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Catch per unit effort (CPUE) analyses and characterisation of Te Waihora commercial freshwater eel fishery, 1990–91 to 2011–12

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This report presents a fishery characterisation for ESA areas in the Te Waihora commercial freshwater eel fishery (*Anguilla australis*, shortfin; *A. dieffenbachii*, longfin) from 1991 to 2012, and a standardised CPUE analysis for shortfin in ESA AS1 (lake fishery) from 2001 to 2012. Temporal trends in the size composition of the commercial catch are also described.

All areas (AS1, AS2, ESA21) 1991 to 2012

The total estimated catch composition from 1991 to 2012 was 99% shortfin and 1% longfin. Longfin were caught in AS2 (migration area), but the proportion of the catch was very low (0.03%). Since 2001 when ESA 21 was split into AS1 and AS2, shortfin catch in AS1 was 1.5 times greater than in AS2, and for longfin it was 56 times greater. The annual proportion of the total eel catch taken in each of AS1 and AS2 varied among years and, with the exception of 2008 and 2009, the proportion contributed by AS2 increased after 2005 to the extent that in the last three years it has provided half or more of the Te Waihora catch.

AS1 (lake fishery) 2001 to 2012

The estimated catch and the landed catch are a close match for all years, with the exception of 2002 to 2004 when the landed catch was higher, and 2010 when the landed catch was lower. We conclude that there are missing data records from 2002 to 2004, and assume that the data incorporated into our analyses are representative of the fishery for those years.

The AS1 catch was 99% shortfin and has varied between about 45 t and 90 t per year with no trend. Longfin contributed 1% of the total estimated eel catch in AS1, and this species was caught in all years with annual catch ranging from 168 kg to 1675 kg. Since about 2007 most longfins have been released in this fishery.

The median number of lifts per day in AS1 has declined throughout the time series from about 20 nets per day in 2001 to 5 nets per day in 2012.

Annual unstandardised catch rates (total catch per lift) for shortfin in AS1 increased steeply from 2001 to 2012 from about 5 kg per day to 170 kg per lift. Standardised CPUE analyses were carried out on core fishers' estimated catch for shortfin from AS1 from 2001 to 2012 using a stepwise Generalised Linear Model (GLM) ignoring zero catches, where the response variable was daily catch. The standardised CPUE for shortfin catch followed the same general pattern as unstandardised catch per lift with a progressive increase over time, however, the increase in standardised CPUE was flatter in the last two years. This divergence is driven by the low number of nets used in 2011 and 2012 compared to previous years. The variables lifts, permit, and month were sequentially included in the GLM in that order and explained 49% of the variation in CPUE with lifts explaining most (45%) of the variability. A sensitivity analysis was carried out where lifts was not offered to the model and the indices were compared to the base case model which included lifts. The CPUE indices show similar trends until 2007 after which the base model increases steeply compared to the sensitivity model which flattens out.

Shortfin eels in Te Waihora are known to increase growth rate when they switch from diets of invertebrates to fish at around 200 g. Incremental increases in the MLS from 140 g to 220 g during the period 1994 to 2002 would have resulted in increased yield per recruit, providing a plausible explanation for the increase and subsequent levelling off of abundance. Analyses of eel size in the lake in the 1990s compared to that in recent years demonstrates that the size of commercially harvested eels has substantially increased over time, supporting the notion of an improved yield per recruit. Patterns

in recruitment are also likely to influence trends in the abundance of the exploited population in the lake.

The lake has experienced enhanced nutrient loading from the growing number of dairy farms surrounding the lake, which may have resulted in increases in both invertebrate and bully populations. Nutrient loading may therefore have increased the carrying capacity of Te Waihora for shortfin eels.

1. INTRODUCTION

This report presents the results of a characterisation of the freshwater commercial eel fishery (shortfin, *Anguilla australis* ; longfin *A. dieffenbachii*) in Te Waihora, Canterbury, from 1990–91 to 2011–12. A catch-per-unit-effort analysis (CPUE) for shortfin eels for the Te Waihora lake fishery (eel statistical area AS1) is also presented for the fishing years 2000–01 to 2011–12, which updates previous analyses (Beentjes & Bull 2002, Beentjes & Dunn 2008, 2013). Temporal trends in the size composition of the commercial catch are also described.

1.1 Commercial freshwater eel fishery

The commercial freshwater eel fishery in New Zealand developed in the late 1960s and landings consist of both the endemic longfin eel and the shortfin eel which is also found in southeast Australia. Landings from the north of the North Island can include the occasional Australian longfin eel (*A. reinhardtii*).

Historical commercial catches

Total New Zealand eel commercial catches peaked in 1972 at about 2100 t and from 1972 to 1999 catch fluctuated somewhat, but there was no clear trend with an annual average catch of about 1300 t. Since 1999, however, New Zealand catches progressively declined to a low of 520 t in 2008–09 before increasing again over the last three years to 752 t in 2011–12 (Ministry for Primary Industries 2013).

In the South Island there is little difference between longfin and shortfin catch until 2003, but over the last 10 years shortfin landings exceeded those of longfin (Figure 1). Both South Island shortfin and longfin catches declined after about 1993–94, although the decline has been most marked for longfin. Over the past ten years shortfin catch has been remarkably stable whereas longfin catch has been variable (Figure 1). The trends of declining catches preceded the introduction of eels into the Quota Management System (QMS), and could have been a result of permit restrictions, and fishers retiring.

Distribution of South Island catch

Although total South Island landings for shortfin and longfin are of similar magnitude, longfin is the dominant species in the south and west of the South Island (i.e., Waitaki AU, Otago AV, Southland AW, and the west coast AX) (Beentjes & Dunn 2008, Beentjes 2013, Beentjes & Dunn 2013). About three quarters of the South Island shortfin landings are from Te Waihora and Lake Brunner, with the remainder from coastal lakes, lower river reaches, and estuaries (Beentjes & Chisnall 1997, 1998, Beentjes 1999, 2004, 2013). In 2010–11 and 2011–12 Te Waihora accounted for 68% and 66% of the South Island shortfin catch, respectively (Beentjes 2013). The longfin catch from Te Waihora historically has been about 1% of the total landed eel catch, but in recent years fishers have been returning legal sized longfin to the water and hence landings in 2011 and 2012 were nil (Beentjes 2013).

1.2 Ecology and fisheries of Te Waihora

Te Waihora is a shallow (maximum depth 2 m), brackish coastal lake just south of Banks Peninsula, separated from the coast by Kaitorete Spit, a narrow 25 km long gravel bank (Figure 2). The lake area is about 20 000 ha with 75 km of shoreline. The lake itself is about half the size of pre-European times when it was surrounded by extensive wetlands and forest. Freshwater input is from run-off from surrounding farmland, many small streams, springs, and the Selwyn and Halswell Rivers. The lake is often closed to the sea by a gravel bar that forms across the mouth opening by wave action of coastal storms. When water levels rise above a specified level (over 1.1 m) or provisions need to be made for fish recruitment, Environment Canterbury employs a mechanical digger to open a channel at Taumutu (southern end) to allow the lake water levels to fall — this has occurred between one and six times per year since 1945. This also allows inward flow of ocean water at high tide, presumably facilitating recruitment of eels and fish species into the lake and migration out of the lake. The lake is defined as eutrophic and receives a high nutrient and sediment load from the surrounding farmland, which has been amplified by the loss of wetlands. The strong winds and shallow nature of the lake facilitate oxygenation of the water and prevent toxic algal blooms. The lake has two main commercial fisheries, tuna (freshwater eels) and flatfish. The flatfish species in the lake include black flounder, yellowbelly flounder, and sand flounder. The lake eel fishers switch to setnetting for flatfish in the winter months when eels are not vulnerable to capture. Black flounder have a limited distribution and tend to be confined to brackish estuaries. Te Waihora is ideally suited to black flounder and is the largest fishery in New Zealand for this species, while the other two flounder species are found coastally and within estuaries throughout New Zealand. Te Waihora is regarded as an important site for mahinga kai by local runanga, particularly tuna (eels). It is also an important recreational fishery for flatfish, trout, perch, and whitebait. The lake is well known for its diverse range of bird species and wildlife reserves.

1.3 Management of Te Waihora commercial eel fishery

The commercial eel fishery of Te Waihora was managed as a Controlled Fishery from 1978, originally with 18 license holders reducing to 11 by the early 1990s. A total allowable catch, originally set at 256 t, was progressively reduced to 136.5 t by the mid-1980s. Licences were renewable each year and quota allocations ranged from 8 to 21 t.

A minimum legal size (MLS) of 140 g was introduced to Te Waihora in 1994, increasing by 10 g per year until 2002 when it reached 220 g, the national MLS. Sorting of legal sized eels was accomplished primarily by using a grading box, but also through incremental escape tube changes, although this is not well documented. In October 1996 the mandatory escape tube diameter in the South Island changed from 25 mm to 28 mm and in October 2001 this was increased to 31 mm. In reality the South Island fishers had been using a 31 mm escape tube since about 1997–98 on a voluntary basis with the aim of increasing the average size of eels caught from 220 g to about 300 g. Discussions with fishers suggest that this was also adopted in Te Waihora (pers. comm. Clem Smith, Te Waihora commercial eel fisher).

In 1995–96 a concession area was introduced to allow fishers to take undersized migrating male shortfins during the months of February and March each year. This concession area, measuring only a few hectares, is near the lake entrance where migrating eels congregate before leaving the lake to spawn at sea (Figure 2). Catches from this area were not distinguished from those caught elsewhere in the lake until 2001 when specific area codes were introduced for the migration area (AS2) and the lake excluding the migration area (AS1). There is no accurate way to identify catches that were from AS1 or AS2 before 2001. Fishers wishing to fish the migration area apply annually to MPI for a concession and they generally fish either AS1 or AS2 during February and March.

The South Island eel fishery, including Te Waihora, was introduced into the Quota Management System (QMS) in 2000–01, with five Quota Management Areas (ANG 11 to ANG 16) and Total Allowable Commercial Catches (TACC) set for both species combined (Figure 3). TACCs have been consistently under caught in all South Island QMAs with the exception of Te Waihora (ANG 13), where the 122 t TACC was caught or exceeded in most years (Figure 4). ANG 13 includes the Halswell and Selwyn River catchments, but these are not fished. Prior to the introduction of Te Waihora eels into the QMS in 2000–01 there were about 11 permit holders landing catch from the lake. After the introduction of eels into the QMS this dropped to about seven permit holders and in more recent years only five permit holders have been actively fishing. These active permit holders are either catching the Annual Catch Entitlement (ACE) for other permit holders or they may have aggregated quota. Distinct from the rest of the country, the fishing year in ANG 13 begins on 1 February and runs to 31 January and was implemented in 2002.

Te Waihora fishers have progressively moved from small standard fyke nets of the type used throughout the South Island for targeting shortfin, to using fewer and larger fyke nets. The transition to larger nets was complete by the late 1990s (i.e., before introduction to the QMS). In the migration area the leaders are short but elsewhere in the lake, long leaders are used to guide shortfin eels into the fyke net chambers. Shortfin fyke nets are unbaited whereas longfin net are baited and tend to have short leaders. Longfins are not targeted in Te Waihora.

1.4 Reporting of catches

The introduction of the Catch Effort Landing Return (CELR) in October 1989 replaced the Fisheries Statistics Unit (FSU) eel returns. Data quality for the first two years of the CELR system was poor (Jellyman 1993), and the data for 1989–90 were deemed unsuitable for inclusion in these analyses. The CELR form was in turn replaced by an Eel Catch Effort Return (ECER) and an Eel Catch Landing Return (ECLR) on 1 October 2001. Changes included dedicated fields for shortfin and longfin estimated catch (i.e., no provision to include EEU unidentified), a field for the name of the catcher (i.e., fisher ID), and the removal of the target species field. The reporting of EEU was prohibited by MPI in about 2000, pre-dating the introduction of the ECER by two years. Before 2000, EEU was commonly used, particularly in the North Island where the proportion of total eel catch recorded as EEU was as much as 83% of the eel catch in ESA AD (Waikato), however it has never been used in Te Waihora. When landing the catch to the Licensed Fish Receiver (LFR) the fisher completes the ECLR (Eel Catch Landing Returns) on which catch is entered by fish stock; for the North Island this is SFE 20–23 and LFE 20–23, and the South Island SFE 11–16 and LFE 11–16. Note that for eels caught in the South Island, the ANG codes are not used on the ECLRs, but are used on Monthly Harvest Returns (MHR).

Since about 2000, longfin eels caught in Te Waihora have been returned alive to the water (Clem Smith, Te Waihora commercial eel fisher, pers. comm.). Any eels of legal size that are returned to the water are required to be recorded as estimated catch on both the ECERs and on ECLRs, and recorded in the destination field as 'X' on the latter form (i.e., for all legal size eels (220 g to 4000 g) that are likely to survive and returned to the water, if listed under Schedule 6 of the Fisheries Act 1996). Destination 'X' has only been used by Te Waihora eel fishers since 2008 because it was not listed as a destination type option on explanatory notes for completing ECERs and ECLRs when these forms were introduced in 2001–02. Te Waihora fishers, have used destination 'A' (Fish of a species that is part of the Quota Management System returned to or lost in the water) as an alternative destination code for destination 'X', but it appears that destination 'X 'is now being used as intended. MPI have recently (September 2013) advised all active fishers by correspondence of the correct reporting procedures for dealing with released fish, and the explanatory notes on ECERs and ECLRs are to be revised at the next re-print of these books.

1.5 Previous Te Waihora shortfin catch effort analyses

The migration area (concession area) was introduced in 1995–96 to allow fishers to harvest undersized migrating male shortfin eels during the months of February and March each year. However, catches for this area were not distinguished from those caught elsewhere in the lake until 2000–01 when specific area codes were introduced for the migration area (AS2) and the lake excluding the migration area (AS1). The most recent CPUE analyses for Te Waihora up to 2009–10, as instructed by the Eel Fishery Assessment Working Group, were carried out only for AS1 from 2000–01 onward, and only for shortfin eels which make up more 99% of the catch (Beentjes & Dunn 2008). Analyses were not carried out for AS2 (migration area) because of the seasonal nature of this fishery and the Eel Fishery Assessment Working Group considered that any indices would be unreliable because of the variable timing around migration. Before 2000–01 there was no accurate way to identify catches that were from AS1 or AS2, hence the previous analyses (Beentjes & Bull 2002, Beentjes & Dunn 2008) which attempted to separate catches from AS1 and AS2 on the basis of when eels were caught, are not considered to have enough spatial accuracy to generate reliable results for these two areas.

The previous shortfin AS1 analyses from 2001–02 to 2009–10 showed a steep increase in standardised CPUE from 2002 to 2007 after which it was generally flat, with indications of a declining trend emerging over the last three years (Beentjes & Dunn 2008).

1.6 Data in these analyses

The data presented in this report are from 1990–91 to 2011–12 for the fishery characterisation and from 2001–02 to 2011–12 for the CPUE analyses. The data are from two sources: catch effort landing returns (CELR) (1990–91 to 2000–01) and eel catch effort returns (ECER) 2001–02 to 2011–12.

Statistical areas for reporting catch effort data were changed from numeric codes (1–23) to alpha codes (AA–AZ) in July 2000 (Table 1). In Te Waihora ESA 21 changed to AS1 and AS2. Table 1 provides a useful key for relating ESAs (numeric and alpha), QMAs, and area names.

1.7 Specific objective

Update CPUE analyses for Te Waihora with 2010-11 and 2011-12 fishing years.

2. METHODS

2.1 Catch effort data extraction

Estimates of catch and effort for each day's fishing were recorded on CELR forms up to 30 September 2001, and then on ECERs after this time, although there was a transition period in early 2001–02 when either form was accepted. The catch effort data used in this report were extracted from the Ministry for Primary Industries Catch Effort Database *Warehou*, and for each daily record from 1 October to 30 September 1990–91 to 2011–12 for ESA 21, and AS1 and AS2, although in Te Waihora the fishing year is from 1 February to 31 January. The following variables were extracted:

CELR (2000–01 to 2001–02)
- Date nets were lifted
- Permit number (encoded)
- Vessel registration number
- Location landed
- Method
- Form number
- Eel statistical area (ESA)
- Number of net lifts
- Nets in the water at midnight
- Target species
- Total weight (weight of shortfin, SFE; longfin, LFE; unidentified, EEU; and bycatch)
- Weight of individual species (includes SFE, LFE, EEU, and bycatch species)

ECER (2001–02 to 2011–12)
- Date nets were lifted
- Permit number (encrypted*)
- Method
- Eel statistical area (ESA)
- Number of net lifts
- Estimated catch weight of shortfin (SFE)
- Estimated catch weight of longfin (LFE)

*the encrypted permit number represents the Ministry of Fisheries *Permit Holder FIN Number* (CELR) and *Client Number of Permit Holder* (ECER). A permit holder is entitled to employ others to fish on their permit, and hence one permit number may have catch landed from more than one fisher. It is more usual, however, for the permit holder to also be the person listed as the catcher on ECERs. The catcher has only been recorded since 2001–02 when ECERs were introduced.

In the current analyses we extracted data for the years 2001–02 to 2011–12 (eleven years) from ECER forms and appended these to the existing groomed data set for 1990–91 to 2000–01 from the CELRs used from the previous analyses, creating a time series from 1990–91 to 2011–12 (22 years) (Table 2). The data are combined and analysed by the standard fishing year (1 October to 30 September) and not by the Te Waihora fishing year (1 February to 31 January). The CELR catch effort data were error checked and groomed using the criteria of Beentjes & Willsman (2000) with very few errors found and these were corrected where possible, or the record was deleted. For the ECER data there were no deletions required and all data were retained.

In this report, henceforth, fishing years are referred to by the second year, e.g., 2000–01 is referred to as 2001 (i.e, 1 October 2000 to 30 September 2001).

2.2 Environmental variables

Moon phase was included as a possible explanatory term to account for changes in catchability with changes in the lunar cycle. The relative phase (0–1) of the moon (moon cycle) was determined for each record in the data set based on the date of each record, using an algorithm from Meeuse (1998). Moon phase was included as predictor variables because it has been shown to affect eel catch rates (Beentjes & Dunn 2008, 2010).

2.2.1 Landings data

To compare estimated catch from ECERs with landed catch, landings data were extracted from ECLRs for the period overlapping the CPUE time series (2001 to 2012). These catches were also compared with those reported in Quota Management Returns (QMR, up to 2001) and Monthly Harvest Returns (MHR, 2002 onward).

2.3 Characterisation of the fishery

For the entire time series (1991 to 2012), data are presented graphically on catches by year, species, season, and management area (ESA21, AS1, AS2), followed by daily catch and effort. The data were then restricted to AS1 from 2001 to 2012 corresponding to the CPUE data set, and a second characterisation was carried out.

2.4 CPUE analysis

2.4.1 Unstandardised CPUE analyses

Unstandardised CPUE analyses (catch per day) were carried out for the full data set (1991 to 2012) for SFE and LFE separately. For AS1 unstandardised CPUE analyses (shortfin catch per lift) were carried out from 2001 to 2012 for shortfin only and this is plotted alongside the standardised CPUE indices.

