Characterisation and Standardised CPUE analyses for blue mackerel (*Scomber australasicus*) in EMA 7, 1989–90 to 2008–09

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EXECUTIVE SUMMARY

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The commercial catch in EMA 7 varies greatly over time, both within and between fishing years. The landings for EMA 7 were low before 1995–96 with the average annual catch below 2000 t. The landings have increased since then and the annual catch has generally ranged between 2500 t and 5000 t, with a peak in 1997–98 at 8800 t. Landings exceeded the TACC in five of the last seven years. Inter-annual variation in catches is thought to reflect variable market demand rather than changes in stock abundance.

Blue mackerel in EMA7 is mostly taken as bycatch from the midwater trawl fishery, and sometimes as a target species from the purse seine fishery. The midwater trawl fishery in EMA 7 is estimated to have accounted for about 86% of the total catch in that fishstock and the target purse-seine fishery for about 13% of the total catch. Most of the catch from the midwater trawl fishery was taken in tows targeting jack mackerel, but there has been an increase of catch in which blue mackerel has been targeted over the last five years.

Catches are highly seasonal, with the target purse-seine fishery in EMA 7 mainly operating between March and May, and with the midwater trawl fishery mainly operating between July and August. The midwater trawl fishery operated off the west coast of the South Island through most of the 1990s, but since then there has been a shift of effort to the north over time where the fishery developed in the North Taranaki Bight and further north off the west coast of the North Island. Over the last five years, Statistical Area 041 has been the most important area for blue mackerel catch in EMA 7.

A standardised catch per unit effort (CPUE) analysis was carried out on the midwater trawl fishery where jack mackerel was targeted and blue mackerel was taken as bycatch. Because there was a dramatic change in the composition of the fleet that occurred during the mid to late 1990s, separate CPUE indices were derived for an early time series covering 1989–90 to 1997–98 and a late time series covering 1996–97 to 2008–09. For both time series, CPUE standardisations were conducted using allocated green weight landings from the trip-level data as stratified by statistical area, target species, and month (merged data), or using estimated catch from the tow-level data based on the TCEPRs. For the trip level data, zeros refer to effort strata with no allocated landings; for the tow-level data, zeros refer to tows with no estimated catch.

Estimates of relative year effects were obtained using a forward stepwise multiple regression method, where the data were fitted using a lognormal model. The CPUE models fitted to various subsets of data explained 24–56% of the deviances and diagnostics suggested no apparent departure from model assumptions. The CPUE indices derived for the trip-level data showed comparable trend to those for the tow-level data. For the early time series, the CPUE indices showed a generally flat trend; for the late time series, the CPUE indices showed a steep declining trend through to the early 2000s, and then remained relative flat with a slight increase over the last two years

A binomial-lognormal model was fitted to the late series of the trip-level data, where the proportion of zero catches was fitted using a logistic regression model. The model suggested there was little trend in the indices derived for the zero catches and the combined indices were similar to those for the positive catches.

An additional model was fitted to the late series of the tow-level data where a year * statistical area interaction was incorporated. The effect of the interaction was significant. However, the CPUE indices for most statistical areas showed a similar trend through the late 1990s to the early 2000s, suggesting that the changes in relative abundance were likely to be similar between subareas within EMA 7.

1. INTRODUCTION

Blue mackerel (*Scomber australasicus*) is a small- to medium-sized schooling teleost inhabiting epi- and mesopelagic waters throughout the Indo-Pacific, including the northern half of the New Zealand Exclusive Economic Zone (EEZ), where it supports moderate-volume commercial fisheries. It was introduced into the New Zealand fisheries Quota Management System (QMS) at the start of the 2002–03 fishing year and is managed as five separate Quota Management Areas (QMAs) or "fishstocks" at this time: EMA 1–3, 7, & 10 (Figure 1).

Little is known about the status of blue mackerel stocks. No estimates of current and reference biomass or yield are available. It is not known if recent catch levels are sustainable or at levels that will allow the stocks to move towards a size that will support the MSY (Ministry of Fisheries Science Group 2010). This report addresses the Ministry of Fisheries project EMA200803 Objective 1 "To update the descriptive analysis of the commercial catch and effort data for blue mackerel (EMA 7) with the inclusion of data up to the end of the 2008–09 fishing year", and Objective 3 "To update the standardised and unstandardised CPUE indices with the inclusion of data up to the end of the 2008–09 fishing year".

1.1 Recent research

Most recent research has focused on stock monitoring, principally commercial catch-sampling in both EMA 1 and 7 during 1997–98 (Morrison et al. 2001a), 2002–03 (Manning et al. 2006), 2003–04 (Manning et al. 2007a), 2004–05 (Manning et al. 2007b), 2005–06 (Devine et al. 2009), and is underway during the 2006–07 and 2007–08 fishing years at this time (P. Taylor, unpublished results from research project EMA2007/01). Age validation has recently been carried out using radioisotope dating methods and may provide support for the age estimates produced in the catch-sampling series (M. Manning, unpublished results from research project EMA2005/02). The age validation study also investigated optimal market sampling designs and some causes of imprecision in the age estimates produced and has led to improved protocols for preparing and interpreting blue mackerel otoliths (Manning & Marriott 2006). Associated biological relationships for New Zealand blue mackerel such as length-at-age, weight-at-length, and length- and age-at-maturity have also been quantified (Manning et al. 2006, Manning et al. 2007a, Manning et al. 2007b).

The catch per unit effort (CPUE) of the northern purse-seine fishery was examined by Morrison et al. (2001). These catch effort data held little or no information that would be useful in a stock reduction analysis. Some of the basic assumptions required for the application of CPUE analyses were also violated, due to the fishery targeting surface schools, and variability in fishing effort due to market forces, and the availability of other target purse-seine species, independent of blue mackerel abundance. Fu & Taylor (2007) developed standardised CPUE indices based on standardised commercial catch-per-unit-effort (CPUE) associated with the midwater trawl fishery for blue and jack mackerels in EMA 7. The indices they produced were split into two separate series to account for radical changes in the composition of the fleet during the mid- to late-1990s. Concerns over inter-annual variation in the indices produced led the Pelagic Fisheries Assessment Working Group to conclude that the extent to which these indices provide information on the true level of stock abundance is also uncertain.

2. BIOLOGY AND DISTRIBUTION

2.1 Stock structure

Using parasite markers and meristic characters, and based on their differences between areas, Smith et al (2005) showed that blue mackerel in the New Zealand EEZ are subdivided into at least three stocks in EMA 1, EMA 2, and EMA 7.

Blue mackerel are widespread in North Island and northern South Island waters. Bagley et al. (2000) presented summary distributions of blue mackerel from various datasets, and found that catches were from North and South Taranaki Bights, northern West Coast South Island southwards to the Hokitika Trench, and around Mernoo Bank. Taylor (2002) found that blue mackerel were distributed over most of the range covered by aerial sightings supporting purse-seine vessels, from the Three Kings Islands around the entire coastline of the North Island, and from the Kahurangi Shoals, outer Golden and Tasman Bays to Kaikoura, with the highest density on the east coast from North Cape to Hawke Bay, and in the area including the South Taranaki Bight to Kahurangi and the outer Golden and Tasman Bays.

Using recorded commercial and research catches, Taylor (2002) found that the geographical distribution and habitat of blue mackerel vary with life history stage. Hurst et al. (2000b) summarised life history stages of bottom trawl data from the research trawl and observer database and found juvenile and immature blue mackerel are northerly in their distribution around the North Island and into Golden and Tasman Bay, whereas adults have been recorded around both the North and South Islands to Stewart Island and across the Chatham Rise to almost the Chatham Islands.

2.2 Spawning

Smith et al (2005) suggested that two spawning centres have been reported for blue mackerel. Crossland (1981, 1982) used egg and larval surveys to show spawning in the Hauraki Gulf and east Northland. Hurst et al. (2000a) produced spatial distribution maps of fish in "ripe and running ripe" and "spent" condition using gonad staging data and showed spawning blue mackerel from a few tows off Tasman Bay and Taranaki in EMA 7.

Gonad staging data of blue mackerel collected from the research trawl and observer databases provide information on the presence and timing of spawning. There were few data available from either source before 2000 (see Table 19 in Taylor 2002). After 2003, more data became available from the observer program (generally over 1000 fish were sampled each year). These data provided some evidence that spawning of blue mackerel took place in EMA 7 over the summer period (Figure 42). However, Taylor (2002) cautioned that the reliability of the gonad staging data is unknown and there may be some difficulty in distinguishing between immature and resting gonads and early stage maturing.

2.3 Age and growth

Morrison et al. (2001a) estimated Von Bertalanffy growth curves using otoliths collected from the Tauranga purse-seine fishery, and from archived otolith from the west coast of the North Island, the Hauraki Gulf, and the Bay of Plenty (see Table 4 Morrison et. al 2001a). Manning et al. (2006) estimated Von Bertalanffy growth curves from the age and length data collected from the EMA 1 purse fishery and reported that the estimates were consistent with those of Morrison et al. (2001a). Both studies have found no apparent difference in growth rate between sexes.

2.4 Natural mortality

Morrison et al. (2001a) estimated instantaneous natural mortality (M) for both male and female fish using the method of Hoenig (1983). Based on age estimates from otoliths collected during the mid-1980s when fishing pressure was presumably light, natural mortality estimates of 0.22 for males and 0.20 for females were derived.

2.5 Length-weight relationships

The length–weight relationship for blue mackerel was estimated from a linear regression of log-transformed length and weight data from EMA 1 fishery (Manning et al. 2007b). This relationship supersedes an earlier relationship derived from Australian data (Manning et al. 2006). Differences in growth between EMA 1 and EMA 7 fish were assumed to be less than differences in growth of fish in New Zealand versus Australia waters (Devine et al. 2009).

3. Review of the fisheries

3.1 Commercial fishery

The commercial catch is caught by a variety of methods in all QMAs, but most is caught north of latitude 43 °S (Morrison et al. 2001a). The largest and most consistent catches across fishing years are by purse-seine vessels targeting blue mackerel schools in EMA 1–3 & 7. Catches by midwater trawl vessels targeting jack mackerels (*Trachurus* spp.) in EMA 7 are also important. Most of the purse-seine catch comes from the Bay of Plenty and east Northland, and the target purse-seine catch in EMA 1 is the single largest component of the catch by any method in any QMA (Morrison et al. 2001a). Total catches by QMA and fishing year are given in Table 1.

Total annual reported landings increased rapidly over the 1989–90 to 1992–93 fishing years and have fluctuated between about 6000 and 15 000 t in every fishing year since then (Table 1). Reported landings peaked at 15 128 t during 1991–92, of which about 70% was caught by purse-seine vessels (Morrison et al. 2001a), and have averaged 10 965 t between 2002–03 and 2006–07. Reported landings declined to 8973 t in 2007–08, and further to 6740 t in 2008–09.

There is considerable temporal variation in the catch within and between fishing years. Within a given fishing year, catches are usually highly seasonal, with the target purse-seine fishery in EMA 1 typically operating between July and December before the summer skipjack (*Katsuwonus pelamis*) season (Taylor 2008). There is somewhat less seasonality in the EMA 7 trawl fishery, but a peak in catch during the winter months (June to September), before the end of the fishing year has been observed in some years.

Manning et al. (2007b) and Taylor (2008) suggested that inter-annual variations in catch may reflect variable market demand and fishing effort rather than changes in stock abundance. In the purse-seine fishery, blue mackerel has become the second most preferred species because of decreased TACCs on kahawai. Skipjack tuna is the preferred species and blue mackerel are seldom targeted once the skipjack season has begun in late-spring, early summer. Thus, early arrival of skipjack can result in reduced volumes of blue mackerel being landed.

Management of company quota is complicated by the relative timing of the fishing season and the fishing year and this, along with the timing of the main market, may influence whether the blue mackerel TACC can all be taken in a particular year. The fishing season usually begins in about July-August, runs through the end of the fishing years, and finishes in about November. The main market for purse-seine blue mackerel takes up to 80% of the catch and requires premium fish to be available from early spring. To meet the demands of this market and to minimise the costs of storing fish from the previous season, fishing companies may carry over some proportion of their quota for a given year until fish become available the following season. If availability is delayed until after October 1, only 10% of the total quota can then be carried over into the new fishing year.

Because blue mackerel is taken principally as bycatch in the jack mackerel TCEPR target fishery in JMA 7, factors influencing the targeting of jack mackerel also affect blue mackerel landings. Other bycatch species taken in this fishery include barracouta, gurnard, John dory, kingfish, and snapper, and, although non-availability of ACE is unlikely to be constraining in the first three of these, the same is not true of kingfish and snapper. Fishing company spokespersons have stated that known hotspots of snapper are avoided. Other factors in this fishery include strategies to avoid the catch of marine mammals, and a code of practice in which gear is not deployed between 2 a.m. and 4 a.m.

3.2 Recreational fisheries

Recreational catch in the northern region (EMA 1) was estimated at 114, 000 fish by a diary survey in 1993–94, 47, 000 fish in a national recreational survey in 1996, 84, 000 fish (c.v 42%) in the 2000 survey and 58 000 fish (c.v 27%) in the 2001 survey (Ministry of Fisheries Science Group 2010). Estimates from other areas are very low (between 500 and 3000 fish) and are likely to be insignificant in the context of the commercial catch. Some confusion exists between blue and jack mackerels in the recreational data.

3.3 Customary non-commercial fisheries

Quantitative information on the current level of customary non-commercial catch is not available

3.4 Illegal and misreported catch

There is no known illegal catch of blue mackerel.

4. Catch per unit effort analysis

4.1 Methods

4.1.1 Catch and effort data sources

Catch and effort data were requested from the Ministry of Fisheries catch-effort database "warehou" as extract 7334. Two sets of data were requested. The first dataset consist of all fishing and landing events associated with a set of fishing trips that reported a positive landing of blue mackerel in EMA 7 between 1 October 1989 and 30 September 2009 (trip-level data). The second dataset consists of all fishing events associated with a set of fishing trips with at least one fishing event where blue or jack mackerels were targeted by either bottom or midwater trawling in all statistical areas in EMA 7 (033–048, 101–104, 701–706, and 801) between 1 October 1989 and 30 September 2009 (tow-level data). The fishing year extends from October 1 through to September 30 of the next calendar year. In this report, fishing year is labelled as the most recent year (*i.e.,* the 1998–1999 fishing year is referred to as 1999). Catches from EMA 7 were reported to FMAs (Fishery Management Area) 7, 8, and 9 before blue mackerel was introduced into the quota management system in October 2002. The fields requested from the database tables are listed in Table A1, Appendix A.

The estimated catch associated with the fishing events were reported on the general Catch Effort Landing Returns (CELR) and the more detailed Trawl Catch Effort and Processing Return (TCEPR). The green weight associated with landing events were reported on the bottom part of the CELR forms, or where fishing was reported on the TCEPR, on the associated Catch Landing Return (CLR). TCEPR forms record tow-by-tow data and summarise the estimated catch for the top five species (by weight) for individual tows. CELR forms summarise daily catches, which are further stratified by statistical area, method of capture, and target species. Trawl vessels less than 28 m in length can use either CELR or TCEPR forms; trawl vessels over 28 m must use TCEPR forms.

Information on total harvest levels are provided via the Quota Management Return (QMR) or the Monthly Harvest Return (MHR) system, but only at the resolution of Quota Management Area. The catch-effort and landing returns report catches at the level of individual fishing events, but the fishers are only required to report the top five species in their catch. This has led to concerns that bycatch species may not be well reported at the fishing event level (e.g. Phillips, 2001). For example, the Adaptive Management Program (AMP) review on SWA 1 (SeaFIC 2007) found that up to 40% of trips that landed from SWA 1 reported no estimated catch on TCEPR/CELR forms, and the landings tended to be small (less than 1 t).

The daily processed part of the TCEPR contains information regarding the catch (of all quota species) that was caught and processed that day, and these data are generally believed to provide a more accurate account of low and zero catch observations (Phillips, 2001). However, it has been suggested (SeaFIC 2007) that processed catch data can suffer from similar problems as the estimated catch data: trips that have no estimated catch, also tend to have no processed catch recorded. In addition, daily processed catch data suffer from the inability to assign processed catch to a specific day because catch is not always processed on the day it was caught and can be split among days. The daily processed catch is not examined in this study.

The extracted data are groomed and restratified to derive the datasets required for the characterisation and CPUE analyses using a variation of Starr's (2007) data processing method as implemented by Manning et al. (2004), with refinements by Blackwell et al. (2005), and Manning (2007) and further modified by Parker & Fu (unpublished results). The method allows catch-effort and landings data collected using different form types that record data with different spatial and temporal resolutions to be combined. It also overcomes the main limitation of the CELR and TCEPR reporting systems (frequent non-reporting of species that make up only a minor component of the catch). The procedure has been developed for monitoring bycatch species in the AMP, and is comprehensively described by Manning et al. (2004) and Starr (2007). The major steps are as follows.

Step1: The fishing effort and landings data are first groomed separately. Outlier values in key variables that fail a range check are corrected using median imputation. This involves replacing missing or outlier values with a median value calculated over some subset of the data. Where grooming fails to find a replacement, all fishing and landing events associated with the trip are excluded.

Step 2: The fishing effort within each valid trip is then restratified by statistical area, method, and target species.

Step 3: The greenweight landings for each fish stock for each trip are then allocated to the effort strata. The greenweight landings are mapped to the effort strata using the relationship between the statistical area for each effort stratum and the statistical areas contained within each fish stock.

Step 4: The greenweight landings are then allocated to the effort strata using the total estimated catch in each effort stratum as a proportion of the total estimated catch for the trip. If estimated catches are not recorded for the trip although a landing was recorded for the trip, then the total fishing effort in each effort stratum as a proportion of the total fishing effort for the trip is used to allocate the greenweight landings.

Step 5: The original intent of the merging process was to allow trip level landings data to be mapped to CELR effort strata. However, many species are captured in fisheries reporting using a combination of form types, and some may use TCEPR forms almost exclusively. The grooming and merging process also allows an evaluation of the amount of catch and effort that is not captured using TCEPR forms at the fishing event level. If significant, the best characterisation dataset is likely to be the merged trip-level data. But if the amount of lost catch and effort is predictable, minor, and stable over time and area, the estimated catch at the level of the fishing event provides a much more detailed dataset for characterisation and CPUE analysis.

