 8987
d.jellyman@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:	CHC2011-094
Report date:	February 2012
NIWA Project:	ENC11529

Contents

Tables

Figures

Reviewed by

Approved for release by

Shan Crow

Marty Bonnett

Executive summary

Te Waihora/Lake Ellesmere is opened mechanically to the sea at pre-determined lake levels to minimise the risk of inundation of marginal lands and promote drainage of low lying areas. Lake openings also enable migratory fish to complete their life-history requirements, but the opening periods are not presently based on these seasonal migrations.This report reviews the biology of the main fish species from the customary and commercial fisheries (eels, flounders, and yelloweye mullet), the most abundant species in the lake (common bullies and common smelt), a species that was formerly abundant (brown trout), and inanga whose juveniles sustain the whitebait fishery. Important habitats for these species are identified and discussed, and also the vulnerability of these habitats to long-term (seasonal) and short-term (wind-induced) fluctuations in lake levels. Although bullies, smelt, and inanga are normally diadromous species (migrate to and from the sea at some stage during their lives), in Te Waihora/Lake Ellesmere they also form non-diadromous stocks, meaning that access to the sea is still desirable but not essential. In contrast, for both species of eel and the three main flatfish species (black, sand and yellowbelly flounders), access to the sea is essential for recruitment of juveniles and spawning migrations of adults. The productivity of the flounder fishery is associated with appropriate lake openings two years previously; as shortfin eels take an average of 12 years to enter the commercial fishery, loss of one year's recruitment is unfortunate but probably not critical. From a fisheries perspective, a seasonally-based opening regime that coincides with the migratory needs of fish is far preferable to the present one that is triggered by lake levels alone.

1 Project Brief

The following brief was supplied by ECan who commissioned the present report.

As part of managing Lake Ellesmere (Te Waihora) through artificial opening of the mouth to the sea Environment Canterbury requires a definitive report on fish passage into and out of the lake, and movements and habitat use within the lake and catchment that might be relevant considerations to lake openings.

Tasks

Provide a report that describes the current state of knowledge in the following areas:

- The timing of when eels/tuna (both longfin and shortfin) require migratory access into and out of the lake.
- The timing of when flat fish such as flounder/patiki (all species) and mullet require migratory access into and out of the lake.
- The identification of other fish species that may use the lake and their requirements and timing to migrate into and out of the lake (including but not restricted to native whitebait species, smelt species, bullies, Torrent fish, lamprey etc.).
- An update on current understanding on sports fish requirements (i.e. sea run trout) should also be considered.
- The minimum length of time an opening of the lake should be maintained for all or any the fish species above at the different times.
- Describe how openings could be made most effective for fish species by identifying prevailing conditions more conducive for fish to make use of openings (i.e. preceding lake levels, water temperatures, moon phase, weather condition etc.).
- Consider how movement to and from favoured habitats may affect the effectiveness of lake openings.

The report should review all the relevant scientific papers and reports and provide these in a bibliography with the report.

2 Background

Te Waihora/Lake Ellesmere is a large (20 000 ha) shallow coastal lake. The lake is highly turbid (Secchi depths < 0.2 m; Glova and Sagar 2000), and salinity normally ranges between 5-10 ppt (Lineham 1983; Gerbeaux 1989). The lake is a taonga to Ngai Tahu and provides a major source of mahinga kai and mana (Te Runanga of Ngai Tahu and Department of Conservation 2005). As part of the Ngai Tahu Settlement Act, the Crown vested the bed with Ngai Tahu. Much of the land adjoining the margins of the lake is administered by the Department of Conservation (DoC) who, together with Ngai Tahu developed a Joint Management Plan (Te Runanga of Ngai Tahu and Department of Conservation 2005) that outlined policies to maintain or enhance the significant values of the lake.

In recognition of its outstanding value as a wildlife (waterfowl) habitat, a National Water Conservation Order (WCO) was granted in 1990. The management of the lake carried out under the provisions of the WCO is generally limited to managing for birdlife.

However, a Technical Working Group was convened in July 2010, at the request of the Te Waihora/Lake Ellesmere Statutory Agencies Group, to consider a variation to the existing Water Conservation Order (WCO) over Te Waihora/Lake Ellesmere. It is understood that among the recommendations from this group are proposals to add two further categories of outstanding feature: native vegetation, considered regionally and nationally significant; and customary fisheries, also considered nationally significant.

While the fisheries of Te Waihora/Lake Ellesmere are not nationally significant on biodiversity grounds (although they may be considered regionally significant), having a species assemblage typical of shallow coastal lakes, the lake is considered to be nationally significant for customary fisheries, representing more of a potential value than a realised value, as the current customary harvest is small.

Although not a value that can be provided for in the WCO, it is of interest to note that Te Waihora/Lake Ellesmere is also nationally significant on commercial grounds as it still sustains a very productive and important commercial eel fishery (presently ~ 25% of national eel catch), and a significant flatfish fishery, e.g., virtually the whole national landings of black flounder come from the lake. The yelloweye mullet fishery is small, but only because the market is limited.

The WCO maintains the present summer and winter opening trigger levels,(1.05 and 1.13 m asl respectively), but has provision for an additional opening during 15 September-15 October pending the granting of water right to an interested party. As the fish species of main customary and commercial significance are diadromous (migrate between the sea and fresh water at some stage during their lives), lake opening times are critical to ensuring regular recruitment of these species. The present report reviews information about migration times of the most important fish species.

3 The lake as fish habitat

There are a number of physical descriptions of the lake and its tributaries (e.g. Hughes et al. 1974, Taylor 1996, Glova and Sagar 2000, Hughey and Taylor 2008). These are not repeated here. However, because of the importance of the lake substrate and shoreline vegetation to fish distributions, these are briefly described/summarised.

The margins and bed of the lake offer a range of habitat types of varying depths, substrates, shoreline cover, and salinity. Figure 3-1 shows the dominant substrate types recorded by Glova and Sagar (2000). The centre of the lake is mainly composed of soft clay, with some soft mud adjacent to Harts Creek. Sand predominates at Greenpark and towards Taumutu, while gravel is the dominant feature near Kaitorete Spit. Glova and Sagar (2000) describe the marginal vegetation as:

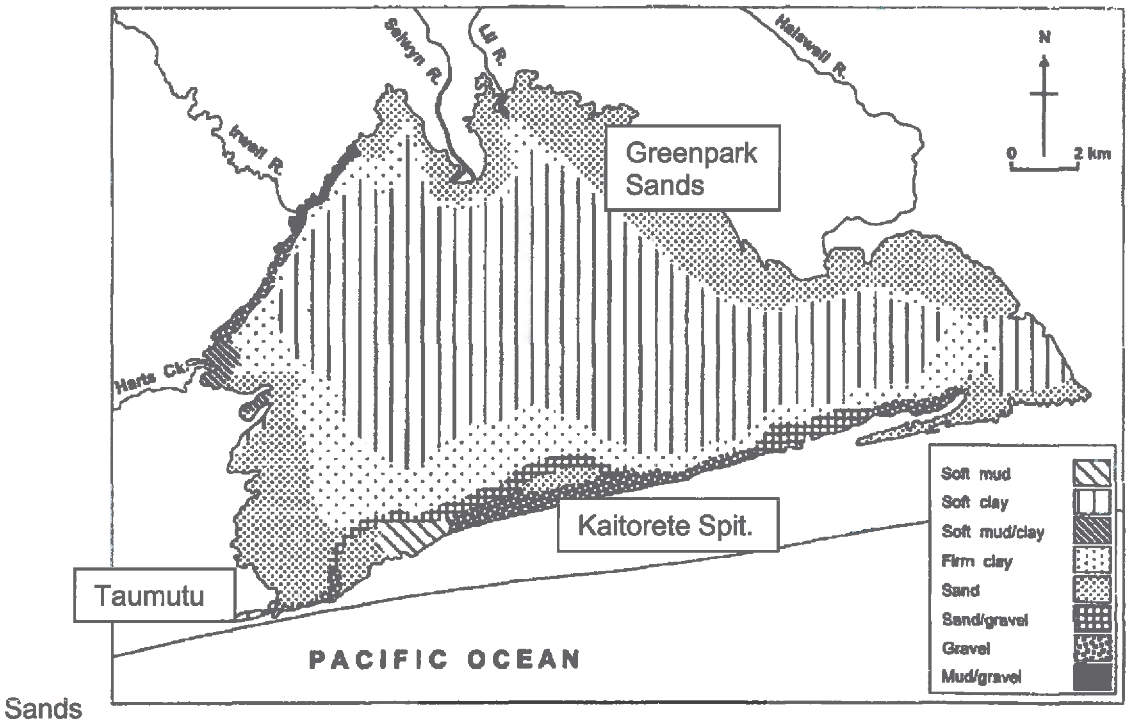

Figure 3-1: The dominant substrate types recorded from Lake Ellesmere, October 1994-March 1995. From Glova and Sagar (2000).

"The vegetation varied considerably around the lake margin, although less so along the northern and southern sides (Figure 3-2). The northern side was dominated by a variety of pasture grasses (Gramineae), sedges (Cyperaceae), and rushes (Juncaceae), typically <0.75 m tall, with small herbs (e.g. *Mimulus repens)* on the exposed sand/mud flats of the Greenpark Sands area. The eastern side consisted mainly of a mix of sea rush *(Juncus maritimus* var. *australiensis)* and pasture grasses, with some flats of glasswort *(Salicornia australis)* and *Mimulus.* Much of the southern side was covered in marsh ribbonwood *(Plagianthus divaricatus)* and sea rushes, with the mudflat areas dominated by *Mimulus* and *Triglochin striatum.* The western side had mainly a mix of short (<0.75 m) and tall (>0.75 m) sedges and rushes and pasture grasses, with patches of raupo *(Typha orientalis)* and willows (e.g., *Salix cinerea, S.fmgilis)* in swampy areas of Harts Creek and Irwell River.

Macrophytes were not common around the lake margin, except for stands of raupo within the vicinities of Harts Creek and Kaituna Lagoon, and rushes and others in shallow waters between Timber Yard Point and the lakeoutlet". Salt water will impact on both macrophytes and shoreline vegetation, especially raupo, which in turn will have some impacts on habitats occupied by fish as this vegetation provides important cover for fish

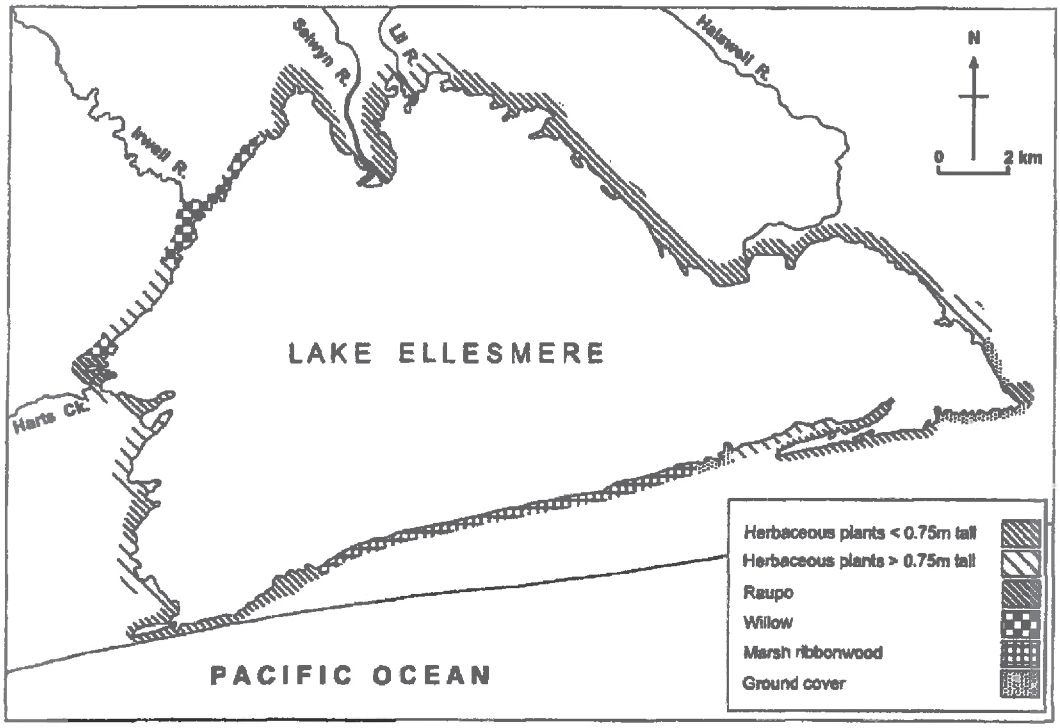

Figure 3-2: Main shoreline plant communities. From Glova and Sagar (2000).

4 Fish of Te Waihora/Lake Ellesmere

4.1 Species recorded

Lists of species recorded from the lake have been provided in Ryan (1974), Hardy (1989),Taylor (1996), and Jellyman and Smith (2008). The most comprehensive list (Jellyman and Smith 2008) is reprinted here (Table 4-1).

Most longterm resident fish species in the lake are euryhaline and tolerant of varying levels of salinity i.e eels, flatfish, smelt, inanga, common bullies. Exceptions would be some of the marine species that occasionally arrive in the lake during a period of extended opening. Fishers commonly report the presence of juvenile soles, although these do not survive until adulthood. Sprats are another common recruiting marine species, although their longevity in the lake is uncertain. The common species will be largely indifferent to the intrusion of salt water, and changes in salinity will have little direct impact on their distribution within the lake.

Species like torrentish prefer fast water, and hence occur in the Selwyn catchment and simply use Te Waihora/Lake Ellesmere as a conduit to and from the sea. Among the freshwater and estuarine species, are several non-diadromous species whose complete life history is carried out in fresh water i.e. Canterbury galaxias, upland bully, and Canterbury mudfish. Brown trout populations are primarily riverine, although many adults will spend extended periods in the lake (Glova 1996).

4.2 Relative abundance

An extensive fyke netting survey of fish was carried out in summer of 1995 (Glova and Sagar 2000). From length-weight relationships (NIWA unpublished data) it is possible to convert their total catches (and mean lengths per species) to biomass (weight) and give an approximate biomass composition of fish species.(Table 4-2).

From these data, the numerical dominance of common bullies is obvious (92 % of all fish caught); despite their small average size, bullies still make up most of the biomass (total weight) of fish in the lake (44%), followed by shortfin eels. The relative weights of flatfish species will vary according to which species is dominant, but at the time of the survey it was black flounders (15% biomass). Longfin eels were numerically insignificant.

More recent surveys (Table 4-3) using a fine-meshed (5.0 mm) seine net (13 m long) confirmed the dominance of bullies; the higher proportions of smelt and sprat are thought to reflect closer proximity of the sampling site to the sea. Trawl samples had higher proportions of flounders, which was probably a consequence of sampling being carried out further off shore (~ 0.5 – 2 km) where numbers are higher. In contrast, smelt are more shoreline in their distribution, and hence not was well represented in trawl catches as in seine catches.

For the purposes of this report, discussion of fish recruitment is confined to those migratory species that (a) comprise significant customary or commercial fisheries. i.e. shortfin and longfin eels, yelloweye mullet, black flounder, sand flounder, and yellowbelly flounder, or (b) comprise a significant proportion of the numbers or biomass (common bullies, smelt, inanga/whitebait). Hereafter, common bullies and common smelt are simply referred to as smelt and bullies respectively.

Table 4-1: Fish species recorded from Te Waihora/Lake Ellesmere. Y = a diadromous species. Y[1] indicates can be voluntarily non-diadromous, Y[2] indicated usually non-diadromous but can also have sea-run stocks ? = status uncertain, * = recorded, ** = often found, *** = common.

Common name	Scientific name	Diadromous species	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: Percent abundance and biomass of the total fish caught in a fyke netting survey of Te Waihora, summer 1995). (Data on numbers are from Glova and Sagar 2000).

	Abundance (%)	Biomass (%)
Common bullies	92.4	44.4
Common smelt	3.3	1.7
Inanga	2.1	1.9
Shortfin eel	1.3	28.4
Black flounder	0.4	15.3
Yellowbelly flounder	0.3	3.6
Sand flounder	0.2	4.2
Sprat	0.05	0.05
Longfin eel	0.005	0.134
Yellow eye mullet	0.003	0.069
Brown trout	0.002	0.255
Goldfish	0.002	0.003
Torrentfish	0.001	<0.000
Total	170021	954.79 kg

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

	Catch			
	Seine		Trawl	
Species	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
	59683	100.00	6758	100.00

5 Principal fish species of Te Waihora/Lake Ellesmere

5.1 Freshwater eels

5.1.1 Overview

The eel population of the lake is dominated by shortfins. As this species prefers slow flowing and muddy habitats, it is frequently encountered in the lower reaches of rivers and coastal lakes and lagoons. Their food is primarily aquatic invertebrates. They are opportunist scavengers and forage readily along newly inundated shorelines associated with floods in rivers or high water levels in lakes (Jellyman 1989). Growth rates in Te Waihora/Lake Ellesmere are typically 25 - 35 mm/year although once eels reach 300 mm they revert to a fish - based diet and their growth rates double (Jellyman 2001). Sexually mature males migrate over a restricted size (30-50 cm) and age (8 – 20 years) range, and there have been concerns that the average size of males has declined significantly over recent decades (Jellyman and Todd 1998). In contrast, the size of female shortfins has increased markedly (Jellyman 2001).

Longfins are unique to New Zealand. While longfins have a preference for flowing water and an ability to penetrate well inland into high country lakes, they are also frequently found in estuaries. In light of their decreased abundance in the lake, they are no longer landed by commercial fishers and are voluntarily released. Recent investigations of tributary populations indicate that these are frequently dominated by longfins (Jellyman and Graynoth. 2010). Growth rates are slower than for shortfins, ranging from 25-30 mm/year. Partly because of this slow growth rate and the large sizes they achieve, migrating eels are of considerable age at the time of their seaward migration in autumn (e.g. females: 25 – 60 years (Todd 1980)). Nationally there are concerns about the well-being of this species, and it has been designated as a threatened species on DoC's threatened species classification (Allibone et al. 2010).

Although there has been little change in the average size of shortfins over the past 30 years, there has been a marked increase in growth rates (Jellyman and Smith 2008); thus in 1974, annual growth of shortfins (feeding eels) averaged 24 mm /year, but by 2007, the rate had increased by 63 % to 39 mm/year. Growth of feeding eels from the tributaries (34.2 mm/year) is slightly lower than that from the lake itself. The growth rate of migrating males does not appear to have changed much over the years but the growth rate and average size (Table 4-1) of (migratory) females have both increased substantially between the 1970's and 1998. Presumably, conditions for growth of larger eels have improved over time, possibly as a result of a reduction in overall numbers and a proliferation of bullies.(Jellyman and Todd 1998)

Female shortfins show accelerated growth rates with increasing size, associated with their change in diet from invertebrates (Kelly and Jellyman 2007) to fish (Jellyman 2001). However, the growth rate of juvenile eels is relatively slow (Graynoth and Jellyman 2002) and this shows in the smaller annual growth increment for migrating males (Table 5-1) which are too small to eat fish. Growth rates of longfins have remained reasonably constant over the years of observation, although rates in the tributaries are slightly faster than in the lake.

Assuming a length of 60 mm upon arrival in fresh water and overall growth rates for shortfin of, c. 35 mm/year and 25 mm/year for longfins, we can estimate the average number of years required to achieve particular sizes e.g. 220 g (minimum commercial size); 500 g (probably the minimum size of interest to a customary fisher), 850 mm for shortfins (mean length of shortfin female eels at migration), and for longfins 1156 mm (the mean length of migrating females (Todd 1980)). Results (Table 5-2) showed that shortfins and longfins are, on average, 12 and 17 years old respectively when they enter the fishery, and are 23 and 44 years old respectively when spawning migrations occur. Such longevity indicates that fisheries management should be cautious when generation times are measured in decades, because cause and effect changes can take many years to manifest themselves.

Table 5-1: Mean annual growth increment (mm/year) for feeding and migrating eels from Te Waihora/Lake Ellesmere, for various years. * = 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	Mean increment (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

Table 5-2: Approximate mean ages of eels from Te Waihora/Lake Ellesmere at specific sizes.

Size	Shortfin – mean age	Longfin – mean age
220 g	12	17
500 g	16	22
850 mm	23	
1156 mm		44

5.1.2 Eel recruitment

Like all other 14 species of freshwater eels, shortfins and longfins spawn at sea. The classical method of determining spawning areas of freshwater eels has been through the collection of progressively smaller leptocephali (larvae) at sea. Unfortunately, collections of leptocephali of Australasian eels are few, with 13 shortfin and no longfin larvae being found - the longfin remains the only species of *Anguilla* for which no larvae have been collected (Jellyman 2003). To determine likely spawning areas, Jellyman and Bowen (2009) developed a simulation model based on surface currents derived from hydrography, satellite altimetry and wind stress. The model used satellite-derived surface currents to simulate drift of larvae to New Zealand and Australia, and required arrival timesto be within the known ages of arriving glass eels. The model indicated that possible spawning areas for both species would be in the north-east of New Caledonia, perhaps within the North Fiji Basin between Vanuatu and Fiji.