2.4.2 Standardised CPUE analyses

Core fishers

Standardised CPUE analyses were conducted for AS1 from 2001 to 2012 for SFE only. A selection criterion was applied to each dataset restricting data analysis to core fishers (identified by permit number) whose catch and effort data are more representative of the commercial fishery. Shortfin core fishers were defined as those that caught shortfin eels in at least three years, in each of which fishing took place in 10 days or more, and caught more than 1000 kg over all years.

The GLM model

Estimates of year effects and associated standard errors were obtained using a forward stepwise Generalised Linear Model (GLM) (McCullagh & Nelder 1989), with daily shortfin catch modelled as the response variable. Using daily catch as the response variable and number of lifts as a possible predictor allows the model to consider non-linear relationships between catch and effort.

The GLM model used the log-normal transformation of positive daily catch. There were very few zero records and these were not included in the analyses. This implies a multiplicative model, i.e., the combined effect of two predictors is the product of their individual effects. The predictor variables used in the model were fishing year, permit number (fisher), number of lifts, month (season), and moon phase. Variables were treated as categorical, except number of lifts, and moon phase, which were entered as continuous variables. Continuous variables were typically fitted as a 3-degree polynomial, with the number of lifts fitted as a 3-degree polynomial in log space.

A stepwise regression procedure was used to fit the GLM of CPUE (daily catch) on these predictor variables. The relative year effect from the model was then interpreted as the CPUE index, and presented using the canonical form, scaled to have a mean of 1.0. Model fits were investigated using standard residual diagnostics. Plots of model residuals and fitted values were investigated for evidence of departure from model assumptions. Influence step plots and coefficient-distribution-influence plots (CDI), were used to interpret the standardisation effects of explanatory variables (Bentley et al. 2012).

The stepwise fitting method began with a basic model in which the only predictor was the year, and iteratively included predictors until there was insufficient improvement in the model. For all analyses, the improvement in the residual deviance, i.e., (new deviance – old deviance) / (saturated deviance – null deviance), and termed R^2 was used as the criterion for including predictors. At each step, the predictor with the greatest improvement in R^2 was included, providing that its inclusion resulted in an improvement in R^2 of at least 0.5%.

The inclusion of first order interaction terms was considered, but it was found that they generally required many additional degrees of freedom and often appeared to have a spurious significance. Interactions tended to be between permit number (typically the most important predictor) and the other variables. These interactions appeared to be a reflection of variability in predictor variables among fishers rather than relative changes in the CPUE index.

Previous analyses of Te Waihora did not offer number of lifts as a predictor variable to the model because the number of net lifts per set declined markedly from 1991 onward as fishers progressively reduced deployment of large numbers of small fyke nets in favour of fewer larger nets (Clem Smith, Te Waihora commercial fisher, pers. comm.) (Beentjes & Bull 2002, Beentjes & Dunn 2008). Without a means to describe or quantify the change in net design it was considered that the effort variable (lifts) would have introduced bias into the resulting CPUE indices. The Eel Stock Assessment Working Group (EELWG-2013-29) recommended that lifts be included in the model this time and compared to the index where it was excluded. The reason for including number of lifts was that the transition to larger nets had occurred prior to 2001 (i.e., when the CPUE index begins) and there is a declining trend in numbers of lifts from 2006, suggesting fishers could maintain daily catches with fewer nets. Hence, the base model and diagnostics includes number of lifts, and a sensitivity analysis was carried out where lifts was not offered to the model. The indices for these two models are plotted on the same figure and are scaled to the mean of the overlapping period. Normally we scale to a mean of 1 to see how it moves above and below this mean.

2.5 Temporal trends in eel size composition

To inform interpretation of trends in CPUE, length and weight data collected in the mid-1990s from MPI funded commercial catch sampling of Te Waihora eels, are compared to recent size grade data collected from the MPI 'monitoring commercial eel fisheries' programme.

Catch sampling

Te Waihora commercial eel landings were sampled from 1995–96 to 1997–98 from four discrete strata (Beentjes & Chisnall 1997, 1998, Beentjes 1999) (Figure 5). Individual length and sub-sampled weight were measured for each species from a sub-sample of the landed catch at Mossburn Enterprises Ltd (Invercargill). Using only shortfin data from strata 1–3 (i.e., excluding stratum 4, the concession area), length was converted to weight using the length weight relationship coefficients for each stratum and year of sampling. For the three combined strata for each year, the individual weight data were converted into proportion of catch by weight grades, equivalent to that used by processors in 2010–11 and 2011–12 (see below).

Size grade data

The 'Monitoring commercial eel fisheries' programme collects data from processors on shortfin and longfin catch within discrete size grades and by fine scale location from all New Zealand eels landings. For Te Waihora, these data are available for 2010–11 and 2011–12 (Beentjes 2013). All shortfin eels caught in the lake fishery (AS1) of Te Waihora in 2010–11 and 2011–12 were landed into two processors: Mossburn Enterprises Ltd (MEL, Invercargill) and Levin Eel Trading Ltd (LET, Levin). They each use specific size grade categories when grading the eels in their factories with MEL using two grades and LET three grades (300–800 g, over 800 g; 300–650 g, 650–1000g, over 1000 g, respectively).

The converted proportion of catch by size grade from the mid 1990s catch sampling was compared with the equivalent proportion of catch by size grade collected in 2009–10 to 2011–12 from the commercial eel monitoring programme to look for any changes that may have occurred.

3. RESULTS

3.1 Descriptive analyses

3.1.1 Estimated catch versus landed catch

A comparison of total groomed estimated eel catch for Te Waihora from 1991 to 2012 extracted from CELRs/ECERs with the reported landings from 2001 to 2012 from ECLRs, QMRs and MHRs, are shown in Figure 4. The estimated catch and the landed catch from ECLRs (including catch recorded as destination 'X' and destination 'A') are a close match for all years with the exception of 2002 to 2004 which were less than the landed catch, and 2010 which was greater than the landed catch. The discrepancy in 2002 to 2004 is not explicable in terms of data grooming because no data were deleted during the grooming process. Discussions with the key eel fisher also provided no explanation for the shortfall in estimated catch (Clem Smith, Te Waihora eel fisher, pers. comm.). The reason for the difference in 2010 is also unclear, but one possible explanation would be that there had been catch of legal sized eels released alive and recorded on ECERs, but not on ECLRs under destination 'X'.

The landed catch recorded from QMR (2001) and MHRs (2002–2012) generally agrees well with that from ECLRs until 2009 onward when it varies in some years. Landed catches for MHRs can be expected to be lower than those from ECLRs when the latter include the estimated catches recorded in destinations 'X' and 'A'.

3.1.2 Fishery characterisation

The relative amounts of estimated catch reported as shortfin, longfin, in each of the three Te Waihora ESAs by year are shown in Table 3. Species eel catch by year is plotted in Figure 6, and total eel catch by area and year is plotted in Figure 7. Overall, the total recorded catch from 1990–91 to 2011–12 was 99% shortfin and 1% longfin (Table 3, Figure 6). Longfin are caught in AS2 (migration area), but the proportion of the catch is very low (0.03%) (Figure 7). Since 2001 when ESA21 was split into AS1 and AS2, shortfin catch in AS1 is 1.5 times greater than in AS2, and for longfin it is 56 times greater (Table 3).

The relative contribution of eel catch by AS1 and AS2 varies among years and, with the exception of 2008 and 2009, the proportion contributed by AS2 increased after 2005 to the extent that in the last three years it has provided half or more of the Te Waihora catch (Figure 7). The low proportions of catch in AS2 in 2008 and 2009 relates to negotiations between Ngai Tahu and the crown regarding lake ownership during which access to AS2 was limited (Clem Smith, Te Waihora commercial eel fisher, pers. comm.).

The Te Waihora shortfin eel fishery from 1991 to 2012 for all ESAs combined shows strong seasonal variability with few catches between April and September and the largest catches in February and March (Figure 8). The AS1 fishery from 2001 shows a similar pattern, whereas the AS2 fishery is restricted to February and March. Longfin catches show a similar pattern to shortfin except there are catches in April and in AS2 catch has only been for the last few years (Figure 9).

All areas (1991 to 2012)

The number of lifts ranges between a few to over 200 per day (mean 22), but most often between 10 to 15 lifts per day have been reported (Appendix A1), with the median number of lifts per day declining throughout the time series from about 40 nets per day in 1991 to 5 nets per day in 2012 (Appendix A2).

There were very few zero records for total eel or shortfin eel catch, indicating that there were few trips where eels were not caught (or recorded) (Appendix A3). The higher proportions of zeros for longfin reflects the low proportion of this species in the lake relative to shortfin. There are no trends for shortfin, whereas the proportion of zero longfin catches, while variable, may be declining.

Annual unstandardized catch rates (total catch per day) for shortfin were variable, but stable at about 200 kg per day until 2003, after which they increased steeply until 2006 when they were about 600 kg per day (Appendix A4). From 2006 to 2013 shortfin catch rates were variable but stable. The median shortfin catch per day shows the same trend as total shortfin catch per day (Appendix A5). In comparison, longfin catch rates and median catch per day are predominantly zero (Appendix A4 and A6).

AS1 (2001–2012)

The catch in AS1 was 99% shortfin and varied between about 45 t and 90 t per year with no trend (Table 3, Appendix A7). Longfin contributed 1% of the total eel catch in AS1, and was caught in all years with annual catch ranging from 168 kg to 1675 kg (Table 3, Appendix A7).

The number of lifts in AS1 ranges between a few to 100 per day (mean 12), but most often between 2 to 14 lifts per day have been reported (Appendix A8). The median number of lifts per day has declined throughout the time series from about 20 nets per day in 2001 to 5 nets per day in 2012 (Appendix A9).

There were very few zero records for total eel or shortfin eel catch in AS1, indicating that there were few trips where eels were not caught (or recorded) (Appendix A10). The higher proportions of zeros for longfin reflects the low proportion of eels in the lake relative to shortfin. There are no trends for shortfin, whereas the proportion of zero longfin catches, while variable, may be declining.

Annual unstandardized catch rates (catch per lift) for shortfin in AS1 increased steeply from 2001 to 2012 from about 5 kg per lift to 170 kg per lift (Appendix A11). The median shortfin catch per lift shows the same trend as total shortfin catch per day (Appendix A12).

3.2 Shortfin standardised CPUE analyses (AS1, 2001 to 2012)

Standardised CPUE analyses were only carried out for shortfin eel caught in AS1 from 2001 to 2012.

Core fishers

The relationship between total shortfin catch and years of participation in the fishery is shown in Appendix A13. The original number of records (positive catches only), fishers, and shortfin catch, and those included in the CPUE model core data following the restrictions are shown in Table 4. The shortfin core data used in the CPUE analyses retain 92% of the catch, but lose nearly half of the original fishers. There are six core fishers in 2001, but from 2006 to 2012 the number declines to two or three and in 2012 although there are three core fishers, the bulk of the catch is taken by one fisher (Appendix 14).

CPUE Indices

The standardised CPUE for shortfin catch followed the same general pattern as unstandardised catch per lift with a progressive increase over time (Appendix A15), however, the standardised CPUE indices flatten out in the last two years. This divergence is driven by the low number of nets used in 2011 and 2012 compared to previous years. The confidence intervals are initially narrow but tend to widen as the number of fishers in the core data set drops off. Overall, however, confidence intervals around the indices indicate that there were adequate numbers of fishers and catch in these analyses. The variables lifts, permit and month were included in the GLM, in that order, and explained 49% of the variation in CPUE (Table 5).

Diagnostics

The expected catch rates from the model predictor variables indicate that expected catch rates have increased from 100 kg to about 600 kg to day from 2001 to 2012 (Appendix A16.). The model residual diagnostics are acceptable (Appendix A17). The influence step plots show that the predictor variable lifts has had the most significant influence on the shape of the CPUE index, particularly in the last two years (Appendix A18); this is also demonstrated in the lifts CDI plot when the influence becomes strongly negative after 2007 (Appendix 19). CDI plots for permit and lifts are shown in Appendices 20–21). Standardised indices, 95% confidence intervals, and CVs are tabulated in Appendix B.

Sensitivity analyses

A sensitivity analysis was carried out where lifts was not offered to the model and the indices were compared to the base case model which included lifts (Figure 10). The CPUE indices show similar trends until 2007, after which the base model increases steeply compared to the sensitivity model which flattens out.

3.3 Temporal trends in eel size composition

The commercial catch sampling length frequency data used to estimate the proportion of catch by size grade from the mid-1990s are shown in Figure 11. Only data from strata 1 to 3 (i.e., equivalent to AS1) were used, thus excluding the migration area where the smaller shortfin males are caught. The 1995–96 length distribution is more skewed to the left than 1996–97 and 1997–98 with a higher proportion of smaller eels. In 1995–96, eels sampled from Kaitorete spit (stratum 2) (see Figure 5) were considerably smaller than from elsewhere in the lake. Kaitorete spit is contiguous with the migration area (stratum 4) and it may have been that eels from this stratum contained a high number of migrating males in 1995–96. In 1997–98 Kaitorete spit was also sampled, but this time the size composition was not dominated by small eels.

The converted size grades from the 1990s catch sampling are compared with those collected in 2009–10 to 2011–12 from the commercial eel monitoring programme (Figure 12). For Levin, the proportion of each of the three size grades varies from year to year within each of the catch sampling and the eel monitoring data sets, but overall it is clear that eel size is larger in recent years compared to the mid-1990s. This is most marked for the medium sized eels between 660 g and 1000 g, which have increased, and the 300 g to 650 g eels, which have declined. For Mossburn, where there are only two size grades, the change is even more pronounced with a dramatic increase in the large eels (over 800 g) and a decline in the smaller eels (300 to 800 g) (Figure 12).

4. DISCUSSION

This report includes a fishery characterisation for the Te Waihora commercial freshwater eel fishery from 1991 to 2012, and a standardised CPUE analysis for shortfin in AS1 from 2001 to 2012.

4.1 Te Waihora eel fishery

Throughout the 22 year Te Waihora time series, shortfin estimated catches have contributed 99% of the landed catch. A voluntary code of practice to release all longfins back into the lake has been in place since about 2007–08. Inspection of the landing data from ECLRs indicates that this practice has been observed with zero or negligible longfin landings from the lake over this period with the exception of 2010–11 when over 2 t were landed and processed.

The establishment of the management areas AS1 (lake fishery) and AS2 (migration fishery) in 1995–96 was designed to allow harvest of migrating male shortfin eels during February and March each year. A special dispensation was needed to harvest these eels which are below the MLS, which in 1995–96, was 160 g, whereas shortfin males migrate from about 80 to 180 g (35 to 45 cm) (Jellyman & Todd 1998, Beentjes 1999). The rationale for this decision was that by transferring effort to male migrators, this would relieve fishing pressure on the larger shortfin female feeders which will not migrate until about 500 g or 60 cm, and in doing so improve the yield and sustainability of the fishery. It was considered that the New Zealand wide shortfin fishery would not be affected by the removal of migrating males from Te Waihora since there is likely to be sufficient escapement elsewhere to ensure that recruitment is adequate. The fishery now takes about half the catch from AS1 and AS2 each year (see Figure 7).

Only eels less than 300 g can be legally landed from AS2 (migration fishery), hence restricting the legal catch to migrant males. Some female migrant shortfin are also caught in AS2 along with the migrant males, becoming more common as the season progresses from February to March. About 5–10 t of shortfin female migrants are caught and released in AS2 each season, although many of these eels will be recaptures (Clem Smith, Te Waihora fisher, pers. comm.). Fishers are unclear if these releases are required to be recorded on ECERs and ECLRs because technically legal sized eels in AS2 are less than 300 g, not between 220 g and 4000 g, as it is elsewhere. Despite this, some fishers have recorded these female migrant releases on the ECERs and ECLRs, but the data are not likely to be consistent for individual fishers or among fishers. Further, fishers are now deploying 'filters' on their fyke nets to prevent shortfin female migrants from entering when this becomes a problem.

In addition, about 1–3 t of female shortfin migrants caught in AS2 are legitimately landed under a customary permit. Any eels caught under a customary permit are not recorded on catch effort and landing forms but are recorded on customary catch returns.

4.2 Estimated catch and factors affecting CPUE indices

Catch effort reporting forms

In the freshwater eel fishery, catch of each species is estimated by observation of catches in fyke nets or in holding bags, rather than from standard fish bins containing separated species as in marine fisheries. There is therefore the possibility that in catches dominated by one species, the minor catch, in this case longfin, may be overlooked or underestimated. Only two species (SFE and LFE) are caught in any abundance in fyke nets and these will always have been included in the catch-effort section of CELRs which only allows reporting of the top five species, whereas the current ECER form (introduced 2001–02) has dedicated fields for SFE and LFE catch.

Mismatch between landed and estimated catch

The trends in total estimated and landed eel catch are similar, except for 2002 to 2004 which were less than the landed catch and 2010 which was greater than the landed catch (see Figure 4). As mentioned this cannot be attributed to grooming losses and Te Waihora fishers can provide no explanation. It seems very unlikely that fishers in these years have underestimated their catch relative to the landed catch by this extent when other years are a close match. Further, landed green weight data is often used to populate the estimated catch field on the ECERs. Given this, we can only conclude that there are missing data records from 2002 to 2004, and assume that the data in our analyses are representative of the fishery for those years. Overall, we consider that the Te Waihora estimated catch can be legitimately used for a fishery characterisation and CPUE analysis.

Reporting of released legal sized eels

Fishers are legally entitled to return eels of legal size (220 g to 4000 g) to the water, but are required by law to complete the catch effort section of the ECER, including estimates of released legal sized eels, and to report this estimated catch as ‘destination ‘X’ in the ECLR destination field. Unfortunately the original instructions to fishers by MPI on ECLRs did not include destination ‘X’ as a reporting option and hence it was not used as intended, but instead Te Waihora fishers used destination code ‘A’ as a substitute. Fishers were sent a reporting requirements information fact sheet in September 2013 by MPI explaining how to correctly complete ECER and ECLR forms. Regardless, this is only likely to have impacted on longfin catch which are returned alive and shortfin female migrators which are released under a voluntary code of practice. Discussions with Te Waihora fishers, and inspection of ECERs suggest that Te Waihora fishers have been correctly completing ECERs and ECLRs and are now using destination ‘X’ as intended. There are no implications for the analyses of CPUE.

Release of over 4 kg eels

Missing from the estimated catch are longfin eels over 4 kg which must legally be returned to the water on capture (in fishing regulations from March 2007), but are not required to be reported on ECERs or ECLRs because they do not fall within the legal size limit. The extent of these over 4 kg longfin eel releases, while unknown, is thought to be minor, but nonetheless will underestimate catch of longfin eels after April 2007. As longfins are no longer harvested from the lake, their overall size can be expected to increase and eels over 4 kg may become more common. The planned introduction of a logbook programme to both the North and South Islands, if successful, will capture the release of over 4 kg longfin eels as well as other information such as finer scale catch location details.