Processed product weights in New Zealand fisheries are converted to greenweight catches using species and product-form-specific conversion factors (multiplicative constants). Product form conversion factors for many New Zealand species have changed several times since the full implementation of the QMS. This means that different amounts of greenweight catch are associated with the same amount of processed catch for particular product forms throughout the database. We standardise these changes relative to the latest conversion factor defined for each product state and apply the catch-consistency checking algorithm designed by Blackwell et al. (2005). This algorithm systematically compares the different catch weights recorded for a particular fishing trip against one another and returns the single most consistent catch type for each trip and explicitly and rigorously accounts for conversion factor changes.

The landings data provide a verified green weight landed for a fish stock on a trip basis. However, landings data include all final landing events – where a vessel offloads catch to a Licensed Fish Receiver, and interim landing events, where catch is transferred or retained, and may therefore appear subsequently as a final landing event (SeaFIC 2007). Starr's procedure separates final and interim landings based on the landing destination code, and only landings with destination codes that indicate a final landing are retained (see Table 2 in Starr (2007)).

4.1.2 Descriptive analyses

The characterisation analysis was based on the groomed, restratified, and merged dataset (trip-level data) where spatial and temporal trends in catch and effort in the fisheries were summarised to provide a description of how the fishery operates. In particular the distribution of blue mackerel catches was described by form type, and each form type was further described by fishing year for fishing method and target species. The spatial and temporal distribution of the purse-seine target fishery and the midwater trawl bycatch fishery was described by statistical area and month. The groomed tow level data were used to summarise finer scale information of catch effort distribution and characteristics of tow variables.

4.1.3 Standardised CPUE analyses

There were two major components in EMA 7: the midwater trawl fishery where effort was directed to jack mackerel and blue mackerel was taken as bycatch; and the purse-seine fishery, where blue mackerel was targeted. Taylor (2002) suggested the target purse-seine fishery was unlikely to provide a reliable set of abundance indices for blue mackerel, because the distribution of the catch and effort was patchy in time and space, and also because the effective effort cannot be easily measured when the species school at the surface and are bulk-caught in purse-seine nets with assistance of spotter planes. Following Fu & Taylor (2007), CPUE standardisations for EMA 7 were based on the midwater trawl jack mackerel target fishery where blue mackerel was caught. The groomed dataset was split into two time series, one extending from 1989–90 to 1997–98 and the other extending from 1996–97 to 2008–09, and separate CPUE indices were derived to account for the dramatic change in the composition of the fleet that occurred during the mid- to late 1990s (a shift from a bottom-trawl fishery executed by vessels about 3000 gross tonnes to a midwater trawl fishery executed by vessels about 4000 gross tonnes). The standardisation analysis was restricted to those data associated with large (more than 28 m in overall length) trawl vessels completing the TCEPR forms.

Separate standardised CPUE models were fitted, using the estimated catch of the tow-level data, or the allocated green weight landings of the stratified trip-level data. Utilising tow by tow data allowed for the trend in catch rates to be modelled using smaller spatial and temporal scales, and also enabled additional factors influencing CPUE to be included (such as tow distance or bottom depth). However, it is noted that under-reporting of estimated catch was common among the fisheries, where trips that landed EMA had reported no estimated catch, though the landed catch from such trips were in general unsubstantial (see Section 3.2.1). This aspect of TCEPR data omission therefore significantly affected effort and recorded number of tows but not catch; therefore changing CPUE. This is one major difference between the merged (stratified) and unmerged (tow-level) data.

Estimates of relative year effects in each CPUE model were obtained from a stepwise multiple regression method in which the data were modelled using a lognormal generalised linear model. A forward stepwise multiple-regression fitting algorithm (Chambers & Hastie 1991) was used to fit all models. The algorithm generates a final regression model iteratively and used the *fishing year* term as the initial or base model in all cases. The reduction in residual deviance relative to the null deviance, R^2, was calculated for each single term added to the base model. The term that results in the greatest reduction in residual deviance is added to the base model if this would result in an improvement in the residual deviance of more than 1%. The algorithm then repeats this process, updating the model, until no new terms can be added. A stopping rule of 1% change in residual deviance was used as this resulted in a relatively parsimonious model with moderate explanatory power. Alternative stopping rules or error structures were not investigated.

For trip-level data, the variables offered to the model were *fish_year, vessel_key, start_stats_area_code, month, and fishing_duration* (as a 3^{rd} order polynomial). For tow-level data, additional variables of *latitude*, *longitude*, *effort depth, effort width,* and *effort height* (as a 3^{rd} order polynomial) were added. The variable *fishing year* was forced into the model as the relative year effects calculated from the regression coefficients represent the change in CPUE over time. Year indices were standardised to the mean and were presented in canonical form (Francis 1999).

Vessel effects were incorporated into the CPUE standardisations to allow for possible differences in fishing power between vessels. Vessels not involved in the fishery for consecutive years, or that had only participated for 1–3 years, were excluded because they provided little information for the standardisations, and could result in model over-fitting (Francis 2001). Thus, CPUE analyses were undertaken for “core” vessels. Core vessels are those vessels that had reported positive catches of blue mackerel in the defined fishery for at least four consecutive years.

The dependent variable was the log-transformed landed catch per effort stratum when data were fitted on a trip-level resolution and the log-transformed estimated catch per tow when data were fitted on a tow resolution. Only the positive catches were retained, with zeros excluded. A zero refers to an effort stratum with no allocated landings for the merged dataset, or a tow with no estimated catch for the unmerged tow level data. Model fits were investigated using standard regression diagnostic plots. For each model, a plot of residuals against fitted values and a plot of residuals against quantiles of the standard normal distribution were produced to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors).

Two additional models were investigated. For the trip-level data, the proportion of strata with zero blue mackerel catch was examined for time trends and the effect of excluding those strata was examined by fitting a logistic model to the number of zeros and combining that time series with the log-normal time series following Vignaux (1994). For the tow level data, differences in the changes of relative abundance between areas were investigated using a model incorporating year*statistical area interaction.

4.2. RESULTS

4.2.1 Summary of catches

The reported QMR/MHR landings, the catch-effort landings (un-groomed), and the TACC for EMA 7 from 1983–84 through to the 2008–09 fishing year are shown in Figure 2. The catch-effort landings in the raw dataset conform closely with the reported MHR landings throughout the time series.

The average annual landings for EMA 7 before1995–96 were below 2000 t. The landings have increased since then and the annual catch generally ranged between 2500 t and 5000 t. The landings peaked in 1997–98 with a total catch of 8800 t. The TACC for EMA 7 was initially set at 3350 t in 2002–03 and has remained unchanged since then. The landings have overrun the TACC in 2002–03, 2004–05, 2005–06, and 2008–09.

The weight, number of records, and description of each potential landed state is given in Table 2. There are a significant number of landing events recorded under "T" (transferred to another vessel) and "R" (retained on board) destination codes (both are defined as interim landing events by Starr (2007). For EMA 7, the "T" events appear in the early part of the series through to the late 1990s and were recorded by vessels using CLR forms (Table 3). It was unknown how the catches from those trips were recorded, as the transferred catches could be landed by foreign vessels to ports outside New Zealand. Those transferred landing events accounted for more than half of the annual landings in some of the early years and excluding them from the dataset would lead to (1) retained landings falling short of the MHR by more than 50%, (2) a large number of trips with estimated catch, but no reported landings, and (3) annual estimated catch exceeding retained landings by up to 40% in some years. It is therefore prudent to retain the "T" landing events in the analysis but exclude other interim landing events as defined by Starr (2007).

The retained landings, interim landings, and total landings dropped during data grooming are shown in Figure 3. The grooming process has excluded a small number of trips with invalid codes in fishing method, target species, statistical area, and trip date that cannot be fixed using the median imputation method. The estimated catch and landings removed from the dataset in this process are generally insignificant throughout the time series. The retained landings were short of the reported MHR in the early 1990s, but match closely for the later part of the time series.

The groomed and unmerged landings are summarised by processed state in Figure 4. The bulk of catches were processed to "Dressed" state (DRE); a small proportion of catches were landed green in recent years, but that proportion was higher in early years; some catches were processed to "Head and Gutted" state (HGU) before 2002–03. The conversion factor for the "DRE" state was decreased from 1.80 to 1.50 from 1 October 1996. This means that different amounts of greenweight catch are associated with the same amount of processed catch for particular product forms throughout the database. Therefore the greenweights are standardised using the most recent conversion factor for each processed state. This assumes that the changes in conversion factors reflect improving estimates of the actual conversion factor when processing blue mackerel, rather than real changes in processing methodology across the fleet. The adjustment has slightly decreased the greenweight for the early part relative to the late part of the series (Figure 5).

The retained landings adjusted for the change of conversion factors were allocated to the effort strata using the relationship between the statistical area for each effort stratum and the statistical areas contained within each fishstock. Difficulties arise with effort strata associated with statistical areas that straddle stock management area boundaries (e.g. statistical areas 016, 017, and 018), as the proportion of catches to be allocated to each QMA cannot be determined. There are two alternative approaches to deal with trips fishing in a straddling statistical area. The first approach assigns a stock to the statistical area depending on where the majority of the straddling area resides. The second approach assumes that the catches of the straddling statistical area were taken from a single fishing stock if the trip only reported on that stock, and to exclude all the fishing and landing events from that trip that reported on multiple fish stocks. The second approach was used in this study to allocate green weight landings to straddling statistical areas. For EMA 7, about 3% of trips had reported on other stocks, accounting for less than 4% of the total catch.

The annual landings present in the raw dataset, retained landings in the groomed and unmerged dataset, and retained landings and estimated catches in the groomed and merged dataset are summarised in
Table 4 and plotted in Figure 6. Manning et al. (2004) calculated the recovery rate, defined as the groomed and merged landings as a proportion of the groomed and unmerged landings. The recovery rates are close to 100% in most years for EMA 7 (see Figure 5), indicating a consistent match between the recorded statistical areas on the CELR/TCEPR and the stocks reported on the CELR/CLR on a trip basis.

The estimated catches track the retained landings well through the time series (see Figure 6). The reporting rate, defined as the ratio of estimated catch to the retained landings appears to be consistent and is generally above 80% for catches recorded on the TCEPR forms (Figure 7). However, the reporting rate is much more variable for the CELR forms. In 1997 the total landings for the CELR forms were about 310 t but only 2.6 t of estimated catch was recorded. The reporting rate is also below 50% for 2001–2003. One reason for this is that many records have recorded the catch in wrong units (i.e. 100 t was recorded as 100 rather than 100000 kg). This has particularly affected the CELR records, as many fishing events are associated with large quantities of catch.

The proportions of estimated catches and retained landings by form type for each fish stock are shown in Figure 8. The bulk of estimated catches are recorded on the TCEPR forms (with the landings recorded on the corresponding CLR forms). The proportion of catch recorded on the CELRs is less than 15% for most years. However in 1998–99, about 50% of the catch was recorded on the CELR forms.

There were relatively large number of trips that landed blue mackerel but reported no estimated catch (Table 5). The proportion of such trips is well above 50% in most years. But this has mostly related to trips where a small amount of landings (usually less than 1 t, though there were exceptions) had been reported, for both CELR and TCEPR forms (Figure 9). Though estimated catches tend not to be recorded when catches are small (as vessels only reported the top five or, depending on form type, (now eight) species caught), overall the estimated catches capture approximately 80% of the harvest reported via the MHR/QMR system for EMA 7. There also appears to be a reasonably close match between estimated catch and reported landings at trip level (Figure 10).

4.2.2 Descriptive analyses

The majority of the blue mackerel catch was taken by midwater trawl (MS) and purse-seine (PS) methods in EMA 7 (Figure 11). MW accounted for 76% of the total catch between 1989–90 and 2008–09, and PS accounted for 20%. Before 1998–99, some catches were taken by the bottom trawl (BT) method, which accounted for up to 18% of the annual catch from 1989–90 to 1992–03. A minor portion of catch was taken by bottom pair trawl, set-net, and Danish seine. The high and low catches by MW generally do not coincide with those by PS except for 1998–99 when catch peaked in both fisheries. All the catches taken by midwater trawlers were recorded on the TCEPR forms, and those by purse-seine were recorded on the CELR forms.

4.2.2.1 Purse-seine fishery

The purse-seine fishery in EMA 7 is largely a target fishery and target fishing has accounted for over 90% of the annual catch since 1997–98. Before 1997–98, a large proportion of the catch was taken when the effort was directed at jack mackerel and kahawai, but those catches varied considerably between years (Figure 12). Blue mackerel was also caught occasionally when skip jack (SKJ) was the target species, which accounted for about 10% of the blue mackerel catch by PS in 2006–07.

The spatial distributions of purse-seine catches appear patchy (Figure 13). Fishing tended to concentrate in areas between Tasman and Golden Bay and the South Taranaki Bight (Statistical Areas 037–041), but also occurred as far north as near the top of North Island (Statistical Area 047). The exceptionally high catch in 1998–99 was mostly taken in Statistical Area 037. Catches were relatively consistent between February and May, and were sporadic in other months with no catch in more recent years (Figure Figure 14).

Distributions of catch rates by the purse-seine method are summarised for periods of every 5 years from 1989–90 to 2008–09 (Figure 16). The catch rates generally ranged between 0 and 100 t per set, but catch rates over 100 t per set were not uncommon. Between 1994–95 and 1999–2000, there appeared to be a large number of sets with catch over 50 t. Between 2000–01 and 2004–05, most fishing events had catch rates below 50 t per set. Between 2005–06 and 2008–09, the number of fishing events with higher catch rates appeares to have increased.

Before 1997, most of the fishing effort was directed at jack mackerel and kahawai, and the catch rates of blue mackerel were low (Figure 16). There was also a small amount of effort targeting blue mackerel in this period, but the catch rates were high (Figure 16). There was a major pure seine jack mackerel target fishery in Statistical Area 017 and 018 in the early 1990s (McKenzie 2008), but the fishery virtually disappeared by the end of 1990s. Since 1997, more effort has been directed at blue mackerel. The target catch rates increased from 2001 to 2005, and has been on average well above 20 t per set over the last few years (Figure 16).

4.2.2.1 Midwater trawl fishery

There was no midwater trawl catch of blue mackerel in 1989–90, but since then Figure 16it has become the largest fishery for blue mackerel in EMA 7. Blue mackerel catch from midwater trawl was taken mostly as bycatch when effort was directed at jack mackerel (Figure 18). The target catch of blue mackerel was usually small and also variable. There was no target catch from 1992–93 to 1993–94, or from 1999–2000 to 2001–02. However, since 2002–03, there has been an increase of targeted catch, which has accounted for 5 to 20% of the annual catches from midwater trawl (see Figure 18 and Table 6). Other target species in the fishery included hoki, barracouta, frostfish, and redbait. Before 1996–97 hoki target tows accounted for up to 30% of annual catches of blue mackerel by midwater trawl.

Fishing effort in the fishery has shifted from the south to the north over time (Figure 19). This appears to be the result of a northward movement of midwater trawl jack mackerel targeted effort in EMA 7 (McKenzie 2008). Before 1999–2000, the catches were stable in Statistical Areas 034–037 off the west coast of South Island. Then the fishery developed off the west coast of the North Island in Statistical Areas 040–042 and 045, and far off shore in Statistical Area 801. The catches in Statistical Area 041 (north Taranaki Bight) have been consistently high in the last 10 years. In 2008–09, about 70% of catch was taken from Statistical Area 041 alone.

Catches of blue mackerel from the midwater fishery exhibited a clear seasonal pattern, when they were caught mostly in the winter period with peaks in July and August (Figure 20). Over the last five years catches between October and January have increased.

Distribution of catch rates of blue mackerel by the midwater trawl are summarised for periods of every 5 years from 1989–90 to 2008–09 (Figure 21). The catch rates were mostly below 10 t per tow. Over the last five years, the number of tows with lower catch rates has apparently increased.

Blue and jack mackerel may be considered separate elements of a single mixed-species midwater trawl fishery in EMA 7. As effort targeting jack mackerel accounted for over 90% of the total catch, further analyses were restricted to jack mackerel target tows. We examined two subsets of data with respect to blue mackerel catch from jack mackerel target tows: one based on the tow-level data, where tows that reported no estimated catch of blue mackerel were considered zero tows, and the other based on the stratified and merged data, where effort strata (a unique combination of trip, target species, statistical area, and month) with no allocated green weight landings were considered zero tows. Figure 22 suggested that almost all trips with jack mackerel target tows had landed blue mackerel. Because a large number of those trips had reported no estimated catch (see
Table 5), the proportion of zeros defined at the tow level were much higher that that defined at the trip-stratum level. The proportion of zeros based on estimated catch ranged from 50% to 80%, and those based on the green weight landings ranged from10% to 40%, but both have shown an overall flat trend (Figure 23–left). The catch rates of blue mackerel (positive catches only) are much lower for the stratified and merged data (it contains many tows with zero estimated catch), but show a similar trend to those for the tow-level data (Figure 23–right).

The catch rates of blue mackerel from midwater trawl jack mackerel target tows were further examined for subareas within EMA 7, based on the stratified and merged data. The catch rates are variable and difficult to interpret (Figure 24). In areas off the west coast of South Island (Statistical Areas 034, 035, and 036), there has generally been an increasing trend in catch rates through the late 1990s, followed by a declining trend from 2000 to 2004. In South Taranaki Bight (Statistical Area 037 and 040), there has been an overall decreasing trend in catch rates through the time series, with the effort increasing through the early 2000s. In North Taranaki Bight and areas off the west coast of the North Island, there was little fishing before 2000. In Statistical Area 041, where most fishing effort was concentrated, the catch rate was exceptionally high in 2001–02, but dropped dramatically in the following year, and since then has remained relatively flat.

Distributions of blue mackerel catches from midwater trawl jack mackerel target tows on a fine spatial scale are shown in Figure 25. Effort moved from the south to the north through the early 2000s. Over the last few years, fishing operated in areas off the west cost of South Island, and the South and North Taranaki Bight.

Distributions of selected tow variables for jack mackerel target tows are shown in Figure 26. Most effort variables were variable in the early years, but they have become more stable in recent years. The average tow duration has increased over the last 10 years. The depth of the tow is generally below 200 m, and appears to have decreased since the late 1990s.

There were about 30 to 40 tows each year since 2004–05 that targeted blue mackerel. The average catch rates were over 15 t per tow (Figure 27). Fishing generally concentrated in the northern areas of the west coast of the South island and the northern Taranaki Bight (Figure 28). The distributions of tow variables are similar to those of the jack mackerel target tows, although fishing duration seems more variable between years (Figure 29).