Further corroboration of this likely spawning area has come from the results of pop-up tags whose eventual ascent positions are located by satellite. Tracking of seaward migrating female longfin liberated from Lake Ellesmere \Te Waihora have indicated a likely spawning area in the South Fiji basin (Jellyman and Tsukamoto 2005, 2010).

Glass eels arrive in New Zealand inshore waters from July – December (Jellyman 1977b), after a larval life of 6-7 months for shortfins and 8 months for longfins (summarised in Jellyman and Bowen 2010). Although the overall recruitment season is extensive (6 months), the main months are usually September and October (Jellyman 1977.b, 1979; Jellyman et al. 1999). Jellyman et al. (1999) recorded peak months for Canterbury as September and October for shortfin and August – September for longfins (Table 5-3). Likewise, a study of recruitment into the Grey River (Jellyman and Lambert 2003) found that for shortfins, October was the main month. Although sampling during the 1970s in the Waikato River found that September was the main month of glass eel arrival (Jellyman 1979), a more recent survey found evidence of an advance in the season to August (Jellyman et al. 2009a), with the suggestion that this could be associated with climate change.

Table 5-3: Proportions of both species of glass eel caught at the mouth of the Ashsley River, 1996-2006.

	Shortfin (%)	Longfin (%)
July	2	5
August	3	49
September	51	34
October	35	6
November	9	6
Total caught (species proportion)	4739 (91%)	481 (9%)

It is worth pointing out two important features of glass eel biology. Their ability to make choices about the type of waterway they enter based on odour, and their lack of "homing" to their parental rearing grounds. Eels have a very highly developed olfactory system (Tesch 2003) and are able to detect odorous substances in very dilute concentrations. Experiments with New Zealand glass eels have demonstrated their ability to make a specific choices based on the odour of the water available to them (McCleave and Jellyman 2002), and this explains why waterways a few kilometres apart can have very different species compositions (Jellyman et al. 1999). Thus the outflow water from Lake Ellesmere \Te Waihora will contain the combined odour of many thousands of eels of both species, and have a substantial attractive effect on glass eels in the inshore environment. The longshore flow of water that accompanies a lake opening (Schwarz et al. 2008) will amplify this effect and be intercepted by glass eels being carried on currents in the vicinity of Banks Peninsula.

The second issue is a lack of "homing", which in a fisheries context usually means adult fish returning to their natal stream (like Chinook salmon). The converse of this would be juvenile fish returning to water formerly occupied by their "parents", but for this to occur it would require pairing of males and females from the same waterway (extremely unlikely as the sexes depart at different times, and mating is thought to be random), and that there be a transference of knowledge of the characteristics of the specific waterway, a highly unlikely scenario. Further, if such segregation did occur, it would be evidenced by geographically discrete differences in DNA, something which does not occur (Dijkstra and Jellyman 1999).

The behaviour of glass eels changes with residence times in fresh water, and thus the suite of environmental variables affecting recruitment will differ according to location and physiological state of the glass eels. Glass eels arriving in fresh water from the sea use flood tides to provide a largely passive mechanism for upstream movement (Creutzberg, 1961;McCleave & Kleckner, 1982; Jellyman and Lambert 2003). Once in fresh water, further upstream migration is delayed as glass eels undergo some physiological adaptations (Jellyman, 1979; Ciccotti et al., 1995). When migration of the now more-pigmented glass eels recommences, they are less inhibited by daylight (Jellyman, 1979; Sorensen & Bianchini, 1986) and actively swim upstream (Jellyman, 1979; Gascuel, 1986). Within riverine reaches, movement may occur at all tide stages, with glass eels becoming more concentrated adjacent to banks during the ebb tide, but more dispersed during flood tides (Jellyman, 1979).

For recruitment into Lake Ellesmere\Te Waihora, it would be expected that glass eels will be in the initial arrival phase whereby they are sensitive to light and prefer to arrive during darkness (Jellyman 1977; Jellyman and Lambert 2003). Typically any recruitment will commence around sunset and peak catches will occur within 1-2 h after sunset. Glass eels will take advantage of any incoming tide to passively transport them into stream mouths and estuaries by a process known as selective tidal transport (STT); when flows reverse during the ebb tide phase, glass eels simply burrow into the substrates to avoid being flushed out of the river mouth and await the next flood tide to transport them further upriver.

Tidal movement is greatest over the twice-monthly spring tide periods. Being both light-avoiding and using tidal flows to facilitate invasion from the sea, it follows that glass eels will have a preference for arrival during the new moon spring tide, being the tide period associated with little or no moonlight (Jellyman and Lambert 2003). Thus the preferred invasion period for glass eels entering Lake Ellesmere \Te Waihora will be spring tide periods during September and October, but especially those periods around the new moon. Glass eels are relatively weak swimmers against a current, and the maximum sustained swimming speed of shortfins is 29 cm/sec, with burst speeds of 79 cm/sec (Langdon and Collins 2000). Thus they will be unable to swim against the outflow of water that accompanies the initial breaching of the bar at Te Waihora\ Lake Ellesmere where velocities frequently exceed 2.0 m/s (Taylor 1996).

Although there have been beliefs that glass eels can penetrate gravel bars to enter lakes like Wairewa (Lake Forsyth), there is no documented evidence of this, and given the nature of the compacted substrates, lack of interstitial spaces and distances involved, it is my belief that such a mechanism is highly unlikely to occur – if it does, I would not expect recruitment to be large from such a source. A recent survey of Wairewa (Jellyman and Cranwell 2005) found evidence of poor recruitment over recent years, something that would not be expected were glass eels able to penetrate the gravel bar in any quantity. Rather, recruitment of barrier lakes requires periodic breaching of the bar during favourable times of the year. There is some evidence that the quantity of glass eels attracted to a particular waterway is in proportion to the outflow – thus the Waikato River receives a substantial recruitment each year, and years of high rainfall resulted in better than average recruitment to a small Wairarapa lake (Jellyman and Ryan 1983).

Longfin glass eels will have a tendency to move through the lake and find the flowing water of tributaries. In common with juvenile eels elsewhere in New Zealand, they will migrate successively upstream each spring and summer (Jellyman 1977, Martin et al. 2006) as they colonise streams and habitats. In contrast, by far the majority of shortfin glass eels will remain in the lake as they prefer the lacustrine environment and can utilise small interstitial spaces in fine substrates as cover (Jellyman et al 2003a).

To summarise glass eel recruitment into Te Waihora\ Lake Ellesmere:

- 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 will be attracted to the outflow of the lake.
- Most glass eels will arrive in "waves" 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 to wriggle 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 outflowsA 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).

5.1.3 Habitats utilised

Sampling of juvenile eels in shallow lakes is difficult, as they seldom enter fyke nets, even fine –meshed ones, probably because small eels spend a considerable amount of their time concealed within the substrates (Glova and Jellyman 2000). Taylor and Graynoth (1995) tried a variety of techniques to catch representative samples of juvenile fish recruiting into the lake including fine meshed fyke nets, a beam trawl, a purse seine, and a beach seine, and concluded that the beach seine was the least size-biased method and also caught a wide range of both benthic and midwater fish species. 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. Most of the small eels they caught were in reasonably shallow water, mainly from 0.6 – 1.2 m depth (Figure 5-1), although eels > 300 mm showed no particular association with depth. Smaller eels (<300 mm) were also likely to be caught closer to the shore, often within 100 m (Figure 5-2) whereas larger eels showed no such preference.

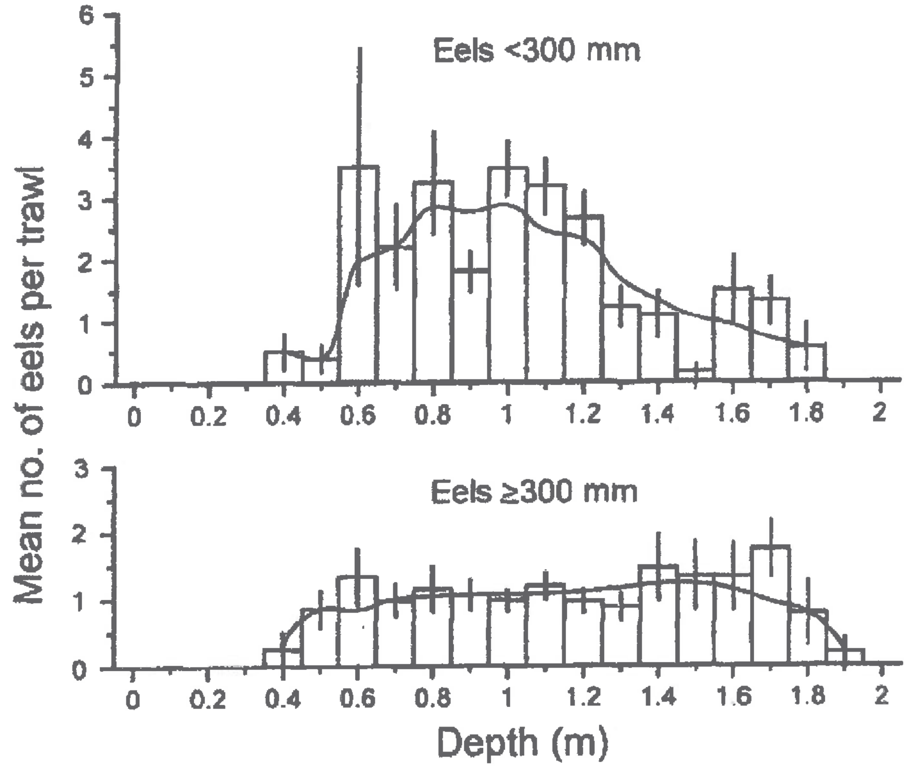

Figure 5-1: The mean of juvenile shortfin eels caught per trawl at various depths off Timberyard Pont, Te Waihora. Vertical lines are ± 1 SE, and a 5-piont moving average has been fitted to show trends.

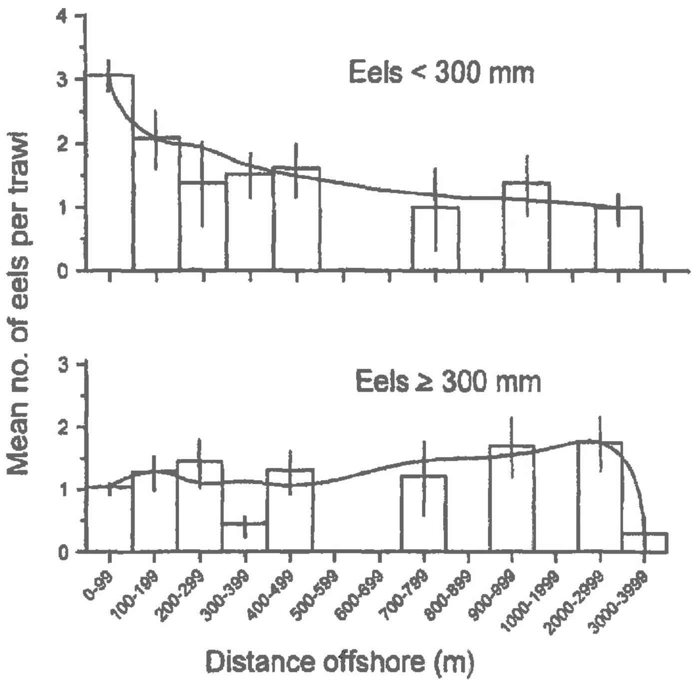

Figure 5-2: The mean of juvenile shortfin eels caught per trawl at various distances offshore off Timberyard Point, Te Waihora. Vertical lines are ± 1 SE, and a 5-point moving average has been fitted to show trends.

When substrates where eels were caught are arranged in order of deceasing compaction, juvenile eels were more likely to be found in gravel and mud (Figure 5-3). Larger eels were more common on sand, although habitat differences for this size group were not significant.

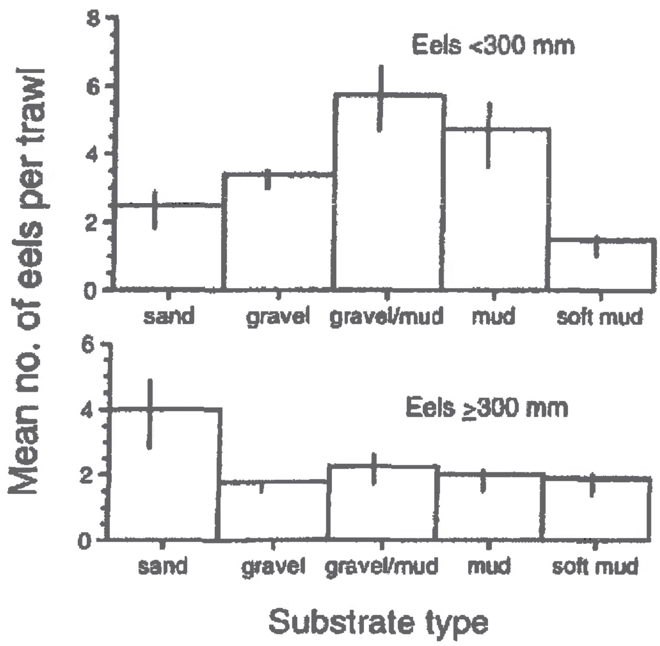

Figure 5-3: The mean of juvenile shortfin eels caught per trawl caught on various substrates. Vertical lines are ± 1 SE.

The length-frequency of juvenile eels in the lake varies by year, and will be a reflection of the success of recruitment in any particular year. Thus, in the 1994/95 season, the length-frequency (n = 533) was dominated by 2 separate size groups with modal lengths ~ 150 mm, and 360 mm (Figure 5-4). Recruitment during the 1996/97 season was much improved, and hence glass eels dominated catches (n = 886). Samples collected during February 2007/08 (n = 102) had no glass eels but had a strong representation of 100-200 mm sizes - at current growth rates, these eels would enter the commercial fishery (> 220 g, ~ 46 cm) between 2011/12 and 2015/16. Over all years where trawling has been carried out, glass eels have not been caught on 3 of the 8 seasons, indicating recruitment can be intermittent (Table 5-4).

For juvenile shortfins, inshore habitat (e.g. <200 m offshore) are preferred. However, trawling was not possible in the very shallow water (0–0.3 m depth) meaning residence in such areas is uncertain. Such shallow areas are subject to considerable wave energy (Jellyman et al. 2009b) and periodic dewatering, meaning 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. In contrast, larger eels are more mobile and spend considerable amounts of time foraging above the substrates (Glova and Jellyman 2000) and 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 (Figure 5-5). Like bullies, shortfins tended to be more concentrated within the vicinity of river mouths and the lake outlet (the latter being mainly shortfin males congregating prior to their seaward migration). "High eel biomass coincided with high abundance of bullies near the extensive sand and gravel bar on the south side adjacent to Kaituna Lagoon. 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. Offshore, the catches of eels were low". Feeding eels move with the wind, possibly taking advantage of wind-derived currents (Jellyman and Smith 2008). Feeding shortfins are inactive in Te Waihora/Lake Ellesmere at water temperature < 12°C (Jellyman et al 1996) (which corresponds to May until September inclusive, ECan data for Timberyard Point), but once temperatures exceed this, they commence feeding and moving, especially in spring and early summer.

There are considerable data on the movement of eels within the lake. Between December 1977 and February 1978, 4968 and 4987 eels were tagged and released 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 5 years. Main results (Figure 5-6) show that eels were mainly recaptured at, or close to, their release site. An important implication of this research is that localised reserve areas can be effective in maintaining a stock of eels.

However, some eels from both release sites moved extensively, and tagged eels were caught up to 5 years after tagging, and in all areas of the lake. Some eels moved extensively over short periods. One eel was recaptured six times over three months (Figure 5-7). This eel was tagged and released in LII Bay, recaptured twice near Greenpark, released in the LII River, recaptured off the Selwyn River mouth, released near the Irwell River mouth on 3 occasions from where it travelled to eastern part of Kaiterete Spit, before being caught off Timberyard Point.

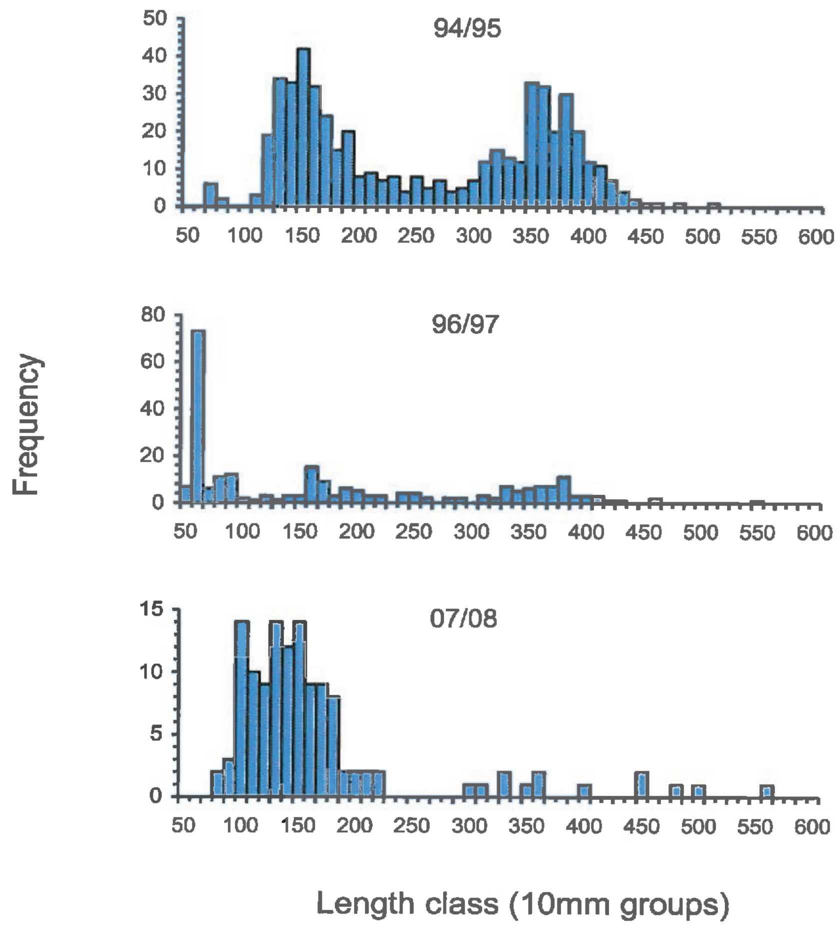

Figure 5-4: The size distribution of juvenile shortfin eels caught by trawl at Timberyard Point.

Table 5-4: The number of trawls and catches of different size groups of shortfin eels (eels/trawl).