Escape tube modifications

In October 1996 the South Island changed from 25 mm to 28 mm diameter escape tubes and in October 2001 this was increased to 31 mm. The current 31 mm diameter tube is designed to allow eels smaller than about 300 g (minimum legal size, MLS) to escape from the fyke nets. It is not clear if Te Waihora adhered to these escape tube changes applied to the South Island because they were operating under a MLS of 140 g in 1994, increasing by 10 g each year until it reached the national MLS of 220 g in 2002. Grading to the annual MLS of Te Waihora was carried out by using grading boxes rather than incremental changes to the escape tube size each year. However, there is anecdotal evidence that some fishers in Te Waihora may have adopted the 31 mm escape tube voluntarily in the late1990s which would have restricted their catch to a size larger than the MLS at the time.

4.3 CPUE analyses

Core fishers used in CPUE analyses

The restriction of CPUE analyses to core fishers ensured that only committed and experienced fishers (at least three years in the fishery) were included in the analyses, hence reducing the overall variability in catch rates. This resulted in very little loss of data, but about half the fishers from the analyses were excluded (see Table 4). There was a further drop off in fishers over time as fishing activities in the lake have been managed under a cooperative arrangement where a few fishers catch the ACE of the bulk of the fishers on their behalf with the aim of maximising efficiency and reducing costs (see Appendix A13). This has also been possible in recent years as catch rates have increased allowing the TACC to be caught with less effort.

Standardised CPUE analyses

The standardised CPUE analyses take into account the effects that the variables lifts, fisher (permit), season (month), and moon phase may have had on catch rates (see Table 5). The three variables lifts, permit, and month were included in the AS1 shortfin model, with lifts and permit explaining most of the variation in the model. The finding that month was an important variable affecting catch rates and the strongly seasonal pattern in catches is understandable since water temperature varies seasonally and eel catch rates have been found to decline markedly in winter (Jellyman 1991, 1997, Beentjes & Dunn 2008). The inclusion of permit indicates the importance of fisher experience and/or ability on catch rates. Lifts had the most effect on CPUE which is understandable since catch rates have gone up while effort (i.e., the number of nets used) has been declining over time. The sensitivity analysis, which excluded lifts, demonstrates the importance of lifts in the model (see Figure 10). Overall it seems clear that catch rates and CPUE have increased markedly over the period from 2001 to 2012 with the daily catch increasing from about 200 kg per day in 2001 to about 600 kg in 2012, despite using fewer nets. Real catch rates could conceivably be higher since fishers have applied the practice of tying off nets when catch is likely to be too large to manage. However, there is no information on the prevalence of this behaviour.

Why has CPUE increased ?

The three fold increase in catch rates and CPUE are consistent with perceptions of commercial fishers who suggest that fishing in Te Waihora is as good as it has ever been. It is very likely that the fishery has experienced a progressive improvement in yield per recruit as the MLS has been incrementally increased over time. Indeed the analyses of eel size in the lake in the 1990s compared to that in recent years demonstrates that the size of commercially caught eels has substantially increased over time, supporting the concept of an improved yield per recruit (see Figure 12). The reason that the MLS was introduced at just 140 g in 1994, compared to the national MLS of 220, was because there were few large eels in the lake at that time. It was considered that an initial MLS set any higher would have essentially closed the fishery. The small size of eels was a result of high fishing pressure before 1978 (i.e., unrestricted access, no MLS, and no catch limits), and a subsequent TACC of 256 t in 1978, reducing to 136 t before being set at 120 t in 2001 under the QMS.

The snail *Potamoprygus antipodarum* was common in Te Waihora in the 1970s and the most important source of food for juvenile eels. They appear to have been replaced by the common bully *Gobiomorphus cotidianus* following the loss of shore line vegetation and increased turbidity of the lake (Jellyman & Kelly 2004). A study of the size and age of migrating male eels indicated that compared to the 1970s they had become smaller overall in the 1990s, but were of the same age (Jellyman & Todd 1998). In other words, growth rates had declined. This was thought to be a result of increased competition with bullies for invertebrates and the lack of large eels which would otherwise prey on bullies. As eels grow their food source tends to change from invertebrate to fish species, generally at about 40 cm (Ryan 1986). Analyses of the stomach contents of shortfin eels in Te

Waihora showed that eels below 30 cm (about 45 g) fed exclusively on chironomids, from 30 cm to 40 cm (about 45 g to 130 g) on a wide range of invertebrates and about 10% bullies, and over 40 cm almost exclusively on bullies and common smelt (*Retropinna retropinna*). Hence, in Te Waihora as the average size of eels has increased through the implementation of a MLS in 1994, incrementing each year, there is likely to have been a shift in the diet of commercially harvestable eels from invertebrates to fish and this may have impacted the yield per recruit in two ways:

1) Less competition for invertebrates resulting in better condition and faster growth of juvenile eels — this is demonstrated by the increase in size of migrant males which have increased in size from an average about 130 g in the mid-1990s (Beentjes 1999) to about 150 g currently (Clem Smith, Te Waihora eel fisher, pers. comm.).
2) The higher proportion of larger eels feeding on fish, a high energy diet (Ryan 1982), may have led to faster growth. Note that all commercial eels caught in the lake are now over 300 g and hence prey predominantly on fish. Shortfin eels in Te Waihora have been shown to demonstrate increased growth rates after switching to fish (Jellyman 2001).

The lake is also experiencing enhanced nutrient loading from the growing number of dairy farms surrounding the lake. The short term effect may be increased productivity of phytoplankton and benthic epiphytic algae. The impact of this on invertebrates and bully populations in the lake is unknown.

5. ACKNOWLEDGMENTS

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Table 1: Eel Quota Management Areas (QMAs) for longfin (LFE) and shortfin (SFE) eel stocks and both species combined (ANG), current Eel Statistical Areas (ESA, from October 2001), and the associated historical ESA up to October 2001.

	QMA		ESA		
Area	LFE	SFE	Alpha (from 1 Oct 2001)		Numeric (before 1 Oct 2001)
Northland	LFE 20	SFE 20	AA		1
Auckland	LFE 20	SFE 20	AB		2
Hauraki	LFE 21	SFE 21	AC		3
Waikato	LFE 21	SFE 21	AD		4
Bay of Plenty	LFE 21	SFE 21	AE		5
Poverty Bay	LFE 21	SFE 21	AF		6
Hawke's Bay	LFE 22	SFE 22	AG		7
Rangitikei-Wanganui	LFE 23	SFE 23	AH		8
Taranaki	LFE 23	SFE 23	AJ		9
Manawatu	LFE 22	SFE 22	AK		10
Wairarapa	LFE 22	SFE 22	AL		11
Wellington	LFE 22	SFE 22	AM		12
Nelson	ANG 11	ANG 11	AN		13
Marlborough	ANG 11	ANG 11	AP	}	14
South Marlborough	ANG 12	ANG 12	AQ	}	14
Westland	ANG 16	ANG 16	AX		15
North Canterbury	ANG 12	ANG 12	AR		16
South Canterbury	ANG 14	ANG 14	AT		17
Waitaki	ANG 14	ANG 14	AU		18
Otago	ANG 15	ANG 15	AV		19
Southland	ANG 15	ANG 15	AW		20
Te Waihora (outside-migration area)	ANG 13	ANG 13	AS1	}	21
Te Waihora migration area	ANG 13	ANG 13	AS2	}	21
Chatham Islands	LFE 17	SFE 17	AZ		22
Stewart Island	ANG 15	ANG 15	AY		23

Table 2: Te Waihora ESAs and the number of groomed records (equivalent to the number of fisher days), and estimated catch for shortfin, longfin, and unidentified eels from 1991 to 2012. ESA, eel statistical area. AS1 and AS2 replaced ESA 21 from 2001 onward.

			Estimated catch (t)			
ESA	Region	Records	Total	Shortfin	Longfin	Unidentified
21	Lake (pre 2001)	4839	960 831	946 347	14 484	0
AS1	Lake (excl. migration area)	2955	813 739	804 002	9737	0
AS2	Migration area	935	561 585	561 412	173	0
Totals		8729	2 336 155	2 311 761	24 394	0

Table 3: Percent of groomed estimated catch by species within and among Te Waihora ESAs from combined years 1991 to 2012. AS1 and AS2 replaced ESA 21 from 2001 onward. ESA, eel statistical area; LFE, longfin; SFE, shortfin.

					Percent species catch among ESAs		
ESA		SFE	LFE	Total	Total	SFE	LFE
21	Lake (pre 2001)	98.5	1.5	100	–	–	–
AS1	Lake (excl. migration area)	98.8	1.2	100	59.2	58.9	98.3
AS2	Migration area	99.97	0.03	100	40.8	41.1	1.7
Overall		99.0	1.0		100	100	100

Table 4: Number of records, fishers and catch in all, and core AS1 shortfin datasets. Records do not include those with zero catch. The percent of the fishers and catch that were included in the core fishers data is also shown.

				Percent retained	
Dataset	Records	Fishers	Catch (kg)	Fishers	Catch
All SFE	2947	11	804 002		
Core SFE	2736	6	739 492	54.5	91.9

Table 5: Predictor variables, degrees of freedom, and R^2 values from GLM stepwise regression analysis for CPUE analyses for shortfin eels from AS1. Variables are shown in order of acceptance by the model with associated cumulative R^2 value. Only variables entered into the model are shown.

	Shortfin	
Predictors	DF	R^2
fish.year	11	0.279
Lifts	3	0.407
Permit	5	0.458
Month	8	0.488

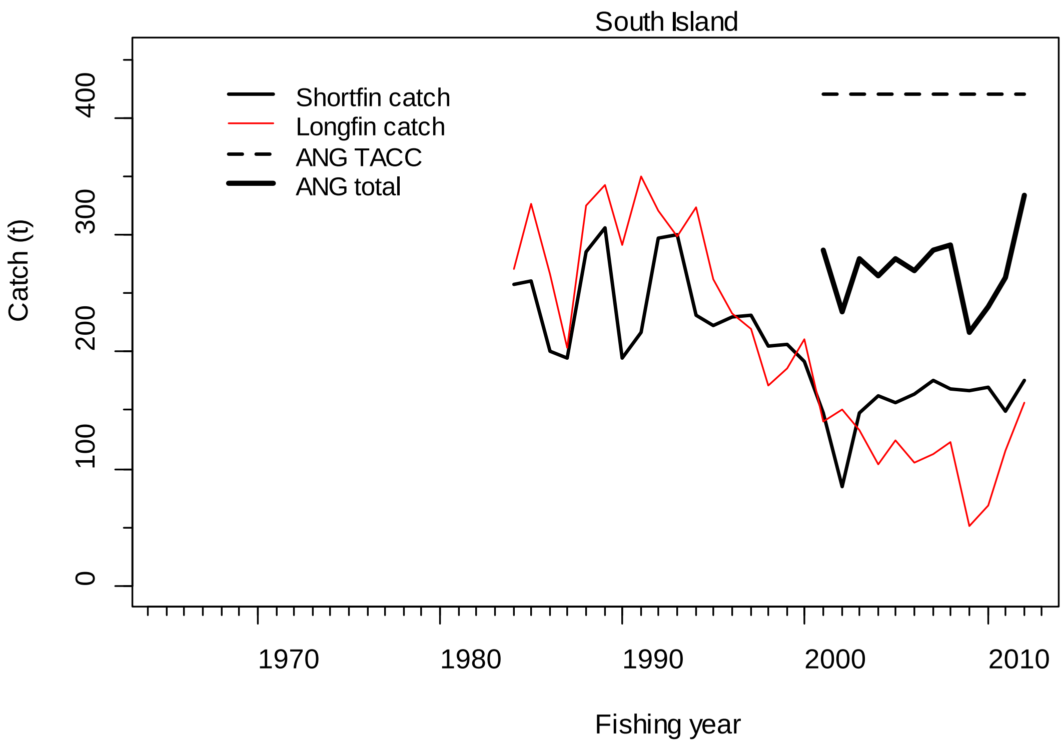

Figure 1: Landed catches of shortfin and longfin eels, and TACC for the South Island. Data are shown by calendar year up until 1988 and by fishing year from 1988–99 onward (Data from Ministry for Primary Industries 2013). These catches are based on MAF Fisheries Statistics Unit (FSU), Licensed Fish Receiver Returns (LFRR), Quota Management Reports (QMR), and Monthly Harvest Returns (MHR).

Figure 2: Google satellite image of Te Waihora. Annotated on the map are eel statistical areas AS1 (lake), AS2 (migration area) and the general location of the lake opening. AS1 also includes the lake catchment of Selwyn and Halswell Rivers.

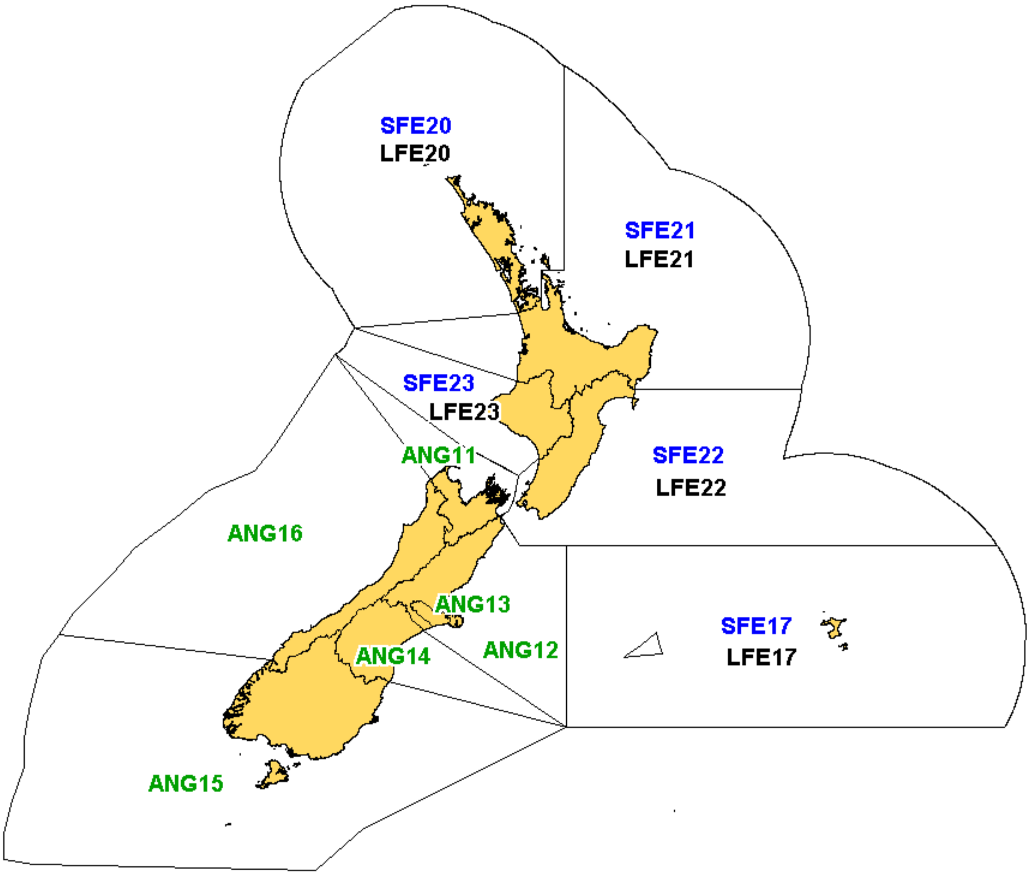

Figure 3: Quota Management Areas for the New Zealand eel fishery (see Table 1 for breakdown by eel statistical areas). Shortfin stocks are denoted by the prefix SFE, and longfin by LFE. ANG comprises both shortfin and longfin combined.). ANG13 includes Te Waihora and the Selwyn and Halswell River catchments (Figure from Ministry for Primary Industries 2013).

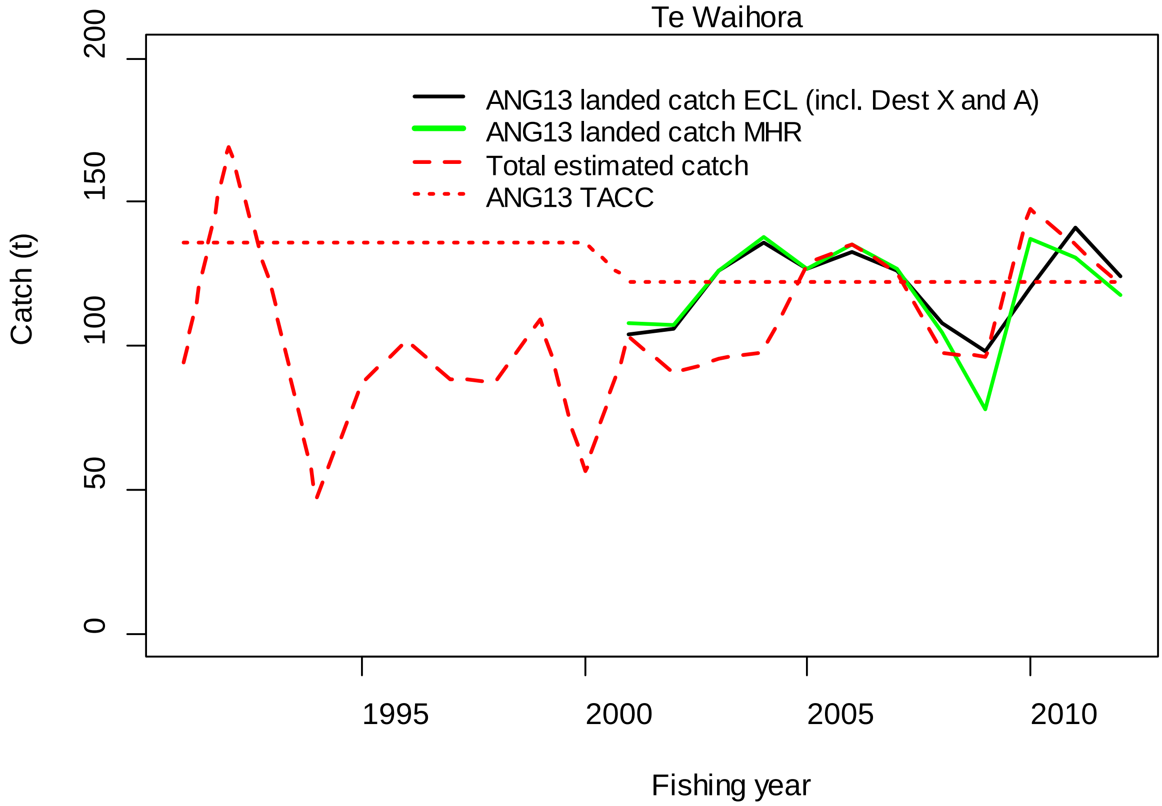

Figure 4: Catches of shortfin and longfin eels combined from Te Waihora (99% shortfin). Estimated catches are from 1990–91 to 2011–12 from Eel Catch Effort Returns (ECE), and landed catches from 2001–02 to 2011–12 from Monthly Harvest Returns (MHRs) and Eel Catch Landing returns (ECL). 2000–01 landed data were from the previous reporting forms (Quota Management Returns, QMR; Catch Landing Return, CLRs). The TACC is also shown for the Controlled Fishery and the Quota Management System (QMS) since 2000–01. 2001 represents 2000–01 fishing year.