4.2.3 Standardised CPUE analyses

4.2.3.1 The split of the vessel fleet

Core vessels were selected using the criteria described in Section 3.13. There were 15 vessels that had reported positive blue mackerel catches for each of at least four years (19 vessels had fished in the midwater trawl jack mackerel target fishery for at least four years, Figure 30). The core vessels made up about 25% of the fleet but accounted for over 80% of total catch of blue mackerel. The distribution of catches by core vessel is shown in Figure 31. There was an apparent temporal change in the fleet composition: most of the vessels that fished in the early 1990s appeared to have dropped out of the fishery by 1997–98, and since then the fishery has been dominated by seven vessels (vessels 1–7 in Figure 31, note that vessel codes were assigned for identifying those vessels in the report and do not correspond to any real vessel code). Those seven vessels are Ukraine vessels over 100 m in length and over 4000 t in tonnage. The early vessels are much smaller in size and power. A summary of the catch and effort by all vessels and by core vessels is given in Table 7. For both the merged and the tow-level datasets, the unstandardised CPUE by core vessels are close to those by all vessels after 1997–98. The proportions of zero catches are much higher for the tow-level data than for the merged data (see Section 3.2.2.1 for the explanation).

Based on the temporal change of fleet compositions, CPUE standardisations were carried out onan early time series from 1989–90 to 1997–98 involving vessels 8–15, and a late time series from 1996–1997 to 2004–05 involving vessels 1–7 (Figure 31). The split in the data series also coincided with the spatial shift of effort in the fishery, where the early vessels mainly fished off the west coast of the South Island (Statistical Areas 034–037) and the late vessels gradually fished towards the north (Statistical Areas 040–042, 045, and 801).

4.2.3.1 Standardised CPUE indices

CPUE indices for the fitted models are shown in Figure 32–Figure 38. Diagnostics for the main models are given in Appendix B. For each of the fitted models, residual plots suggested no apparent departures from model assumptions, and predicted catch rates by selected variables appeared to be reasonable (Figures B1–B8).

For the model fitted to the early time series of the stratified and merged data, variables *vessel*, *fishing duration*, *month*, and *statistical area* were selected, and 56% of the variability was explained by the model (Table B1, model 1). The standardised CPUE index declined from 1991 to 1993, and then increased to 1996, but overall the indices appeared to be relatively flat (Figure 32).

For the model fitted to the early time series of the tow-level data, variables *vessel* and *start latitude* were selected, and the model explained 39% of the variability in the data (Table B1, model 2). The standardised CPUE index increased to 1992, and then remained relatively flat with some fluctuations (Figure 33).

For the model fitted to the late time series of the merged data, the same variables were selected as for the early series with a different order of importance, and the model explained 45% of the variability in the data. The standardised CPUE indices showed a steep declining trend through to 2003, and then remained flat. The indices have increased over the last two years (Figure 34).

For the model fitted to the late time series of the tow-level data, variables *vessel*, *fishing day*, *start latitude*, and *effort height* (headline height) were selected, and the model explained 26% of variability in the data. The standardised CPUE indices declined sharply from 1998 to 2003, and then remained flat with a slight increase over the last two years (Figure 35).

The CPUE indices for the merged data were comparable to those for the for tow-level data. For the early series, the CPUE indices of the merged data exhibited different fluctuations to those of the tow-level data, but both showed a generally flat trend. For the late series, the CPUE for the two datasets showed similar trends, though the CPUE for the merged data had a much steeper decline (Figure 36).

For models fitted to the tow level data catch per hour was used as a measure of the CPUE. When catch per tow was used instead, variable *fishing duration* did not enter the model in the step-wise regression, and the resulting CPUE showed a less steep decline (see Figure 36). Given that there is a trend in the tow duration over time (see Figure 26), it is important that the effect of fishing duration on catch rates are incorporated in the standardisations.

For the binomial-lognormal model fitted to the late series of the merged data, the indices for the proportions of zeros show a flat trend, and the combined indices are very close to the indices based on the positive catches (Figure 37).

The last model investigated the differences in CPUE trends between statistical areas using the late series of the tow-level data. This was carried out in two steps. In the first step, the same regression used for model 4 was repeated, except that *start latitude* was replaced by *statistical area as* an explanatory variable. The resulting CPUE for each statistical area were different in scale (due to the differences in area effects), but have the same trend (Figure 38–the red line in each panel). In the second step, a *year * statistical area* interaction term was offered to the model and was subsequently selected. The CPUE for each statistical area represented the final standardised indices incorporating the interaction effects (Figure 38–the black line in each panel). The final standardised indices for each statistical area showed comparable trends to those from the model without the *year * statistical area* interaction, except for some evidently high catch rates in some areas and in some years (e.g. Statistical Area 036 in 1996–97). This suggested the changes in relative abundances were likely to be similar between statistical areas with EMA 7.

5. FISHERY DEPENDENT OBSERVATIONS

5.1 Aerial sighting

Taylor (2002) summarised the aerial sighting data from 1976 to 2001 from the purse-seine fishery to describe the spatial distribution of surface aggregations of blue mackerel schools (or mixed schools). The bulk of the aerial sighting data were from EMA 1. For EMA 7 the data were mostly recorded throughout the area north of Golden and Tasman Bays to the coast of the South Taranaki Bight, with some distributed sparsely inshore on the west coast of North Island. The aerial sightings data were also used to determine if there were any seasonal trends in the presence of aggregations at the surface. The mean monthly sightings were used as indicators of seasonal fluctuations and to determine any consistent patterns of seasonality. In EMA 7 the peak in mean monthly sightings generally occurred in March, but this pattern was not consistent over constituent years. However the seasonal pattern of blue mackerel sightings in EMA 7 was considered unreliable because of inconsistencies in search effort by spotter pilots between years (Taylor 2002).

5.2 Commercial catch length data.

Commercial catches of blue mackerel were sampled from a number of sources. Length and age data of blue mackerel were collected during limited sampling of purse-seine catch in EMA 1 during 1997–98 (Morrison et al 2001a) and 2002–03 (Manning et al 2006). A new sampling program was developed under the Ministry of Fisheries research project EMA200401 with the aim to representatively sample the target purse-seine catch in EMA 1 and the target purse-seine catch and catches by midwater trawl vessels targeting jack mackerels in EMA 7 since 2003–04.

Landings by purse-seine vessels targeting blue mackerel in EMA 1 and EMA 7 were sampled in fish processing factories in Tauranga using a stratified scheme in 2003–04 (Manning et al. 2007a), 2004–05 (Manning et al. 2007b), and 2005–06 (Devine et al. 2009). There was no formal spatial or temporal allocation of sampling effort. Samples were systematically collected from the vessel-hold strata in each landing where about 100 fish were randomly sampled from each hold at a rate of up to three samples per hold per day. Most samples were from EMA 1, and for EMA 7, the sample size was generally small, with only two or three landings being sampled each year (Table 8). The spatial and temporal distribution of the catch and sampling effort suggested that sampling data collected from EMA 1 may be representative of the fishery, and data collected from EMA 7 may not be representative at least for some years (Devine et al. 2009). In 2003–04 no target purse-seine vessel operated in EMA 7. Samples were taken from inshore trawlers who caught blue mackerel as bycatch (Manning et al. 2007b).

Blue mackerel catches by midwater-trawl vessels targeting jack mackerel in EMA 7 have been sampled at sea by the Ministry of Fisheries Observer Programme since 1987. The sampling scheme was described in full by Sutton (2002). Typically, about 100 fish were randomly sampled for length from the catch every two to three days during each fishing trip for length measurements. Samples were collected more frequently when larger catches of blue mackerel were made. However, observers were assigned to vessels opportunistically with no formal spatial or temporal allocation of sampling effort. The sample size was small in the early years, with generally fewer than 500 fish sampled each year. The sampling effort has significantly increased since 2003–04 under the new sampling Programme, with more tows sampled and over 2000 fish measured each year (Table 9). The MW-JMA fishery in EMA 7 appears to have been sampled adequately with respect to area, month, and target species, and the data collected were thought to be representative of the fishery in EMA 7 since 2003–04.

Scaled length frequencies were estimated for each of the fisheries using NIWA's catch-at-age software (Bull & Dunn 2002). For the purse-seine fishery, the catch samples were scaled up to each landed catch, summed over all landings. For the midwater trawl fishery, the length frequency of fish from each tow was scaled up to the tow catch weight, summed over all tows, scales up to the total catch in each trip, and then summed across the all trips, to yield overall length frequencies.

Length distributions of blue mackerel sampled from in EMA 7 generally ranged from 30 cm to 55 cm, and were strongly unimodal with the mode roughly centred around 48 cm in most years (Figure 39 and Figure 40). No fish smaller than 30 cm or larger than 55 cm in the purse-seine fishery were sampled, the fish sampled in 2004–05 and 2005–06 were smaller than those sampled in 2003–04 (samples in 2003–04 were from non-target catch). The midwater trawl bycatch fishery in EMA 7 caught few fish in the 30–40 cm size range and there were slightly more large fish caught before 2003–04. There appears to be no sign of mode progression present over time in the length distribution in any of the fisheries.

Otoliths were collected from all sampled landings, as well as by observers for each observed fishing trip between 2003–04 and 2005–06 for EMA 7. Scaled age distributions for the EMA 7 purse seine fishery and the midwater trawl fishery have been estimated by applying the age-length key to the scaled length frequency for 2003–04, 2004–05, and 2005–06 fishing years (see Figure 10 of Devine 2009, Figure 8 of Manning et al 2007b, and Figure 9 of Manning et al 2007b). The age distribution generally ranged between 2 and 25 years with slightly more young fish caught in the purse-seine fishery. Catch from the midwater trawl fishery had a slightly broader range.

6. FISHERY INDENDENT OBSERVATIONS

6.1 Research surveys

Bottom trawl surveys have been conducted since the early 1990's using either the *Tangaroa* (Chatham Rise survey or Sub-Antarctic Survey) or the *Kaharoa* (ECSI, ECNI, WCSI, WCNI). Some of those surveys encounter blue mackerel, but are not optimized to estimate biomass for this species. The length data collected from those research trawl voyages throughout New Zealand waters are summarised in Table C1, Appendix C). Length data of blue mackerel sampled in some of the early exploratory surveys conducted in the 1970s by other vessels (Ikatere and James Cook) were summarised by Taylor (2002).

Trawl surveys covering EMA 7 include time series of surveys conducted off the west coast of the North Island between 1985–86 and 1998–99 (Morrison et al 2001b, Morrison & Parkinson 2001), and surveys conducted off the west coast of the South Island and in Tasman and Golden Bays by RV Kaharoa in March-April from 1991–92 to 1996–97 (Stevenson & Hanchet 2000), and in July from 1994–95 to 1995–96 (Stevenson 1996, Blackwell & Stevenson 1997), as well as some of the early Kaharoa survey in Tasman and Golden Bay in the early 1990s, and three James Cook surveys in 1982–83, 1983–84 and 1984–85, and the 1990 Cordella survey on the west coast South Island, Taranaki Bight and Tasman Bay (Table 10).

Unscaled length frequencies of blue mackerel collected from those trawl surveys are shown in Figure 41. In most years, the length data were too few to provide useful length distributions, except for 1989–90 and 1995–96 when more than 300 fish were sampled. The resulting frequency distribution showed possibly four modes, centred at about 12, 20, 30 and 45 cm, two of which seem to be represented in a number of years: 20 cm in 1986–87, 1994–95, 1996–98, and 1999–2000, and 50 cm in 1991–92, 1994–95, 1996–97, and 1999–2000. This suggested some size classes may be more vulnerable to the gear, but the small sample size prevent any reliable interpretation. In 1989–90, length ranged from 11 cm to 53 cm, which was similar to the ranges recorded in 1981–82, 1994–95, 1996–97, and 1999–2000.

7. DISCUSSION

The commercial catch in EMA 7 varies greatly between fishing years. Inter-annual variation in catches is thought to reflect variable market demand rather than changes in stock abundance (Morrison et al 2001a). For example blue mackerel has become a more valuable alternative to jack mackerel as replacement for kahawai during the skipjack tuna off-season in EMA 1. Taylor (2002) suggested that irregular fluctuations in catch for bottom trawl, midwater trawl and purse-seine may have indicated lack of concurrence in availability of fish to main gear types rather than provided evidence of years of high or low abundance. There are other factors which influence catch and thus reduce the validity of using catch as an indicator of abundance. The low abundance of skipjack tuna in 1998-99 was considered to be the key factor that resulted in high catches of blue mackerel occurring for both the purse-seine and midwater trawl.

Catch seasonality showed mutually exclusive patterns for the purse-seine and midwater trawl methods in EMA 7: purse-seine catches were taken in most months except between June and August; midwater trawl catches were low for most of the year with a large peak in July and August. Taylor (2002) examined patterns in aerial sighting data and found that a large proportion of blue mackerel in EMA 7 is absent from surface schools during winter, but is present in subsurface schools mixed with jack mackerel, although these data were too patchy to provide a definitive seasonal pattern. He argued that blue mackerel change their behaviour in June–August and become more vulnerable to the midwater fleet, and that the fleet switch their strategy to take advantage of the change in fish behaviour.

Taylor (2002) suggested that CPUE is likely to be an unreliable indicators of changes in abundance for blue mackerel as they are highly mobile, both vertically within the water column and geographically between areas, and have the tendency to school by size. For the purse seine fleet, there is the tendency for fishers to target blue mackerel by size and the tendency for the catch rates to remain high when abundance is low. For the midwater trawl fleet where blue mackerel is taken as bycatch in the jack mackerel target fishery, there is the tendency at times to avoid blue mackerel as the preference for blue mackerel catch is driven by market conditions and also differs by fishing companies depending on the amount of blue mackerel quota each company own (Devine et al. 2009). However, fishers have suggested that a sounder-mark for jack mackerel schools has the same appearance as a mark for mixed schools of jack mackerel and blue mackerel (Taylor 2002), in which case the blue mackerel catch is largely beyond the control of vessel operators and will fluctuate according to the abundance of fish and the amount of fishing effort in the fishery.

The main CPUE models in this study were based on positive catches of blue mackerel from the midwater trawl jack mackerel target fishery using the merged data and/or the tow-level data. The CPUE indices produced for the two datasets were broadly similar. The merged data has incorporated trips that reported no estimated catch, but the landed catch from such trips is generally not substantial and there has been no apparent trend over time. Therefore CPUE indices based on tow-level data with catches from non-reported tows ignored may be preferable as factors affecting catch rates on fine spatial and temporal scales can be incorporated into the standardisations. However, if there have been changes over time in the amount of effort when under-reporting of blue mackerels occurred, it would be more appropriate to base the CPUE standardisations on the merged data.

The standardised CPUE indices have suggested a large decline of abundance from the late 1990s through to the early 2000s. However, there has been little evidence in the commercial catch sample data to support the decline of abundance in that there has been no great change in the length distribution. However it was noted that there appeared to be more large fish in the catch before 2003 although the sample size was generally too small in the early years to draw any firm conclusion.

Trends in proportion of zero catches could potentially inform changes in stock abundance, distribution, or fishing behaviour. The proportions of zero catches defined at tow-level were most likely to under-estimate the true encounter rate of blue mackerel in the fishery given the substantial amount of non-reported catch in the data. The proportions of zeros defined at trip-stratum level with allocated landings could partially correct for zero trips where under reporting occurred for all fishing events, but not for trips where some fishing events have under-reported the catch (an effort stratum will get zero allocated landing weight if all effort within the stratum has no estimated catch). Therefore the extent to which the use of merged data can improve the definitions of zero remains unknown. Some indication can be taken from the proportions of zeros defined for the two datasets which differed in magnitude but were similar in trends.

Length frequency distributions from observer and research trawl data presented here show differences in size ranges: length frequency distributions showed wider length ranges for the research trawl data (about 9–50 cm) with a predominance of small fish, and length frequency distributions from observer data were tighter and more structured, with narrower ranges (40–55 cm). Taylor (2002) suggested that the distribution of small fish is more coastal, resulting in their not being vulnerable to the TCEPR fleet fishing outside the 12 mile zone.

Blue mackerel catch in EMA 7 should be well monitored because most catches are captured by TCEPR forms although some minor catches are not reported as one of the top five species on this form. In addition, the fisheries encountering blue mackerel have several dominant vessels that account for most of the catch. Observer and market shed sampling in this area provides consistent length frequency and age distributions. Biology is reasonably well understood, but a few directed studies of reproductive development will enable robust maturity ogives to be determined. One limiting factor is that no biomass estimates are available from existing fishery independent surveys, which are not optimised for this species. The use of trawl or acoustic survey methodologies in monitoring jack mackerel in JMA 7 is currently under review, which suggest that a combined trawl or acoustic survey may be feasible (Cordue unpublished data).

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Table 1: Reported landings (t) of blue mackerel by QMA and where area was unspecified (Unsp.), from 1983–84 to 2004–05.

QMA	1	2	3	7	10#	Unsp	Total
1983–84*	480	259	44	245	0	1	1 029
1984–85*	565	222	18	865	0	73	1 743
1985–86*	618	30	190	408	0	51	1 297
1986–87†	1 431	7	424	489	0	49	2 400
1987–88†	2 641	168	864	1 896	0	58	5 627
1988–89†	1 580	<1	1 141	1 021	0	469	4 211
1989–90†	2 158	76	518	1 492	0	<1	4 245
1990–91†	5 783	94	478	3 004	0	0	9 359
1991–92†	10 926	530	65	3 607	0	0	15 128
1992–93†	10 684	309	133	1 880	0	0	13 006
1993–94†	4 178	218	223	1 402	5	0	6 026
1994–95†	6 734	94	154	1 804	10	149	8 945
1995–96†	4 170	119	173	1 218	0	1	5 681
1996–97†	6 754	78	340	2 537	0	<1	9 710
1997–98†	4 595	122	78	2 310	0	<1	7 106
1998–99†	4 505	186	62	8 756	0	4	13 513
1999–00†	3 602	73	3	3 169	0	0	6 847
2000–01†	9 738	113	6	3 278	0	<1	13 136
2001–02‡	6 368	177	49	5 101	0	0	11 695
2002-03‡	7 609	115	88	3 563	0	0	11 375
2003–04‡	6 523	149	1	2 701	0	0	9 374
2004-05‡	7 920	8	<1	4 817	0	0	12 746
2005-06‡	6 713	13	133	3 784	0	0	10 643
2006-07‡	7 815	133	42	2 698	0	0	10 688
2007-08‡	5 926	6	122	2 929	0	0	8 983
2008-09‡	3 147	2	88	3 503	0	0	6 740

* FSU data.
† CELR data.
\# Landings reported from QMA 10 are probably attributable to Statistical Area 010 in the Bay of Plenty (i.e., QMA 1).
‡ QMS data.