	Year								
Size	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2002**	**2008**	**Total/ mean**
< 70 mm	0	0	1.0	0.5	0.1	0.7	0.1	0	0.4
70-300	7.3	1.9	1.0	3.2	6.7	7.7	2.5	2.7	3.0
> 300	3.7	1.6	0.9	0.6	0.3	0.5	0	0.2	0.9
Total	11.0	3.5	2.9	4.3	7.1	8.9	2.6	2.9	4.3
No. of Trawls	*3*	*174*	*156*	*101*	*62*	*51*	*15*	*35*	*597*

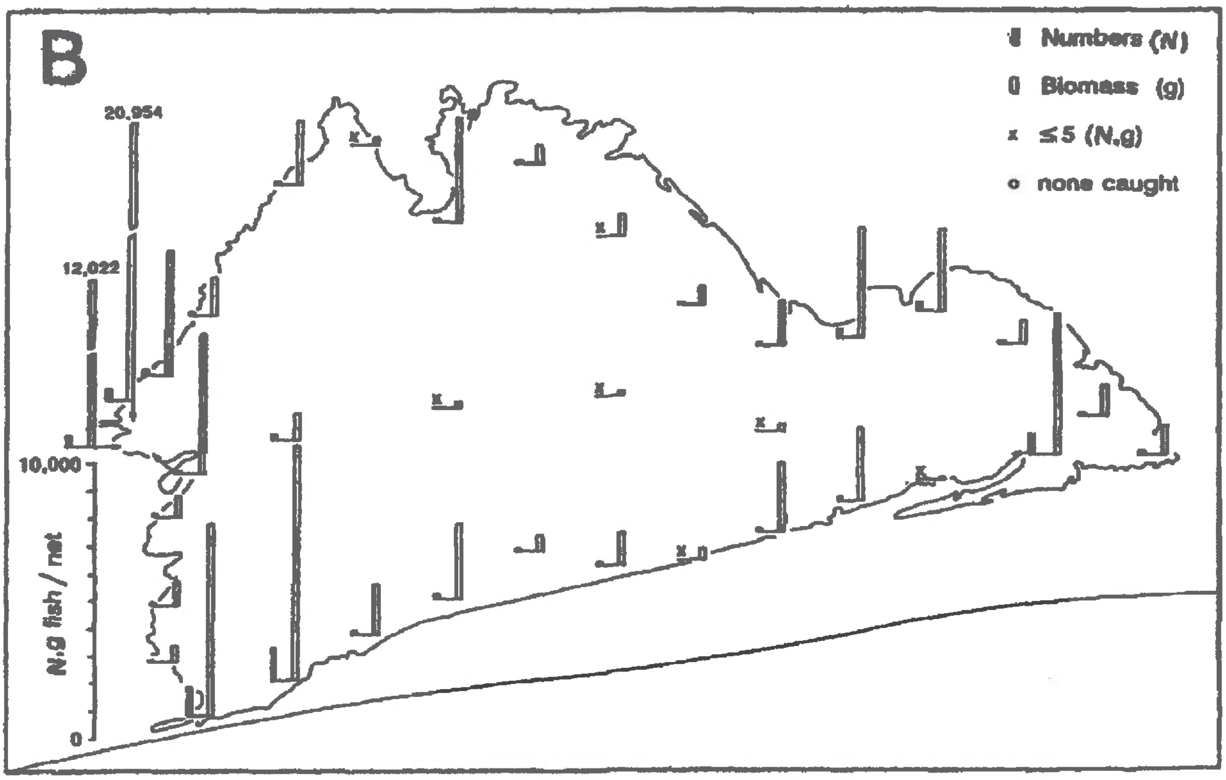

Figure 5-5: The mean numbers (solid bars) and biomass (g; open bars) of shortfin eels for three fyke nets at each site. January-March 1995. From Glova and Sagar 2000.

Movements of sonic-tagged eels. To study short-term movements, 10 shortfin eels were equipped with sonic tags (Jellyman et al. 1996). For these eels, most movement occurred between the time of release and the first relocation, an indication that tagging had initially affected their behaviour. Overall, eels from the centre of the lake moved substantially further than those tagged in the Selwyn River and Harts Creek areas (Figure 5-8). Over the period of study, the final locations of the centre-of-lake eels were 3.3 to 10.8 km away from the release point, and all had moved in a downwind direction of the prevailing north-westerly wind. In contrast, eels at both inshore sites remained close inshore near their release site, particularly those eels released at Harts Creek. Unexpectedly, three of the four eels from the Selwyn River site moved some 2—3 km up river after being released. However, they gradually made their way back into the lake within about a week and thereafter remained close inshore within 1-2 km of the release site. The fourth eel of this group (920 mm long) was never relocated. Both eels from the Harts Creek release site remained within a 0.5 km radius of the area, either adjacent to, or within the dense raupo stands along the shoreline. Water temperature declined from 18 to 9°C during the study, and the movement of all tagged eels virtually ceased at temperatures of 12°C and less.

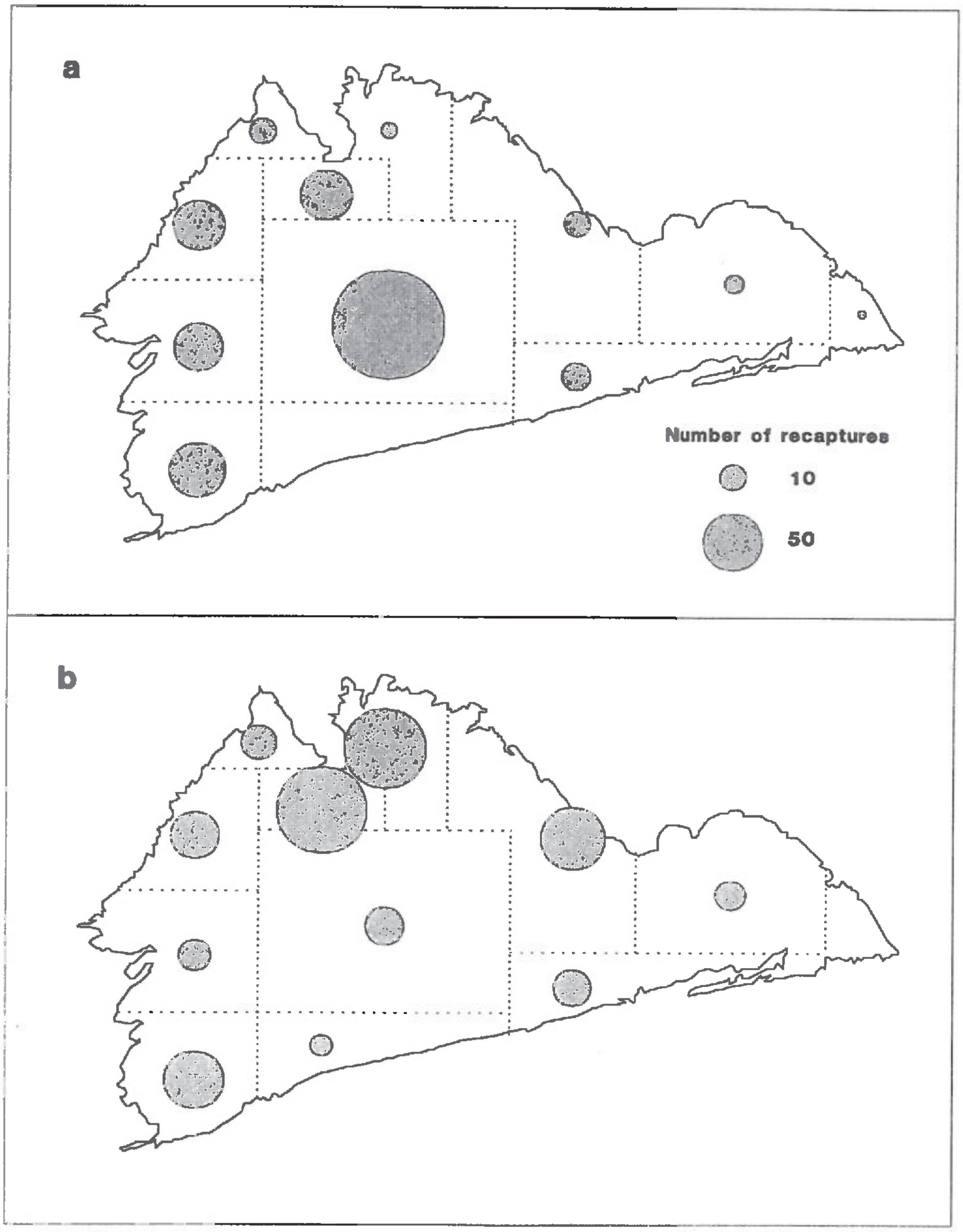

Figure 5-6: First recaptures of eels tagged in the centre of lake (a) and at LII Bay (b). Sizes of the recapture circles are proportional to the number of eels recaptured. (From Jellyman et a. 1996).

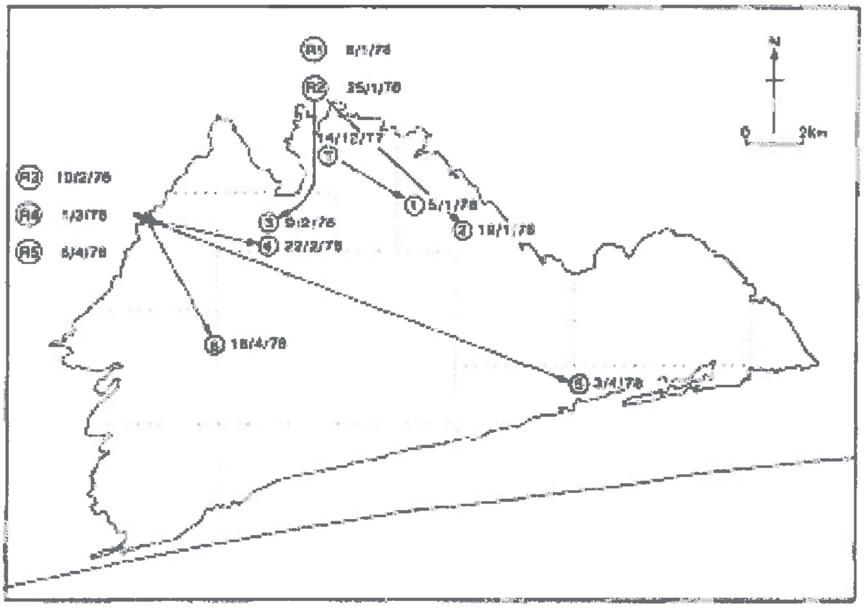

Figure 5-7: Recaptures of one eel over a 15-week period, January-May 1978. T = tagging site; 1 = first recapture site (etc.); R1 = first release site (etc.).

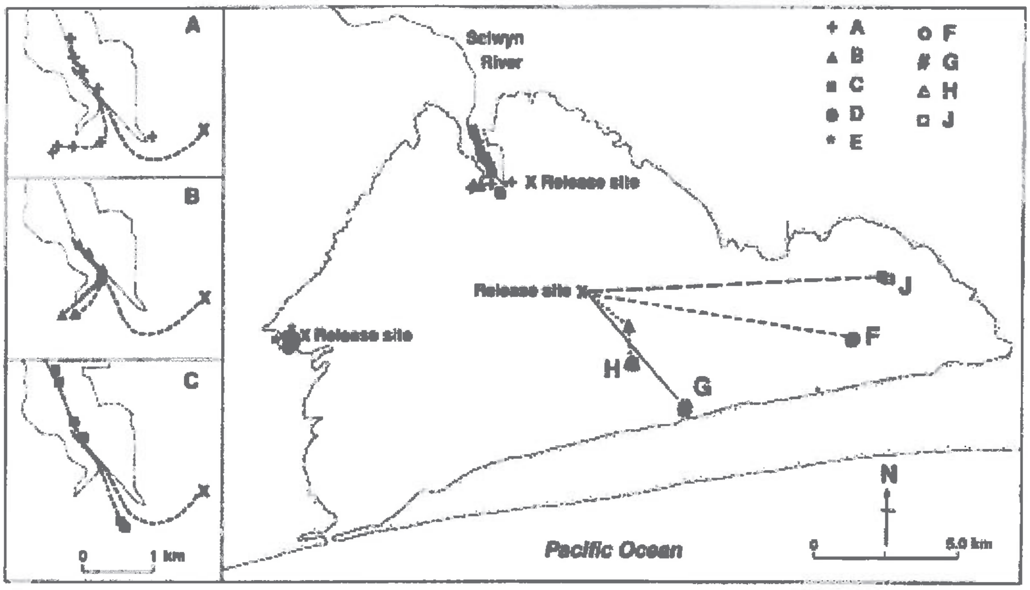

Figure 5-8: Successive locations of sonic-tagged eels released at Harts Creek, the Selwyn River mouth and the centre of the lake. Insets refer to eels A-C released at the Swleyn River mouth.

Reserve areas. While there is evidence of some extensive movement by a few eels (and also from recently tagged eels), in general larger eels forage within a restricted area, and therefore reserve areas are an effective means of safeguarding a portion of the population. 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 Ngai Tahu have indicated their intention of establishing a more extensive kohanga are (recreational and customary use area) that includes the Kaituna Lagoon (Joint Management Plan, JMP, section in Figure 5-9).

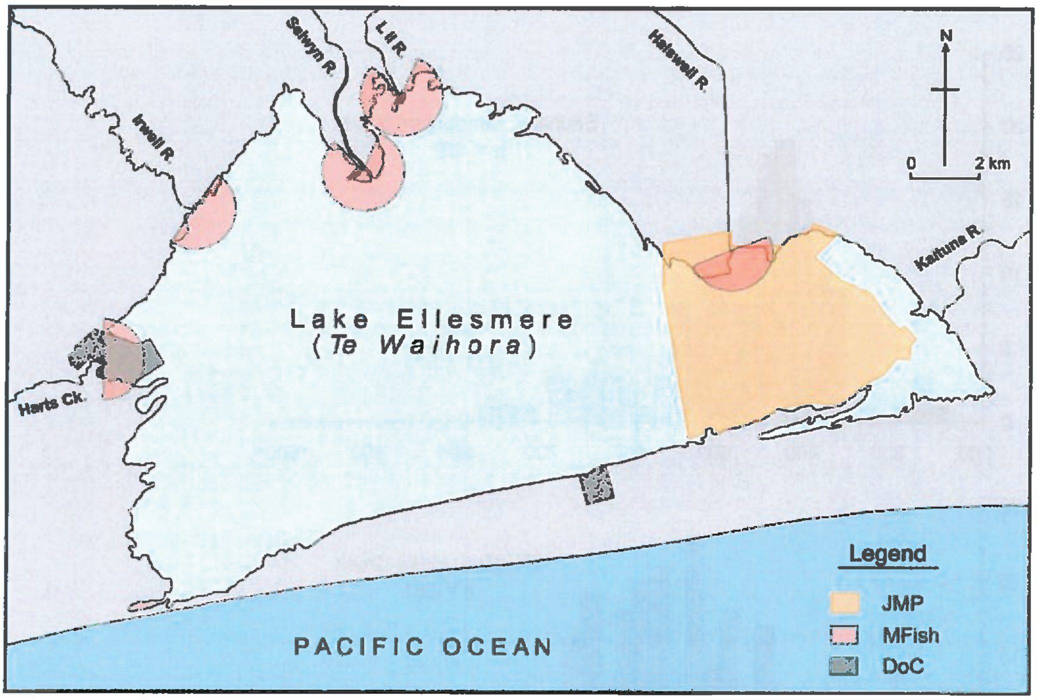

Figure 5-9: Areas closed, or proposed, to commercial tuna fishing in Te Waihora/Lake Ellesmere.

The value of reserve areas is seen in Figure 4-10 where fyke net catches from the mouth of Harts Creek (reserve area) can be compared with catches from 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. 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 = 0.000).

Shortfin eels always dominated eel stocks in the lake, but the proportion of longfins has declined with time – thus 1974-82, N = 4.3% compared with 0.5% in 1997-98 (Jellyman and Smith 2008). More recent surveys on the significance of eel populations in lake tributaries have underscored the importance of non-fishing areas to maintaining future spawning stocks of female eels, especially longfins (Jellyman and Graynoth 2010).

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 size of resident eels. The sites sampled are shown in Figure 5-11.Overall results (Table 5-5) showed an almost equal representation of both species from electric fishing, with the numbers of longfins exceeding those of shortfin at 6 of the 9 sites. From fyke netting data, 61% of all eels caught were shortfins, although this was due to the dominance of shortfins at the lower river sites of Harts Creek and the Selwyn Huts

– these catches were unusual and were composed of 86% shortfin. If these sites were removed from the database, the total catch was dominated by longfins (80%).

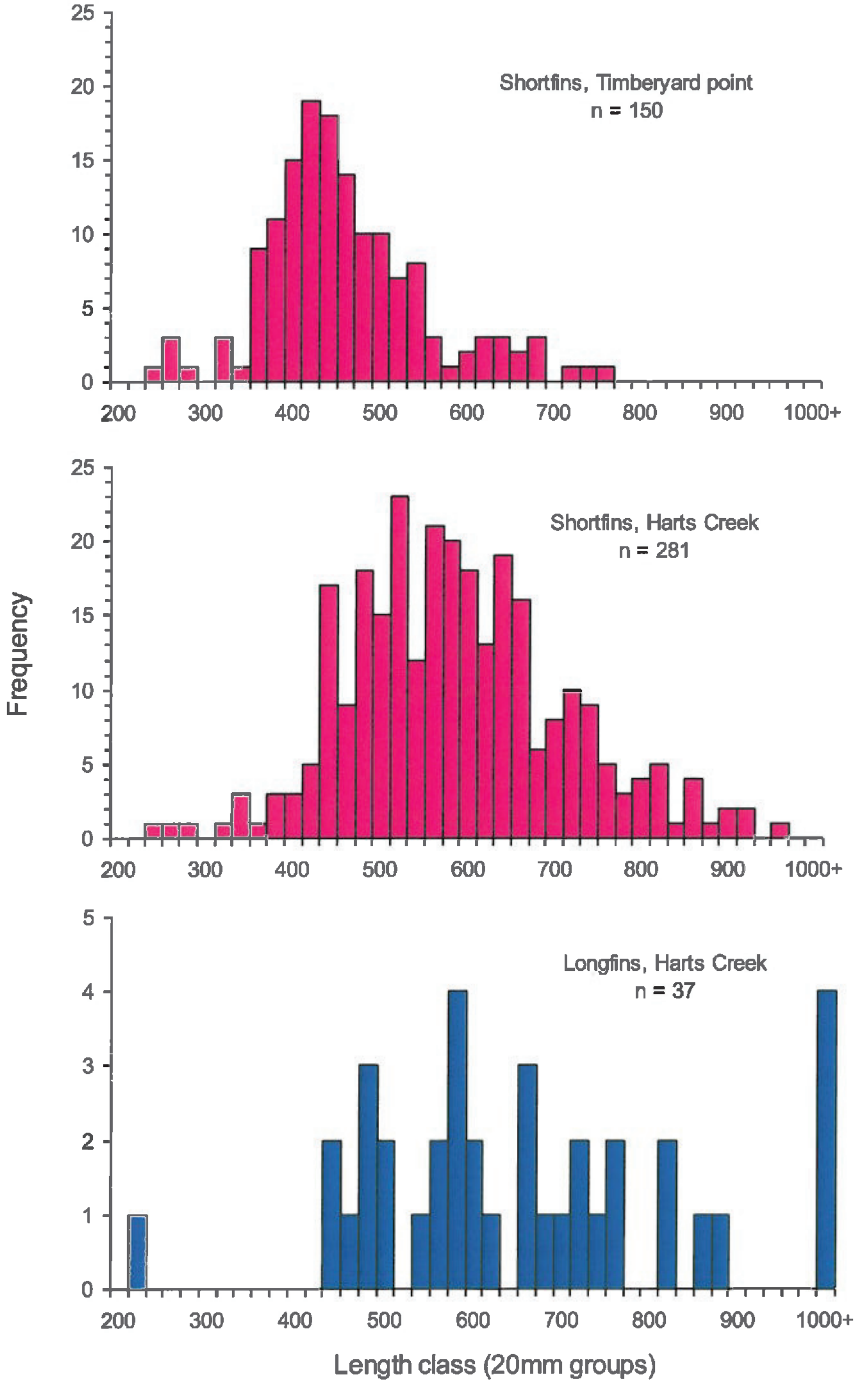

Figure 5-10:Sizes and species of eels caught at Timberyard Point, and within the Harts Creek reserve, March 2007.

Figure 5-11:Sampling locations of tributaries (Jellyman and Graynoth 2010). Red dots are electric fishing sites, yellow dots are fyke netting sites.

Of particular interest was the proportion of small eels (< 300 mm) caught (Table 5-6). The table shows that almost 50% of shortfins were < 200 mm, compared with only ~17 % of longfins. Lower Harts Creek had the best representation of small longfins, 55 %, compared with Birdlings Brook at 23 %, Hanmer Road Drain at 12 %, 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 %.

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

Table 5-5: The numbers of each eel species and species composition of all eels sampled in tributaries of Lake Ellesmere. Number in brackets = number measured.

			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**

Table 5-6: The percentage of electric fished small eels of both species.

	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**

- 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 should the lake become prone to multiple stressor events like a combination of high water temperatures and significant algal blooms, with a consequent reduction in dissolved oxygen.
- The national status of longfins is a cause for concern. The critical factor in managing eel stocks is maximising the number of females that escape to sea to spawn each year. The Te Waihora/Lake Ellesmere tributaries could potentially provide ~ 2 % of the annual New Zealand production of longfin female eels, and

hence their continued protection from exploitation is of particular importance. Likewise, any habitat and water quality improvement can only enhance this situation.

Summary of habitat utilisation

Glass eels enter the lake during the annual winter/spring recruitment period. There is no evidence that glass eels can penetrate through the gravel, meaning the opportunities for recruitment are associated with the lake being open to the sea. Once in the lake, glass eels will gradually disperse, mainly by moving around the margins. Most shortfins will remain in the lake, while most longfins will probably seek the flowing water environment of the tributaries. Present low recruitment of longfins is a concern, but one shared by other South Island east coast rivers (Jellyman 2011Juvenile shortfins will mainly inhabit the shallow inshore littoral zone, and although not studied to date, it seems likely that because of their limited movements and strong likelihood of spending considerable time within substrates, they will largely avoid the shallowest littoral areas as these can be subject to short-term but relatively rapid dewatering.