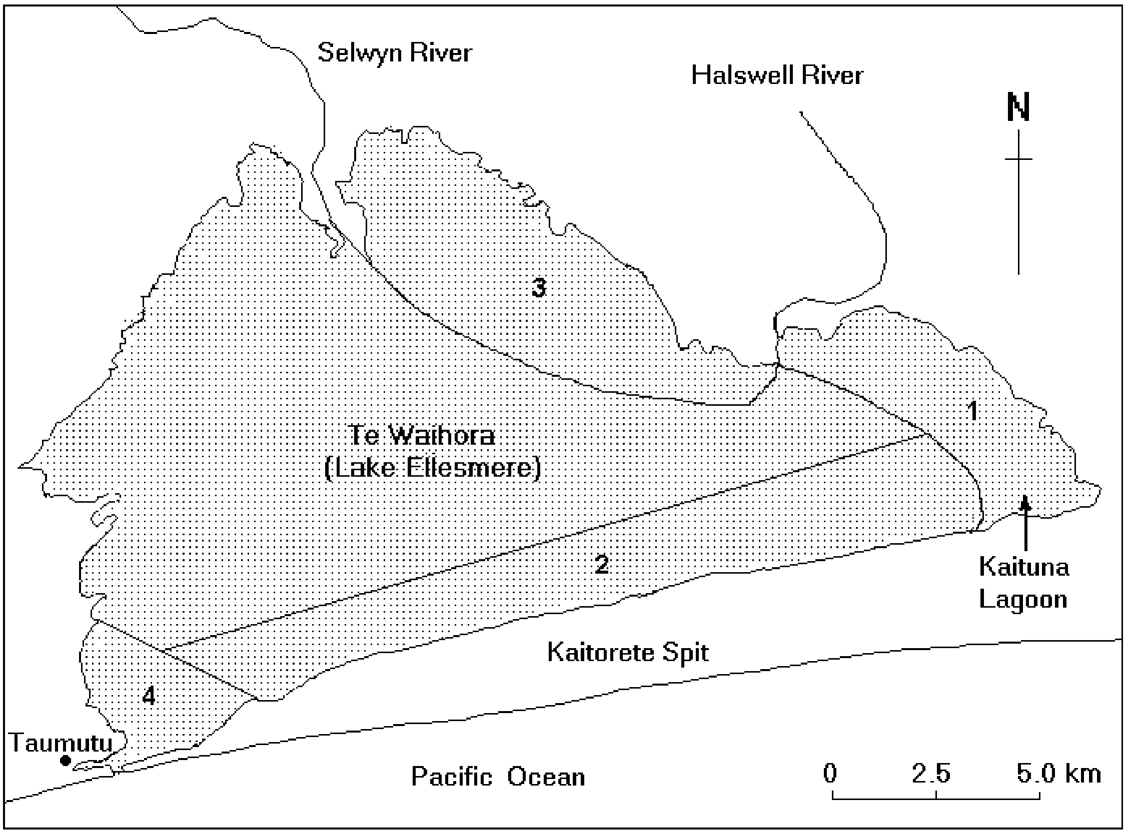

Figure 5: Te Waihora strata used in the 1995–96 to 1997–98 commercial catch sampling programme. Stratum 1, Kaituna Lagoon to Halswell; stratum 2, Kaitorete spit; stratum 3, Selwyn to Halswell; stratum 4, concession area for migrating eels (from Beentjes 1999).

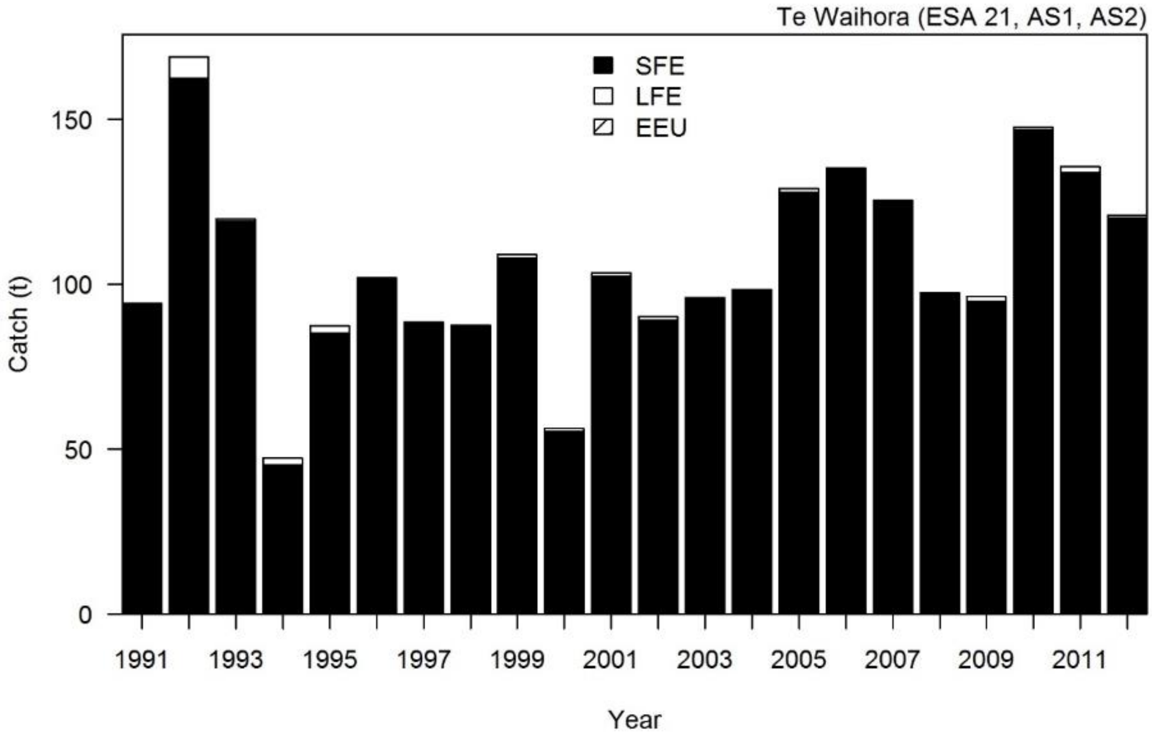

Figure 6: Total estimated commercial catch of shortfin (SFE), longfin (LFE), and unclassified eel catch (EEU) for the years 1990–91 to 2011–12 (Te Waihora (ESA 21, AS1, AS2)).

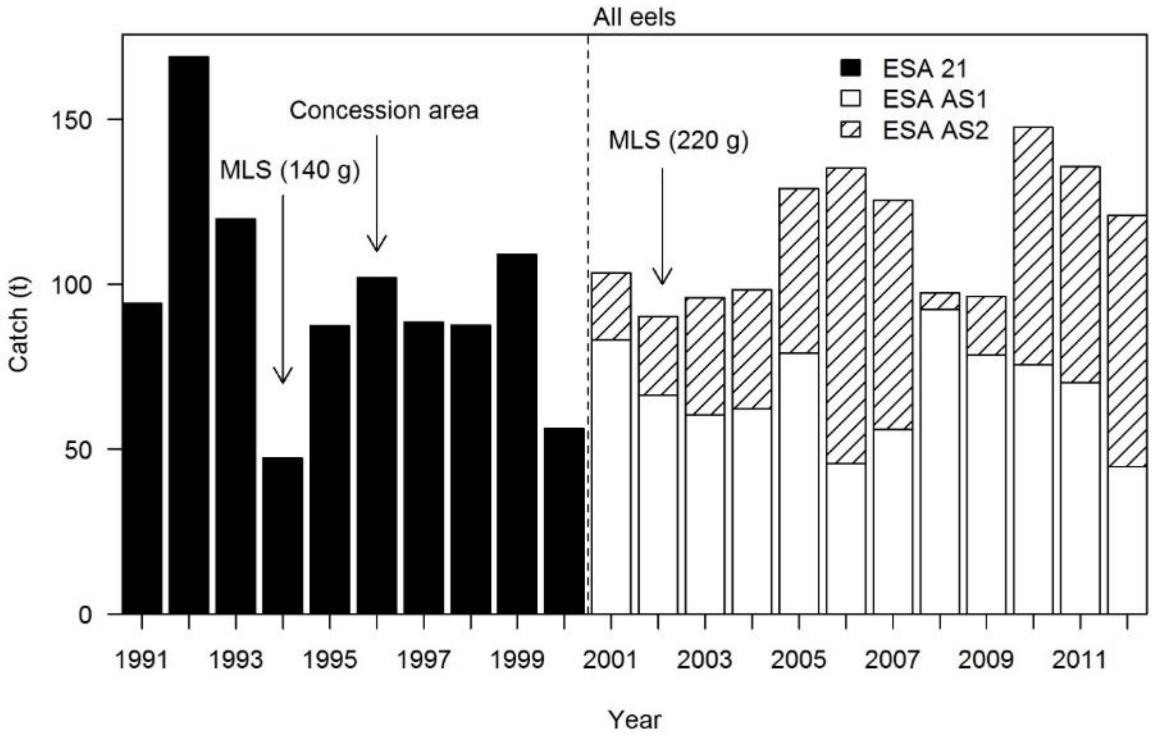

Figure 7: Total estimated commercial catch of all eels (shortfin and longfin) from Te Waihora by statistical area from 1990–91 to 2011–12. Data are expressed by fishing year (1 Oct to 30 Sept.). 2001 represents 2000–01 fishing year.

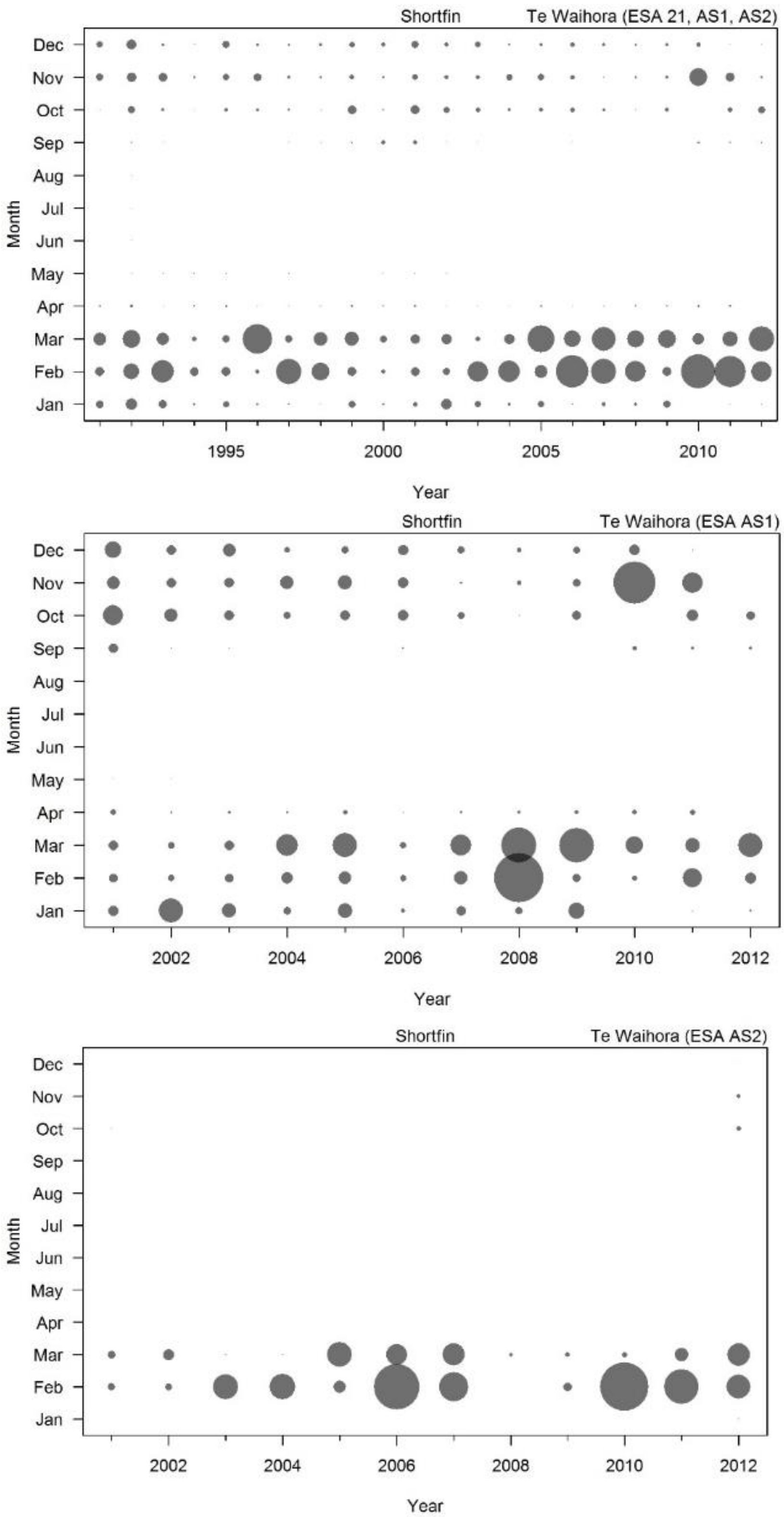

Figure 8: Te Waihora relative groomed estimated commercial catch of shortfin eel by month for all ESAs combined (1991 to 2012) (top panel), AS1 (2001 to 2012) (middle) and AS2 (2001 to 2012) (bottom). Bubble size is proportional to the catch within each panel, and the scales are different among the panels.

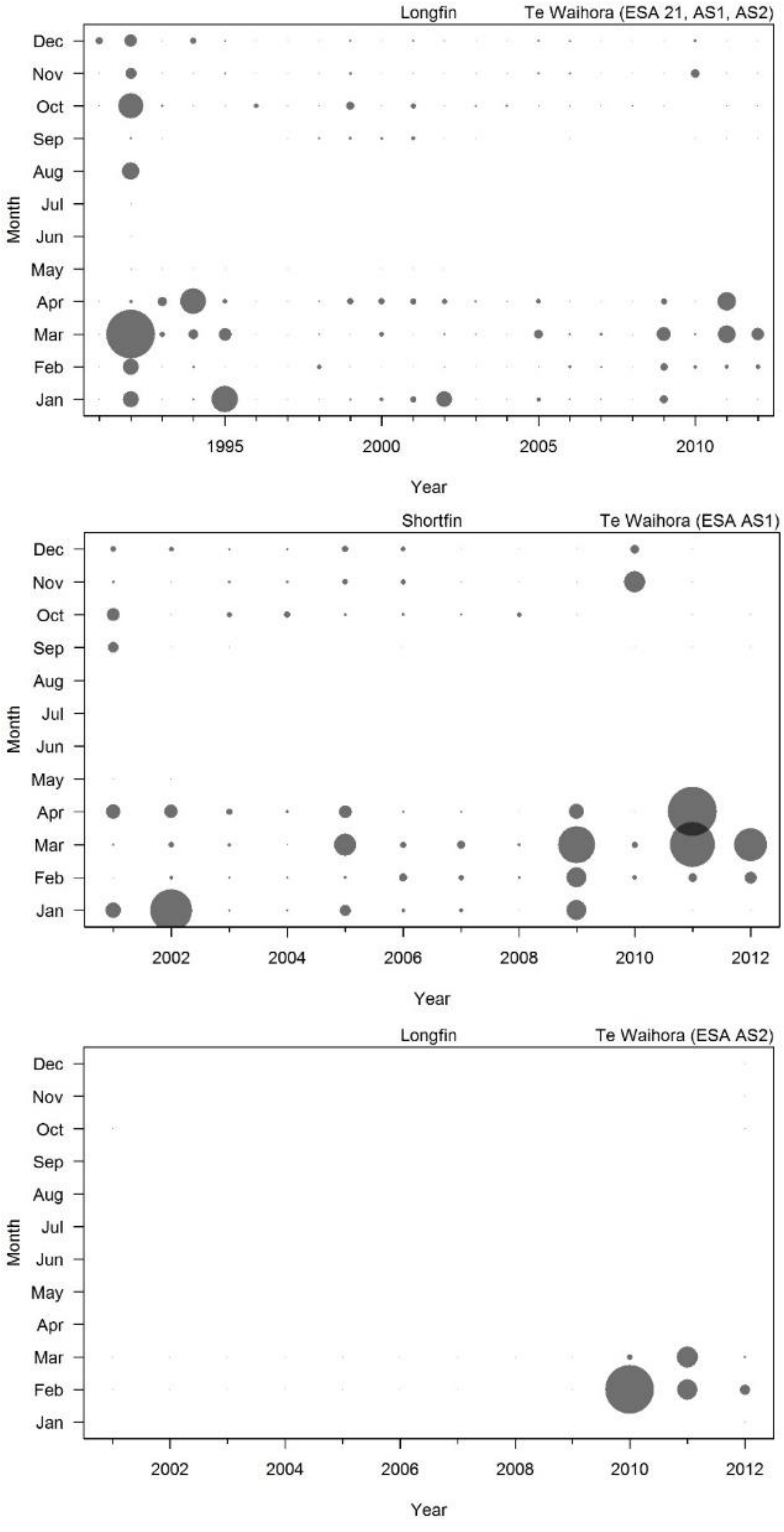

Figure 9: Te Waihora groomed estimated commercial catch of longfin eel by month for all ESAs combined (1991 to 2012) (top panel), AS1 (2001 to 2012) (middle) and AS2 (2001 to 2012) (bottom). Bubble size is proportional to the catch within each panel, and the scales are different among the panels.