Table 2: Destination codes, total landing weight, number of landings and if the records were kept or discarded for all EMA catch in EMA 7 for 1989–90 to 2007–08.

Destination code	Greenweight (t)	No. records	Description	Action
L	59333.230	5137	Landed to a Licensed Fish Receiver	Keep
O	136.032	29	Conveyed outside New Zealand	Keep
D	30.815	43	Discarded	Keep
E	30.483	533	Eaten	Keep
A	3.178	4	Accidental loss	Keep
U	1.69	25	Used as bait	Keep
S	0.200	2	Seized by the Crown	Keep
C	0.014	1	Disposed to the Crown	Keep
F	0.012	4	Recreational catch	Drop
W	0.005	1	Sold at wharf	Drop
T	3976.395	264	Transferred to another vessel	Keep
R	2433.934	316	Retained on board	Drop
B	23.156	224	Stored as bait	Drop
Q	1.262	23	Holding receptacle on land	Drop
Null	0.212	1	Missing destination type code	Drop

Table 3: Number of landing events by major destination code and form type for EMA 7 in 1989–90 to 2008–09. "L" refers to "landed to NZ"; "T" refers to "transferred to another vessel"; "R" refers to "retained on board".

	CLR[1]				CEL				NCE		Total
	L	R	T	Other	L	R	T	Other	L	Other	
1990	17	34	21	13	119			1			205
1991	22	38	44	10	141			4			259
1992	32	42	56	4	182			14			330
1993	29	33	45	7	363			31			508
1994	58	43	25	26	344			27			523
1995	83	13	17	29	264			20			426
1996	65	2	12	5	151	4		16			255
1997	96	14	17	13	94	5		27			266
1998	155	11	11	42	41			18			278
1999	203	7	1	34	85	1		2			333
2000	176	2		15	73			9			275
2001	186	2		32	62			13			295
2002	265	6		43	26	1		15			356
2003	200	1		32	71			12			316
2004	170	7		36	30	3		24			270
2005	197	1		40	29	1		15			283
2006	155	5		32	32	1		10			235
2007	184	9		52	20			6	32	6	309
2008	202	7		46	6			4	63	17	345
2009	159	9		50	14			2	106	5	345
Total	2 654	286	249	561	2147	16	0	270	201	28	6 412

1. CLR are the landing forms for vessels using TCEPR forms

Table 4 The reported MHR, raw landings, retained landings in the groomed and unmerged dataset, and retained landings in the groomed and merged dataset, and estimated catches in the groomed and merged dataset for EMA 7 from 1989–90 to 2008–09.

Year	MHR	Raw landings	Groomed landings	Merged landings	Merged estimated catch
1990		1 536	1 489	1 255	1 465
1991		3 005	2 555	2 219	2 095
1992		3 607	3 468	3 296	2 953
1993		1 880	1 335	1 326	1 001
1994		1 402	1 236	1 229	1 010
1995		1 680	1 658	1 658	1 380
1996		1 480	1 025	1 022	653
1997		2 657	2 308	2 308	1 921
1998		2 425	2 315	2 297	2 082
1999		8 839	8 761	8 637	7 452
2000		3 171	3 169	3 168	2 922
2001		3 281	3 278	3 277	2 636
2002		5 098	5 087	5 087	4 338
2003	3 563	3 578	3 317	3 260	2 514
2004	2 701	2 747	2 565	2 565	2 330
2005	4 817	4 947	4 946	4 946	4 698
2006	3 784	3 888	3 662	3 662	3 367
2007	2 698	2 616	2 714	2 714	2 520
2008	2 929	2 972	2 851	2 787	2 528
2009	3 503	3 607	3 319	3 319	3 008

Table 5: Total number of trips, number of trips with zero estimated catch and percent of trips with zero estimated catch, by form type for EMA 7 from 1989–90 to 2008–09.

	CELR			TCEPR		
Year	Total	Zero	Percent	Total	Zero	Percent
1990	106	42	0.40	40	19	0.48
1991	138	75	0.54	47	14	0.30
1992	184	112	0.61	55	14	0.25
1993	363	123	0.34	40	11	0.28
1994	338	136	0.40	51	16	0.31
1995	263	116	0.44	67	16	0.24
1996	120	69	0.58	56	24	0.43
1997	88	58	0.66	74	25	0.34
1998	46	28	0.61	111	31	0.28
1999	69	20	0.29	151	95	0.63
2000	65	38	0.58	132	91	0.69
2001	60	30	0.50	126	93	0.74
2002	27	19	0.70	142	93	0.65
2003	66	34	0.52	134	87	0.65
2004	30	18	0.60	104	70	0.67
2005	27	14	0.52	130	80	0.62
2006	31	25	0.81	93	49	0.53
2007	18	8	0.44	106	53	0.50
2008	6	1	0.17	94	48	0.51
2009	9	0	0.00	93	53	0.57

Table 6: Landed catch (t) by fishing method and by target species, 1989–90 to 2008–09. PS, Purse-seine ; MW, midwater trawl; BT, bottom trawl; DS, Danish seine; SN, set net. KAH, kahawai; SKJ, skip jack; JMA, jack mackerel, EMA, blue mackerel; HOK, hoki, BAR, barracouta.

						PS						MW	BT	DS	SN	Other	Total
Fishing year	EMA	KAH	JMA	SKJ	Other	Total	JMA	EMA	HOK	BAR	Other	Total					
1990	629	346	99	0	0	1074	55	0	2	1	0	58	121	0	1	0	1254
1991	388	81	50	0	0	519	512	419	360	0	1	1294	402	0	3	0	2218
1992	50	8	58	0	0	116	2542	54	32	0	2	2631	546	0	4	0	3297
1993	290	22	77	0	0	389	520	0	110	54	0	685	240	0	12	0	1326
1994	210	9	76	0	0	296	625	0	210	3	0	842	76	0	15	0	1229
1995	107	50	2	0	0	159	1250	1	150	40	11	1448	32	0	19	0	1658
1996	274	1	138	0	0	413	364	0	170	14	1	544	60	0	4	0	1021
1997	0	126	181	0	0	306	1790	10	150	16	0	1964	33	0	4	0	2307
1998	0	0	0	0	0	0	1853	59	7	82	4	2006	289	0	2	0	2297
1999	3950	12	23	0	0	3986	4046	302	9	1	1	4358	23	268	1	0	8636
2000	419	13	0	0	0	432	2706	0	7	0	0	2713	22	0	1	0	3168
2001	524	20	0	0	0	544	2694	0	5	22	4	2725	6	0	2	0	3277
2002	483	3	0	0	0	486	4486	0	4	56	43	4588	12	0	0	0	5086
2003	929	55	27	1	0	1011	2130	112	0	0	0	2243	4	0	1	0	3259
2004	54	0	0	1	0	55	2269	133	0	100	0	2507	1	0	1	0	2564
2005	540	31	0	0	0	572	3486	413	1	450	16	4368	6	0	1	0	4947
2006	252	9	0	0	0	260	2636	743	0	2	18	3399	2	0	1	0	3662
2007	300	21	0	38	0	359	1953	358	0	36	0	2347	7	0	1	0	2714
2008	331	1	0	0	0	332	2119	281	7	34	11	2452	2	0	1	0	2787
2009	446	0	0	8	0	454	2386	461	0	12	2	2861	1	0	3	0	3319

Table 7: A summary of the CPUE datasets for all vessels and for core vessels, for the trip-level dataset and for the tow-level dataset. Effort is the number of tows and CPUE is catch (t) per tow. For the trip-level dataset, Zeros is the proportion of effort strata with zero landed catch; for the tow level dataset, Zeros is the proportion of tows with zero estimated catch.

Trip-level data					All vessels					Core vessels
Year	No records	Zeros	Catch	Effort	CPUE	No records	Zeros	Catch	Effort	CPUE
1990	18	0.39	55	88	0.63	12	0.17	55	86	0.64
1991	50	0.14	478	325	1.47	27	0.11	219	194	1.13
1992	114	0.32	2542	938	2.71	35	0.29	404	284	1.42
1993	55	0.35	520	388	1.34	23	0.30	211	191	1.1
1994	91	0.31	625	603	1.04	59	0.31	507	410	1.24
1995	110	0.28	1250	1248	1	60	0.28	939	821	1.14
1996	33	0.27	364	288	1.26	22	0.23	264	241	1.1
1997	95	0.27	1788	831	2.15	50	0.22	1244	539	2.31
1998	114	0.25	1849	874	2.12	74	0.26	1747	589	2.97
1999	77	0.17	4046	979	4.13	59	0.12	3227	801	4.03
2000	69	0.23	2706	879	3.08	64	0.22	2688	856	3.14
2001	100	0.14	2694	1423	1.89	93	0.13	2693	1414	1.9
2002	134	0.23	4486	1715	2.62	113	0.25	4484	1644	2.73
2003	183	0.32	2130	1971	1.08	175	0.32	2128	1947	1.09
2004	166	0.34	2269	1888	1.2	166	0.34	2269	1888	1.2
2005	167	0.26	3486	2185	1.6	162	0.26	3486	2179	1.6
2006	164	0.34	2635	1702	1.55	164	0.34	2635	1702	1.55
2007	211	0.33	1950	1886	1.03	197	0.32	1804	1796	1
2008	197	0.3	2119	1998	1.06	195	0.30	2119	1997	1.06
2009	185	0.27	2370	1741	1.36	178	0.28	2370	1730	1.37

Tow-level data					All vessels					Core vessels
Year	No records	Zeros	Catch	Effort	CPUE	No records	Zeros	Catch	Effort	CPUE
1990	104	0.35	51	68	0.75	90	0.26	51	67	0.76
1991	333	0.36	460	212	2.17	198	0.27	227	144	1.58
1992	1045	0.51	2397	509	4.71	305	0.64	340	110	3.09
1993	445	0.67	436	147	2.97	220	0.71	209	63	3.32
1994	717	0.71	496	210	2.36	474	0.7	381	142	2.68
1995	1379	0.64	1009	496	2.03	895	0.6	743	362	2.05
1996	376	0.67	265	125	2.12	310	0.64	228	112	2.04
1997	928	0.6	1702	367	4.64	568	0.57	1202	243	4.95
1998	974	0.54	1745	450	3.88	667	0.5	1645	336	4.89
1999	1039	0.4	3787	620	6.11	848	0.41	2969	499	5.95
2000	933	0.44	2456	520	4.72	908	0.44	2437	509	4.79
2001	1459	0.64	2427	520	4.67	1448	0.64	2427	517	4.69
2002	2009	0.66	3978	682	5.83	1921	0.65	3977	678	5.87
2003	2516	0.81	1869	475	3.93	2482	0.81	1868	469	3.98
2004	2224	0.67	2068	729	2.84	2224	0.67	2068	729	2.84
2005	2446	0.59	3282	1007	3.26	2438	0.59	3282	1006	3.26
2006	2177	0.76	2416	527	4.58	2177	0.76	2416	527	4.58
2007	2415	0.65	1855	835	2.22	2305	0.66	1720	787	2.18
2008	2338	0.66	1948	799	2.44	2336	0.66	1948	798	2.44
2009	2071	0.7	2106	625	3.37	2060	0.7	2106	625	3.37

Table 8: Number of landings, and number of fish measured for length for blue mackerel collected market sampling program in EMA 7 from the 2004, 2005, and 2006 fishing years.

Fishing year	Landings	Males	Females	Total
2004	3	30	26	56
2005	2	200	224	424
2006	2	313	281	594

Table 9: Number of trips, tows, and fish measured for length for blue mackerel collected by observers off the west coast of North Island and off the west coast of the South Island since the 1986–87 fishing year.

Fishing year	Trips	Tows	Males	Females	Total
1987	2	2	16	17	34
1989	1	3	63	79	197
1994	1	1	10	14	24
1995	1	5	33	102	135
1997	1	1	20	21	41
1998	2	7	218	209	427
2000	1	1	56	41	97
2002	4	27	197	181	378
2003	4	57	268	289	557
2004	3	38	938	1060	1998
2005	6	34	448	439	3288
2006	7	69	1637	1590	3462
2007	14	138	2691	2367	5071
2008	15	162	3092	3869	6971
2009	12	136	3738	4015	7757
2010	3	34	1491	1285	2796

Table 10: Sources of fish length data and key information of blue mackerel collected from research trawl voyages in EMA 7 since 1981–82.

Year	Trip code	Vessel	length (cm) Min	Max	No of fish measured	Areas*
1981–82	kah8205	Kaharoa	16	30	6	TASB,GLDB
1982–83	jco8306	James Cook	46	51	5	WCSI,TASB
	kah8216	Kaharoa	17	18	2	TASB,GLDB
1983–84	jco8415	James Cook	47	51	6	WCSI
1984–85	jco8420	James Cook	53	53	1	PALL,SNDS ,WCNI,TASB
1986–87	kah8612	Kaharoa	15	27	68	WCNI
1987–88	kah8715	Kaharoa	20	20	2	WCNI
1989–90	cor9001	Cordella	15	53	313	WCSI,NTKB,STKB,TASB
1991–92	kah9111	Kaharoa	48	51	2	WCNI
	kah9204	Kaharoa	46	49	2	WCSI,TBGB
1994–95	kah9410	Kaharoa	13	22	73	WCNI
	kah9504	Kaharoa	46	51	12	TBGB,WCSI
	kah9507	Kaharoa	18	18	1	TBGB
1995–96	kah9608	Kaharoa	10	21	325	TBGB
1996–97	kah9615	Kaharoa	12	26	39	WCNI
	kah9701	Kaharoa	47	50	5	TBGB,WCSI
1999–00	kah0004	Kaharoa	48	50	5	TBGB,WCSI
	kah9915	Kaharoa	15	48	183	WCNI
2002–03	kah0304	Kaharoa	47	49	3	TBGB,WCSI
2004–05	kah0503	Kaharoa	49	49	3	TBGB,WCSI
2006–07	kah0704	Kaharoa	49	49	1	TBGB,WCSI

*** Areas descriptions as follows:**
GLDB, Golden Bay; TASB, Tasman Bay; TBGB, Tasman Bay and Golden Bay combined; NTKB, North Taranaki Bight; STKB, South Taranaki Bight; WCSI, West Coast South Island; WCNI, West Coast North Island; PALL, Palliser Bay; SNDS, Malborough Sounds

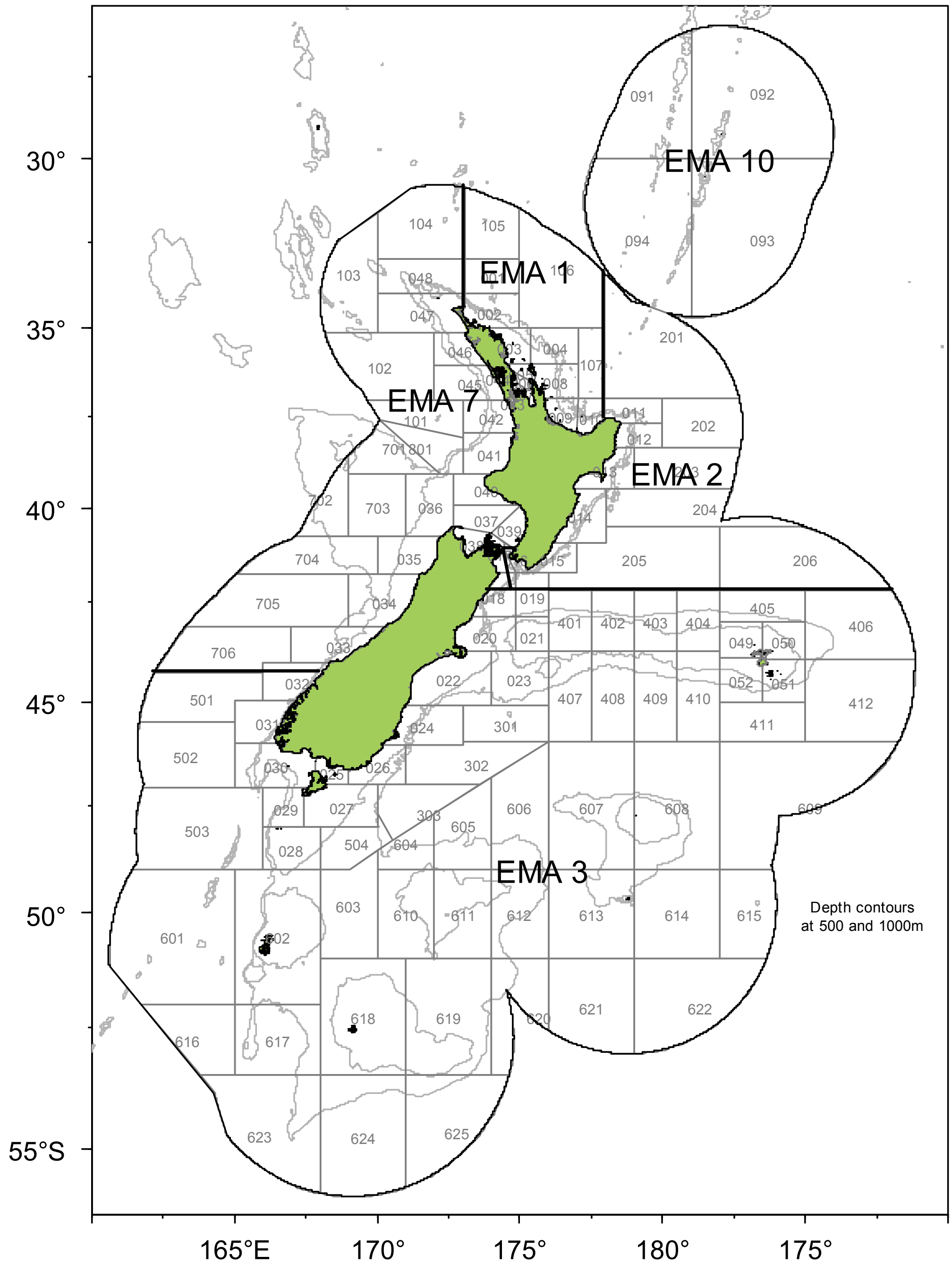

Figure 1: Map showing the administrative fishstock boundaries for EMA 1, EMA 2, EMA 3, EMA 7 and EMA 10, including statistical areas, and the 500 m and 1000 m depth contours