Adult eels are not distributed evenly across the whole lake (Figure 5-5) and their distribution will largely reflect the availability of soft sediments (cover) and foodThere is a significant association between bully numbers and eel biomass (Glova and Sagar 2000), although this correlation was not improved when the test was limited to eels >450 mm in length, the size at which they are likely to become piscivorous feeders. Glova and Sagar (2000) also noted high numbers and biomass of eels towards the eastern shoreline, low numbers along the Kaitorete Spit and in the centre of the lake. Commercial eel fishers have previously commented that the centre of the lake is populated with smaller eels and previous measurements have tended to substantiate this (Jellyman et al. 1995).

Most adult eels have a small foraging range, and hence stay resident in a general area for extended periods. This is beneficial for creating effective reserve areas and protected populations. Tributaries are of special importance for longfin eels, with reaches containing cobbly riffle and runs of particular importanceas they provide ideal habitat for juvenile longfins.

5.1.4 Seaward spawning migration

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 vary according to species and sex, with males preceding females, and shortfins preceding longfins. It seems that relatively short residence in the brackish water is adequate for transition to their saltwater migration as eels will emigrate from the lake immediately if it is opened. Earliest observations on this emigration in Lake Ellesmere 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. He 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 his records (Table 5-7) indicates that

February – March are the main months for shortfin males, with March – April for shortfin females; for longfins, April and May were the main months for males, with May – June for females.

Table 5-7: The percentage of migratory shortfin and longfin eels of both sexes, caught during sampling of Te Waihora/Lake Ellesmere 1975-79. (After Todd 1981).

	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 at the early part of the season (late January), 76% of the catch was non-migratory (feeding) eels, but the proportion of these declined and at the peak of the season such feeding eels comprised only 1.5% of the catch. The arrival period for longfin is shorter than that for shortfin (Todd 1981) but activity on particular nights is associated with environmental conditions. For Te Waihora/Lake Ellesmere, 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 such association. Commercial fishers have observed that migrating eels are very sensitive to moonlight and also to wind, and 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, and males have been getting smaller but females getting 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 migratory eel fishery focuses on shortfin males, and females are voluntarily released by fishers, often directly to sea, although some are still harvested for customary purposes.

5.1.5 Eel fishery

The eel fishery in Te Waihora/Lake Ellesmere commenced in the early 1970's and rapidly rose to be the largest single fishery in 1976 (Figure 5-12), when it comprised almost half of the total New Zealand eel catch. Because of concerns over declining catches, the lake was declared a controlled fishery in December 1978, with the initial total allowable catch (TAC) set at 256 t (which did not include migratory eels) and allocated to 17 fishers. The TAC (Total Allowable Catch) was reduced to 136.5 t in 1986 and distributed among 11 fishers. Although the lake had an initial size limit of 150 g (1994), this was progressively increased at 10 g/year to reach the national minimum size of 220 g. With the entry of South Island eels into the Quota Management System (QMS) in 2000, the TAC was reviewed and allocations made for customary and recreational use (customary = 31.26 t, recreational = 3.13 t). There are presently 5 commercial eel fishers on the lake, and the TACC (121.93 t) is almost invariably caught (Jellyman and Smith 2008). By agreement, longfin eels are not commercially harvested.

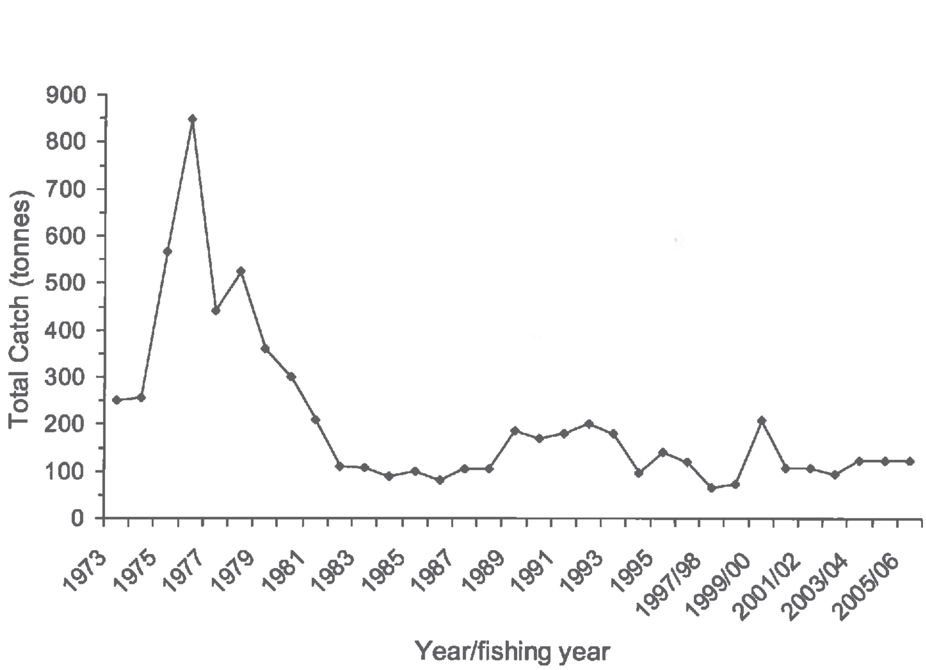

Figure 5-12:Trends in the Te Waihora/Lake Ellesmere commercial eel fishery.

Very few migratory shortfin males exceed the minimum commercial size of 220 g. In the absence of access to these males, the commercial fishery would be exclusively for females, not a desirable situation (Jellyman and Todd 1998). To allow commercial fishers access to migrating shortfin males prior to their seaward migration in late February – March, a concession area and period was introduced at Taumutu in 1996, whereby fishers could target theses migrating shortfin males. Unlike anywhere else in New Zealand, the fishing year for the Te Waihora/Lake Ellesmere eel fishery commences on 1 February to allow fishers access to this migration, but 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 t, fishers often take as much as 90 – 100 t of shortfin males (Jellyman and Smith 2008). Assuming an average weight of 116 g (Beentjes 1999), then 100 t equates to approximately 862 000 eels.

Te Waihora/Lake Ellesmere is the only fishery in New Zealand that targets migratory (silver) eels, and elsewhere there are "gentlemen's agreements" or policy (eg. South Island Eel Industry Association 2009), to not take silver eels – any silver eels caught are normally released by fishers as a conservation measure.

Over 50 years, the average size of male eels has declined from 200 g to 120 g; reasons for this were not targeted fishing of larger feeding eels but males achieving maturity at a smaller size, perhaps associated with some of the significant environmental changes in the lake itself (Jellyman and Todd 1998). While the average size of females declined from the 1940's to the late 1970's, size has since dramatically increased from ~ 600 to 900 mm (Jellyman 2001) – this has been attributed to changes in diet with larger eels predating on the plentiful bullies in the lake, and female eels adopting a size-maximising strategy that results in significantly increased fecundity (Jellyman 2001).

Measures of the catch-per-unit-effort in the fishery (1991 – 2006, Figure 5-13) show a steady increase over the last 5 years, indicative (for shortfins) of a productive fishery, and one that could sustain more customary or commercial harvest. However, CPUE alone is not the only measure to be assessed when determining the well-being of a fishery, and trends in growth rate and size of fish are also important indicators.

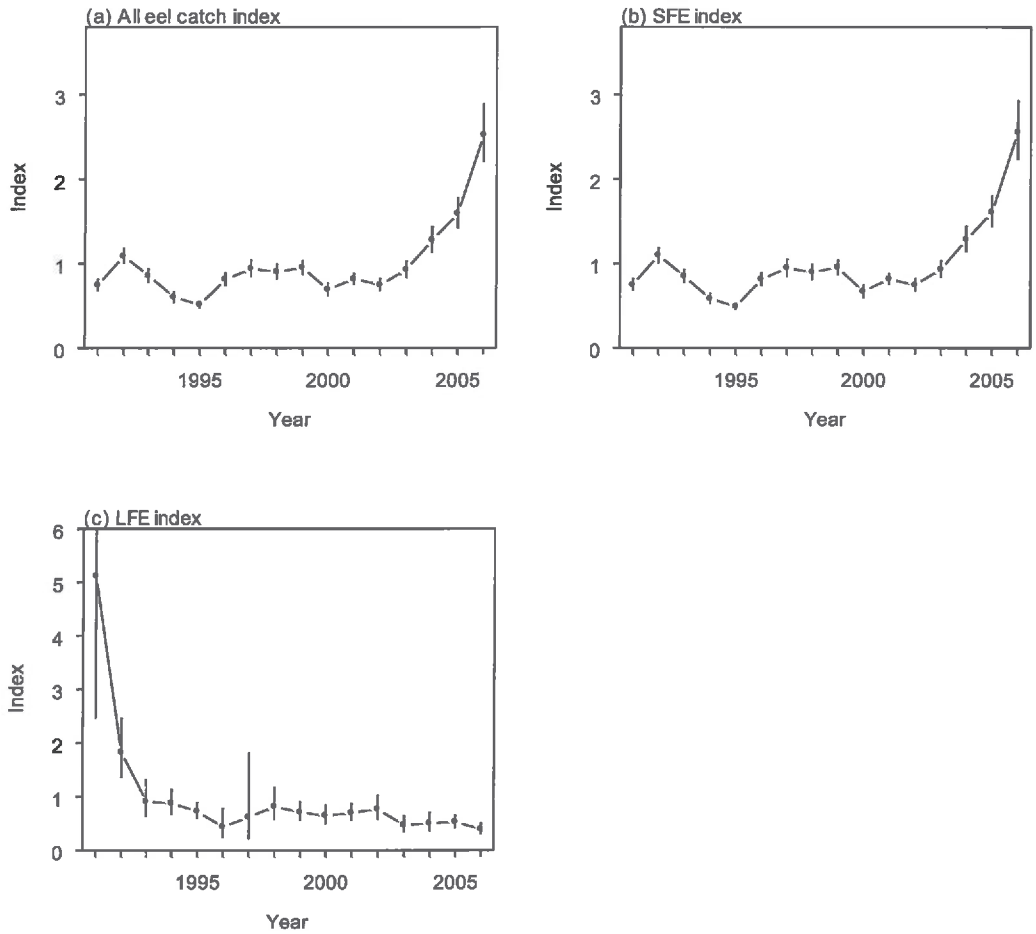

Figure 5-13:The catch-per-unit-effort (CPUE) trends for Te Waihora/Lake Ellesmere eels. Note that the All eel catch index (top left) is almost identical to that for SFE index (shortfin eels), indicating that longfins make a negligible contribution to the fishery (data from Beentjes and Dunn 2008).

A summary of the commercial eel fishery indicates:

- Pre Wahine Storm, diets of small eels were mainly snails, whereas now diets are mainly midge larvae
- The commercial fishery will always have been dominated by shortfins, although prior to the Wahine Storm there were more longfins in the lake. Reduction of longfins will have been largely attributable to their capture in the commercial fishery, although loss of weed beds and reduced recruitment are likely to be contributing factors also.
- While initial commercial harvest reduced the average size of shortfin eels, there has been no significant change over the last 30 years.
- Present growth rates are faster than historic rates, and CPUE has increased markedly over recent years.

- Collectively, these data indicate a healthy stock of shortfin eels. In general, the indicators of fishery well-being have improved as the fishery has become managed at a lower harvest level. The change from a macrophyte -dominated lake may have been somewhat detrimental for longfins, but the shortfin population is in a healthy state
- A different perception may be held by customary fishers, as eels are not as accessible to customary harvest methods as formerly. Historically, eels could be clubbed or speared when weed was rolled back (O'Connell 1996), but with the disappearance of the weed beds, use of this technique is no longer possible.

The yield of eels from the lake can be compared with yields from other recognised lake eel fisheries (Table 5-8). On this basis it is apparent that the present yield ranks the lake alongside other productive fisheries – from this perspective, the lake continues to provide a significant yield of fish, despite concerns over its ecological well-being and overall health

Table 5-8: The fishery yields (kg/ha) from Te Waihora/Lake Ellesmere and a selection of temperate lakes. (Data from Tesch 2003). (a) = eutrophic lakes, (b) = oligotrophic lakes.

Lake	Eel yield (kg/ha)	All fish yield (kg/ha)
Te Waihora	6.3	11.2
Lough Neagh, Ireland	17	
Lake Constance	3-6	
Small German lakes (a)	9-20	21-51
Small German lakes (b)	2-6	13-26
Large German stocked lakes	2.6	
Polish lakes	5.2	
Commachio Lagoon, Italy	5-7	
Ijsselmeer, Holland	10	
Coastal Baltic lakes	3	15
Central Baltic lakes	4.2	13

5.2 Flatfish

The flatfish population in Lake Ellesmere \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 flatfish population is dominated by two features – the abundance of fish varies hugely from year to year, and the proportions of the three main species also varies considerably.

Annual variation in abundance of flatfish can be seen from the commercial catches of flatfish over the past 60 years (Figure 5-14), which shows that flounder catches in adjacent years can vary up to 10 fold. As there has been an active commercial flatfish fishery in the lake since the late 1890's (Singleton 2007), there is no reason to suppose the variability reflects lack of fishing effort, meaning it reflects flatfish abundance. 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.

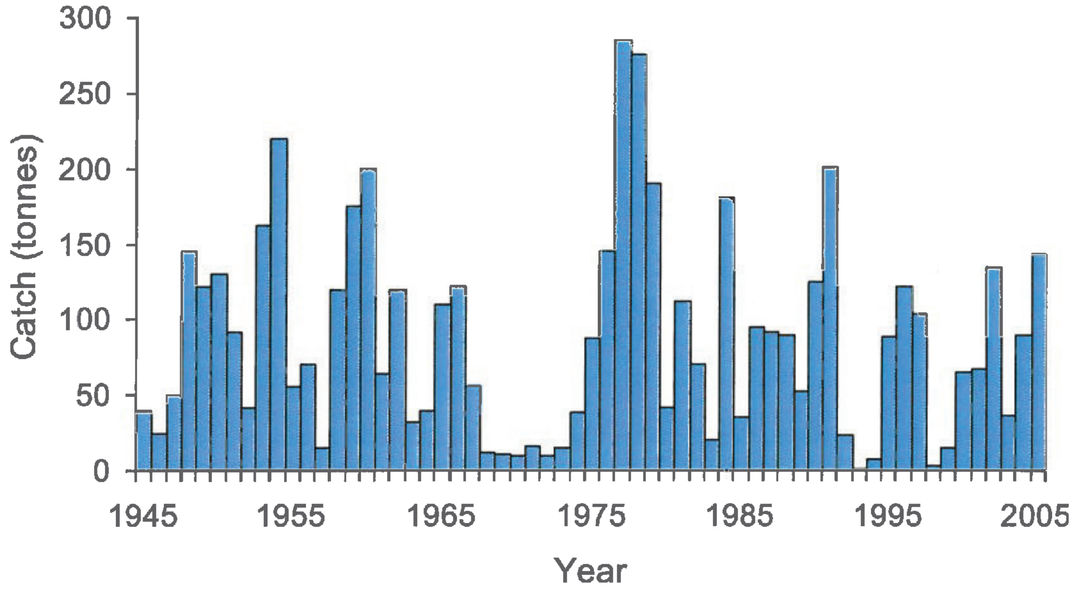

Figure 5-14:The annual commercial catch of flatfish from Lake Ellesmere/Te Waihora, 1945-2005.

5.2.1 Species proportions

A plot of the species from the commercial fishery returns from 1983-2006 (Figure 5-15), shows that black flounders provide the bulk of the catch (58% over past 23 years), followed by sand flounders (22%) and yellowbelly flounders (20%). While these are the proportions derived from fishers' estimates, a previous review (Jellyman and Smith 2008) recorded surprise at the high proportion of sand flounders, and suggested coding errors have lead to an over-representation of this species.

During a recent research programme aimed at understanding the biology of flatfish in the lake, two methods were used to obtain representative samples of flatfish (seine and trawl). The results (Table 4-9) indicated that the population at that time was dominated by yellowbelly flounder.

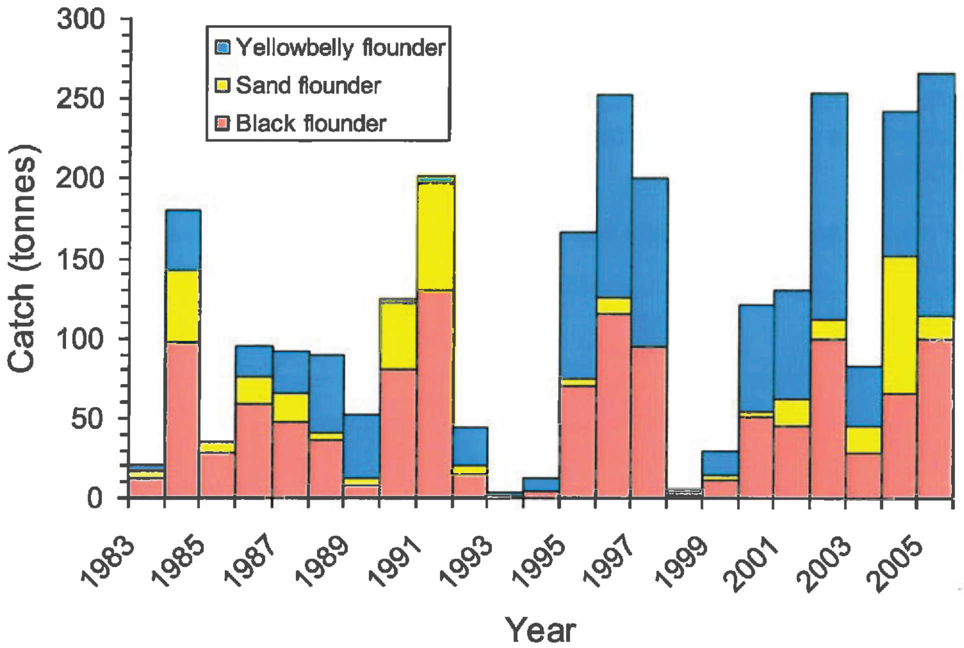

Figure 5-15:The species proportions of flatfish reported from the Te Waihora/Lake Ellesmere commercial fishery 1983-2005.

Table 5-9: The proportions of the three species of flatfish caught in Te Waihora/Lake Ellesmere from November 2005-March 2008.

	Species composition (%)			
Method	**Black flounder**	**Sand flounder**	**Yellowbelly flounder**	**N**
Seine	19	17	64	237
Trawl	21	8	71	193

5.2.2 Spawning and recruitment

Relatively few juvenile flatfish were caught during the 2005-2008 study (Jellyman in press) but data from a previous investigation (Taylor and Graynoth 1995) were available. Rather fortuitously, their sampling coincided with an extended period of the lake being open. For the first four months of the sampling period (July – October) there was some period when the lake was open, and the catch data provide an index of the seasonality of recruitment of the various species over these months. Yellowbelly flounders arrived earliest (Table 4-10), with August and September being the main months (85% of all recruits). Relatively few sand flounder were collected, but August was also the main month of recruitment for this species. Black flounders arrived later, with 87% recorded during October and November (in reality, the lake closed on 20 October, meaning that the fish caught in November and December must have arrived in the lake during one of the preceding openings).

Flatfish spawning often occurs over many months (Table 5-10), and hence juvenile fish can recruit into the lake over an extended period. Maturing adult flounders emigrate from the lake to spawn at sea. In Te Waihora/Lake Ellesmere, maturing flounders migrate from the lake during any opening in winter; yellowbellies and sands often have pronounced ovaries throughout long periods of the year, indicating prolonged breeding seasons, while blacks appear to mature more rapidly, with nearly mature fish congregating at Taumutu in July and August. As flounders are essentially shallow-water species, spawning grounds will be inshore (Paul 2000).

Table 5-10: The mean numbers of juvenile flounder species caught per seine net haul, July-December 1994.

Month	Black flounder	Sand flounder	Yellowbelly flounder	Total (N)	Days lake open
July	0	0	4.5	9	15
Aug	0.0	4.4	29.4	270	4
Sept	0.7	0.3	11.2	73	5
Oct	31.4	0.3	2.1	338	14
Nov	53.3	0.0	0.5	215	-
Dec	13.2	0	0.2	67	-

A review of other studies of flatfish recruitment (Table 5-10) confirmed that juvenile black flounders were first found in lagoons and estuaries in October – December. Yellowbelly flounders were regarded by Colman (1973) as having a more restricted spawning season (September – November) than sand flounders, yet smallest fish were recorded from the Ahuriri estuary (Napier) over six months (July – December), and in the Waimakariri River lagoon from March to August, earlier than Colmans (1973) spawning season would suggest. While most sand flounder spawning takes place from June – November, they appear to spawn throughout the year, as evidenced by larvae being present from January to October (Hickford & Schiel 2003). The single record of a sexually mature male and female black flounder was recorded from the mouth of the Turakina River in late June (Stevens 1993).