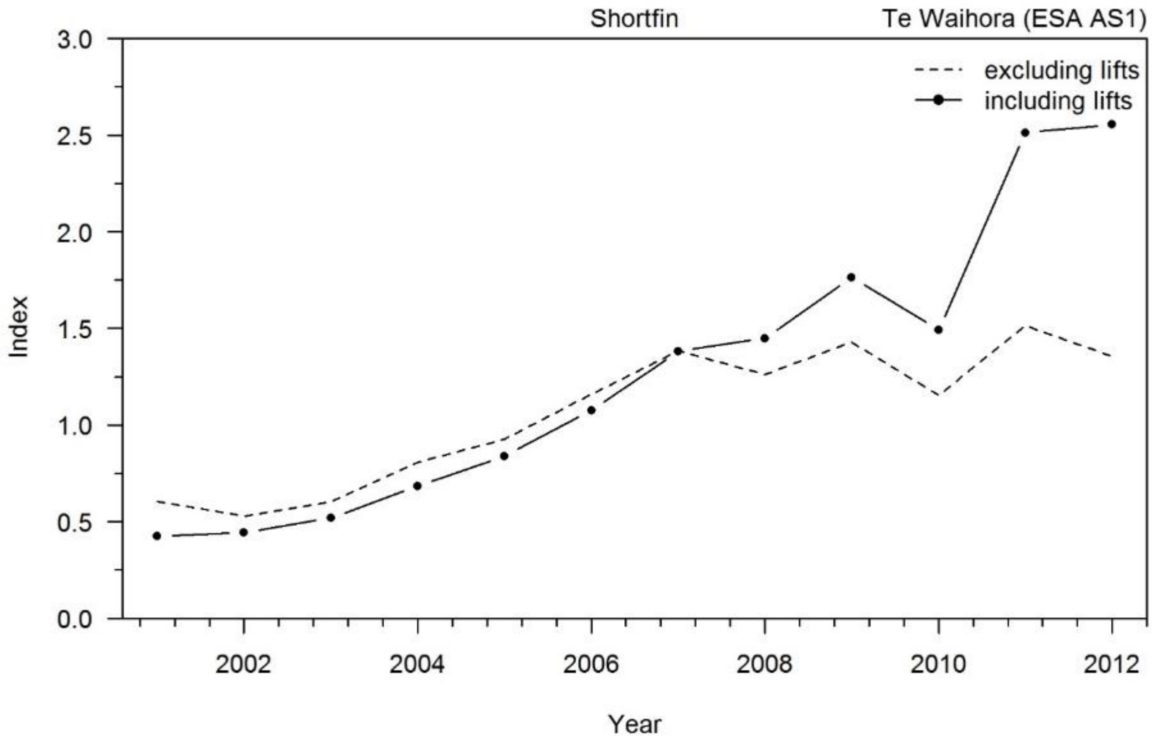

Figure 10: Standardised CPUE indices for shortfin eels in AS1 (lake) for the years 2001–2012. The base model includes lifts and the sensitivity model excludes lifts. 2001 = 2000–01 fishing year.

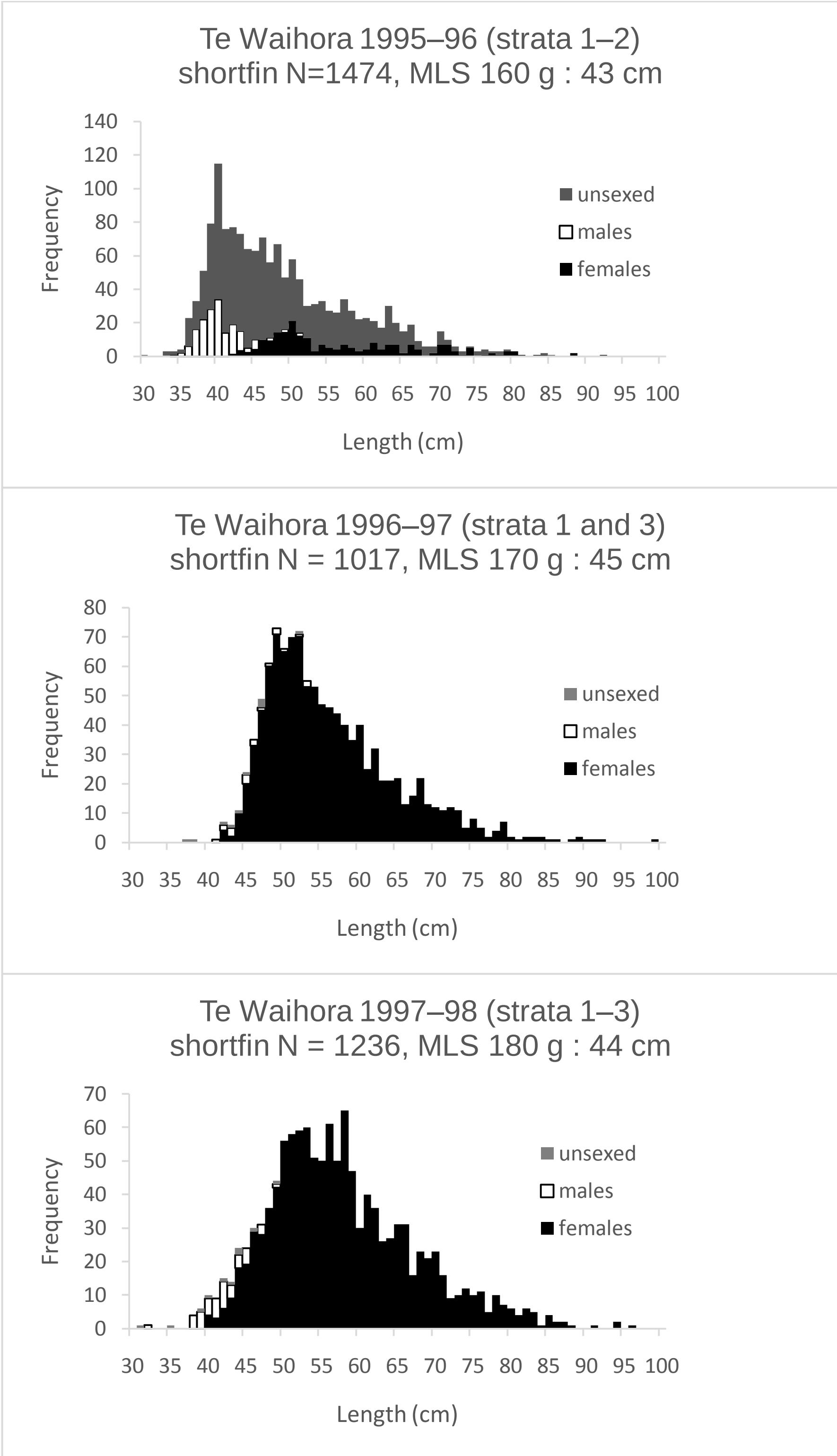

Figure 11: Length frequency distributions of shortfin eels sampled from Te Waihora AS1 in 1995–96, 1996–97 and 1997–98 during the commercial catch sampling programme. Bars are cumulative within each length class.

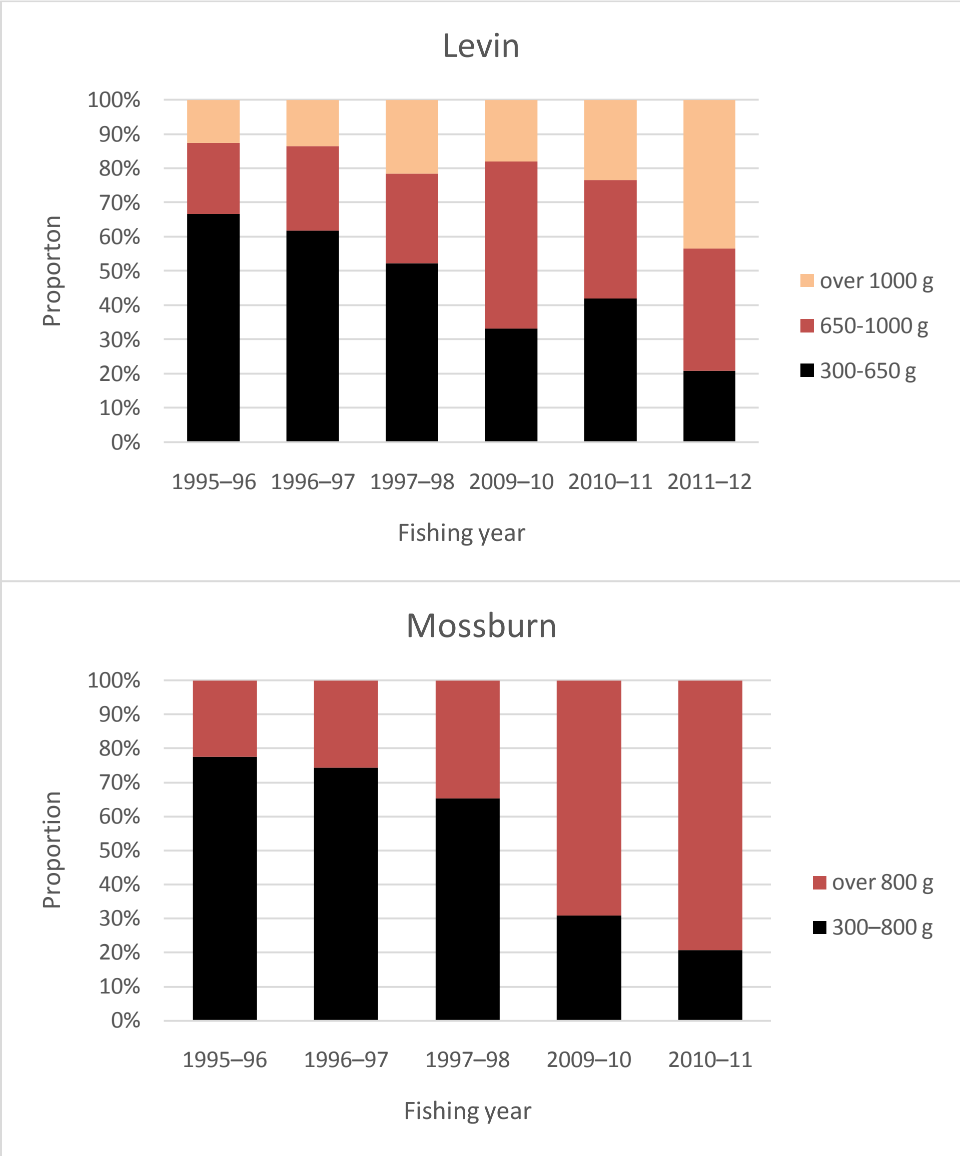

Figure 12: Size grade proportions of shortfin eels harvested from Te Waihora AS1 (lake) from eel processors Levin Eel Trading Ltd in 2009–10 to 2011–12, and Mossburn Enterprises Ltd in 2010–11 and 2011–12. The equivalent size grades have been estimated from the length of eels taken during commercial catch sampling of the commercial catch in 1995–96 to 1997–98 at Mossburn Enterprises. The length frequency data are shown in Figure 11.

Appendix A: Plots of eel fishery characterisation and CPUE analyses for Te Waihora.

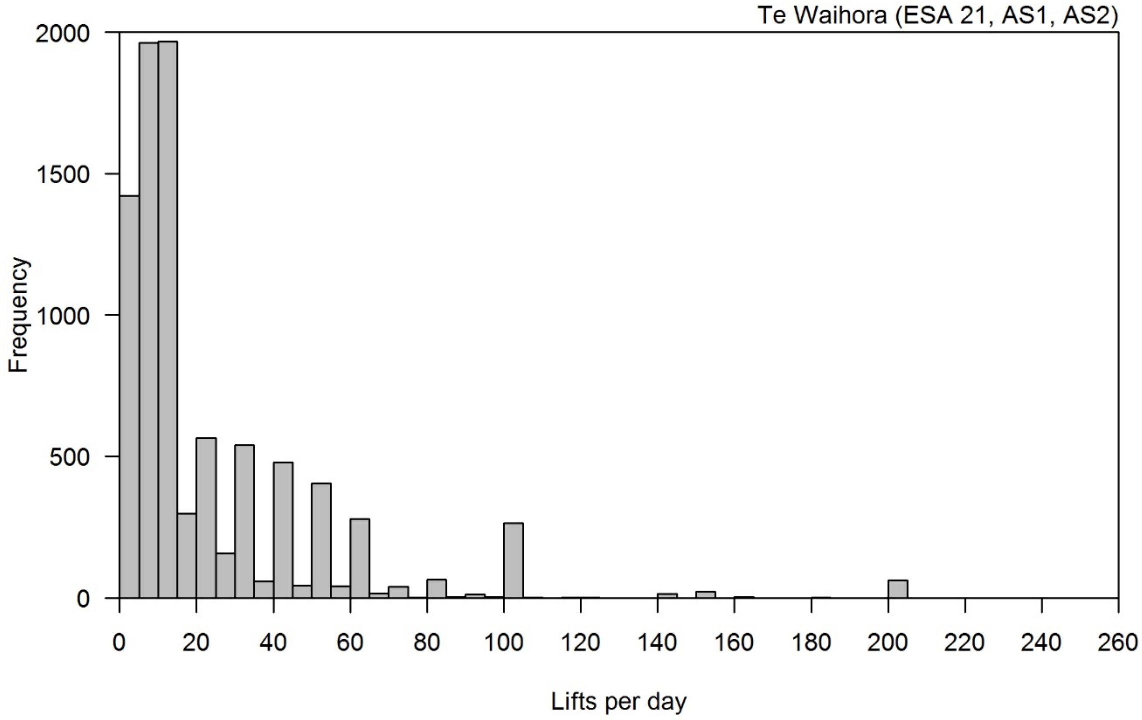

Figure A1: Frequency of total lifts per day for the years 1990–91 to 2011–12 (Te Waihora (ESA 21, AS1, AS2)).

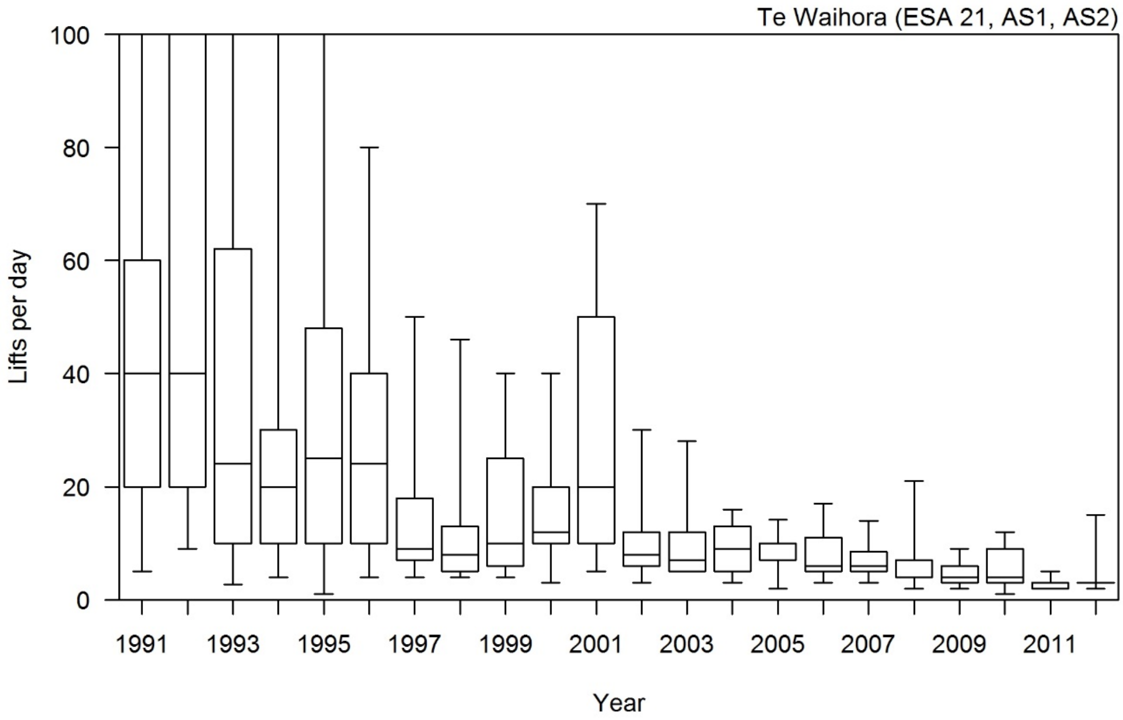

Figure A2: Total lifts per day for the years 1990–91 to 2011–12. The horizontal line is the median, the top and bottom of the box are the interquartiles (25th and 75th), and error bars are the 95th percentile range (Te Waihora (ESA 21, AS1, AS2)).

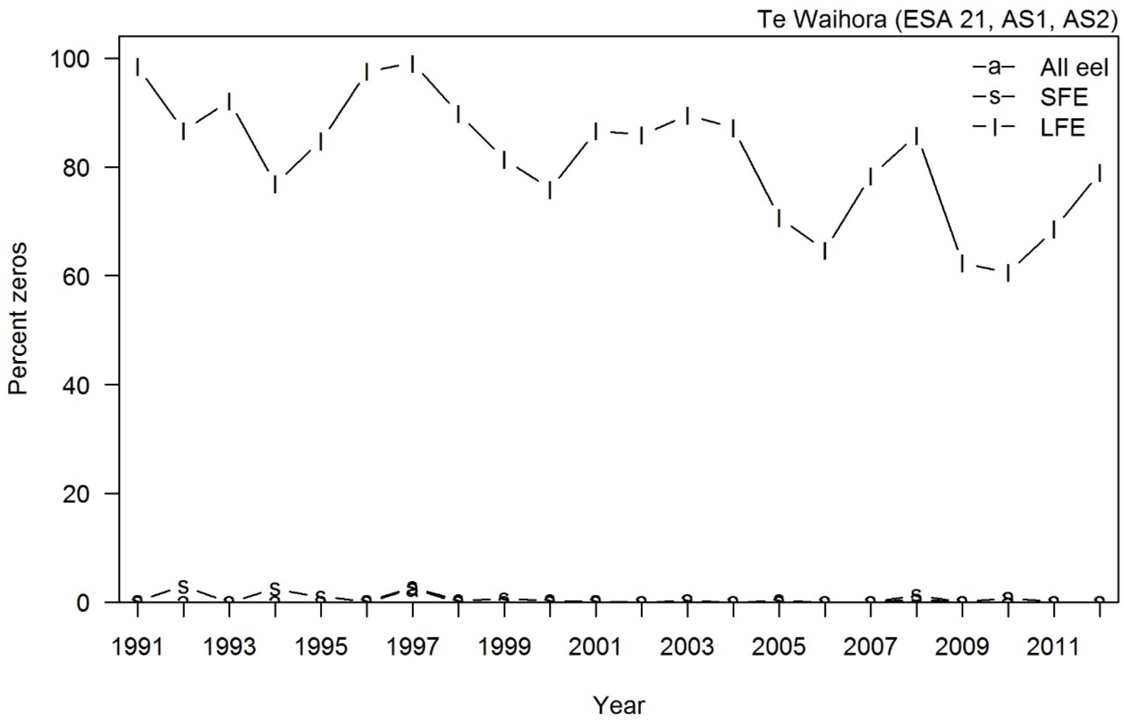

Figure A3: Proportion of zero records for all eel, shortfin (SFE), and longfin (LFE) catch for the years 1990–91 to 2011–12 (Te Waihora (ESA 21, AS1, AS2)).