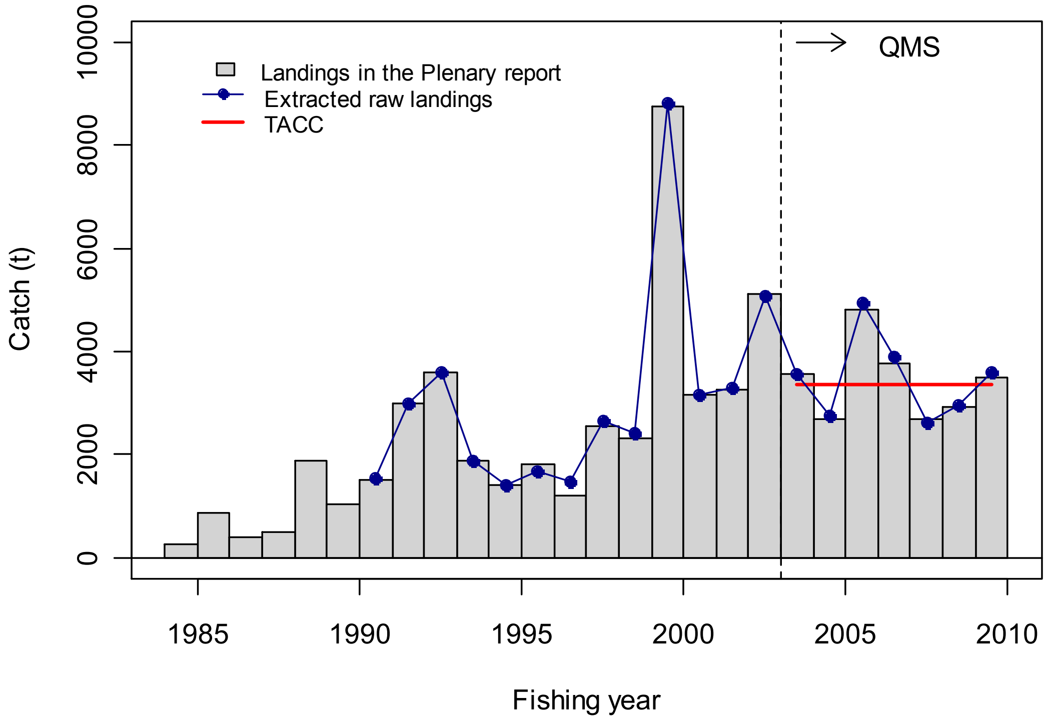

Figure 2: The QMR/MHR landings (gray bars), un-groomed catch effort landings (dotted line), and TACC (line) for EMA 7 from the 1983–84 to 2008–09 fishing year.

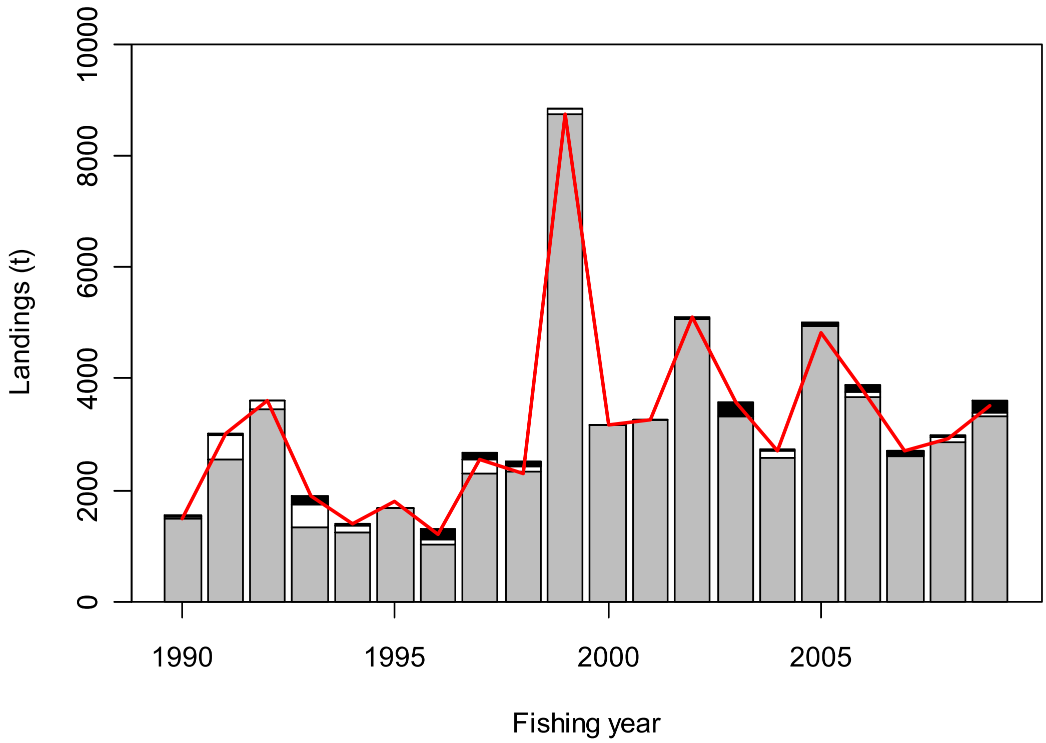

Figure 3: The retained landings (gray bars), interim landings (white bars), and landings dropped during data grooming (black bars), and MHR landings (line) for EMA 7 from the 1989–90 to 2008–09 fishing year

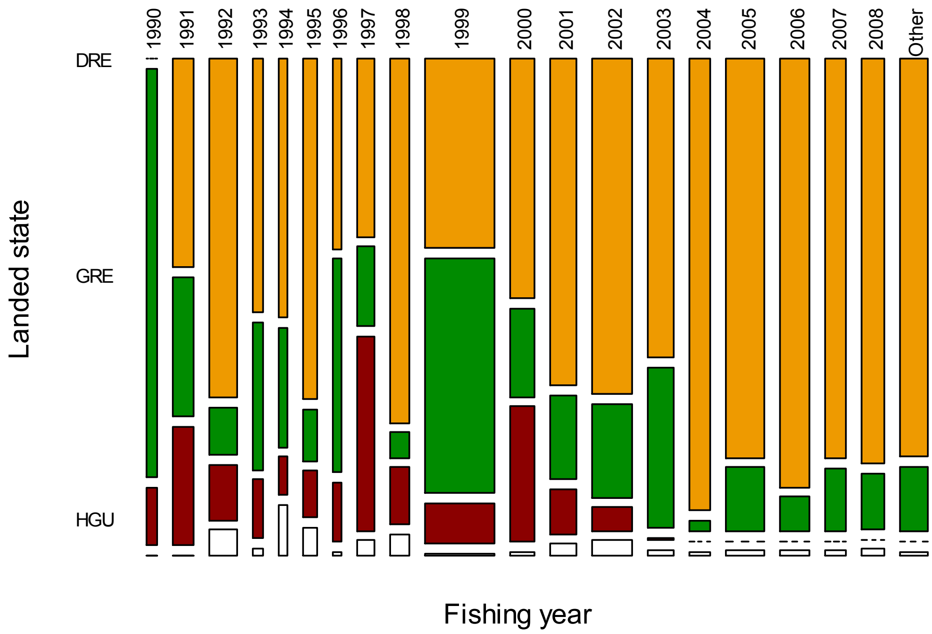

Figure 4: The proportion of retained landings (greenweight) by processed state for EMA 7 from the 1989–90 to 2008–09 fishing year in the groomed and unmerged dataset. "DRE", "dressed"; "GRE", "Whole or Green"; "HGU", "Headed and Gutted". White portion of the bar represents other processed state combined.

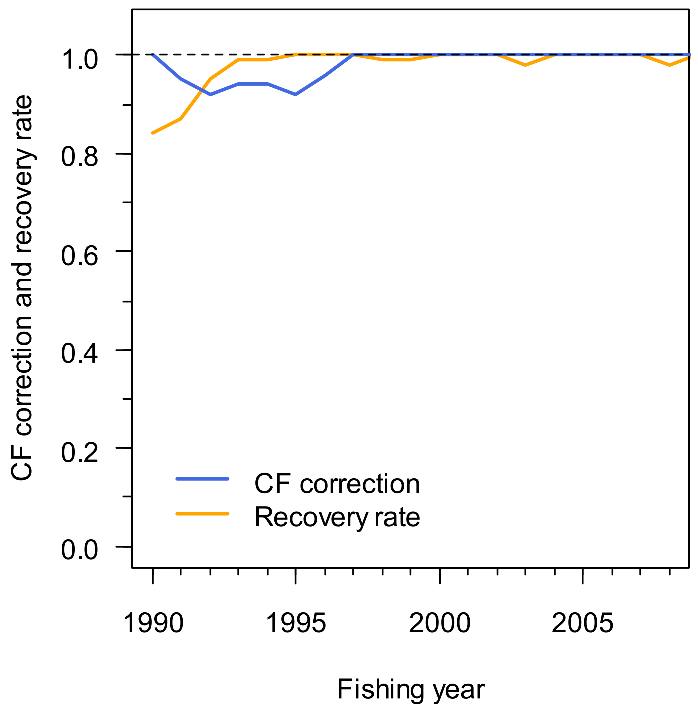

Figure 5: The conversion factor (CF) corrections, defined as the ratio of annual green weight recalculated using the most recent correction factors for each processed state to the reported green weight, and the recovery rate, defined as the ratio of annual landings in the groomed and merged dataset to those in the groomed and unmerged dataset, for EMA 7 from the 1989–90 to 2008–09 fishing year.

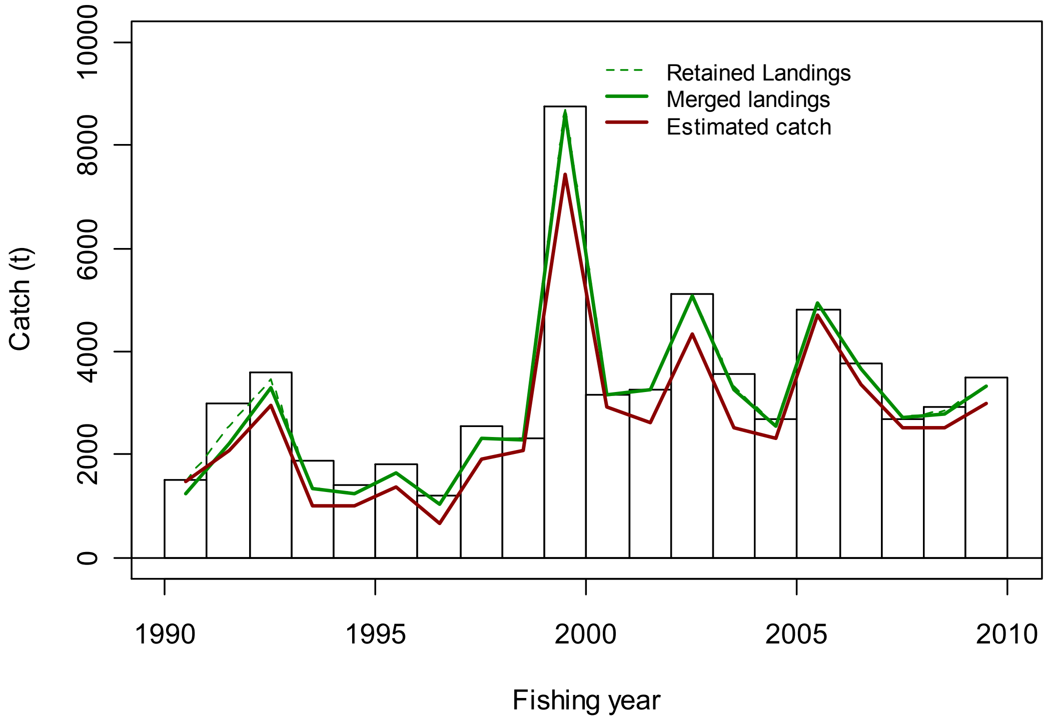

Figure 6: The QMR/MHR landings (white bars), retained landings in the groomed and unmerged dataset, retained landings in groomed and merged dataset, and estimated catch in the groomed and merged dataset, for EMA 7 from the 1989–90 to 2008–09 fishing year.

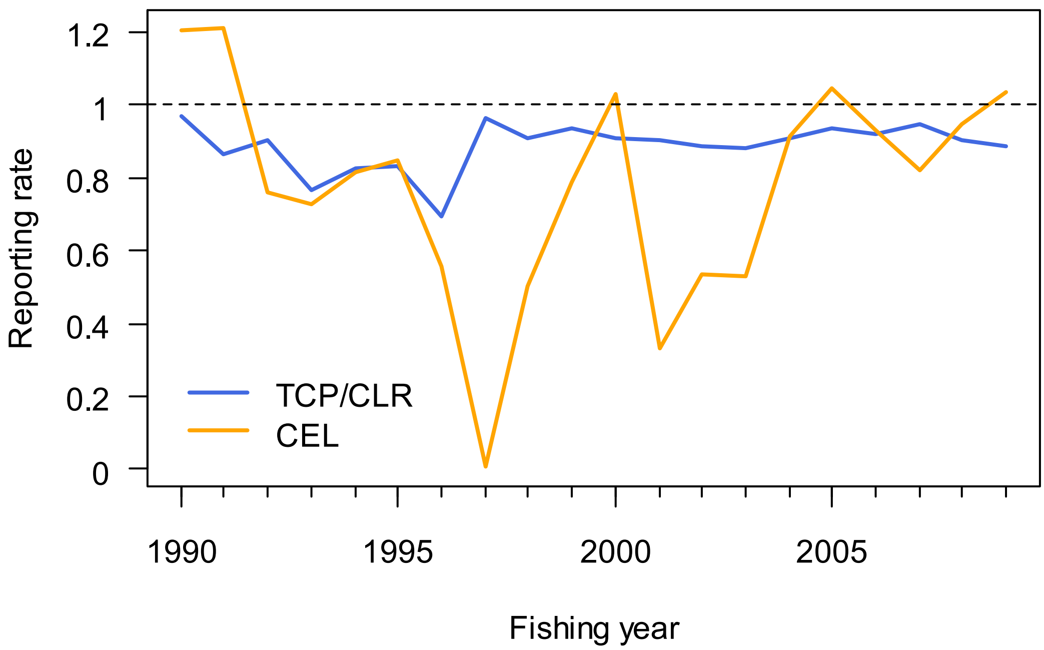

Figure 7: The reporting rate, defined as the ratio of estimated catch as a proportion of retained landings in the groomed and merged dataset by form type, for EMA 7 from the 1989–90 to 2008–09 fishing year.

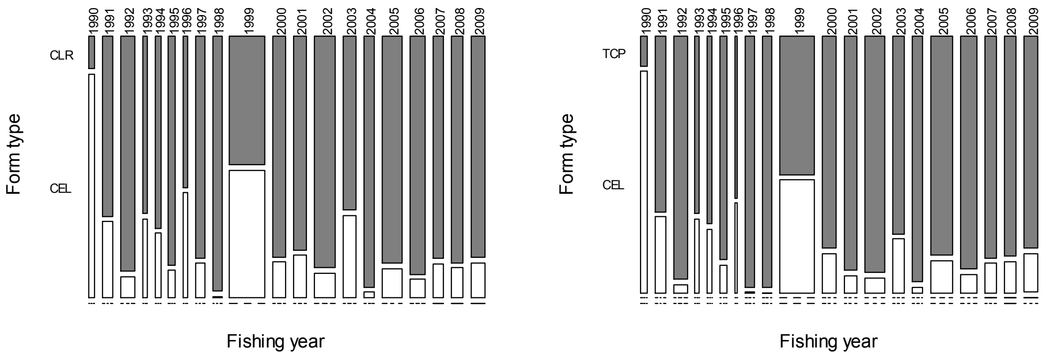

Figure 8: Proportion of landings by form type (left panel) in the groomed and unmerged dataset, and proportion of estimated catches by form type (right panels) in the groomed and merged dataset, for EMA 7 from 1989–90 to 2008–09 fishing year. The width of the bar is proportional to the annual catch (only comparable within each panel).

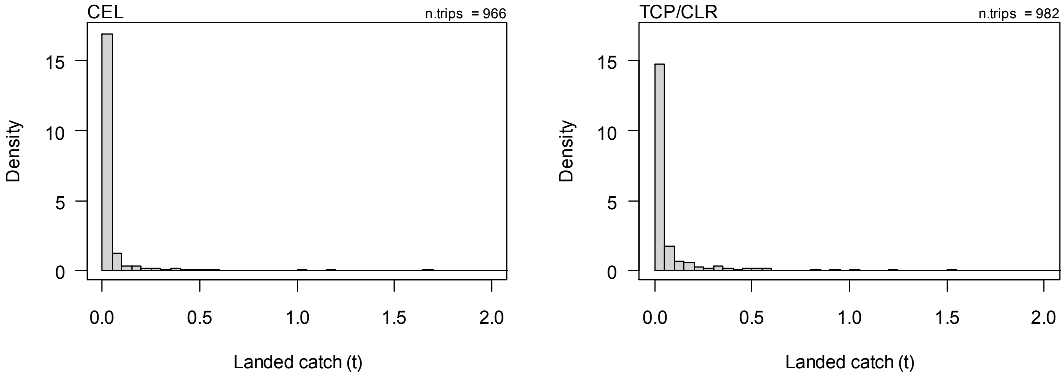

Figure 9: The distribution of reported landing weights for trips that recorded no estimated catch by form type for EMA 7 from the 1989–90 to 2008–09 fishing year

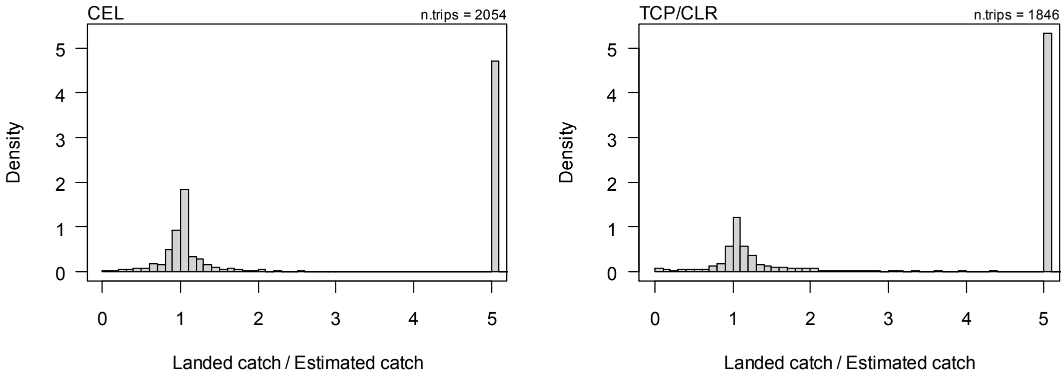

Figure 10: Distribution of the ratio of the landed catch to estimated catch for the CELRs and TCEPRs/CLRs respectively. Where estimated catch is zero, the ratio is arbitrarily placed at 5 in the x axis.