Combining these results means that a calendar of preferred opening times can be constructed according to the desired recruitment of the various species of flounders (section 5.2). Note that the data from Taylor and Graynoth (1996) do not extend to November and December, meaning that data from Table 5-11 are required to augment this). Defining > 50% of the yearly recruitment derived from Taylor and Graynoth (1996) as "high" (H), 25 – 50% as Medium (M), and < 25% as low (L), and assuming the November and December data from other sites are indicative of the later part of the season, then Table 5-12 shows that an opening in August should give a high likelihood of recruiting both sand and yellowbelly flounders, whereas a September opening encompasses all three species but at only medium to low probabilities (Table 5-12). As the fishery is based on 2 and 3 year old fish (Jellyman in press), loss of a year's recruitment will have a profound effect, unlike eels where fish are typically > 10 years at entry into the commercial fishery.

Table 5-11: 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).

Species	Location	Spawning	Recruitment	Author
Black flounders	Lake Ellesmere		Dec	Jellyman (in press)
	Lake Ellesmere		Oct - Dec	Taylor & Graynoth 1996
	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	Lake Ellesmere		Sept - Dec	Jellyman (in press)
	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	Lake Ellesmere		Nov-Dec	Jellyman (in press)
	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

Table 5-12: The likelhood of recruitment of different flatfish species per month.

Month	Black flounder	Sand flounder	Yellowbelly flounder
July			L
Aug		H	H
Sept	L	L	M
Oct	M	L	L
Nov	M	L	L
Dec	L		L

A further factor associated with flatfish recruitment is the relationship between Te Waihora/Lake Ellesmere and the availability of juvenile flatfish in the inshore areas that will act as "catchments' for recruitment to the lake. Juvenile flatfish worldwide are renowned for their widespread use of specific nursery areas, typically shallow embayments; for instance, Roper & Jillet (1981) noted juvenile sand flounders in Otago were almost exclusively restricted to coastal inlets with extensive tidal mudflats. Low salinity water and distinctive olfactory cues are important factors for directed movements of juvenile flatfish (Boehlert & Mundy 1987). Both factors would result from the freshwater plumes that are associated with the opening of Lake Ellesmere – such plumes are visible up to 20 km offshore (Schwarz et al. 2008) while their northward drift is noticeable in the southern bays of Banks Peninsula and as far north as eddies in Pegasus Bay. Based on observations in Otago where nursery areas for juvenile flatfish were tidal sandflats within coastal inlets (Roper & Jillet 1981), the complex of bays in Banks Peninsula should provide extensive nursery areas. Probably the arrival of low-salinity water in nursery areas of Banks Peninsula provides the stimulus and direction for migration, and like glass eels, juvenile flatfish then take advantage of any bottom counter currents and tidal transport to arrive offshore of the lake mouth.

The flatfish fishery in Te Waihora/Lake Ellesmere commenced in the 1860's and has always been subject to considerable annual fluctuations in harvest (Singleton 2007). The probable association between flounder abundance and lake openings has been suggested on several occasions (Jellyman 1992, Taylor 1996, Singleton 2007) and Taylor (1996) found a reasonably predictable relationship between total flounder catch and the duration of lake openings (August – November) three years previously ($R^2 = 0.36$). A subsequent analysis (Jellyman in press) used a more extensive dataset comprised of commercial "flatfish" data for Flatfish Area 22 obtained from the Ministry of Fisheries, and the Te Waihora\ Lake Ellesmere data extracted by Port of Landing. The total catch of flatfish for that calendar year was regressed against the proportion of time the lake was open (lake opening data obtained from ECan). A second series of regressions were run using the "fishing year" of 1 October – 30 September – unfortunately, while this seasonal parameter makes more biological sense than calendar year, the "fishing year" was only introduced from 1989 onwards which limited the dataset. Lake opening times were calculated as the proportion of each month (August – November) or combination of months, whenthe lake was open – months were treated separately, and then combined in all possible combinations of consecutive months (e.g. August, August+ September, August+ September + October etc). These various lake opening proportions were then regressed against the total annual flatfish catch for that year, and also catches one, two or three years previously.

Calendar years results: For the range of 10 regressions per lag (0, 1, 2 or 3 years), a two year lag was more promising (P = 0.026-0.497) than lags of one year (P = 0.180-0.827) or three years (P = 0.103- 0.801). However, the only significant relationship ($P < 0.05$) was for the proportion of time the lake was open from September – November with a lag of 2 years ($P = 0.026$, $R^2 = 0.085$). This time lag conformed to the 2-year life history pattern of some flounder in the lake.

Fishing year results: this analysis was restricted to 18 years of data (post 1989); using catches per month against all lags (0,1,2, or 3 years) the only significant relationship (P = 0.035) was for August openings and catches for the same year – this made no biological sense as the fish do not enter the fishery within the first year. Although not significant, openings in August-September were more influential than openings between August and November, and lags of either 2 or 3 years (P = 0.219, 0.184 respectively) were much more influential than lags of 1 or 0 years (P = 0.854, 0.884 respectively). Overall, these data indicated that openings between August and November two or three years previously, were the most influential on catches in a given year.

While the timing of lake opening can influence the species that recruit, it should not be assumed that there are excess quantities of juveniles of each species at sea, that could then take advantage of a lake opening to immigrate into Te Waihora/Lake Ellesmere. The success of sand flounder spawning in the upper part of the North Island has been related to water temperatures (Coburn and Beentjes 2005), so it seems reasonable to assume that widespread changes in sea conditions might influence overall species spawning success. To investigate this, relationships between flatfish catches in Lake Ellesmere, catches in Flatfish Area 3 (includes the Canterbury Bight which has the largest flatfish catches in this very large area; Mfish 2007), and the rest of New Zealand, were examined to see whether Te Waihora\ Lake Ellesmere catches were correlated with catches in these larger areas (Table 5-13).

Table 5-13: P values for the relationship between flatfish catches from Te Waihora/Lake Ellesmere, and from the Canterbury Bight or the total New Zealand catch (190-2005). Figures in brackets show the percentage that Te Waihora contributed to the Canterbury Bight or total New Zealand catch. Figures in bold indicate a significant relationship.

	Canterbury Bight catches	All New Zealand catches
Black flounder	**0.00** (95 %)	**0.00** (63 %)
Sand flounder	**0.02** (14 %)	0.42 (3 %)
Yellowbelly flounder	**0.00** (30 %)	**0.05** (3 %)

The strong relationship for black flounder is not surprising given the regional and national dominance of Te Waihora catches 95 and 63% repectively). For sand flounder, Lake Ellesmere catches reflect regional catches but not national catches, while yellowbelly catches reflect both regional and national catches (yellowbelly regional catches were significantly related to national catches, $p = 0.04$). Thus the species catches in Lake Ellesmere strongly mirror regional recruitment, and yellowbelly flounders catches also have national signals, such that a strong Te Waihora\ Lake Ellesmere or Canterbury Bight year is indicative of a strong year New Zealand- wide. Sand flounder catches seem to be independent of New Zealand catches, suggesting the fishery in Te Waihora and Canterbury is uniquely abundant.

Summary flatfish recruitment

- All three species of flounders spawn at sea. Hence lake opening is critical to recruitment and the emigration of pre-spawning adults
- The best available data indicate some seasonality in recruitment, with August and September being the main months in Te Waihora. However, data from elsewhere in New Zealand indicate that sand flounders and yellowbelly flounders have extensive spawning seasons with sand flounder spawning almost year-round.
- The relationship between lake openings and subsequent commercial catches is not a very predictive one, but it indicates that catches in a given year are most influenced by recruitment either two or three years previously
- Growth rates and the rate of sexual development determine the length of time that flatfish will stay in the lake. Black flounders and sand flounders will tend to migrate between 1.5 and 2 years; and yellowbellies after 2.5 years
- While recruitment success depends on the timing and duration of lake opening, it is also influenced by the amount of regional spawning (both sand flounder and yellowbelly flounders) and national spawning (yellowbelly flounders)

5.2.3 Movement of adult flounders

Wind has a major influence on lake ecosystem, including influencing movements of fish. Flounders move with the wind at all stages of their lifecycle (Jellyman and Smith 2008). The most obvious movements are the arrival of mature black flounders at Taumutu in July and August during northeast winds, whereas they move away during a southerly. 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 2 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 periods of reproductive maturity, in December/January and again from May – July (Jellyman in press). 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 or any relationship between lake openings and flounder catches in subsequent years.

Unlike eels that have a stricter seasonal migration, maturing flounders will take advantage of whatever opportunities are available to exit the lake during late summer, autumn and early winter, although it is likely that they will show a preference for later (May - July) than earlier (Feb - Mar). If the lake is not open during these times and flounders are unable to leave, their gonads will regress and they will spend a further year in the lake.

5.3 Yelloweyed mullet

Mullet are a euryhaline marine species, able to tolerate a range of salinities, and so are frequently found in estuaries and harbours, but penetrate well inland in low gradient rivers.

Mullet are a shoaling species, and move upstream on incoming tides to feed on algae and some small invertebrates like snails and amphipods (McDowall 1990). Spawning is at sea, probably in early summer and autumn. Unlike eels and flatfish, mullet may recruit into the lake at a variety of sizes.

The mullet fishery is also rather variable, with fluctuations reflecting both recruitment from the sea, and also market demands. In an earlier review of the mullet fishery of the lake, Gorman (1960) noted that the fishery peaked in mid winter, with a lesser peak in summer. While this winter fishery was partly because eels were less active over this period (and eels frequently attacked mullet caught in the gill nets), it will also be because mullet are affected by cold weather and frosts result in them forming schools meaning they are more accessible to fishers (Jellyman and Smith 2008).

Over the past 18 years, the annual catch has averaged 6.4 t (SE 1.4 t), with a maximum of 22.8 t in 1992. The fishery is essentially a winter one, with an average of 2/3 of the catch taken between June and August inclusive and 92% between May and September. Mullet are a Quota Management species, but Te Waihora/Lake Ellesmere is part of Fishstock YEM 3, east coast South Island. Catches from the lake will reflect favourable opening times for entry of juveniles and pre-spawning adults, usually in spring – early summer, and market demand. At present, the demand is relatively small and the yield from the fishery could be easily increased if required.

Seasonal catches of mullet from fyke nets at Taumutu gave peak catches from May-July and December (Hardy 1989), but few mullet were caught at Timberyard Point. Seasonal seine net catches (September 2005 – May 2008) also failed to catch mullet with not a single fish being caught from a total of almost 60 000 fishes (Table 3-3). Likewise, a study of fish recruitment (Taylor and Graynoth 1996) caught few mullet (~ 0.05% of all fish, N = 27 390), and only in July, September and October. Similarly, 2/3 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. They seldom recorded juvenile mullet (< 100 mm) and only during December and January. In a similar study of the Waimakariri Lagoon, Eldon and Kelly (1985) recorded juvenile mullet (< 60 mm) during February and March. Spawning is in early summer and autumn (McDowall 1990), and Webb (1973) considered there were two spawnings per year with 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.

Based on the above, recruitment of juvenile mullet into Te Waihora\ Lake Ellesmere will be from December – 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 – June, although as fish are known to move in and out of estuaries on tidal cycle, it is possible that there is emigration of immature fish over a wider period.

5.4 Common bullies

5.4.1 Life histories

Numerically, bullies dominate the fish fauna of the lake. They comprised 92% of the numbers (and 44% of the biomass) of all fish collected by Glova and Sagar (2000). Bullies also dominated trawl catches (Graynoth and Jellyman 2002), comprising 93.4% of all fish caught (with smelt comprising 3.5 %, and shortfin eels 3.1%). Bullies spawn in spring and summer (McDowall 1990), and in diadromous populations, the newly hatched larvae are swept out to sea, to return as juveniles 15-20 mm long in autumn. Each female may spawn more than once per season, and eggs are deposited in crude "nests', usually located beneath firm and flat surfaces like large rocks. Bullies will also spawn on aquatic weeds, and in Te Waihora/Lake Ellesmere where solid flat surfaces are rare, bullies have been recorded as spawning prolifically on the legs of maimais and in old tyres used as breakwaters and bank stabilisation devices near the mouth of the Halswell River. NIWA staff have observed substantial upstream movements of adult bullies in the lower reaches of the Selwyn River in early summer, and it is likely that this is part of a short upstream migration to find suitable spawning substrates. While the eggs of lake spawning bullies could be subject to desiccation if laid within 0.5m of the surface, eggs laid in stream mouths and riverine habitats should be safe from short-term water level fluctuations. Males guard the eggs until hatching, and are able to disperse any accumulated sediment by fanning with their fins. Larval bullies are pelagic 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.

In some situations, common bullies form non-diadromous populations where they carry out their complete life history within fresh water and larvae do not go to sea. Usually this lifestyle occurs in inland lakes that are beyond the normal distance of recruitment from the sea. For example, landlocked common bullies occur in Lakes Hawea, Pukakai, Wanaka, Ruataniwha, and Tekapo (all > 100 km inland). 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 our unable to find their way out of a lake, usually because the lake is large with a relatively small or intermittent outflow (McDowall 2010), as is the case with Te Waihora/Lake Ellesmere. It is not uncommon for both diadromous and non-diadromous forms of the same species to coexist in the same lake, and both groups may interbreed (McDowall 2010). Indeed, in a study of the life histories of common bullies from Southland rivers, Closs et al. (2003) recorded both diadromous and non-diadromous forms in the lower Mataura and Taieri\Waipori systems, suggesting that diadromy in this species was facultative (not essential) even when access to the sea was continuously available; these authors postulated that in such large river systems, a proportion of the common bully population may be non-diadromous provided suitable larval/juvenile rearing habitat was present.

The migratory status of common bullies in Te Waihora/Lake Ellesmere has not been determined biochemically, but it is presumed that the majority of fish are non-diadromous. Reasons for this are;

- Voluntary landlocking of common bullies is common and can occur in large lakes with small (or infrequently opened) outlets like Te Waihora/Lake Ellesmere, Lake Wairarapa, Wairewa etc
- 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).

5.4.2 Role of bullies

Bullies are a very important food chain link between invertebrates and predatory fishes (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 (> 500 mm, Ryan 1986). Acceleration in growth rates of shortfin in Te Waihora/Lake Ellesmere at lengths between 380 – 660 mm has been attributed to eels becoming piscivorous (Jellyman 2001), and thus reaping the benefits of a high energy food. Although primarily an invertebrate feeder, flounders are also known to occasionally predate on bullies (NIWA unpubl. data). Bullies are also very important in the diets of herons, cormorants, and also gulls and terns (Sagar et al. 2004). The importance of bullies is shown in Figure 4-16, where bullies are a pivotal link between the invertebrate community and other fish and birds. The strongest links in this somewhat conceptual figure are associated with bullies.

5.4.3 Size and abundance

There is some suggestion that numbers of bullies in the lake have increased over time (Jellyman and Todd 1998), possibly associated with a reduction in larger eels, especially longfins, and perhaps also associated with loss of macrophytes. Whatever the reason, densities of bullies are high. For example, trials of super-fyke nets (Chisnall and West 1996) in Lake Waaahi and Te Waihora/Lake Ellesmere recorded catches of common bullies in Te Waihora/Lake Ellesmere (1544 fish/night) that were twice those recorded from Lake Waahi (784 fish/night).

The size range of bullies varies with distance offshore. Thus bullies caught by trawl (100-4000 m offshore) exceeds that from seines (0-100 m) (Figure 5-17): and differences in length were significant ($n = 1747$, df 1,1745, $F = 867.7$, $P < 0.001$). Sampling by a hand-towed benthic sled caught a smaller size range (Figure 5-18, mean 29.9 mm, NIWA unpubl. data), and small bullies were found in water as shallow as 10 cm (Figure 5-19). However, small bullies (< 40 mm) were found throughout the depth range, whereas bullies larger than this were seldom caught in shallow water (< 0.35 m deep).

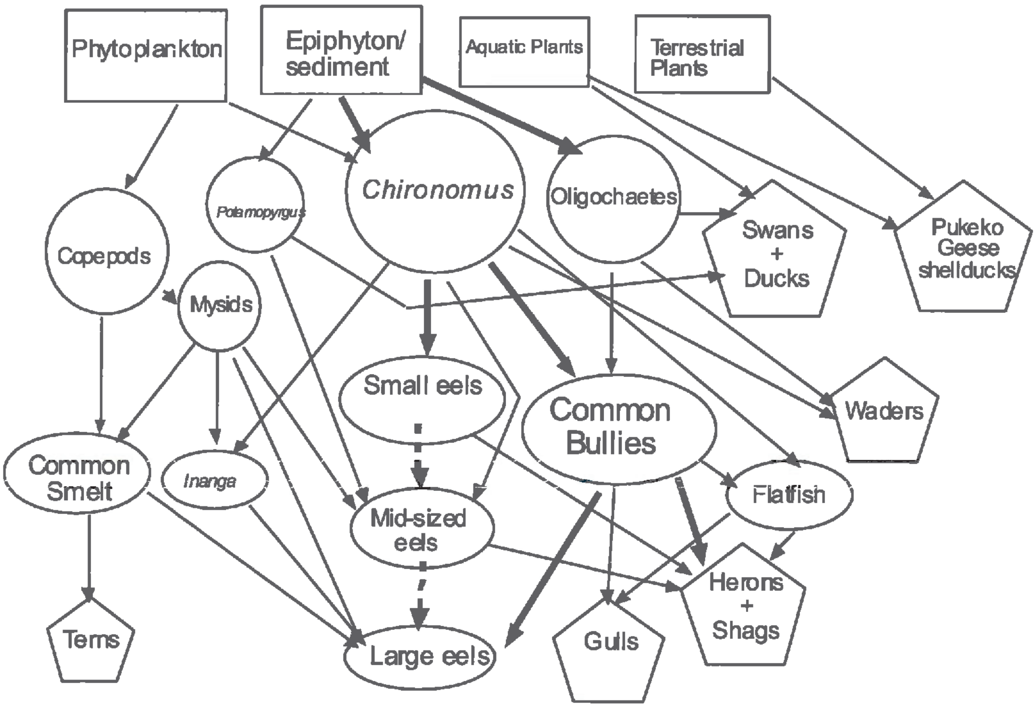

Figure 5-16:Te Waihora/Lake Ellesmere foodweb - carbon flow diagram. Squares are primary produces: circles are invertebrates; ellipses are fish, pentagons are birds. Sizes are proportional to available biomass, and thickness of arrows indicates importance of pathways for energy transfer. Dashed lines represent growth rather than feeding relationships for shortfin eels (from Sagar et al. 2004).

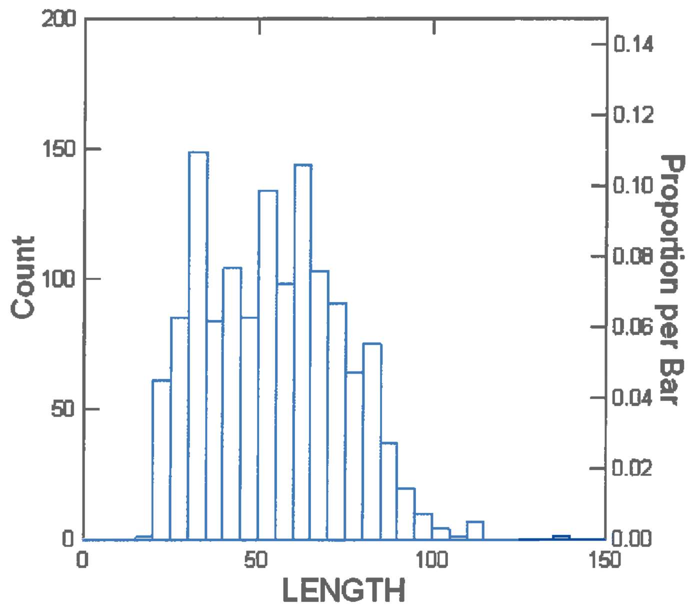

Figure 5-17:The length distributions of common bullies caught by seine (top) at Taumutu, and by trawl (bottom) off Timberyard Point, 2007-2009.