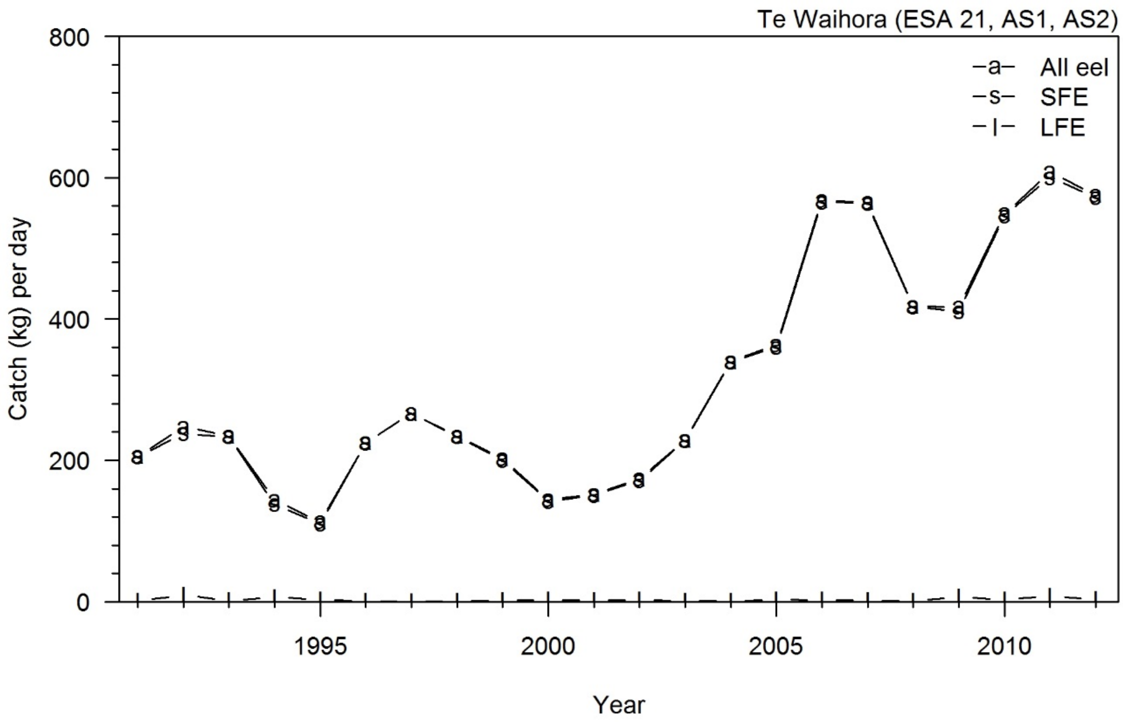

Figure A4: Unstandardised catch per day for all eel, shortfin (SFE), and longfin (LFE) for the years 1990–91 to 2011–12 (Te Waihora (ESA 21, AS1, AS2)).

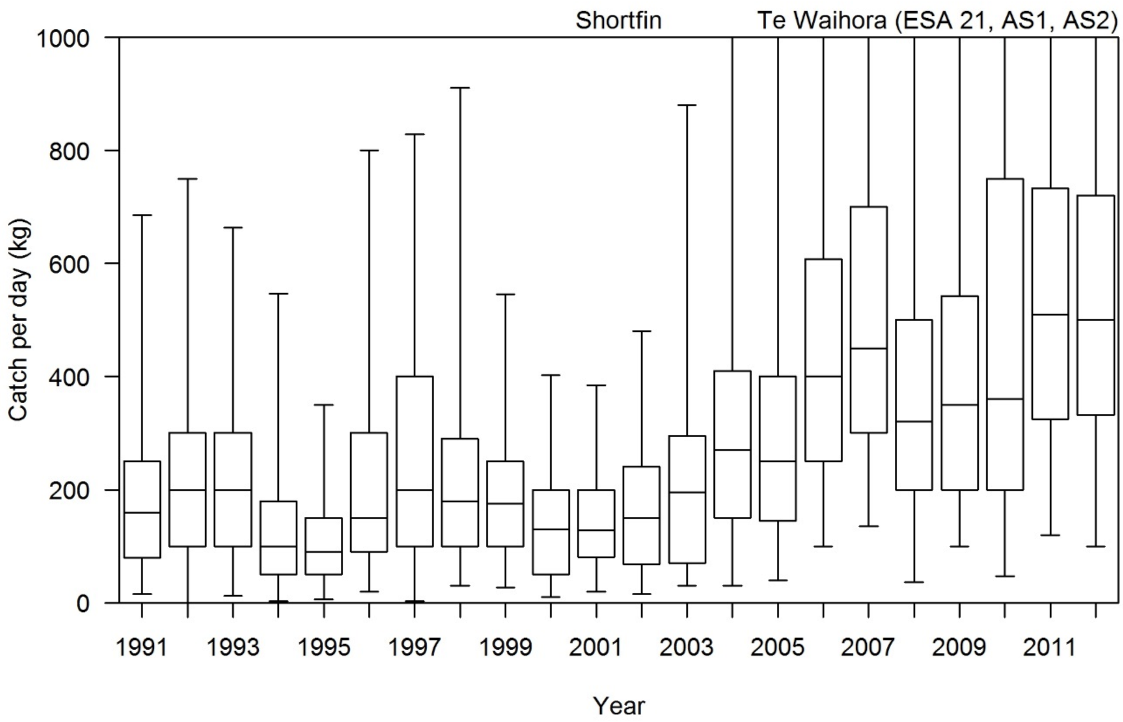

Figure A5: Shortfin eel catch per day for the years 1990–91 to 2011–12. The horizontal line is the median, the top and bottom of the box are the interquartiles (25th and 75th), and error bars are the 95th percentile range (Te Waihora (ESA 21, AS1, AS2)).

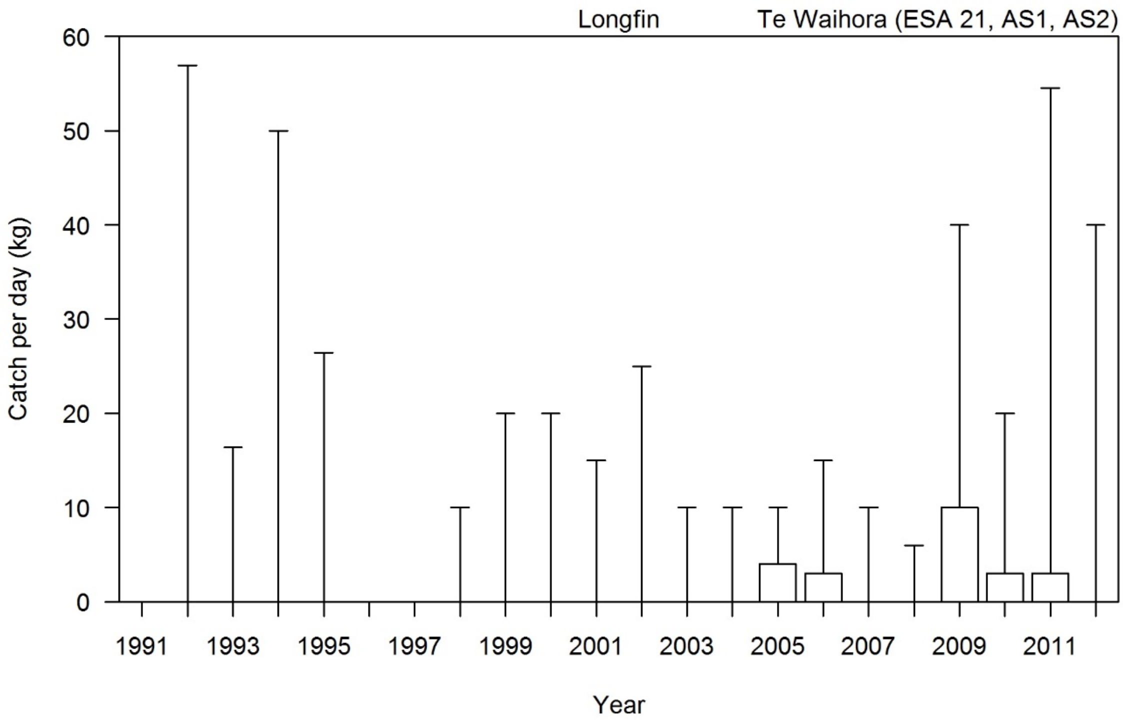

Figure A6: Longfin eel catch per day for the years 1990–91 to 2011–12. The horizontal line is the median, the top and bottom of the box are the interquartiles (25th and 75th), and error bars are the 95th percentile range (Te Waihora (ESA 21, AS1, AS2)).

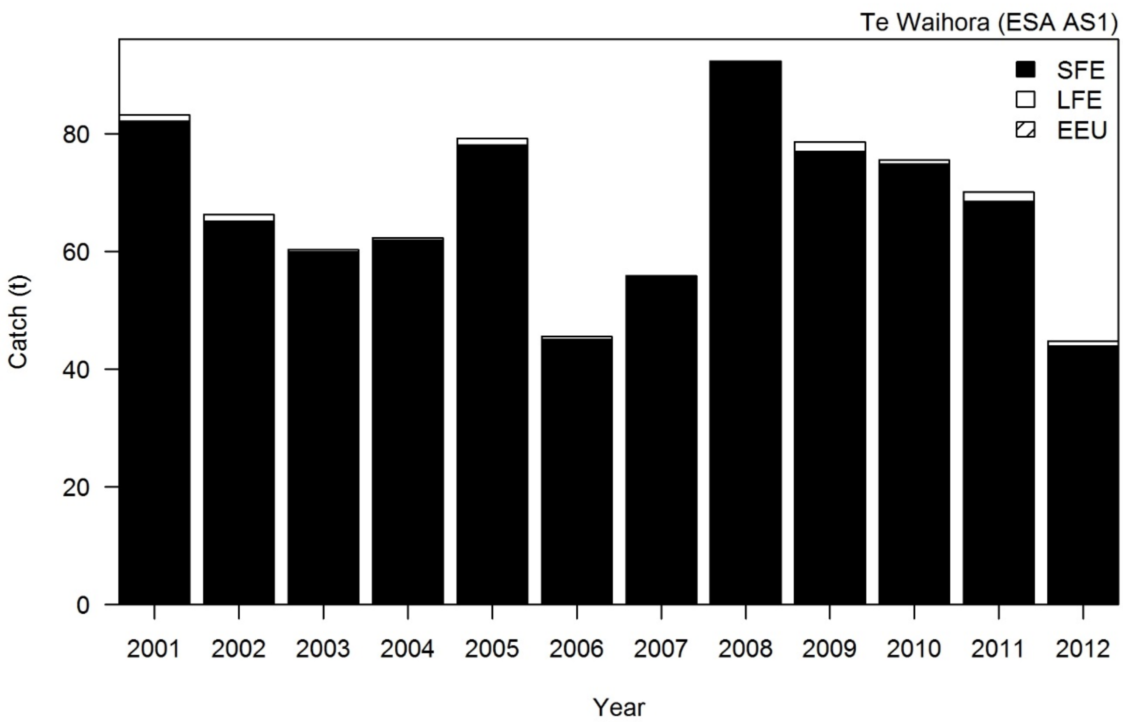

Figure A7: Total estimated commercial catch of shortfin (SFE)and longfin (LFE) from AS1 (lake) for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

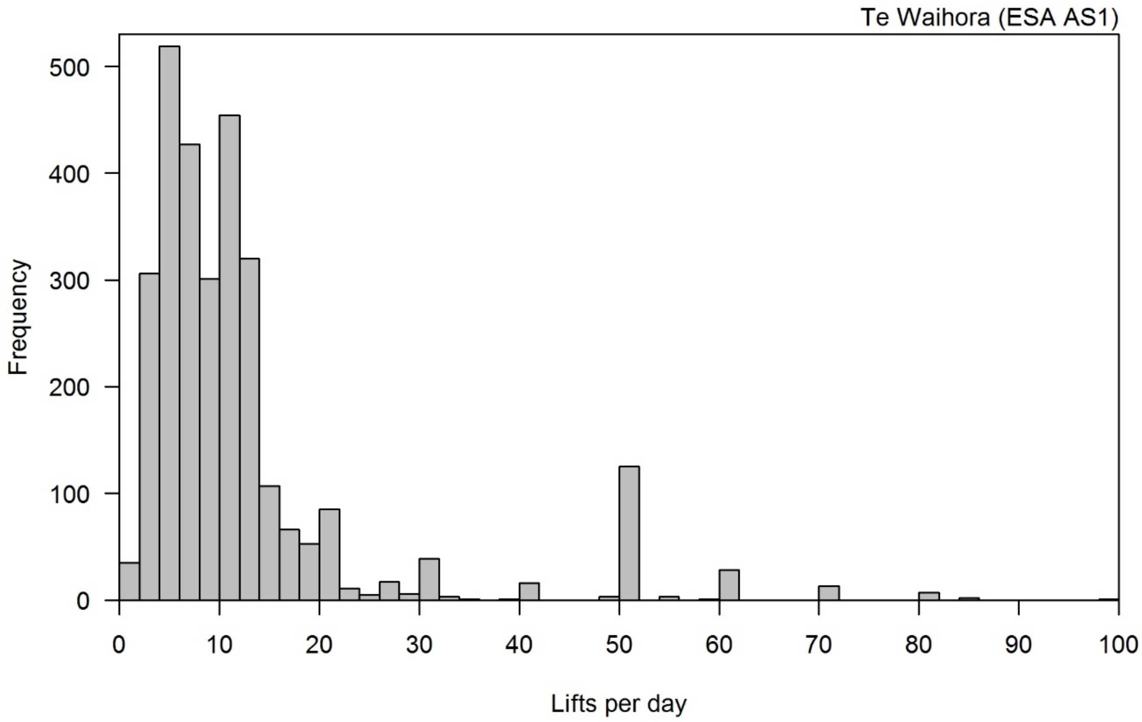

Figure A8: Frequency of total lifts per day from AS1 for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

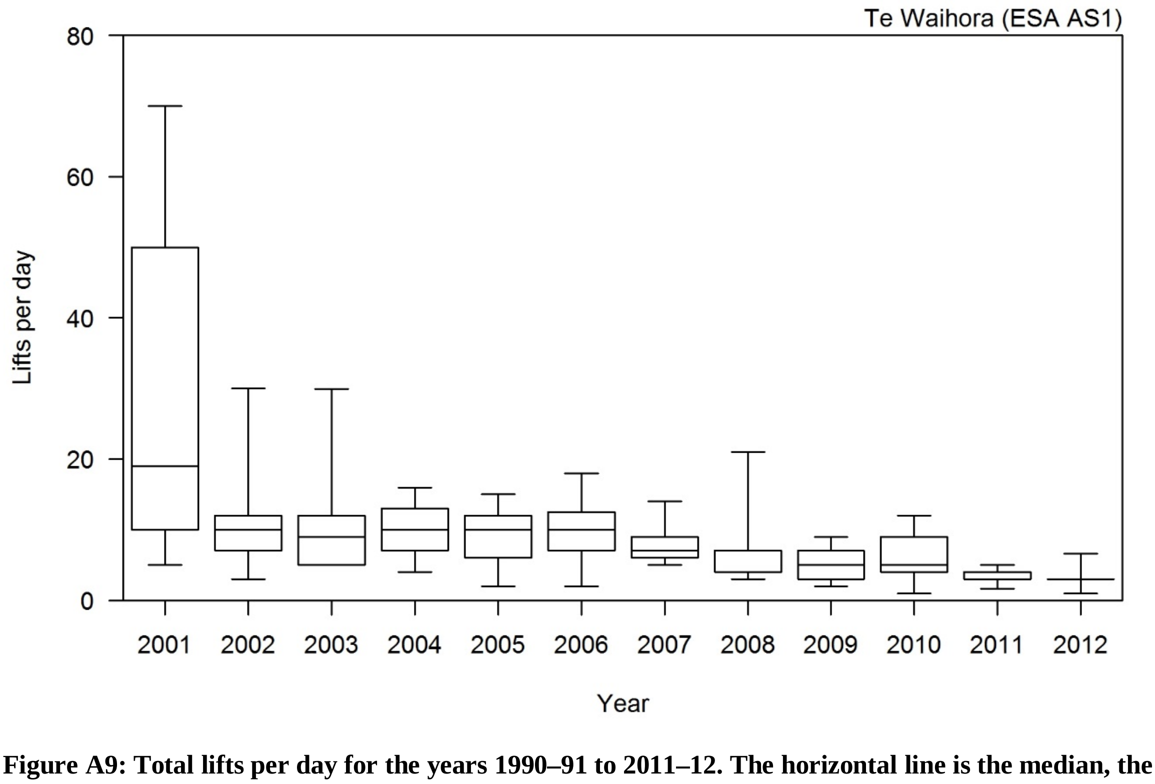

Figure A9: Total lifts per day for the years 1990–91 to 2011–12. The horizontal line is the median, the top and bottom of the box are the interquartiles (25th and 75th), and error bars are the 95th percentile range (Te Waihora (ESA AS1)).

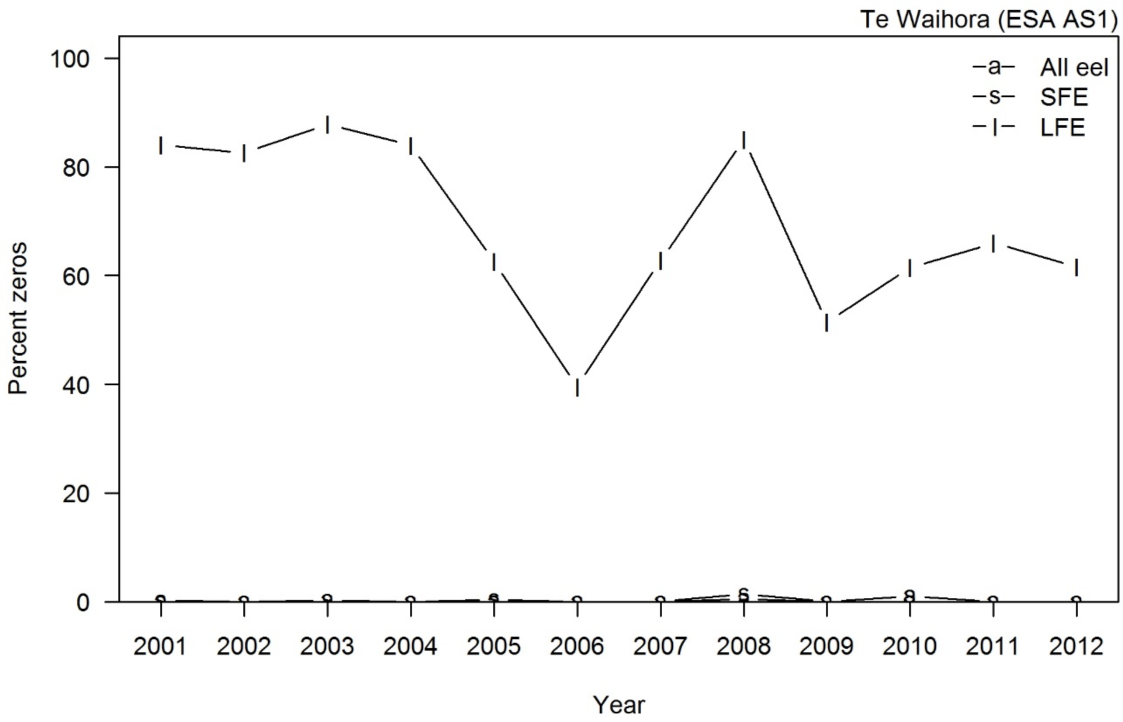

Figure A10: Proportion of zero records for all eel, shortfin (SFE), and longfin (LFE) catch for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