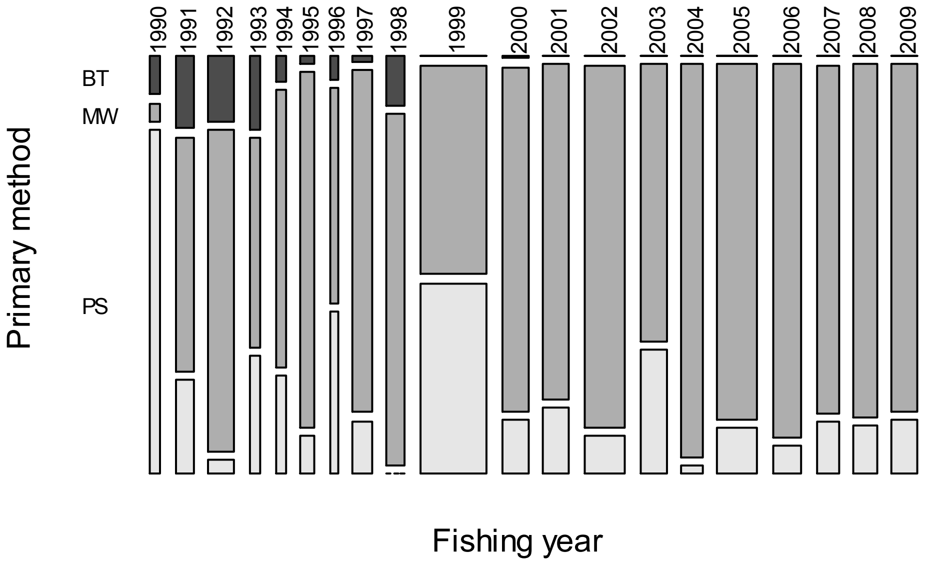

Figure 11: Distribution of catch in EMA 7 by major fishing methods, 1989–90 to 2008–09 fishing year. The top three fishing methods are shown. BT, bottom trawl; MW midwater trawl; PS, purse-seine. The width of the bar is proportional to the annual catches.

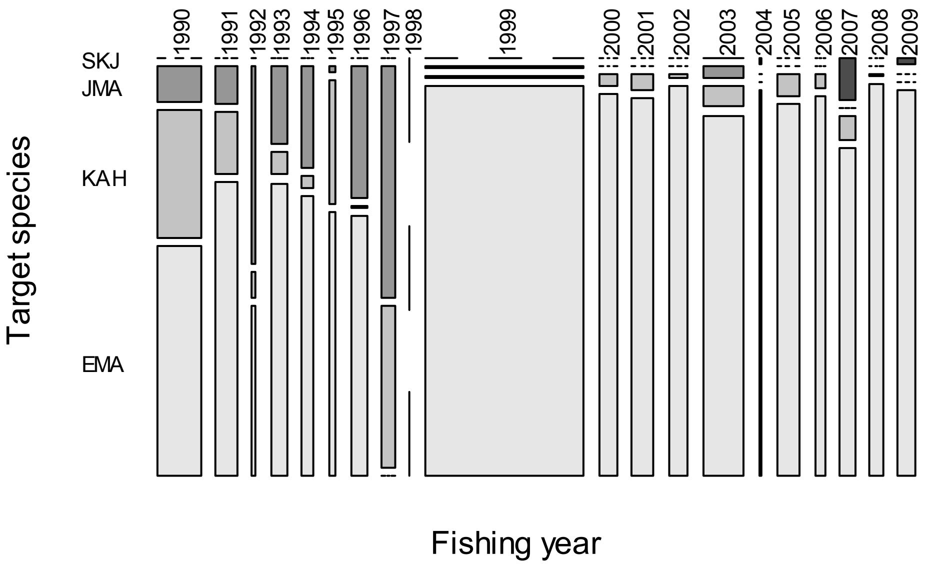

Figure 12: Distribution of catch in EMA 7 by target species for the purse-seine method, 1989–90 to 2008–09 fishing year. Only the top four target species are shown. EMA, blue mackerel; KAH, kahawai; JMA, Jack mackerel, SKJ, skip jack.

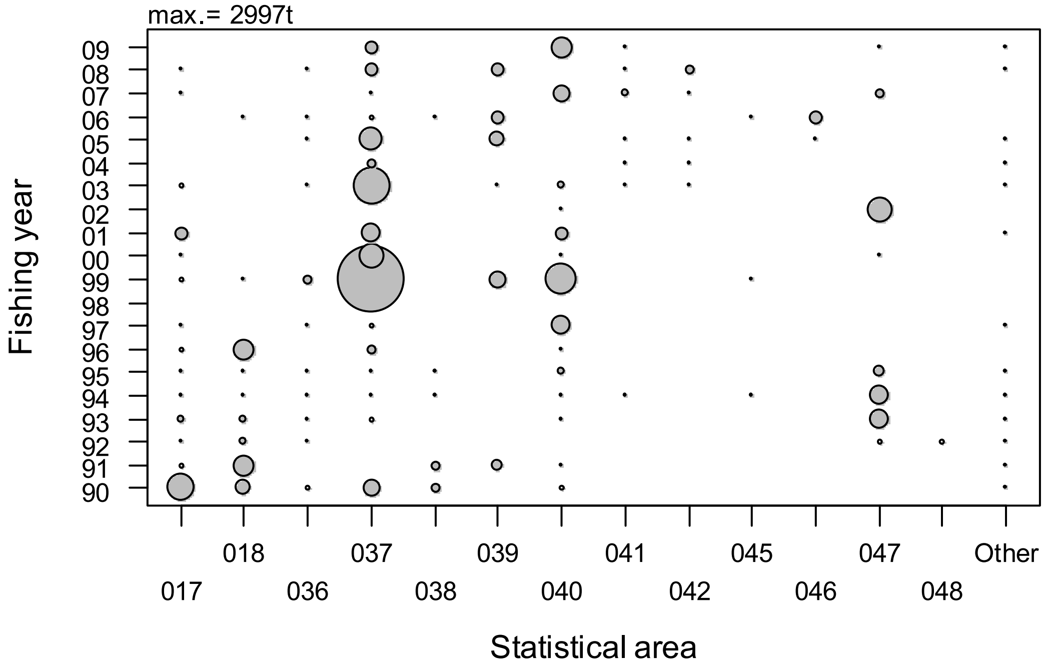

Figure 13: Distribution of catch by statistical area for the Purse-seine fishing method, 1989–90 to 2008–09 fishing year.

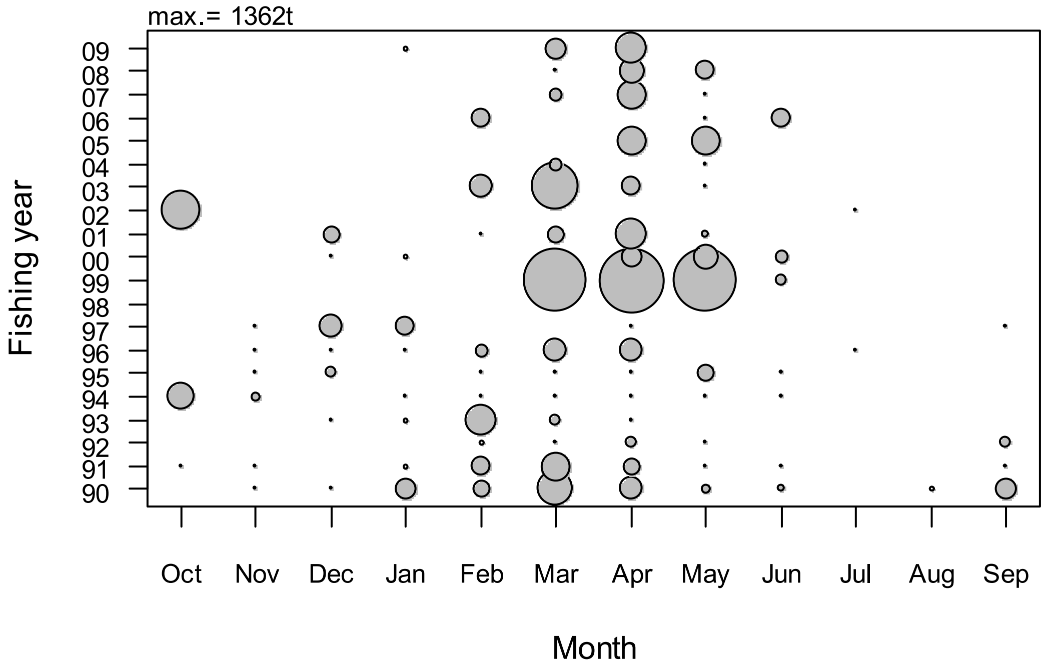

Figure 14: Distribution of catch by month for the Purse-seine fishing method, 1989–90 to 2008–09 fishing year.

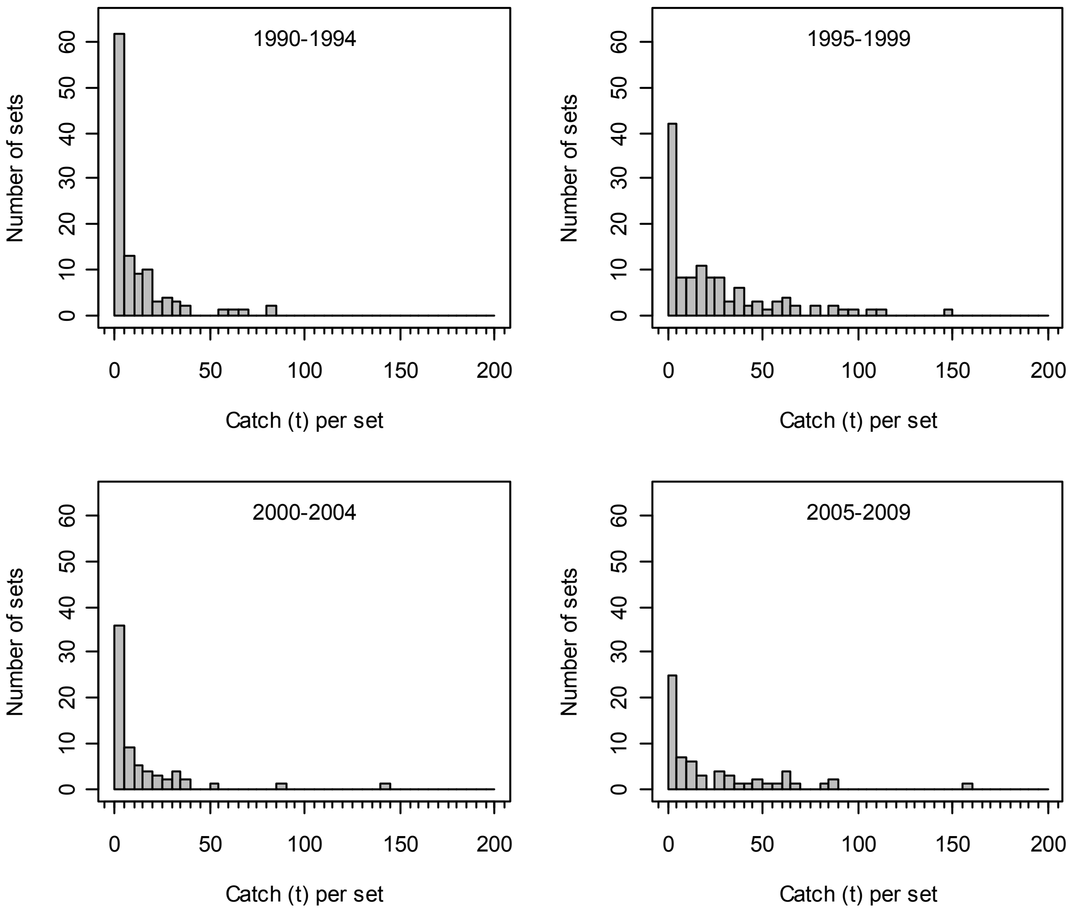

Figure 15: Distribution of catch rate (catch per set) for the Purse-seine fishing method, from 1989–90 to 1993–94, from 1994–95 to 1998–99, from 1999–2000 to 2003–04, and from 2004–05 to 2008–09, respectively.

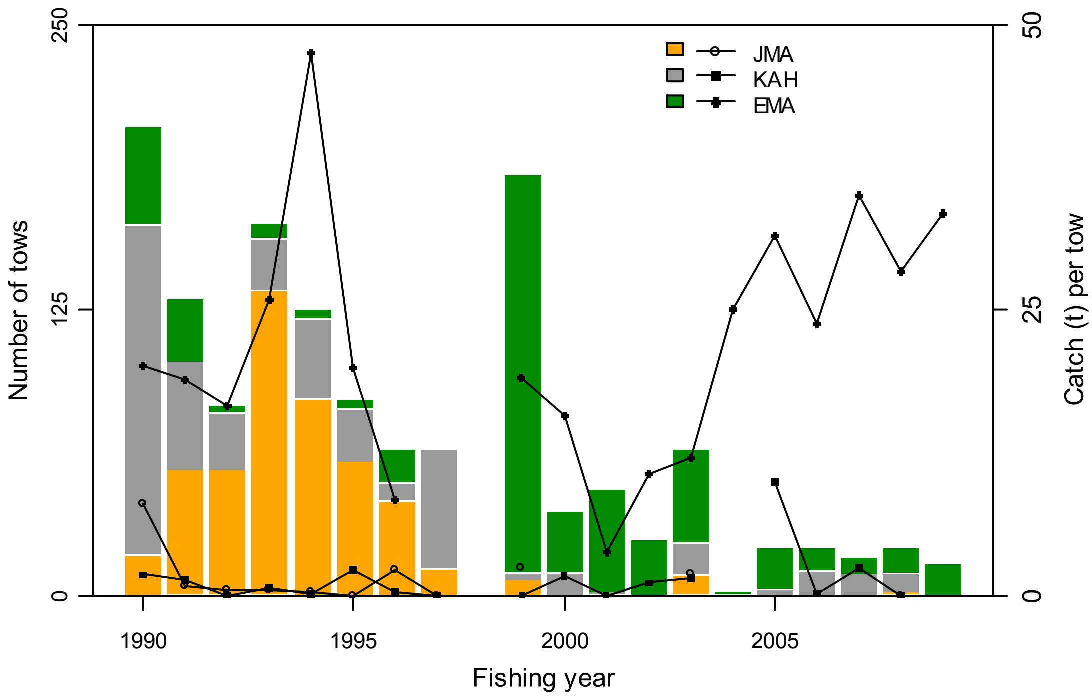

Figure 16: Number of tows (bars) and catch per tow (lines) by target species for the Purse-seine fishing method 1989–90 to 2008–09.

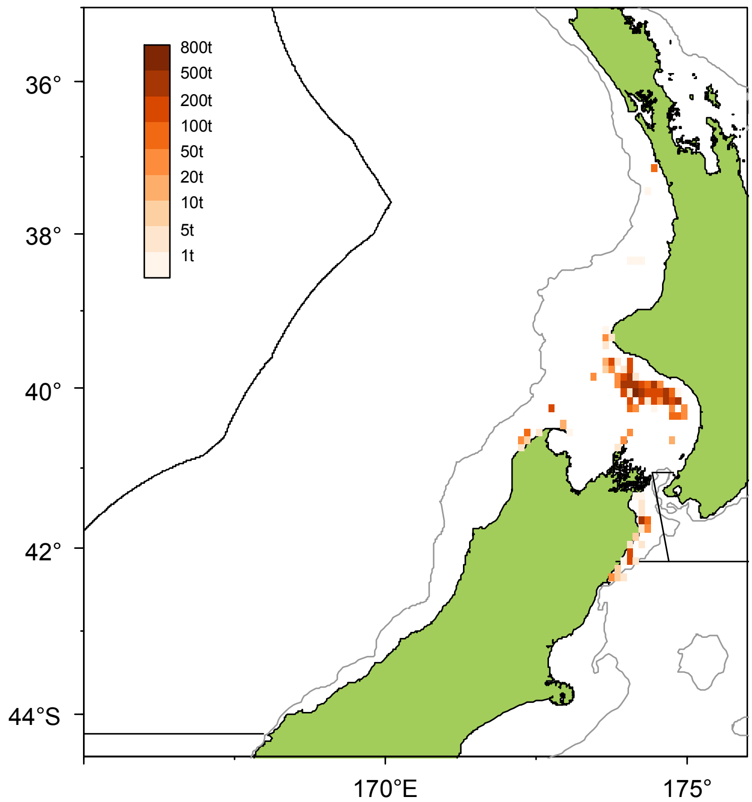

Figure 17: Distribution of EMA catch within EMA 7 aggregated into 0.1 degree spatial blocks from the purse-seine method for 1989–90 to 2008–09 combined

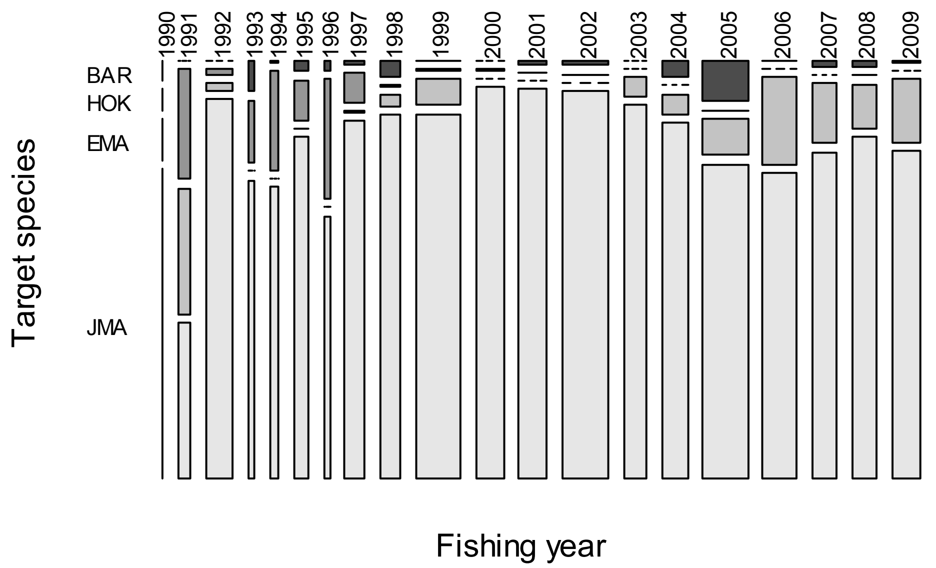

Figure 18: Distribution of catch by target species for the midwater trawl fishing method, 1989–90 to 2008-09 fishing year. Only the top four target species are shown. Jack mackerel, EMA, blue mackerel; HOK, hoki, BAR, barrakouta.