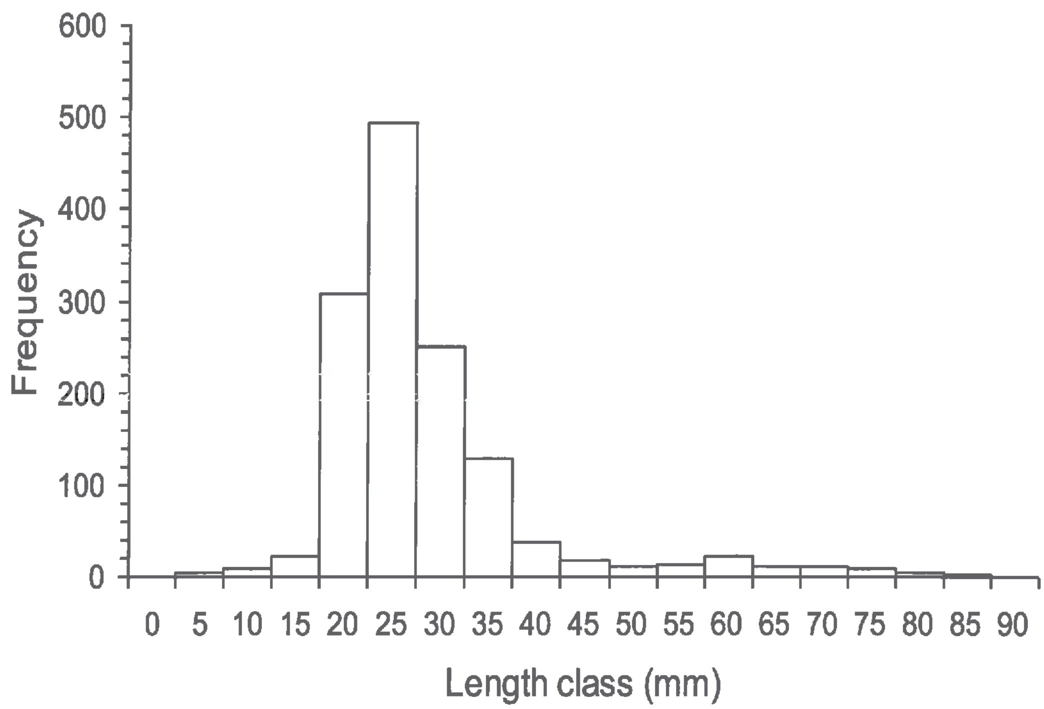

Figure 5-18:Length of 1354 common bullies (5 mm size groups) caught in benthic sled tows around Lake Ellesmere, March 2007-May 2008.

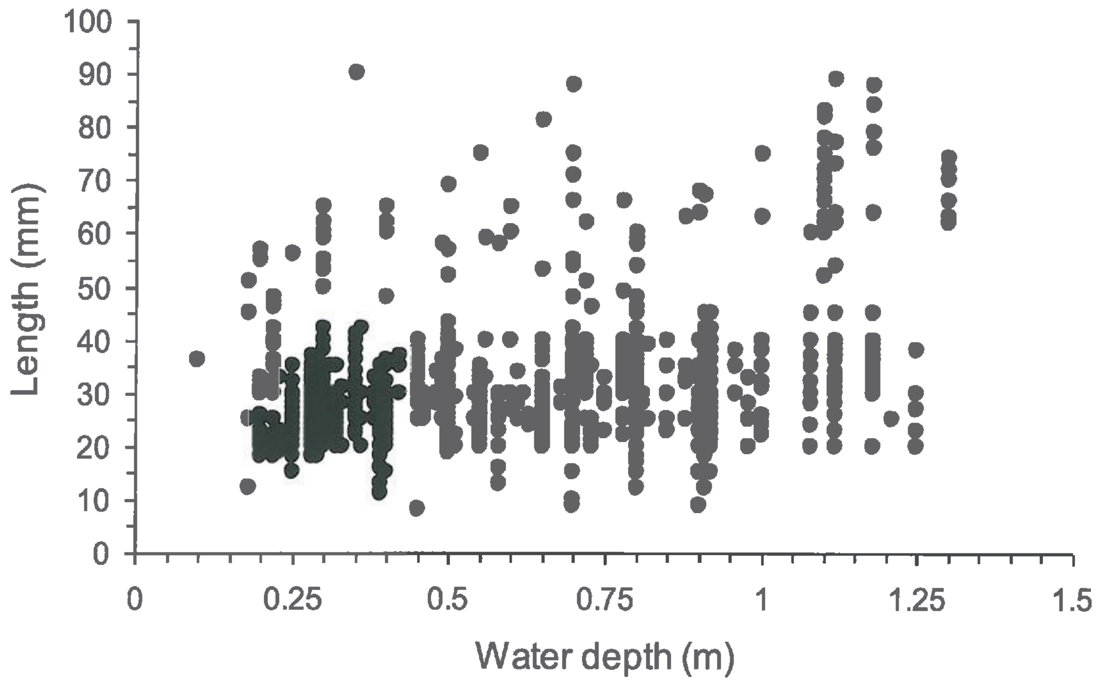

Figure 5-19:Length of common bullies caught in benthic sled tows around Te Waihora/Lake Ellesmere with respect to water depth.

The density of bullies from the sled catches, 1.21 /m^2 exceeded densities from either a beam trawl (0.27/m^2, beach seine (0.26/m^2) (trawl data from Graynoth and Jellyman 2002; seine data is NIWA unpubl. data). Thus the shallow littoral zone supports a relatively high density of small bullies, even though this zone is subject to high wave energy, and occasional dewatering. Using the more conservative density of 0.27 bullies /m^2, and assuming uniform density across the whole lake (an oversimplification) gives a crude population estimate of 53.2 million bullies. Of interest though is an observation by NIWA staff (Marty Bonnett, NIWA, pers. comm.) that no bullies were caught in the sled on the Greenpark Sands in water < 0.5 m; seemingly bullies avoid this area, at least during the day, as water recession can be rapid and they would risk being stranded during periods of strong offshore wind. However, bullies do inhabit similar zones at Timberyard Point where water recession would be slower due to the steeper slope of the lake bed.

5.4.4 Habitats

In their fish community study of the lake, Glova and Sagar (2000) also recorded that while common bullies were distributed throughout the lake, densities inshore were much greater than offshore (Figure 5-20). They also found that the mean abundance and biomass of bullies species were significantly (P < 0.001) greater on the north than the south sides of the lake. The largest catches of bullies occurred within the vicinity of river mouths, particularly those of the Halswell and Irwell. By comparison, catches of bullies within the vicinity of the Selwyn River mouth were moderate. Slightly higher catches (mostly small bullies <60 mm long) were taken immediately west of Kaituna Lagoon and within the vicinity of the lake outlet. Catches were low on the Greenpark Sands, along the western half of Kaitorete Spit and between the lake outlet and Timberyard Point, and bullies were least abundant in Kaituna Lagoon, along the eastern half of Kaitorete Spit, and around Harts Creek.

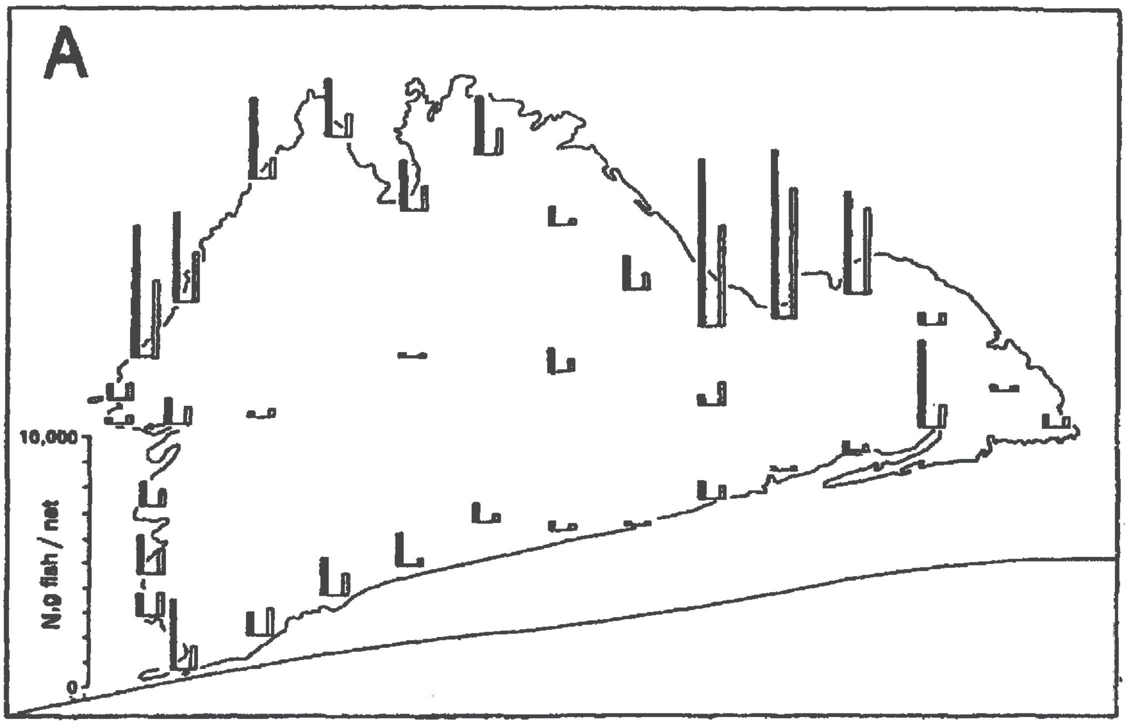

Figure 5-20:The mean abundance (N, solid bars) and biomass (g, open bars) per three nets of common bullies, January-March 1995 (from Glova and Sagar 2000).

5.5 Smelt

5.5.1 Life histories

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

In contrast, common smelt are frequently encountered in the lake. Like common bullies, both diadromous and non-diadromous types of common smelt can co-exist – for example, both types coexist in Lake Waahi (Northcote and Ward 1985), and also in Lakes Wairarapa, Forsyth, Ellesmere and possibly Waituna Lagoon (McDowall 2010). The two forms are generally similar in appearance, but differ in morphological characters like vertebral counts - the diadromous form typically in Te Waihora/Lake Ellesmere has a vertebral count of 56 vertebrae whereas the non-diadromous ("landlocked") form has about 61 vertebrae (McDowall 1990). There are more subtle changes in characters like eye size, head length and the number of gill rakers.

Spawning of smelt occurs in fresh water; although this has not been observed in Te Waihora/Lake Ellesmere. Spawning is likely to be similar to other lakes which takes 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). The eggs sink and open areas clear of algal mats are preferred sites. 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). The presence of juvenile fish in January in Te Waihora/Lake Ellesmere would indicate a spring spawning. For example, assuming the above mean lengths are indicative of growth, then juvenile smelt grew 9 mm between January and March (~ 4.5 mm/month). Size at hatching is ~ 6 mm (McDowall 1990), so to achieve 32 mm of growth by January would equate to a spawning in June/July. Certainly, Northcote (1988) recorded spawning smelt in North Island lakes ranged between winter and summer, while Rowe et al. (2002) noted that spawning in Lake Taupo was from September – December; so while winter spawning is possible, spring spawning seems more likely in Te Waihora/Lake Ellesmere. If open during spring and summer, the lake could attract juvenile fish that had been born elsewhere (as there is no evidence of "homing' in smelt).

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

Juvenile smelt are plankton feeders, and typically disperse widely throughout lakes where they feed on planktonic crustacea (ostracods, copepods). While these organisms will occur throughout the lake, as they will respond to the availability of phytoplankton, it is likely that there will be greater concentrations in areas adjacent to tributary inflows, meaning inshore areas will be of greater importance as nursery areas than offshore areasAdults eat larger food organisms, and in Te Waihora/Lake Ellesmere have been reported to feed extensively on mysid shrimps (McDowall 1990), similar to the feeding pattern observed in Waikato turbid lakes (Hayes and Rutledge 1991). Although feeding rates in smelt are adversely affected by increased turbidity (Rowe and Dean 1998), their abundance in the lake would indicate that they are able to feed effectively at present levels of turbidity. Should the lake ever return to its partially clear condition, then the diet of smelt would be expected to revert to being dominated by chironomids, similar to that recorded from relatively clear Waikato lakes (Hayes and Rutledge 1991).

5.5.2 Abundance

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 as although smelt are found throughout the lake, they predominantly occur along western shorelines (Glova and Sagar 2000) and are sparse offshore (Figure 5-21). Smelt are also a shoaling fish, and thus numbers can fluctuate considerably, depending on the likelihood of encountering a school.

From the length distribution of samples caught in January 2007 (Figure 5-22), 2 year classes can be seen with juveniles present(38 – 47 mm, mean 40.3 mm) as well as an older year class (63 – 85 mm). The same two size groups are also evident for all months combined (Figure 5-23). Thus earliest recruits were recorded from January and by March these fish had grown to an average size of 49 mm, and 54 mm by August. At entry into fresh water, juvenile smelt of diadromous origin can be as small as 45 – 60 mm, but are usually 70 – 90 mm (McDowall 1990). Therefore the smallest size group in the January sample would be smelt of non-diadromous origin.

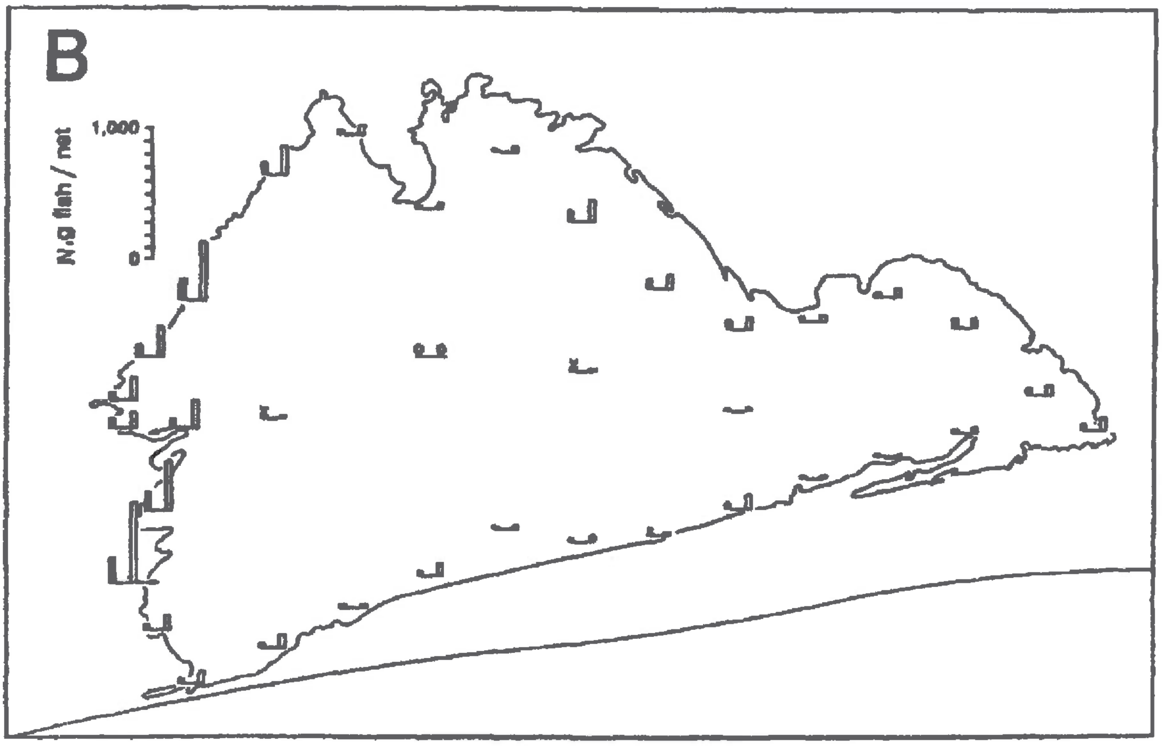

Figure 5-21:The mean abundance (N, solid bars) and biomass (g, open bars) per three nets of common smelt, January-March 1995. (From Glova and Sagar 2000).

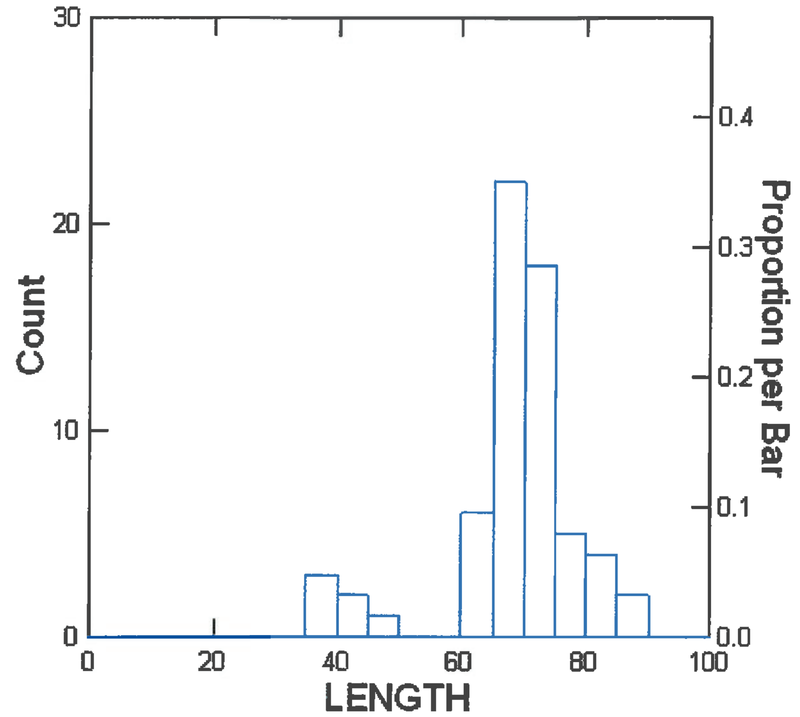

Figure 5-22:The length-frequency of common smelt caught by seine, Taumutu, January 2007.
N = 63.

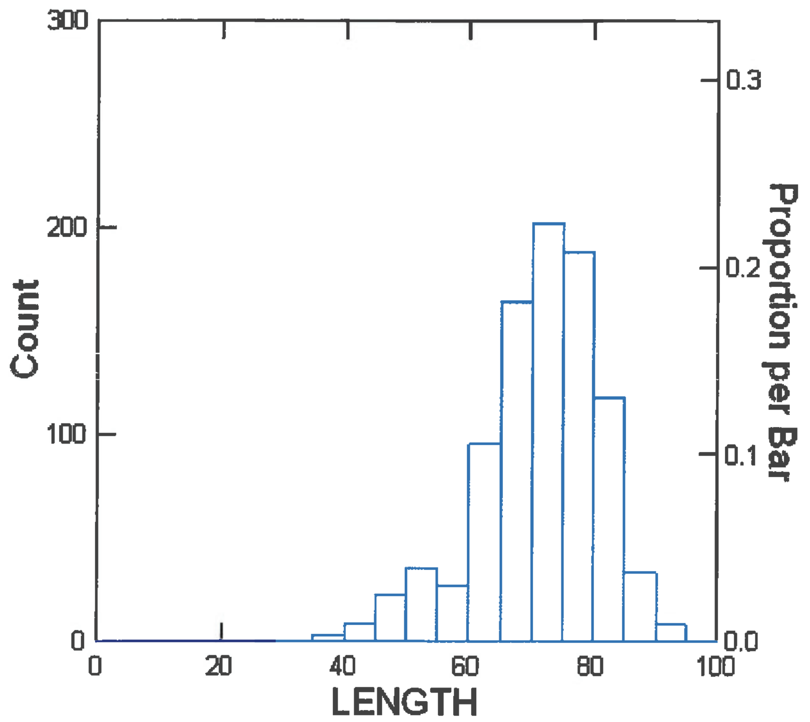

Figure 5-23:The length-frequency of all common smelt caught by seine, Taumutu, 2005-2007.
N = 904.

5.5.3 Habitat

Most smelt in Te Waihora/Lake Ellesmere have been recorded along the western shorelines, and the embayments here are likely spawning areas, especially those sheltered areas like the mouth of Harts Creek where the stream inflow will lessen the extent of dewatering during an offshore wind. The eggs will not be tolerant of exposure to the air and would be easily desiccated if dewatered. In a study to predict the effects of varying water levels on smelt spawning success in Lake Taupo, Rowe et al. (2002) found that low levels could significantly reduce available spawning habitat, while high lake levels during spring spawning tended to result in high recruitment. Thus lowering of the level of Te Waihora/Lake Ellesmere during spring by > 0.5 m could have a negative impact on developing smelt eggs; fortunately the incubation period is only 8-10 days, and as the spawning period is likely to cover several weeks at least, eggs laid after the lake was lowered should have a reasonable chance of hatching (provided they are deeper than any wind-induced dewatering).

5.6 Inanga

Inanga is a species that does not readily abandon its links with the sea and become landlocked (non-diadromous; McDowall 2010). However, like common bullies and smelt, it is highly likely that both diadromous and non-diadromous forms of inanga coexist in the lake. For example, the spawning recorded during may 1989 by Taylor et al. (1992) was during a period when the lake was closed to the sea- hatching would have occurred 2-4 weeks after spawning (late April – early May) but the lake did not open until 24 June. It stayed open for 21 days and many inanga larvae would have been swept out to sea during this period, but there is no reason to suppose that others did not stay and rear within the lake. Likewise, Taylor (1996) recorded spawning in April 1990, 3 months before the lake was next open.