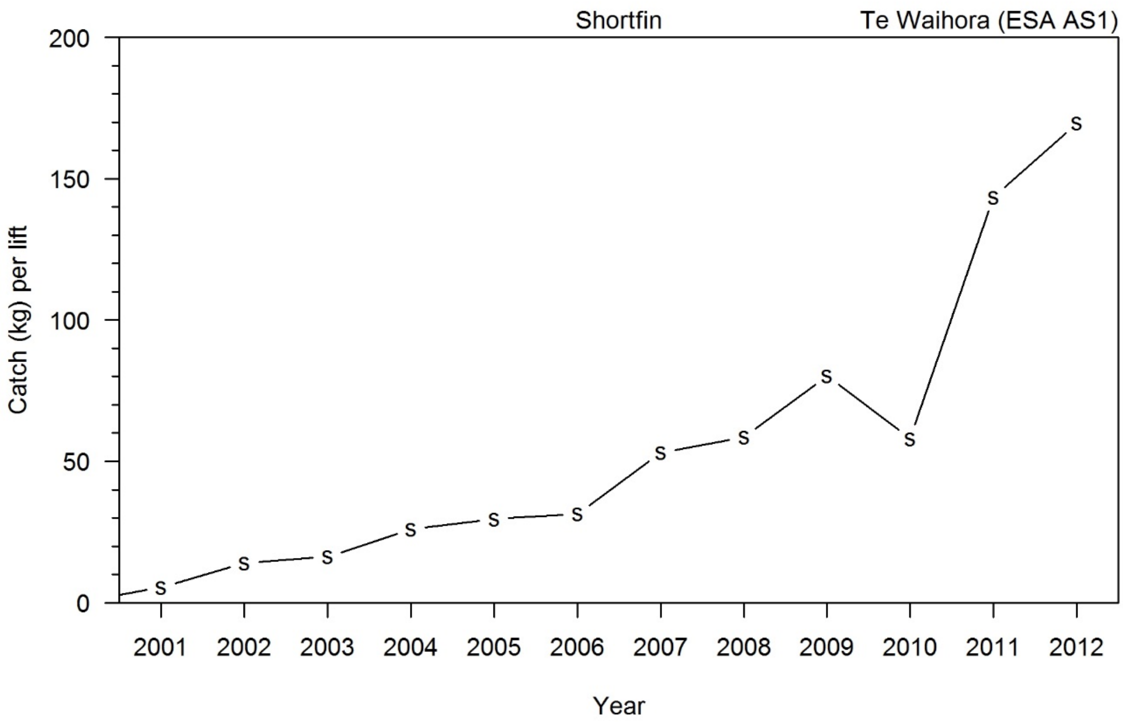

Figure A11: Unstandardised catch per lift for shortfin eels for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

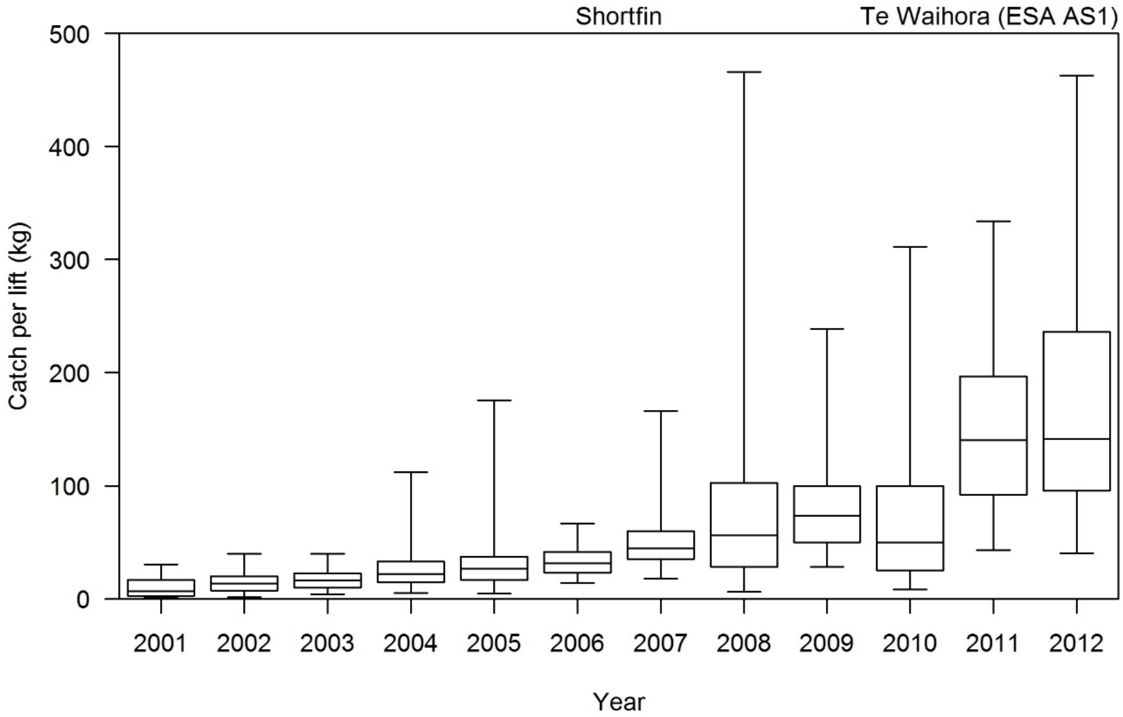

Figure A12: Shortfin eel catch per lift for the years 2000–01 to 2011–12. The horizontal line is the median, the top and bottom of the box are the interquartiles (25th and 75th), and error bars are the 95th percentile range (Te Waihora (ESA AS1)).

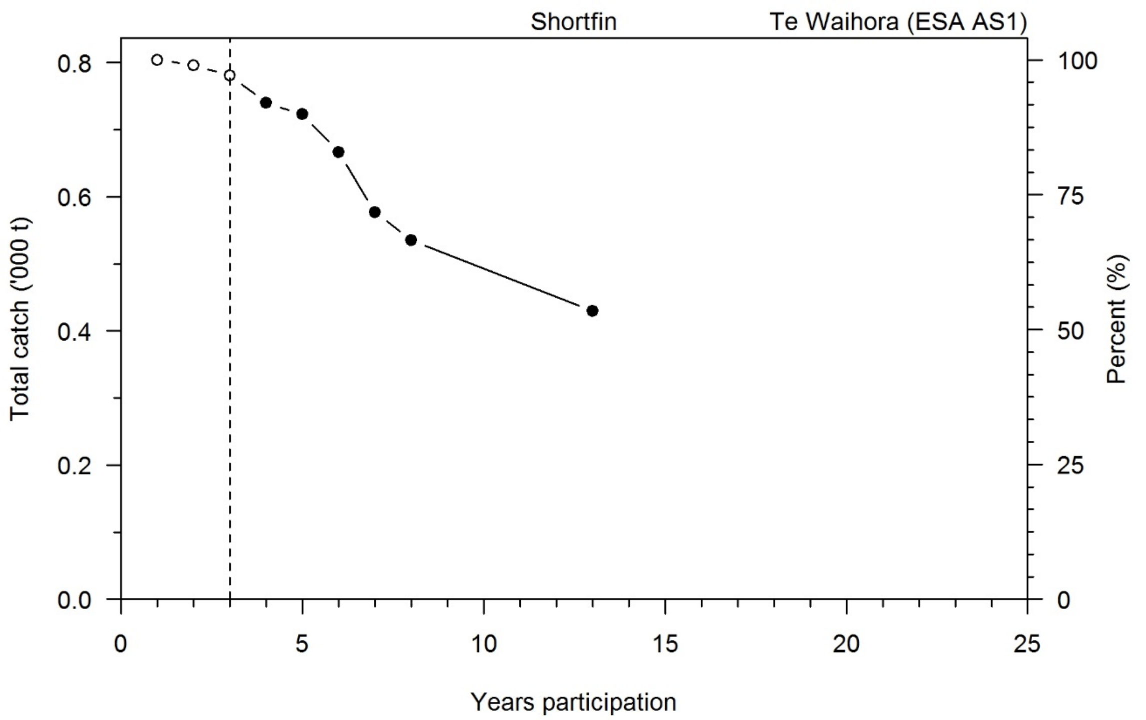

Figure A13: Relationship between years of participation in the AS1 (lake) fishery and shortfin total catch. The open circles represent all shortfin catch and the closed circles shortfin catch data from fishers who 1) caught shortfin in at least three years in each of which fishing took place in 10 days or more, and 2) caught more than 1000 kg over all years. Dotted vertical line represents 3 years participation and indicates the data included in the core shortfin fisher analyses for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

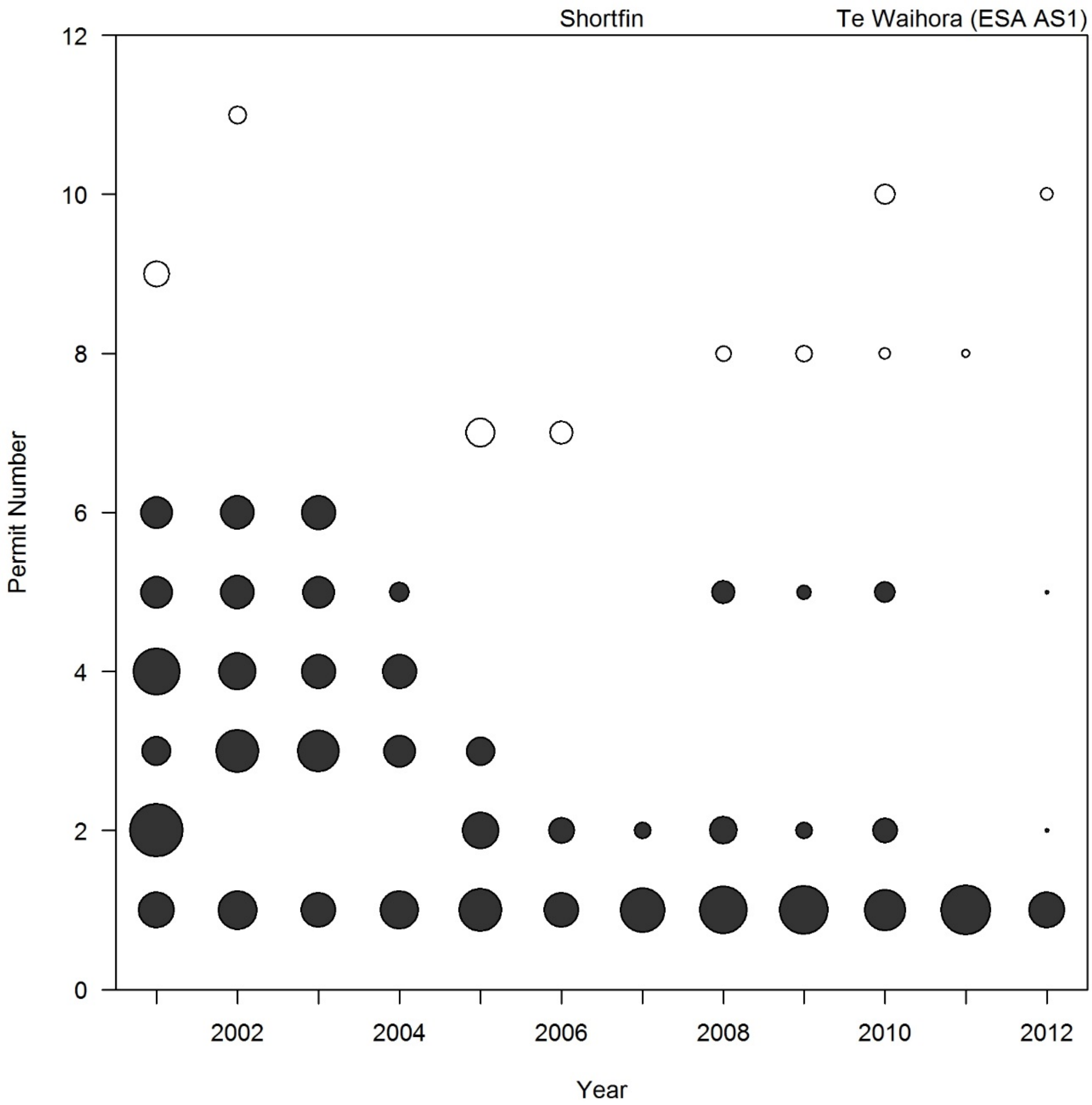

Figure A14: Relative catch of shortfin from all fishers (all circles) from AS1 (lake) for the years 2000–01 to 2011–12, and for core fishers (dark shaded circles) included in the catch per unit effort analyses (Te Waihora (ESA AS1)).

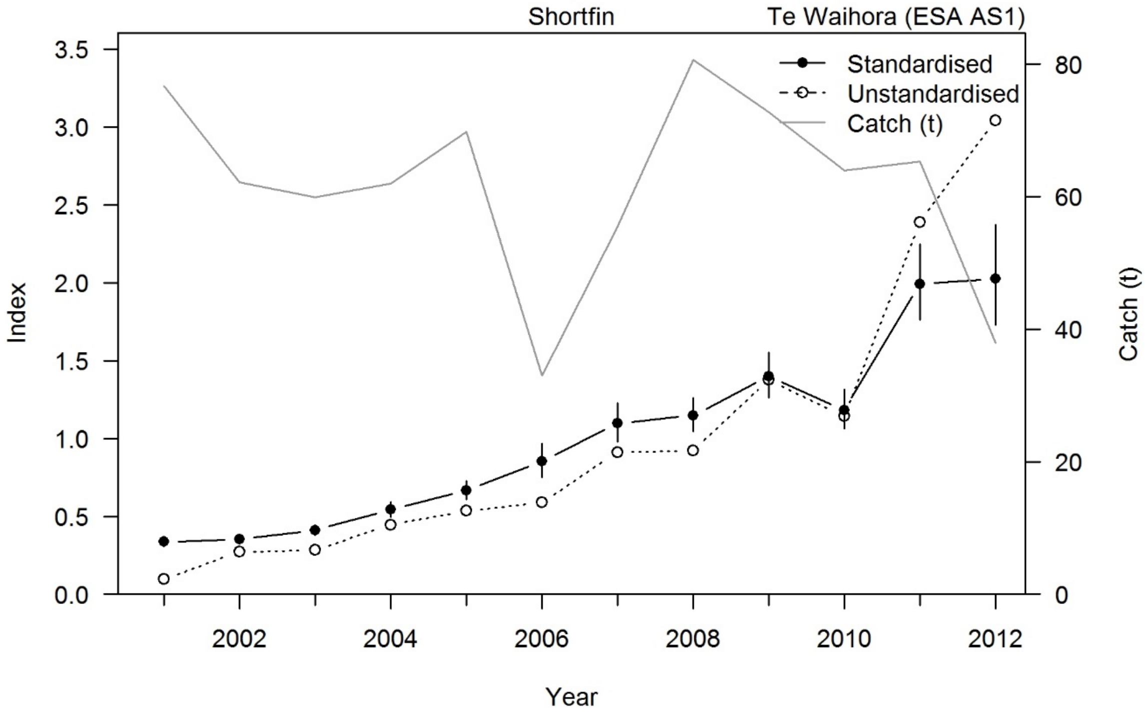

Figure A15: Indices of unstandardised catch per lift and standardised CPUE from AS1 (lake) for the core fishers shortfin CPUE model for the years 2000–01 to 2011–12. The catch by core fishers is also plotted (Te Waihora (ESA AS1)).

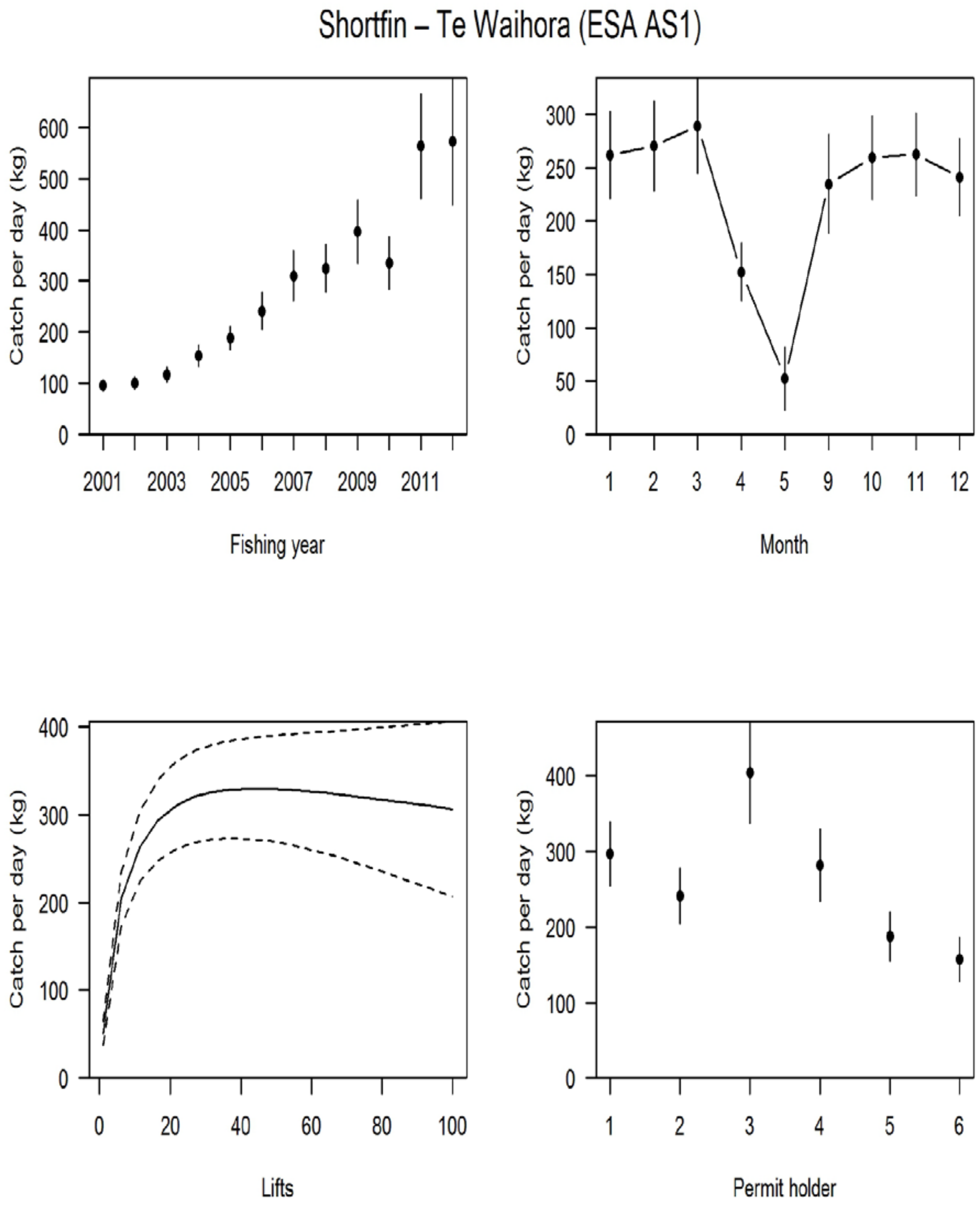

Figure A16: Expected catch rates (catch per day) for the shortfin CPUE model from AS1 (lake) for the years 2000–01 to 2011–12, for variables permit holder, lifts, and month. Bounds show the expected values and ±2 standard deviations (Te Waihora (ESA AS1)).