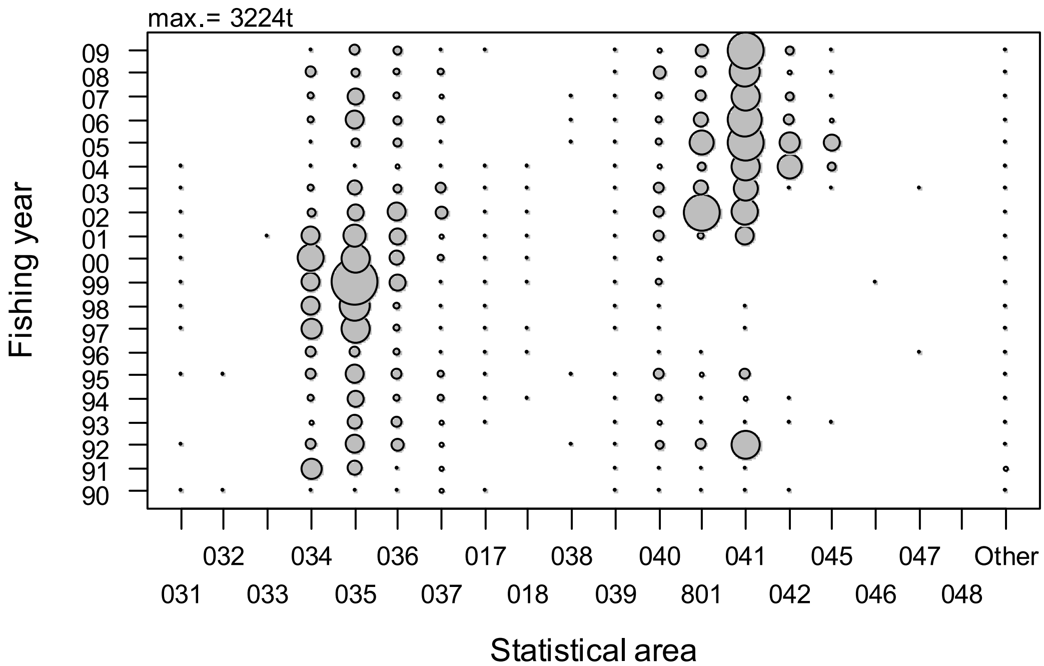

Figure 19: Distribution of catch by statistical area for the midwater trawl fishing method, 1989–90 to 2008–09 fishing year

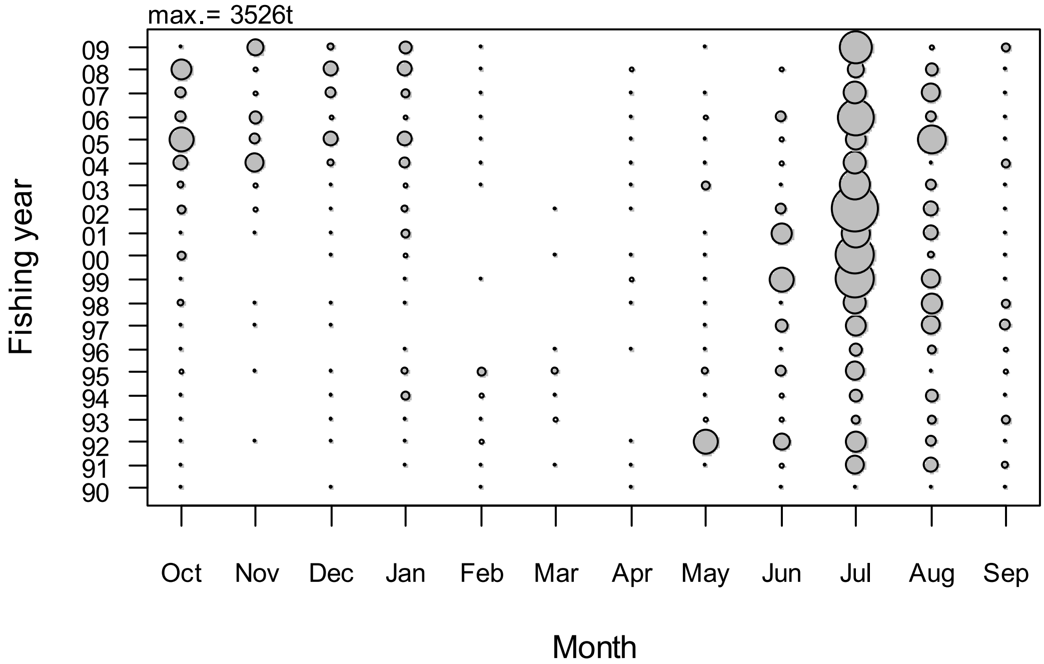

Figure 20: Distribution of catch by month for the midwater trawl fishing method, 1989–90 to 2008–09 fishing year.

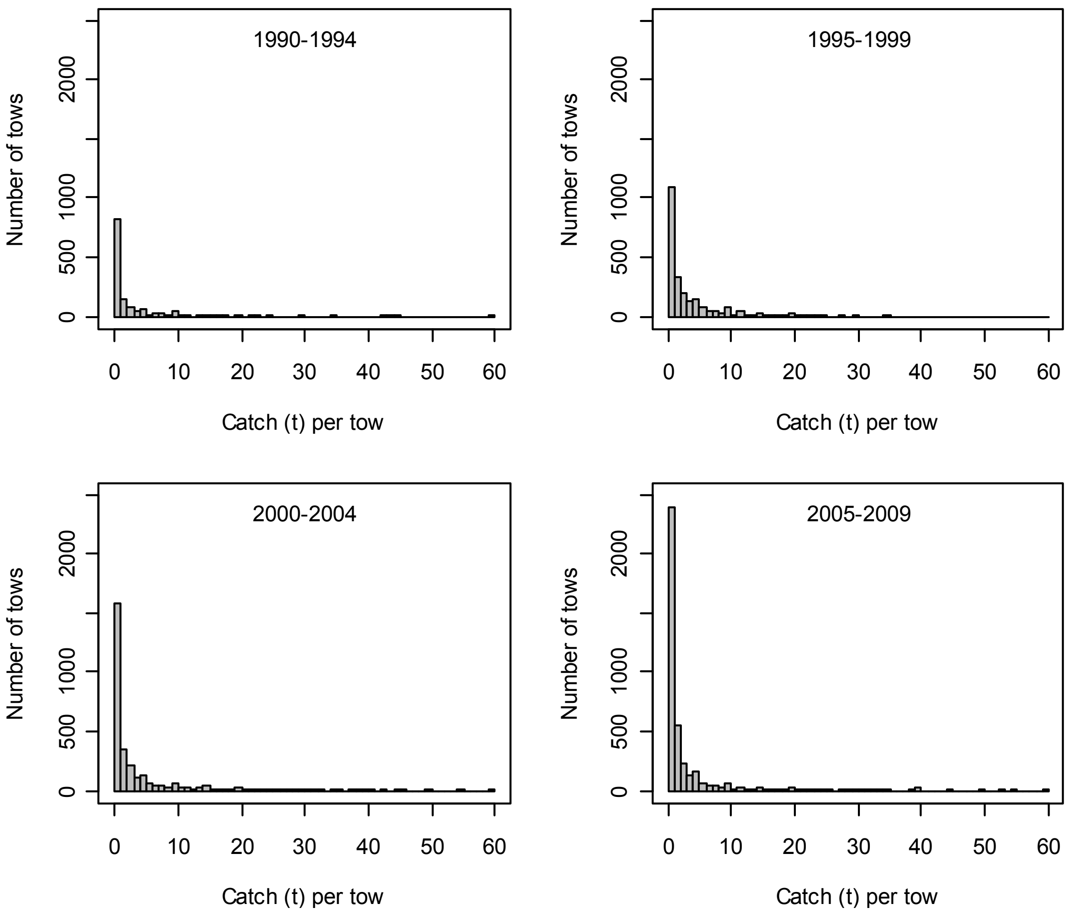

Figure 21: Distribution of catch rate (catch per tow) for the midwater trawl fishing method, from 1989–90 to 1993–94, from 1994–95 to 1998–99, from 1999–2000 to 2003–04, and from 2004–05 to 2008–09, respectively.

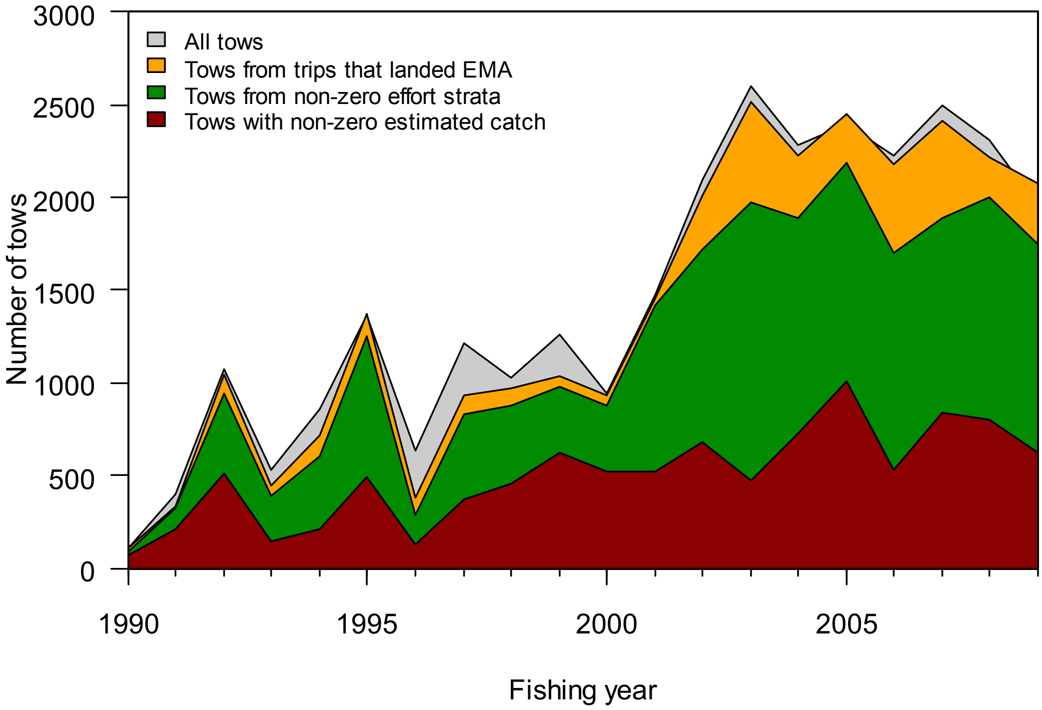

Figure 22: Fishing effort (number of tows) from the midwater trawl jack mackerel target fishery defined as follows: (1) all JMA target tows from the tow-level dataset; (2) all JMA target tows that reported non-zero estimated catch of blue mackerel from the tow-level dataset; (3) all JMA target tows from trips that has landed blue mackerel in EMA 7 from the trip-level dataset; (4) all JMA target tows from effort strata with non-zero blue mackerel catches from the trip-level merged dataset.

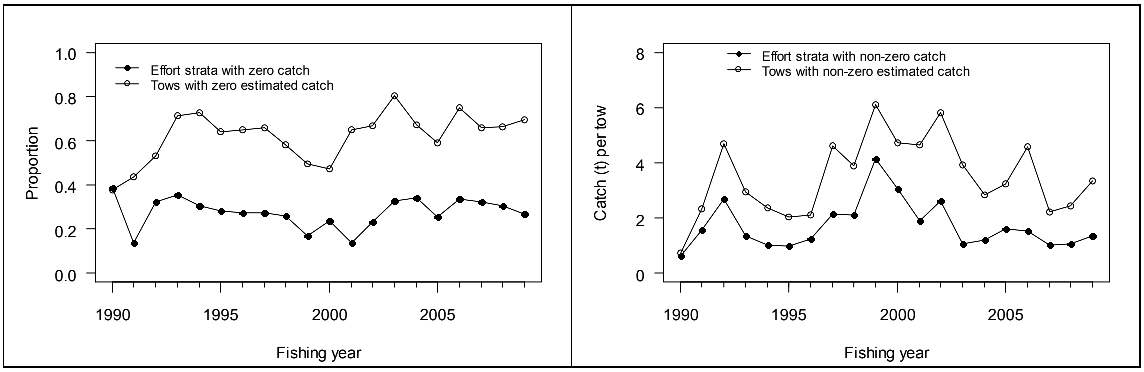

Figure 23: Proportions of zero catches of blue mackerel for the midwater trawl jack mackerel target fishery, from the trip-level merged dataset and the tow-level dataset respectively (left); Catch (t) per tow of blue mackerel for the midwater trawl jack mackerel target fishery, from non-zero effort strata for the merged dataset, and from non-zero tows for the tow-level dataset (right), 1989–90 to 2008–09 fishing years.

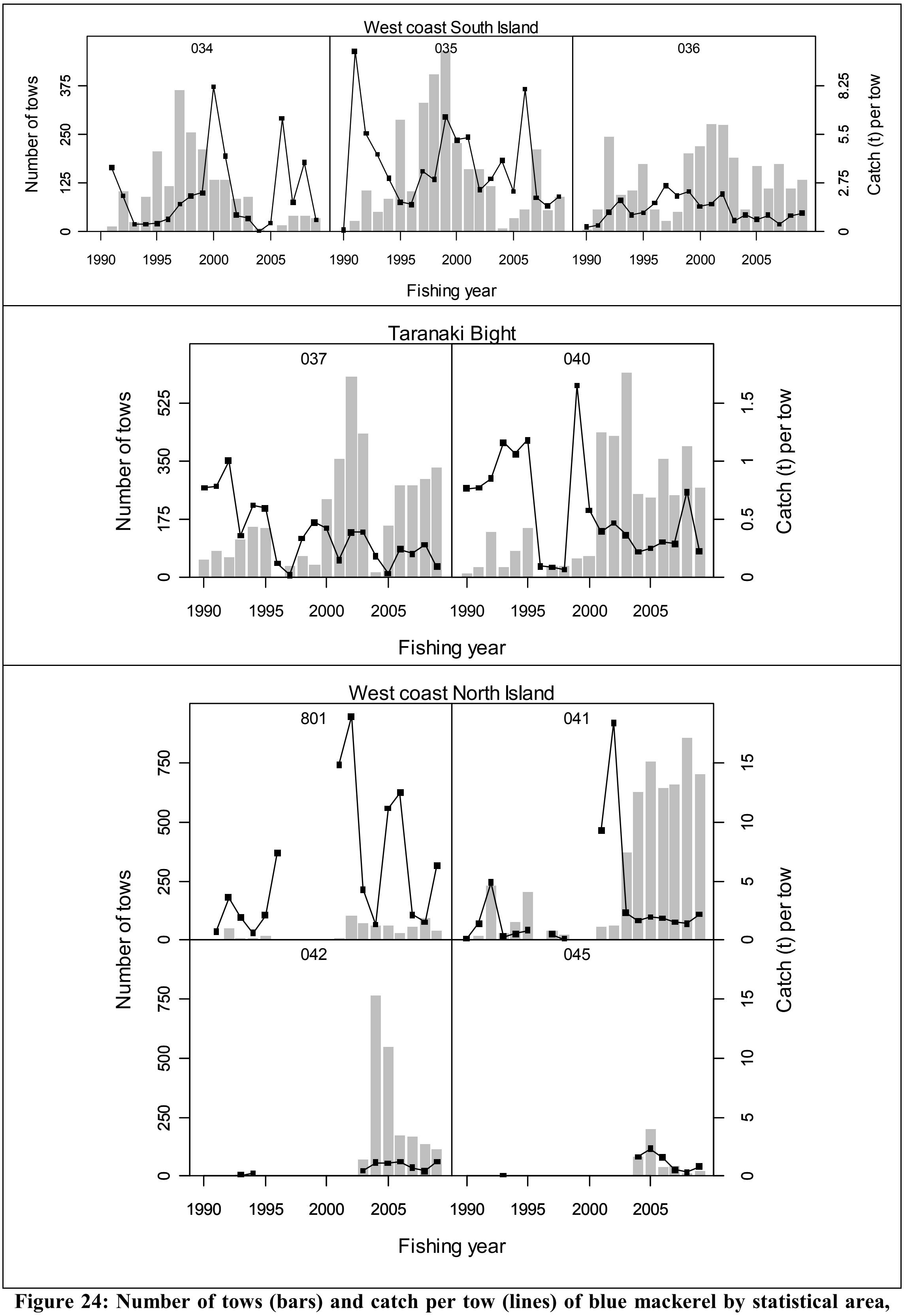

Figure 24: Number of tows (bars) and catch per tow (lines) of blue mackerel by statistical area, 1989–90 to 2008–09 for the midwater trawl JMA target fishery from the non-zero effort strata of the merged datasets.