In their study of fish communities in the lake, Glova and Sagar (2000) found that inanga were distributed around the lake margin, mostly along the western side with few fish recorded along the northern and southern sides; no inanga were caught at offshore sites (Figure 5-24). Glova and Sagar (2000) suggested that wind would have a major influence on the distribution of fish, particularly those like inanga that live in the water column, as significant displacement of water to the lee shore by wind-driven currents is reported (Taylor 1966) to occur in the lake. They hypothesised that such pelagic species could become displaced by winds, through experience with frequent winds fish may learn to occupy the sheltered embayments along the lake margins.

During more recent surveys (2006 – 2008), gravid male and female inanga were recorded 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. Unfortunately, the spawning area was destroyed in May 1990 when a mechanised digger was used to dredge the area (Taylor et al. 1992). Inanga eggs are laid in areas where they are exposed to the air and survive as long as the relative humidity is high (hence the importance of 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 made 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 upstream as far as 4-5 km.

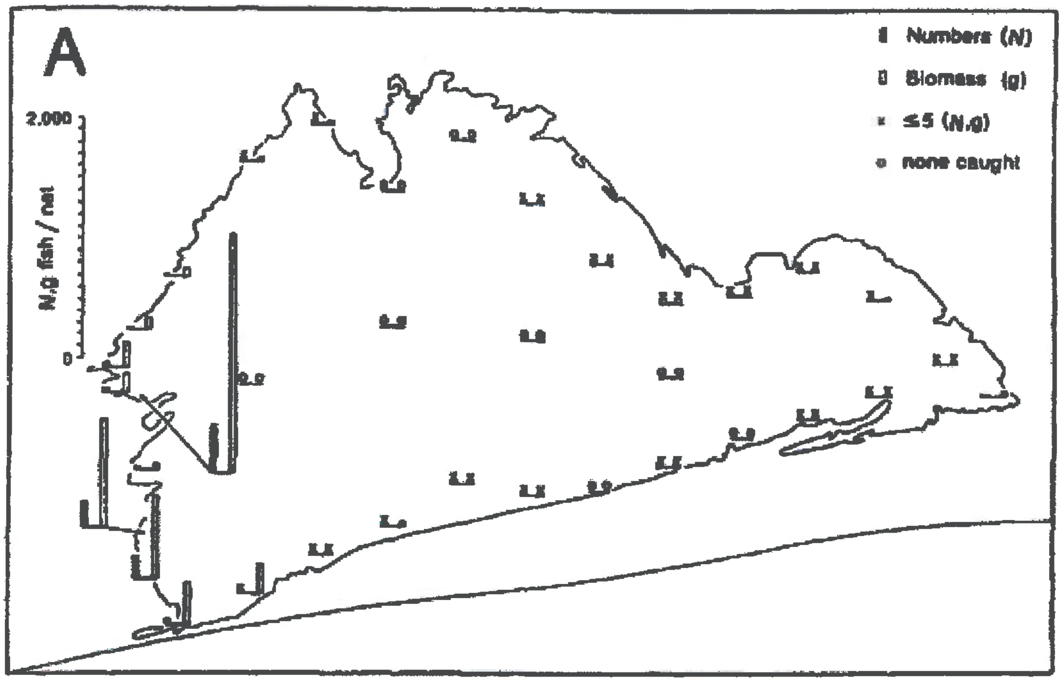

Figure 5-24:The mean abundance (N, solid bars) and biomass (g, open bars) per three nets of inanga, January-March 1995. (From Glova and Sagar 2000).

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 feeding areas and some 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 will also provide significant habitat for rearing juvenile and adult inanga.

5.7 Brown trout

5.7.1 History of brown trout abundance

Historically, Te Waihora/Lake Ellesmere and the Selwyn River maintained a world-class fishery for brown trout. To quote the North Canterbury Acclimatisation Society annual Report of 1936 (cited in McDowall 1994): "for many years the lower Selwyn has borne the reputation of being the best three miles of brown trout fishing in the Dominion, or probably in the world, taking into consideration the numbers taken from the lower waters each season, and their large average sizes".

At present, trout numbers in the lake itself are low – in their comprehensive fish survey, Glova and Sagar (2000) recorded only 3 trout (220 – 281 mm) from a total of 170 021 fish captured (Table 4-2), and NIWA seine netting neat Taumutu also recorded a single trout amongst a total fish catch of 59 683 fish (Table 4-3). Monthly fyke net catches at Timberyard Point and Taumutu (April 1979 – March 1980) recorded slightly higher catches of trout at 3.3% (215 trout) and 0.9% (41 trout) respectively (Hardy 1989), probably indicating a slightly higher trout population in the lake at that time.

Whereas the annual spawning run of trout in the Selwyn River was measured in tens of thousands (Table 5-14), more recent trapping has produced dismal results with numbers reduced to a few hundred. Likewise, survey of trout redds (nests) showed that "the extent of trout spawning activity has declined markedly since the 1980s, with a total redd count of 480, compared with a count of approximately 1284 redds over comparable reaches in the 1980s. The largest decline (in percentage terms) is in the Silverstream and Baileys Creek sub-catchments in the Selwyn catchment, and the Powells Road Drain in the LII catchment, where almost all (ca. 95%) of the trout spawning habitat has been lost. In particular, Baileys Creek appeared to have lost all trout spawning habitat" (Taylor and Good 2006). The authors suggested that the main major reason for habitat loss was siltation of spawning gravels, caused by widespread stock access. Of particular concern are those springfed streams where the lack of flow variability provides little opportunity for re-suspension and flushing of sediment.

In a survey of anglers perceptions of changes in lowland river trout fisheries over the previous 20 years, Jellyman et al. (2003b) recorded that the Selwyn River was "a river showing a marked decline in angling quality", which anglers put down to "low flows due to excessive water abstraction for irrigation".

Table 5-14: Results from trapping of the spawning run of brown trout in the lower Selwyn River. (Data from Hardy 1989, Taylor and Good 2006).

Year	No. of weeks operating	No. of trout trapped	Estimated run size
1941	10	12 430	37 000
1949	17+	12 105	65 367
1956	9	12 142	15 560
1958	15+	4 779	15 600 – 19 800
1960	8+	12 177	
1966	10	14 247	
1970	14+	13 280	
1985		309	
1987		562	
2004		87	

Certainly, the lake still has the potential to grow large trout as Glova (1996) found that recaptured hatchery-reared brown trout were all in excellent condition, and growth had been rapid. A conclusion from this study was that recruitment was limited, and that "a major input of trout into the system could help to reverse the decline of the fishery".

Anglers often speak of “searun” brown trout in the lake, meaning trout that have spent most of their lives at sea and entered the lake to spawn in tributary streams. Such trout are typically recognised by being of large average size, good condition, light colouration, and deciduous scales (i.e. easily dislodged). The extent of true searun trout among anglers or trap catches is difficult to determine, as trout that live in estuaries also share many of the same physical characteristics as searun trout, and anglers tend to term light-coloured and good conditioned trout as “searun”. In reality, most of these will be fish that live in the lower reaches of rivers and perhaps make periodic movements to and from the sea. There is some evidence of tagged trout from Te Waihora/Lake Ellesmere going to sea as a tag-recapture study conducted by the North Canterbury Acclimatisation Society in 1962 and 1963, showed that 13% of the trout tagged at the Selwyn River trap that were subsequently caught by anglers, were recaptured in different catchments including the Rangitata and Ashburton Rivers (Hardy 1989; Millichamp 2008). Similarly, of 376 recaptures of brown trout tagged at the Glenariffe salmon trap in the upper Rakaia catchment, 7 fish were from other catchments (Rangitata and Ashburton Rivers, and Te Waihora/Lake Ellesmere; Fox et al. 2003).

McDowall (1990) recorded that the movement of juvenile brown trout to the sea may occur at any age from a few months to several years. Such downstream movement takes place over an extended period, from September to April (Fox et al, 2003), and a similar pattern of movement is possible in Te Waihora/Lake Ellesmere, although such movement is not obligatory and numbers of fish will be relatively small. The arrival of searun fish in the mouths of rivers usually takes place in autumn, and a lake opening between February to April is likely to attract some searun fish. However, as indicated, most fish caught in the lower reaches of the tributaries will be fish of lake origin, and not true searun trout.

5.7.2 Reasons for loss of the trout stock

The demise of the fishery is well known (e.g. Hardy 1989; Singleton 2007), although the reasons are less well understood. Hardy (1989) suggested a combination of issues including:

- increasing eutrophication of the lake
- disappearance of the macrophyte beds
- extensive bycatch, especially from flounder gill nets
- habitat degradation, especially land drainage, channelisation, weed clearing, and removal of streamside vegetation
- frequency and timing of lake openings
- maintaining the lake at low levels
- inadequate food supply
- insufficient recruitment of juvenile trout associated with low flows preventing access of adult fish to spawning grounds, losses of fish through stranding, and the failure of juvenile trout to survive in the lake partly because of the lack of weed beds which formerly provided food and cover from predators.

Records of net-marked trout (from gill nets used for flounders and mullet) were frequent – Percival (1958) recorded over 6% of spawning trout had such scars. As a result, netting was banned within a 1.2 km radius from the mouths of the Selwyn, Halswell, Irewll, Harts Creek and LII rivers. In a review of the lake fisheries, Glova and Todd (1987) stated that "over the years, the cumulative loss of adult trout in this manner (gill netting for flounders) is believed to have had a major impact on stocks in the lake, and may well be the single most important factor in the decline of this once abundant sport fishery".

The loss of aquatic weeds has been suggested as one of the contributing factors in the loss of the lake and Selwyn River trout fishery (Hardy 1989, Glova 1996). One hypothesis was that with the lack of juvenile rearing habitat in the Selwyn River, juvenile fish enter the lake at a small size and are subject to extensive predation as there is little cover from predators (eels and birds), whereas previously the extensive weed beds would have provided such cover and also food. Certainly an experiment that released juvenile trout as yearlings (~ 50 g) produced encouraging returns of trout at a comparatively large size between 1 and 3 years later (Glova 1996).

Taylor (1996) discussed a number of possible causes – overfishing by anglers, the water quality of the lake and lower tributaries, disappearance of the macrophytes beds, by-catch from commercial fishing, reduction in available lake habitat as a result of lower opening levels, lake opening regime (for ingress of food fishes and possibly searun trout), reduction/loss of flow in the Selwyn River, river works (aquatic weed removal, drain maintenance). This review concluded that the impacts of habitats of most of these factors individually was likely to have been minor, but "in combination they may have had a significant influence on trout stocks, with the greatest impact likely to have resulted from the loss of the lake weed beds and the effects of commercial fishing". More recently, Millichamp (2008) reviewed possible reasons for the decline and considered the most likely causes were commercial fishing bycatch, the quality and quantity of spawning habitat, loss of access to the Selwyn River headwaters, and loss of rearing habitat; he considered that the angler harvest, lake water quality, and food supply were probably relatively unimportant.

In a further review of the trout fishery Painter (2009) drew attention to the lack of connection between the lake and extensive parts of the Selwyn River catchment. Subsequently (Painter 2011), he suggested that flow permanence in the central portion of the river was important for migrations to and from the spawning grounds of the upper catchment, although the supporting data are somewhat equivocal. In addition, climate projections for a continued drying trend and increasing ENSO phases raise doubts about whether an extensive trout restocking programme would be effective (Painter 2011).

Irrespective of the causes for the demise of the brown trout stock (which are almost certainly multiple), there is no doubting the fact that the present day population is a small remnant of the population of the 1930's and 40's. Fish and Game have stated that while restoration of stocks to the 1940's levels is probably unachievable, it should be achievable to build stocks to the to levels of the 1980's (Millichamp 2008), although even this is a very ambitious goal given the degradation and loss of habitat and surface flows within the major tributaries. While there is evidence that this river has always been subject to ephemeral flows, it is acknowledged as being over-abstracted, although some ground and surface-water recharge would accompany the Central Plains irrigation scheme should this proceed.

Given the very large population of bullies in the lake, food for trout is abundant. The limiting factor(s) for rejuvenation of the trout population is more likely to be associated with the status of tributary streams (spawning and juvenile rearing habitats) than the status of the lake itself. Trout will continue to be an occasional bycatch in fyke nets, although the use of larger nets will have improved the likelihood of surviving capture. In contrast, accidental capture in gill nets will result in mortality, although with the low number of trout present in the lake, this is not an issue at the present time (Glova and Sagar 2000).

6 Lake management

6.1 Overall effects of varying lake levels on fish

Table 6-1 indicates (subjectively) that high lake levels are generally beneficial for fish (details of the actual impacts are given in Appendix I). High lake levels are especially advantageous for shortfins, as this species will take advantage of seasonal flooding of pastures and scrub, to forage for terrestrial foods like earthworms, insects, and spiders (Jellyman 1989). Longfins are less responsive to increased water level, and the largest populations live in the tributaries. The responses of the smaller species, bullies, smelt, and inanga will be less pronounced; being strongly associated with vegetated embayments. Inanga will be expected to forage and seek refuge in flooded margins where they will also feed to some extent on terrestrial food (McDowall 1968).

Table 6-1: General impacts on main fish species of changes to the lake and tributaries. Stars are positive impacts, minus signed are negative impact, * or - = minor importance, **** or ----- = major importance.

Species	High lake levels	Low lake levels	Slow drop	Rapid drop	Tributary water quality	Tributary water quantity
Shortfin	*****	- - - -	- -	- - - -	- -	- - -
Longfin	**	-	-	-	- -	- - - - -
Flatfish	***	- - -	-	- -	-	-
Bullies	**	- -	-	- - -	- -	- - -
Smelt	**	- -	-	- - -	- -	- -
Inanga	***	- -	-	- - -	- - -	- -

The relative importance of the various lake and tributary habitats (Table 6-2) indicates that inshore lake habitats are extremely important for each of the species listed, with the exception of longfin eels where the tributaries are of more importance. The vegetated margins of the lake are of high importance 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 6-2: The relative importance of generalised habitats to the main fish species of the lake. - = seldom occurs, * =minor importance; ***** = major importance.

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

Low lake levels are generally detrimental for fish for a number of reasons. Decreased levels restrict feeding areas, and can lead to decreased water quality conditions through elevated water temperatures with an enhanced likelihood of associated algal blooms. Low levels also restrict opportunities for mouth openings at desired times. Also, low levels result in increased resuspension of sediment during windy periods, which in turn can further reduce feeding opportunities for species that are at least partly visual feeders; this issue may not be a major disadvantage as species like common smelt and common bullies are adept at feeding in highly turbid water (Rowe and Dean 1998), and bullies have been found to be relatively insensitive to the direct effects of increased turbidity (Rowe et al. 2003).

One issue that has not been researched is the assertion by commercial fishers that a low lake is preferred in summer to a partially-low lake – the reason being that a partially low lake can be high enough to just cover Greenpark Sands, and this acts as a "heat trap" during warm summer days, and elevates water temperature appreciably (Colin Arps, pers. comm..). It would be of considerable interest to carry out a series of temperature measurements, and/or create a temperature model, to see if this scenario would result in a significant source of heat to the lake.

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 the extent of this in the lake, although there are records of Maori harvesting stranded eels:–

"Another way in which eels were taken at Waihora was when the shoal waters of the lagoon were much affected by strong winds. The result was that a considerable area out of the lake-bed was exposed and many eels would be seen wriggling on the mud. The lake-bed was so affected for perhaps a mile. When natives heard a strong wind blowing they knew that soon the waters of Waihora would recede: hence they would proceed to the lagoon and wait until the bed was exposed. As the waters receded, the people advanced and found stranded eels wriggling about on the mud. Then all they had to do was to string them on cords by means of a bodkin-like implement, and so full cord after cord. But ever they warily watched for the retuning waters. Ere the waters came sweeping back, the eel collectors would return, dragging the strings of eels after them in an energetic manner, lest they be caught by the waters and drowned. Some natives have so lost their lives at such times, for should the wind die away quickly, then the water is swiftly returned, and should any person be overtaken by them they would be submerged" (Best 1929).

While there are no direct observations on the impact of varying lake levels on eels in Te Waihora/Lake Ellesmere, the overall effects of varying lake levels are known from other studies. Thus in a small lowland lake in the Wairarapa, Jellyman (1991) found that with increased lake levels, catches of shortfin increased markedly, while catches of longfin did not. Shortfins took advantage of the higher levels to feed over newly inundated pasture and marginal vegetation, and predated on terrestrial food, especially earthworms and grassgrubs (*Porina* sp.) (Jellyman 1989). However, the effect of short-term changes associated with wind is unknown – commercial fishers consider it unlikely that eels would respond to such water level changes due to the rapidity of change and the risk of being stranded once the water recedes. Dewatering of > 0.5 m is not uncommon during periods of strong wind; areas like Greenpark Sands are prone to rapid recession and water here can recede faster than a person can comfortably walk (Paul Sagar, NIWA, pers. comm.). i.e. ~ 1.3 m/s. There are also anecdotal reports of eels moving onto the Greenpark Sands in response to wind-lash events (the rapid inundation of a low-lying area driven by a strong onshore wind). Whether these events constitute an important feeding opportunity for eels and possibly flounders, is uncertain.

Thus for shortfin, gradual increases in water level are beneficial, especially during spring when eels will be resuming feeding after stopping during autumn and winter when water temperatures fall below 5.5 – 6.0°C (Jellyman 1991, 1997).

The slow dropping of water levels is of less significance to fish, although again, the overall impact will be negative due to possible reductions in habitat, feeding opportunities, and elevated water temperatures.

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), although 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/Lake Ellesmere 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).

6.2 Lake openings

A calendar of the preferred opening times by species and life stages (Figure 6-1) shows that most recruitment occurs during winter and spring (August-November), and some opening during these seasons/months will accommodate both species of eel, the three main flounder species, mullet, and also any diadromous juvenile inanga (whitebait) and smelt. Juvenile common bullies will tend to be available earlier, April – June, although given that most of the bullies within the lake and catchment are expected to be non-migratory, the recruitment of diadromous stocks of bullies is not essential to the ecology of the lake.

Most seaward migrations occur in late summer-early autumn (February-June); the most critical of these are for migrating (silver) eels as these have transformed into the non-feeding migratory stage and are physiologically adapted to life in salt water. Failure to reach the sea will generally be non-fatal, as after repeated failures, many eels will eventually revert back into the feeding stage; however, this phenomenon is not well studied, but it is likely that the associated loss of condition will mean these eels will need to regain this lost biomass and are unlikely to be able to migrate the following season – rather they will probably skip a year but attempt to migrate the following year provided they have regained sufficient condition. There are observations of mass deaths of shortfin male eels prevented from migrating, when these have been forced to take up residence in Waikekewai Stream – whether the deaths are due to an inability to revert back to the feeding stage, or simply due to overcrowding in limited habitat, is unknown. Hobbs (1947) recorded the presence of poorly conditioned shortfin male and females migrating eels which he referred to as "stockwhip eels" because of their thinness – he assumed these were survivors from an unsuccessful migration in previous years that had not regained condition – this has not been confirmed as such eels have not been recorded since.

Direction														
	Species	Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Inwards														
	Shortfin eel	Glass eel												
	Longfin eel	Glass eel												
	Black flounder	Juvenile												
	Sand flounder	Juvenile												
	Yellowbelly flounder	Juvenile												
	Common bully	Juvenile												
	Common smelt	Juvenile												
	Inanga	Juvenile												
	Yelloweye mullet	Juvenile												
	Brown trout	Adult												
Outwards	Shortfin eel	Adult male												
	Shortfin eel	Adult female												
	Longfin eel	Adult male												
	Longfin eel	Adult female												

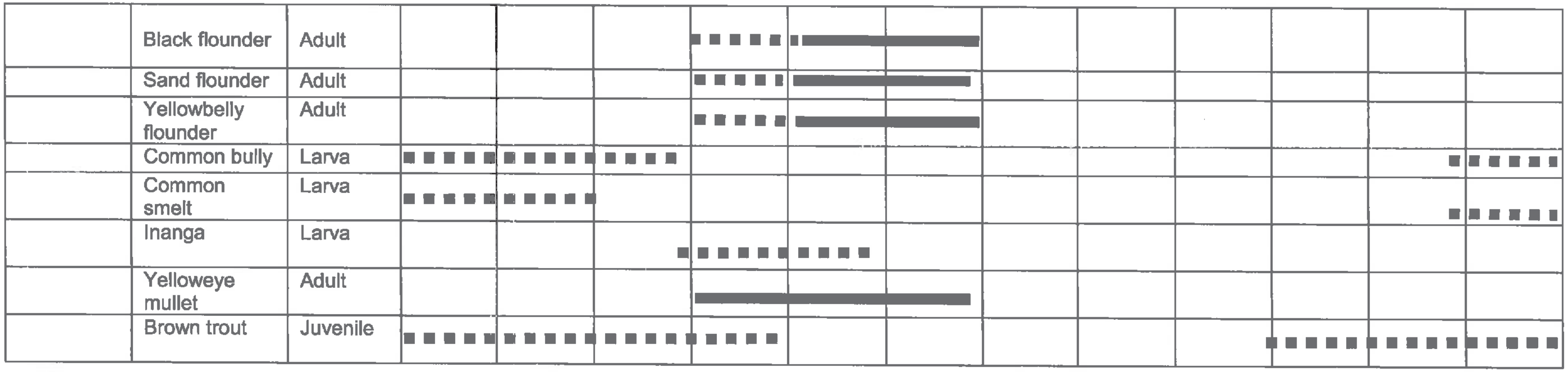

Figure 6-1: Calendar of fish movements in Te Waihora/Lake Ellesmere. Solid lines are periods of main movement, dashed lines periods of lesser movement.