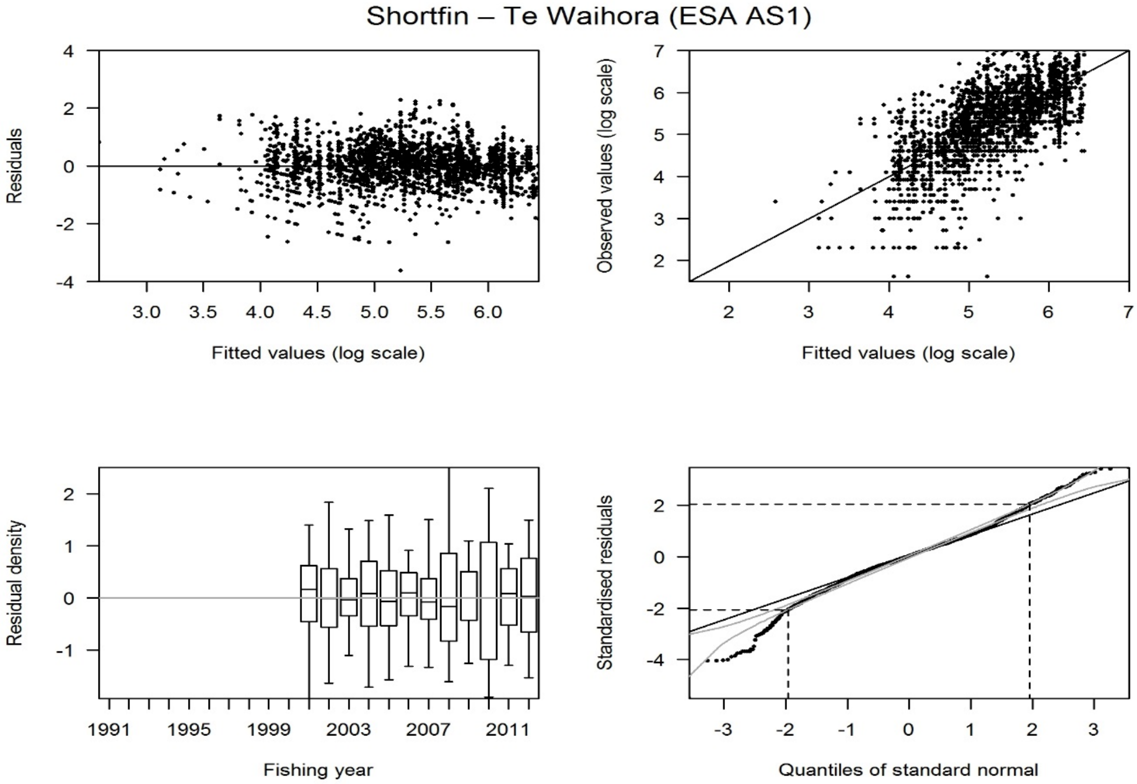

Figure A17: Residual diagnostic plots for the shortfin CPUE model from AS1 (lake) for the years 2000–01 to 2011–12. The grey lines on the quantile-quantile plot represent the 95% confidence envelopes of a standard normal distribution (Te Waihora (ESA AS1)).

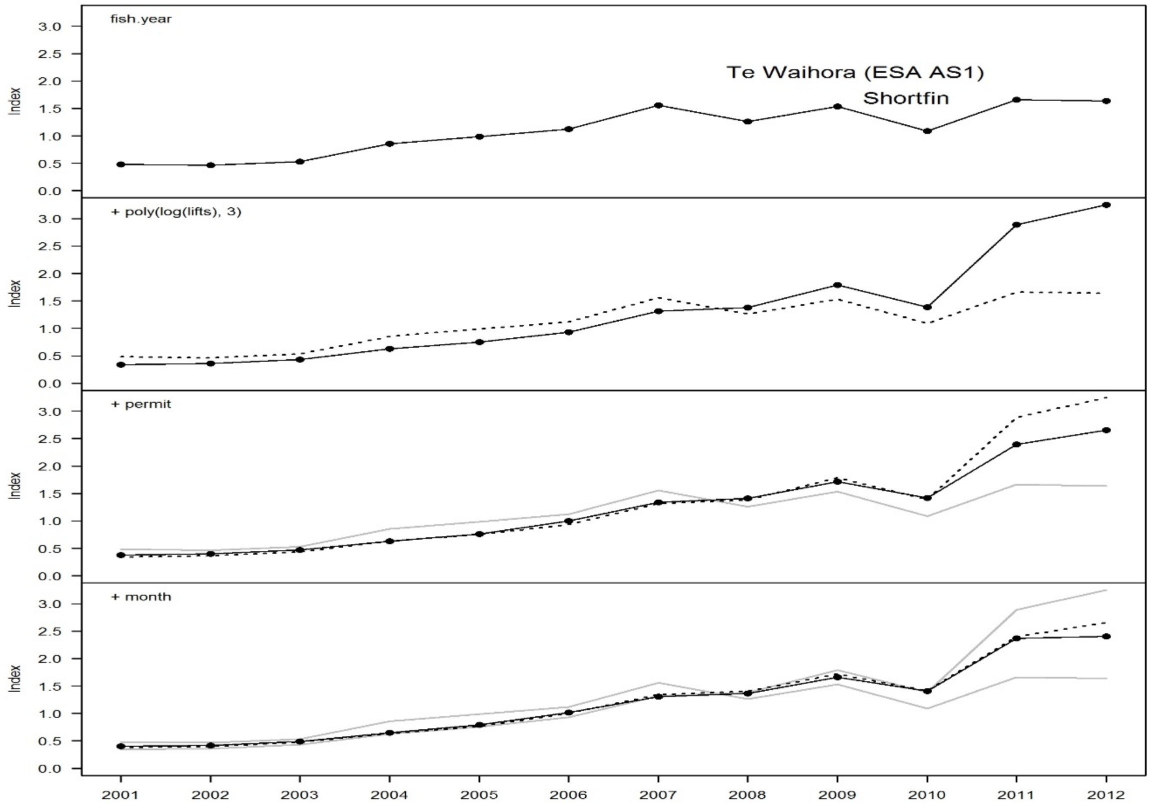

Figure A18: Step plot for the shortfin eel CPUE model from AS1 (lake) for the years 2000–01 to 2011–12. Each panel shows the standardised CPUE index as each explanatory variable is added to the model with the previous index shown by the dotted line and the grey lines for steps before that (Te Waihora (ESA AS1)).

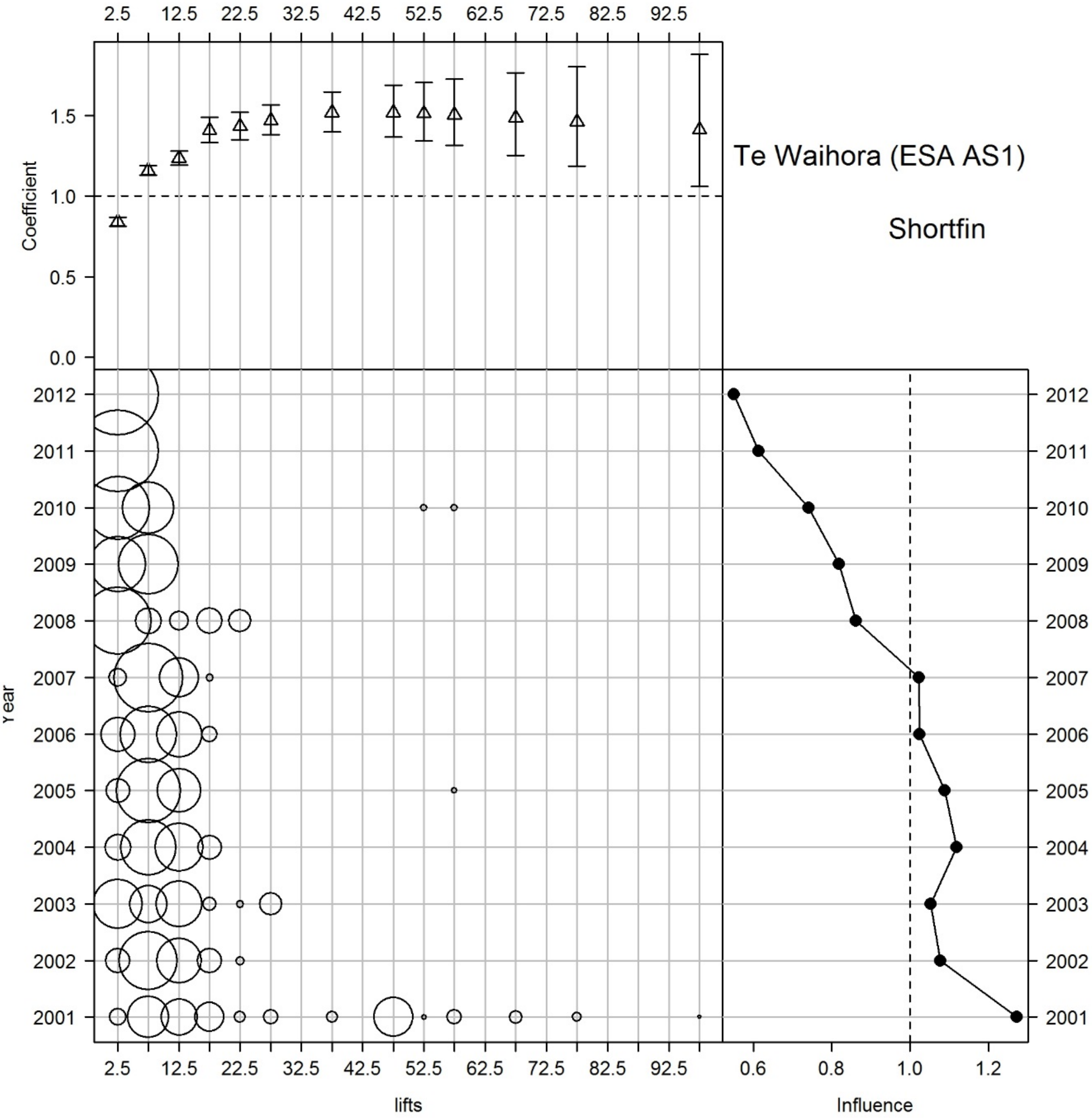

Figure A19: Influence of lifts for the shortfin CPUE model from AS1 (lake) for the years 2000–01 to 2009–10 (Te Waihora (ESA AS1)).

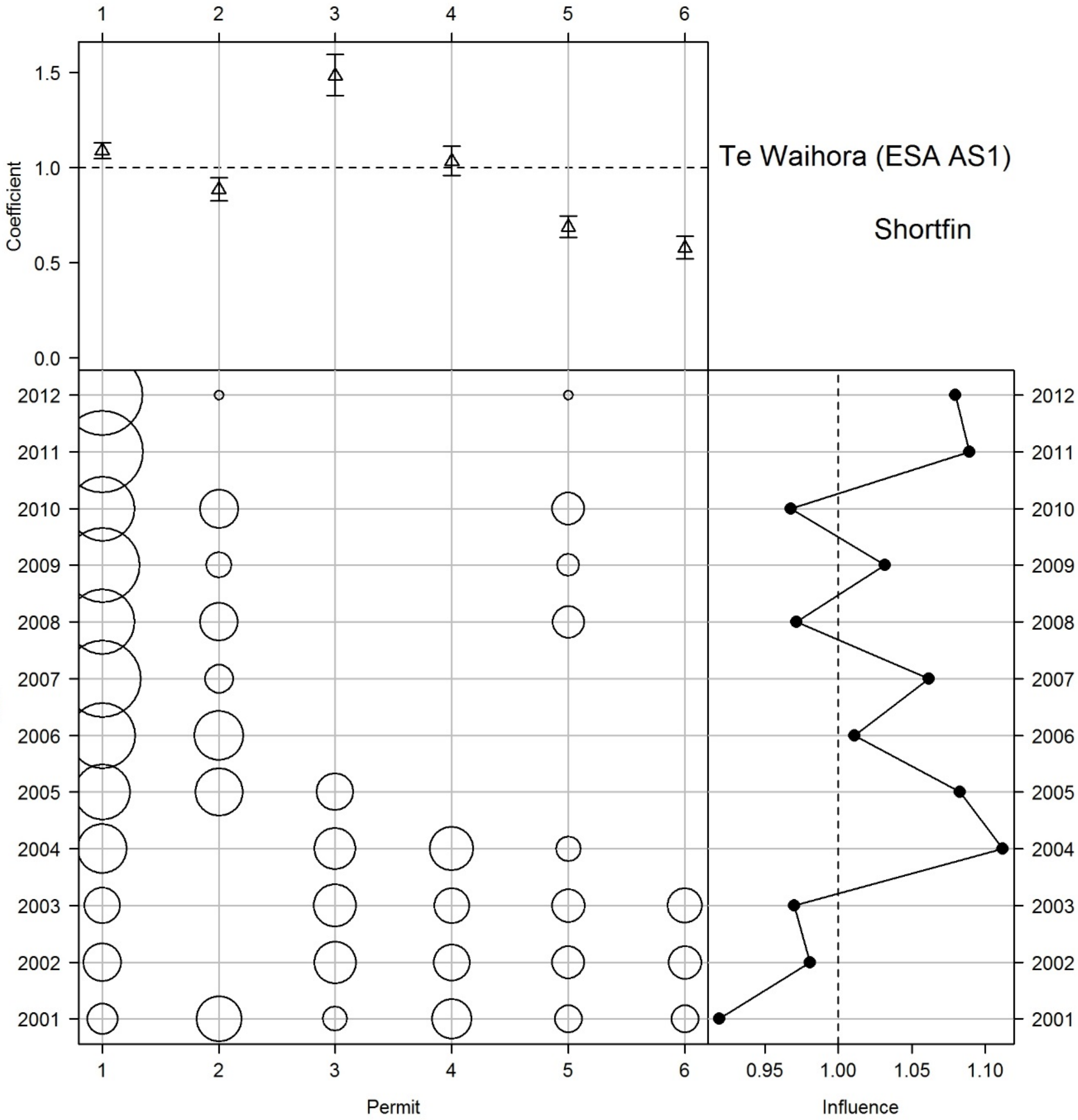

Figure A20: Influence of permit number for the shortfin CPUE model from AS1 (lake) for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

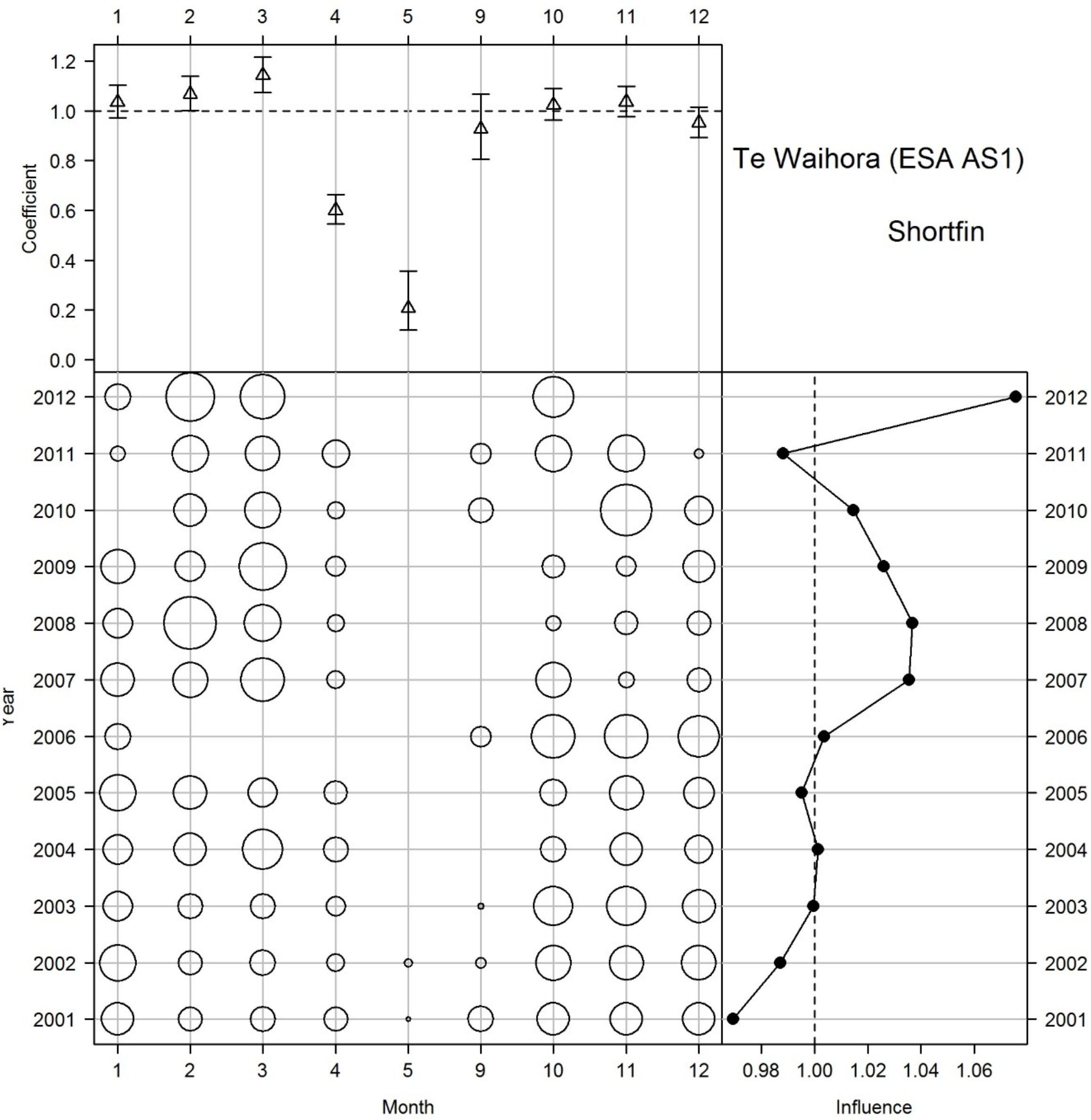

Figure A21: Influence of month for the shortfin CPUE model from AS1 (lake) for the years 2000–01 to 2011–12 (Te Waihora (ESA AS1)).

Appendix B: CPUE indices for shortfin for AS1. CI, 95% confidence intervals; s.e., standard error; CV., coefficient of variation; 2001 represents 2000–01 fishing year.

Year	Index	Lower	Upper	se	CV
2001	0.40	0.37	0.44	0.04	0.04
2002	0.42	0.39	0.45	0.04	0.04
2003	0.49	0.45	0.53	0.04	0.04
2004	0.65	0.59	0.71	0.05	0.05
2005	0.79	0.72	0.86	0.04	0.04
2006	1.01	0.89	1.15	0.06	0.06
2007	1.30	1.16	1.46	0.06	0.06
2008	1.36	1.24	1.50	0.05	0.05
2009	1.66	1.50	1.84	0.05	0.05
2010	1.41	1.26	1.56	0.05	0.05
2011	2.37	2.10	2.67	0.06	0.06
2012	2.41	2.05	2.82	0.08	0.08