Maturing flatfish have a long time window when they can leave the lake. As spawning generally occurs from July onwards, maturing fish can be expected to take opportunities from March, or possibly even February, through to June. Should the lake not be open at all during this period (which happens on average, about one year in four), then the flounders are forced to stay in the lake for up to a further year. These years result in larger than average flatfish in the lake, although whether the fish choose to stay in the lake for another complete year or take the earliest available opening to emigrate, is uncertain.

Mullet are another marine species with a reasonably long time window for movement in and out of the lake. Emigration of ripening adults (fish > 220 mm) will probably take place from April – June, although it is possible that immature fish will emigrate over a wider period. Recruitment of juvenile mullet will be mainly from December to February, but some recruitment could take place over a wider time period. Freshwater residence is not obligatory for mullet, and if the lake is not open, juveniles will congregate in the bays around Banks Peninsula, and river mouths/estuaries to the north and south.

A collation of 60 years of lake opening data (Figure 6-2) indicates that there is a high likelihood of opening during spring, especially August – as would be expected, there is a much lower likelihood of an opening during late summer – early autumn.

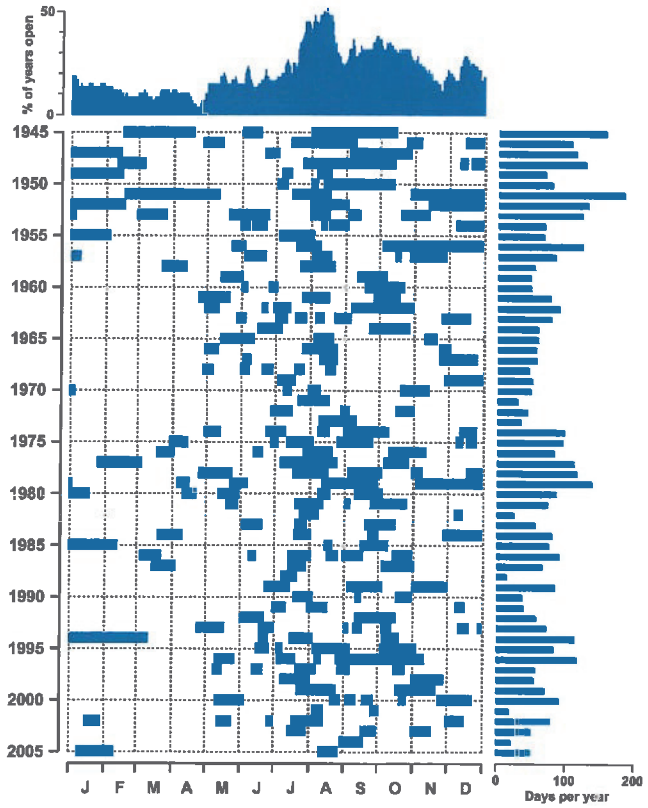

Figure 6-2: The history of lake openings 1945-2005. Horizontal bars indicate actual duration of openings per month, or total duration of openings (far right). The top graph shows the % of time the lake is open throughout the year.

6.3 Recommended opening regime to benefit fish stocks

Opening the lake to allow for fish immigration or emigration is only one of the suite of factors that need to be considered when establishing an optimal opening regime. For some factors, failure to open might be an inconvenience whereas for many fish species it is essential. The main species group affected are flounders, as loss of a year's recruitment means virtually no fishery in 2 or 3 years' time; for eels, the loss of a year's recruitment is less dramatic as shortfins spend an average of 12 years in the lake before they enter the commercial fishery, and loss of one cohort is undesirable but not of major importance – as growth rates vary between individuals, nil or low recruitment in one year is not detectable in the relative sizes of eels when they achieve minimum commercial size..

As there is some movement of fish going on at all months of the year, whatever opening regime is adopted will not be ideal for all species, and the best that can be hoped for is to provide maximum opportunities for recruitment and emigration of the key species i.e eels, flatfish and mullet. For the most abundant species, bullies and smelt, access to the sea is desirable but not imperative as they can carry out their life histories completely within the lake and tributaries.

An optimal regime for fish to immigrate and emigrate depends on whether the goal is to maximise conservation of stocks or yield from the fishery, as access to migrating shortfin males is very important to the commercial fishery – as indicated previously, these male eels can comprise as much as 90 % of the total TACC in a given year. To ensure access to these eels, the lake needs to remain closed from mid-February – mid-March. The remaining stages of eel migration (shortfin females, longfin males and females) are not harvested commercially, although there will be some customary harvest of shortfin females and an extended period of closure through March would benefit this fishery.

From a stock conservation perspective, the most important life history stage to protect is mature female eels, especially longfins. This species is on the threatened species list (Allibone et al. 2010), and has a generation time measured in decades. To ensure escapement of these females, an opening time of mid-April – mid-June is optimal. Given a choice between an "early" (April) or "late" opening (June) during this period, a late opening would be preferred as migrating eels will accumulate in the vicinity of Taumutu and await an opportunity to emigrate; thus a later opening accommodates both early and late arrivals.

The eel 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. Most glass eels will arrive in "waves" associated with spring tides, especially the spring tide of the new moon phase. To accommodate this, a preferred opening duration would be > 4 weeks as that would ensure at least one new moon spring tide (whereas 3 weeks would ensure a spring tide but not necessarily a new moon spring tide).

Maturing adult flounders will endeavour to go to sea to spawn from early summer (say February) through until June/July. However, unlike eels that have a stricter seasonal migration, flounders will take advantage of whatever opportunities are available during that time, although there is probably some preference for later (May - July) rather than earlier (February - March). For recruitment of flounders, there is likely to be considerable annual variability in recruitment time as it will be driven by spawning season, which will vary according to water temperature in the Canterbury Bight. Of the 3 species (black, sand and yellowbelly flounders), blacks arrive later than the other two species. While all three species are important to customary and commercial fisheries, usually blacks or yellowbellies are the dominant species. The preferred opening time for black flounders would be October – November, whereas the preferred time for yellowbellies and sand flounders would be August – September. To accommodate all three species, the most suitable opening time would be mid-August to mid-November. As a continuous opening over that period is unlikely, the next best option would be mid- August to mid- October (which would also be suitable for glass eels of both species). Within this timeframe, the most important period is from mid-September to mid- October – this would suit glass eels, be reasonable for yellowbelly and sand flounders, but not so good for black flounders.

Recruitment of juvenile mullet into Te Waihora/Lake Ellesmere will be from December – February, although 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 – June, although as fish are known to move in and out of estuaries on tidal cycle, it is possible that there is emigration of immature fish over a wider period.

Summary. From a conservation viewpoint, opening between mid-February to mid-June will cater for all migrating eels (species and sexes) and migrating adult flounders and mullet. However, this regime would disadvantage both customary and commercial harvesting of eels, and a more restricted regime would be beneficial for these interests i.e. opening from May to mid-June. For recruitment of juveniles, flounders have an extended season, but a reasonable compromise would be mid-August to mid-October. This timetable would also allow for glass eel recruitment, but not recruitment of mullet which will be mainly from December to February.

6.4 Optimal conditions associated with an opening regime

Taylor (1996) mentions that the conditions required for a successful opening to occur are an easterly wind, neap tides, calm seas, and a high lake level. From a fisheries perspective, a "successful" opening will be within the time windows mentioned above (section 5.3), and preferably be > 4 weeks duration to ensure at least one new moon spring tide, as these tides will be the main periods of recruitment for glass eels and probably juvenile flounders.

Juvenile fish are relatively weak swimmers. As previously indicated, the maximum sustained swimming speed of shortfin glass eels is only 0.3 m/s (Langdon and Collins 2000), whereas velocities of outflowing lake water can average > 2 m/s (Taylor 1996); detailed velocity measurements of cross sections of the outlet (Horrell 2008) also showed regions of high velocity (> 3 m/s) although bottom and edge velocities were slower (often < 1 m/s). However, these velocities are too great for juvenile fish to swim against, and juvenile fish attracted to the outlet will need to wait until velocities reduce before they are able to enter the lake. Therefore the duration of any opening needs to be long enough for the loss of hydraulic head to allow some flood-tide movement into the lake. The length of time for this to occur varies with the height of the lake (head), the width and scour depth of the opening, and heights of the tides, but would often be a week or more (G. Horrell, hydrologist, NIWA, pers. comm.).

Another important feature of an extended opening is the extent of the resulting freshwater plume, as this provides the odour cue for recruiting juvenile fish. A more prolonged opening will produce a larger plume, with consequent enhanced likelihood of attracting juvenile fish to the lake outlet.

In summary, from a fisheries viewpoint, a single prolonged opening is preferable to a number of shorter openings, but the timing of that opening is of considerable importance. It is to be hoped that future management of the lake opening regime will not be solely based on lake levels, but will include seasonal effects like fish recruitment.

7 Acknowledgements

I wish to thank Marty Bonnett, NIWA for access to unpublished data on bullies, and to Graeme Horrell for informative discussions about the mouth opening. Shannan Crow and Marty Bonnett provided helpful comments

8 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.

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.

Beentjes M.P.; Chisnall B.L. (1998). Size, age, and species composition of commercial eel catches from market sampling, 1996-97. NIWA Technical Report 29: 124.

Beentjes M.P.; Dunn A. (2008). Catch per unit effort (CPUE) analysis of the South Island commercial freshwater eel fishery, 1990-91 and 2005-06. Draft Fisheries Assessment Report 110 p.

Beentjes, M.P.; Dunn, A. (2010). CPUE analysis of North Island commercial eel fishing 1990/91 - 2006/07. New Zealand Fisheries Assessment Report 2010/5 100. p.

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

Boehlert, G.M.; Mundy, B.C.M. (1987). Recruitment dynamics of metamorphosing English sole, *Parophorys vetulus*, to Yaquina Bay, Oregon. *Estuarine Coastal and Shelf Science 25:* 261 - 281.

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.

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.

Ciccotti ,E.; Ricci, T.; Scardi M.; Fresi E.; Cataudella S. (1995). Intraseasonal characterization of glass eel migration in the River Tiber: space and time dynamics. *Journal of Fish Biology 47*: 248-255.

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

Coburn, R.P.; Beentjes, M.P. (2005). Abundance estimates for flatfish in FLA 1 from standardized catch per unit effort analysis of the set net fisheries, 1989-92 to 2003-04. New Zealand Fisheries Assessment Report 2005/57: 46.

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.

Creutzberg, F. (1961). On the orientation of migrating elvers (*Anguilla vulgaris* Turt.) in a tidal area. *Netherlands Journal of Sea Research 1*: 257-338.

Dijkstra, L.H.; Jellyman, D.J. (1999). Is the subspecies classification of the freshwater eels *Anguilla australis australis* Richardson and *A. a schmidtii* Phillipps still valid? *Marine and Freshwater Research 50*:261-263

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.

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

Fox, S.; Unwin, M.; Jellyman, D. (2003). The migration and growth of brown trout in the Rakaia River system. NIWA Client Report CHC2002-045. 35 pp. p.

Gascuel, D. (1986). Flow-carried and active swimming migration of the glass eel (*Anguilla anguilla*) in the tidal area of a small estuary on the French Atlantic coast. *Helgolander Meeresuntersuchungen 40*: 321-326.

Glova, G.J. (1996). Propsects for enhancement of the Lake Ellesmere trout fishery. *Water and Atmosphere 4*:

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

Glova G. J.; Todd P. R. (1989).: Submission to the Water Conservation Order for Lake Ellesmere 1989. Fisheries Research Division, Christchurch.

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.

Hayes J.W.; Rutledge M.J. (1991). Relationship between turbidity and fish diets in Lakes Waahi and Whangape. *New Zealand Journal of Marine and Freshwater Research 25:* 297-304.

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

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.

Horrell, G. (2008). Lake Ellesmere (Te Waihora) seawater inflows: June - July 2008. NIWA Client Report CHC2008-131. 47 p.

Hughes, H.R.; McColl, R.H.S.; Rawlence D.J. (1974). Lake Ellesmere. A review of the lake and its catchment. New Zealand Department of Scientific and Industrial Research. 27 p.

Hughey, K.F.D.; Taylor K.J. W. (Eds.). (2009): Te Waihora/Lake Ellesmere: state of the lake and future management. EOS Ecology, Christchurch 150 pp.

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

Jellyman, D.J. (1977b). Invasion of a New Zealand freshwater stream by glass-eels of two *Anguilla* spp. *New Zealand Journal of Marine and Freshwater Research 11*: 193-209.

Jellyman, D.J. (1979). Upstream migration of glass-eels (*Anguilla* spp.) in the Waikato River. *New Zealand Journal of Marine and Freshwater Research 13*: 13-22.

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. (1991). Factors affecting the activity of two species of eel (*Anguilla* spp.) in a small New Zealand lake. *Journal of Fish Biology 39*: 7-14.

Jellyman D.J. (1992). Lake Ellesmere - an important fishery with an uncertain future. *Freshwater Catch 48*: 3-5.

Jellyman, D.J. (1997). Variability in growth rates of freshwater eels (*Anguilla* spp.) in New Zealand. *Ecology of Freshwater Fish 6:* 108-115.

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. (2003). The distribution and biology of the South Pacific species of Anguilla. In: Aida K, Tsukamoto K, Yamauchi K ed. Eel Biology. Tokyo, Springer. Pp. 275-292.

Jellyman, D. (2011). Survey of the tuna in customary areas of ANG14. Research Report, Ministry of Fisheries. 55 p.

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.; 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.; 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.; Ryan, C.M. (1983). Seasonal migration of elvers (*Anguilla* spp.) into Lake Pounui, New Zealand, 1974-1978. *New Zealand Journal of Marine and Freshwater Research 17*: 1-15.

Jellyman, D.J.; Chisnall, B.L.; Bonnett, M.L.; Sykes, J.R.E. (1999). Seasonal arrival patterns of juvenile freshwater eels (*Anguilla* spp.) in New Zealand. *New Zealand Journal of Marine and Freshwater Research 33:* 249-262.

Jellyman, D.J.; Bowen, M. (2009). Modelling larval migration routes and spawning areas of Anguillid eels of New Zealand and Australia. American Fisheries Society Symposium 69. 255–274.

Jellyman, D.J.; Cranwell, I. (2005). The status of eel stocks in Wairewa (Lake Forsyth). Final Research Report for Ministry of Fisheries Research Project EEL 2004-03. 38 p.

Jellyman, D.; 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. Pp. 41-48. *In*: Hughey, K.F.D.'; Taylor, K.J.W. (Eds.). Te Waihora/Lake Ellesmere – the 2007 State of the Lake and Management Futures Report.

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.; Tsukamoto, K. (2005). Swimming depths of offshore migrating longfin eels, *Anguilla dieffenbachii. Marine Ecology Progress Series 286*: 261-267.

Jellyman, D.J.; Tsukamoto, K. (2010). Vertical migrations may control maturation in migrating female *Anguilla dieffenbachii. Marine Ecology Progress Series 404*: 241 – 247.

Jellyman, D.J.; Booker, D.J.; Watene, E. (2009). Recruitment of glass eels (*Anguilla* spp.) in the Waikato River, New Zealand. Evidence of declining migrations? *Journal of Fish Biology 74:* 2014 – 2033.

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.

Jellyman, D.J.; Unwin, M.J.; James, G.D. (2003b). Anglers' perceptions of the status of New Zealand lowland rivers and their trout fisheries. NIWA Technical Report 122. 61 p.

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.; Bonnett, M.L.; Sykes, J.R.E.; Johnstone, P. (2003a). Contrasting use of daytime habitat by two species of freshwater eel *Anguilla* spp. in New Zealand rivers. *American Fisheries Society Symposium 33*. 63-78

Jellyman, D.; Walsh, J.; de Winton, M.; Sutherland, D. (2009b). A review of the potential to re-establish macrophyte beds in Te Waihora (Lake Ellesmere). NIWA Client Report CHC2008-142.49 p

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.

Langdon, S.A.; Collins, A.L. (2000). Quantification of the maximal swimming performance of Australasian glass eels, *Anguilla australis* and *Anguilla reinhardtii*, using a hydraulic flume swimming chamber. *New Zealand Journal of Marine and Freshwater Research 34*: 629-636

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

McCleave, J.D.; Jellyman, D.J. (2002). Discrimination of New Zealand stream waters by glass eels of *Anguilla australis* and *Anguilla dieffenbachii. Journal of Fish Biology 61*: 785-800.

McCleave, J.D.; Kleckner, R.C. (1982). Selective tidal stream transport in the estuarine migration of glass eels of the American eel (*Anguilla rostrata). Journal du Conseil International pour L'exploration de la Mer 40*: 262-271.

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. (1994). Gamekeepers for the nation. The story of New Zealand's Acclimatisation Societies 1861-1990. Christchurch, New Zealand, Canterbury University Press. 508 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.

Martin, M.; Boubee, J.; 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.

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.

Millichamp, R. (2008). Brown trout fishery. Pp 49 – 56. *In*: Hughey, K.F.D. and Taylor, K.J.W. (eds.). Te Waihora/Lake Ellesmere – the 2007 State of the Lake and Management Futures Report.

Ministry of Fisheries (2007). Report from the Fishery Assessment Plenary, May 2007: stock assessments and yield estimates. Ministry of Fisheries, Wellington, New Zealand. 1015 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.

Northcote T. G. (1988): Merisitic variation in the New Zealand smelt, *Retropinna retropinna* (Richardson): new questions for an old problem. *Verhandlugen*

Internationale Vereingung fur Theoretische und Angewandte Limnologie 23: 1797 - 1804.

Northcote T.G.; Ward F.J. (1985). Lake resident and migratory smelts *Retropinna retropinna* (Richardson), of the lower Waikato River system. *New Zealand Journal of Marine and Freshwater Research 17*: 113 - 129.

O'Connell, D. (1996). Nature and extent of Te Waihora customary eel fishery. Report of Te Taumutu Runanga and Te Waihora Eel Management Committee. 43 p.

Painter B.D.M. (2009). Sustainable water allocation for families, fish and farming: a wicked problem or a wicked solution? Proceedings of the 53rd Annual Meeting of the ISSS. July 12-17, 2009. University of Queensland, Brisbane, Australia. 20 p.

Painter, B.D.M. (2011). Analysis of linkages between climate, hydrology and a brown trout (*Salmo trutta*) fishery: a case study on the Selwyn River. unpublished manuscript 31 p.

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

Percival, E. (1958). Report on examination of the brown trout spawning run in the Selwyn River, 1958. North Canterbury Acclimatisation Society Annual Report 94: 18 - 20.

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.

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

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.

Rowe D. K.; Dean T. L. (1998). Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. *New Zealand Journal of Marine and Freshwater Research 32*: 21-29.

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

Rowe D.; Graynoth E.; James G.; Taylor M.; Hawke L. (2003): Influence of turbidity and fluctuating water levels on the abundance and depth distribution of small, benthic fish in New Zealand alpine lakes *Ecology of Freshwater Fish 12*: 216-227.

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.

Sagar, P.; Hawes, I.; Stephens, S.; Jellyman, D.; 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.

Schwarz, J.N.; Pinkerton, M.H.; Wood, S.; Zeldis, J. (2008). Remote sensing of river plumes in the Canterbury Bight : Stage I report. NIWA Client Report CHC2008-169. 68 p.

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

Sorensen, P.W.; Bianchini, M.L. (1986). Environmental correlates of the freshwater migration of elvers of the American eel in a Rhode Island brook. *Transactions of the American Fisheries Society 115:* 258-268.

South Island Eel Industry Association (2009). Eel Fishery Plan for the South Island. 63 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

Taylor, M.J.; Good, M. (2006). Brown trout spawning in the Lake Ellesmere (Te Waihora) tributaries, and some surrounding catchments. Aquatic Ecology Limited Report No. U06/79. 125 p.

Tesch, F. W. (2003) The eel, Vol. Blackwell Science Ltd, Oxford

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.

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.