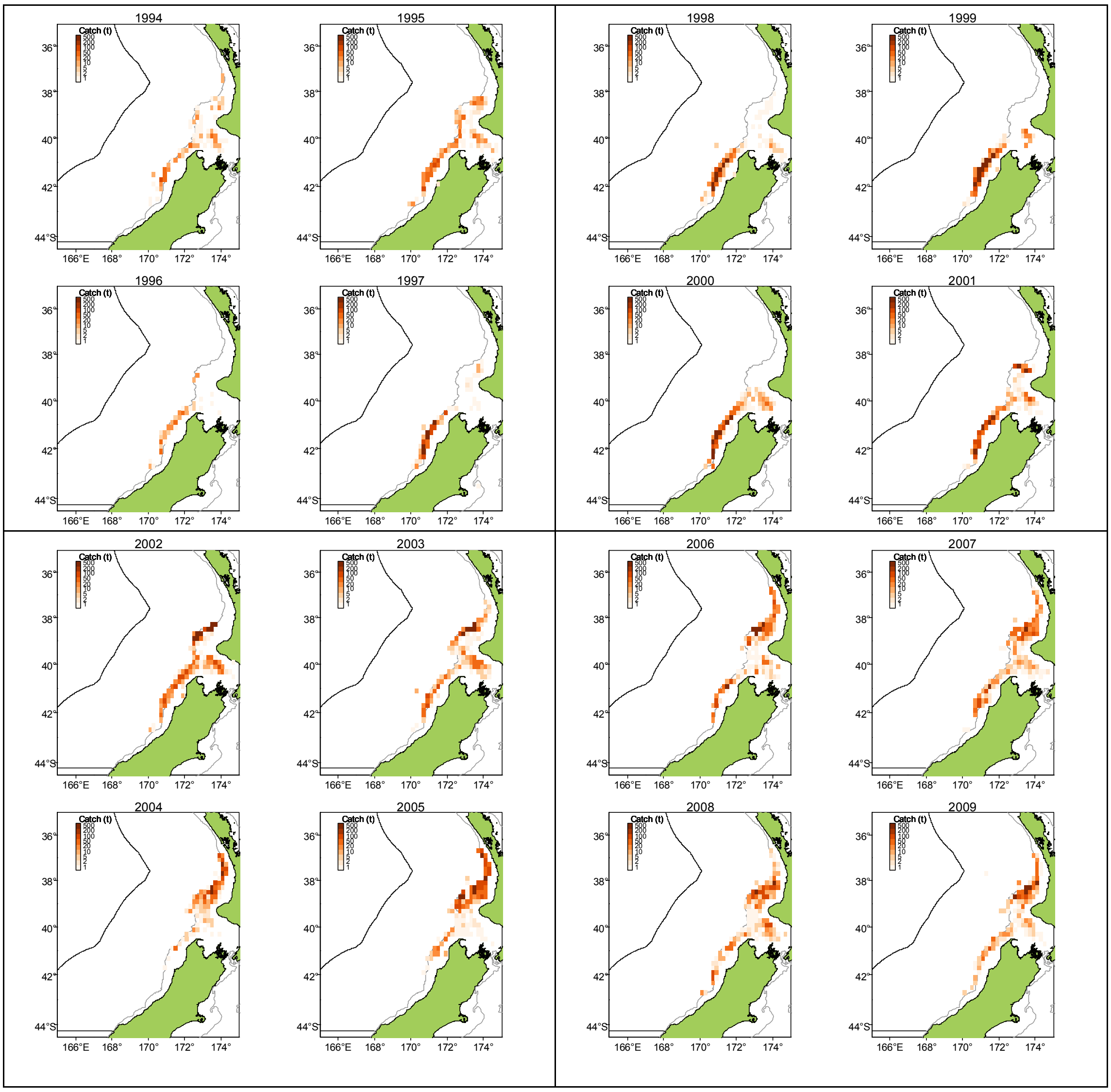

Figure 25: Distribution of EMA catch within EMA 7 aggregated into 0.2 degree spatial blocks from the midwater trawl JMA target fishery for 1989–90 to 2008–09.

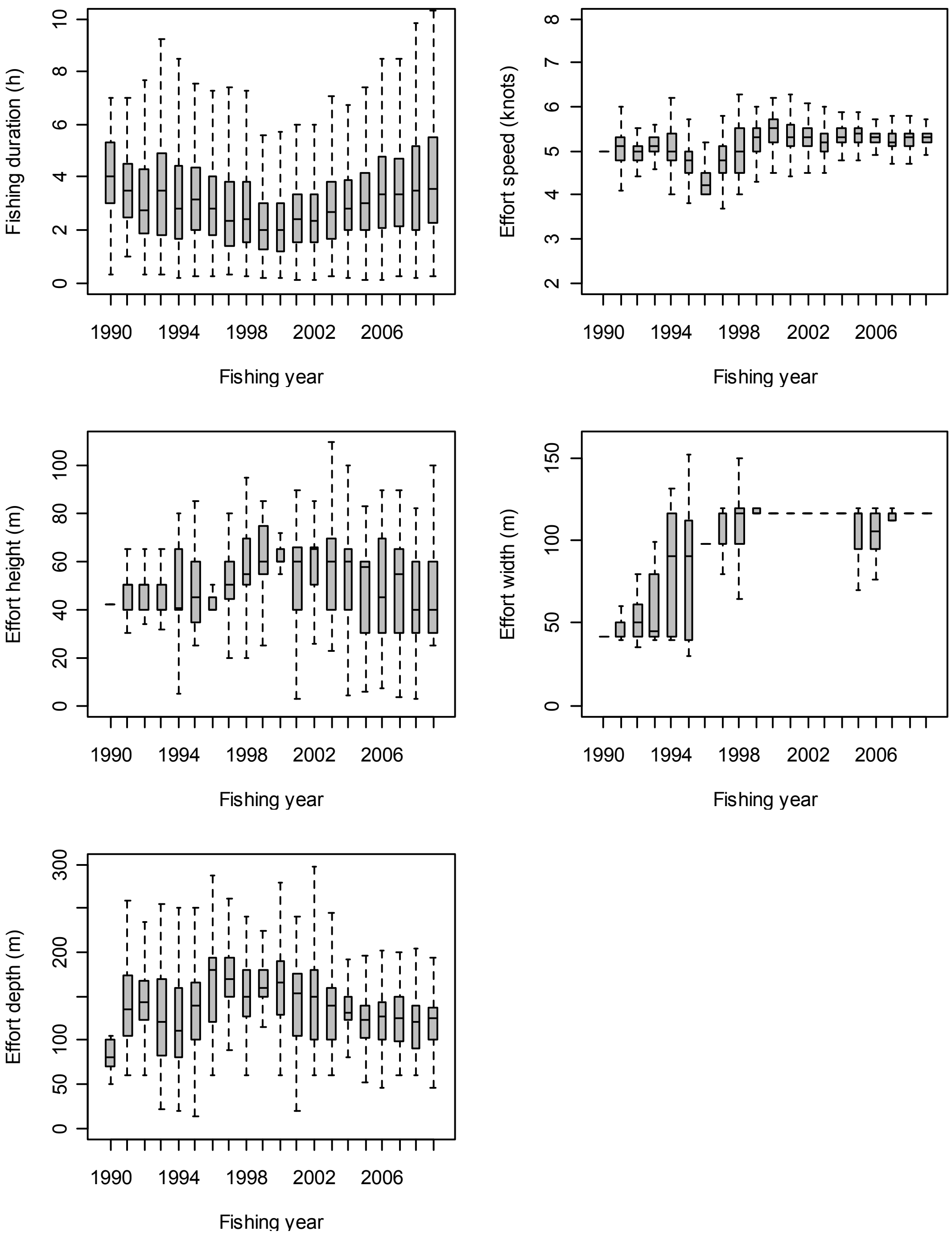

Figure 26: Distribution of selected tow variables including fishing duration (hours), effort speed (knots), effort height (m), effort width (m) and effort depth for the midwater trawl JMA target tows which reported non-zero blue mackerel catches.

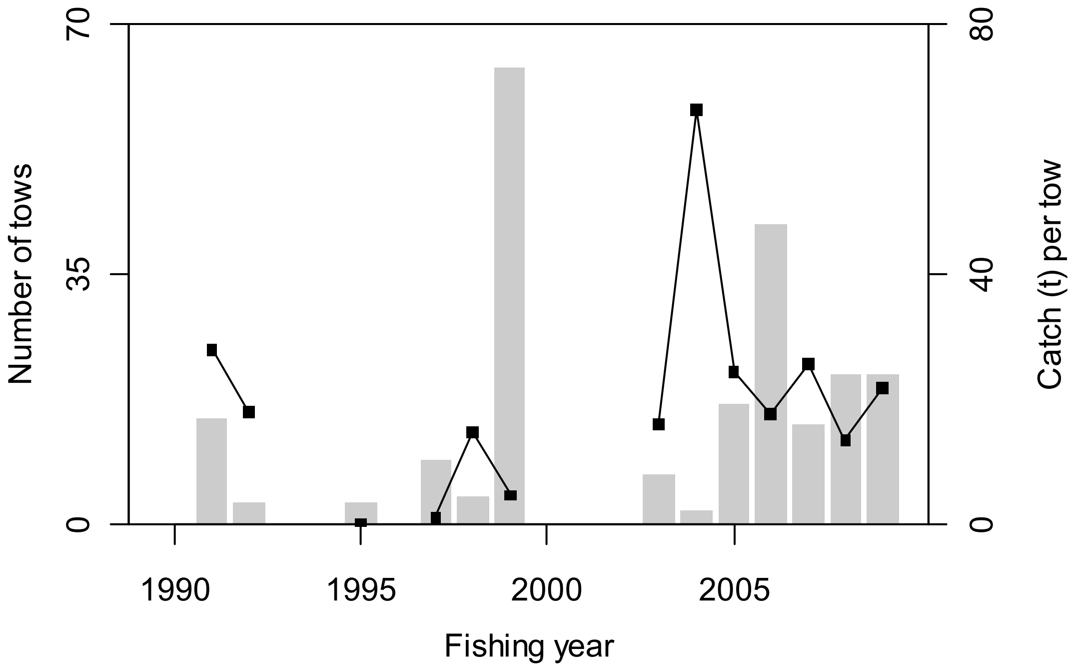

Figure 27: Number of tows (bars) and catch per tow (lines) of blue mackerel by statistical area, 1989–90 to 2008–09 for the midwater trawl EMA target fishery from the non-zero effort strata of the merged datasets.

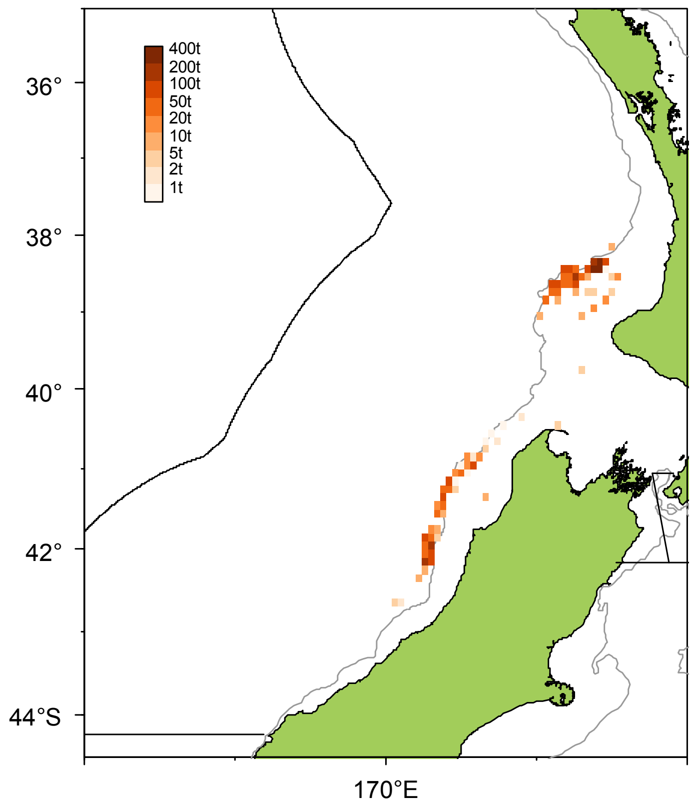

Figure 28: Distribution of EMA catch within EMA 7 aggregated into 0.1 degree spatial blocks from the midwater trawl EMA target tows for 1989–90 to 2008–09 combined.

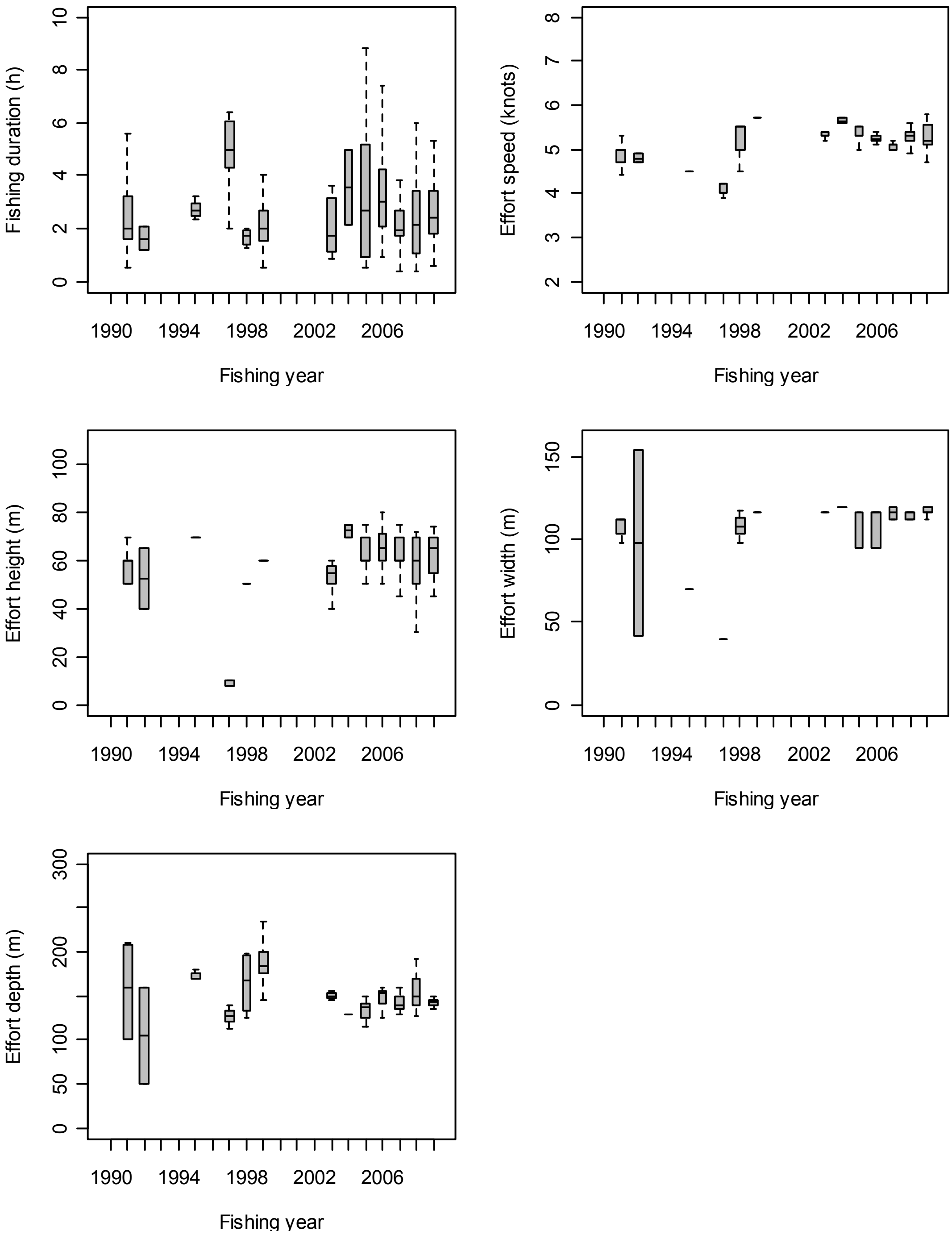

Figure 29: Distribution of selected tow variables including fishing duration (hours), effort speed (knots), effort height (m), effort width (m) and effort depth for the midwater trawl blue mackerel target tows which reported non-zero blue mackerel catches.

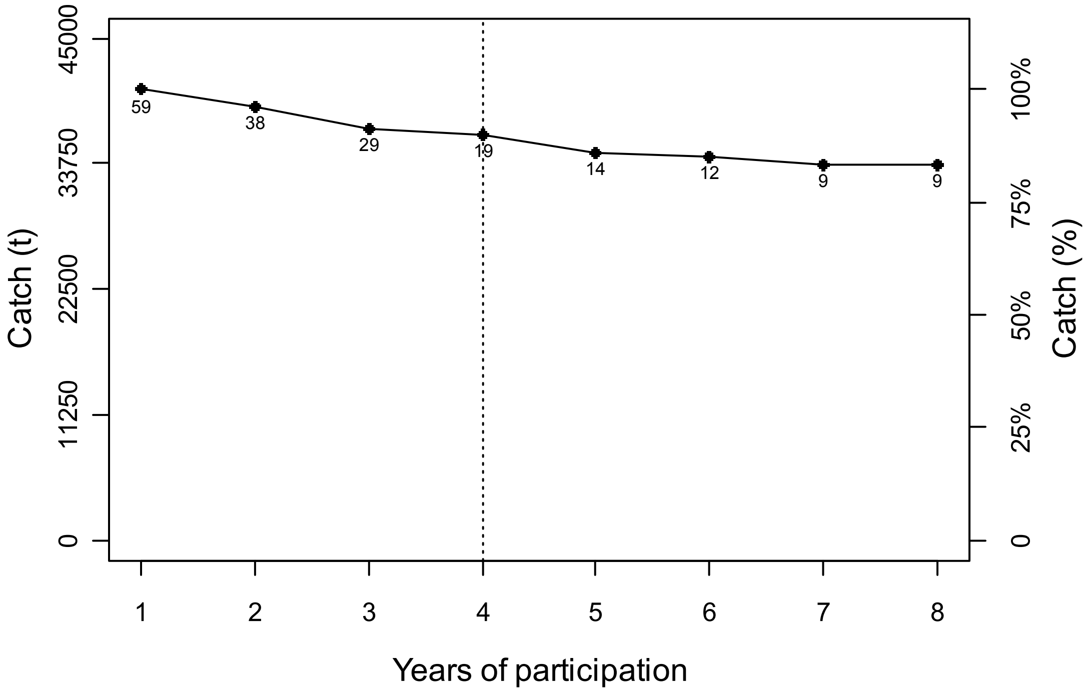

Figure 30: Relationship between years of vessel participation and total blue mackerel catch for the midwater trawl JMA target fishery in EMA 7. The number under each circle (closed or open) indicates the number of vessels with the corresponding years of participation. Dotted vertical line represents 4 years participation.

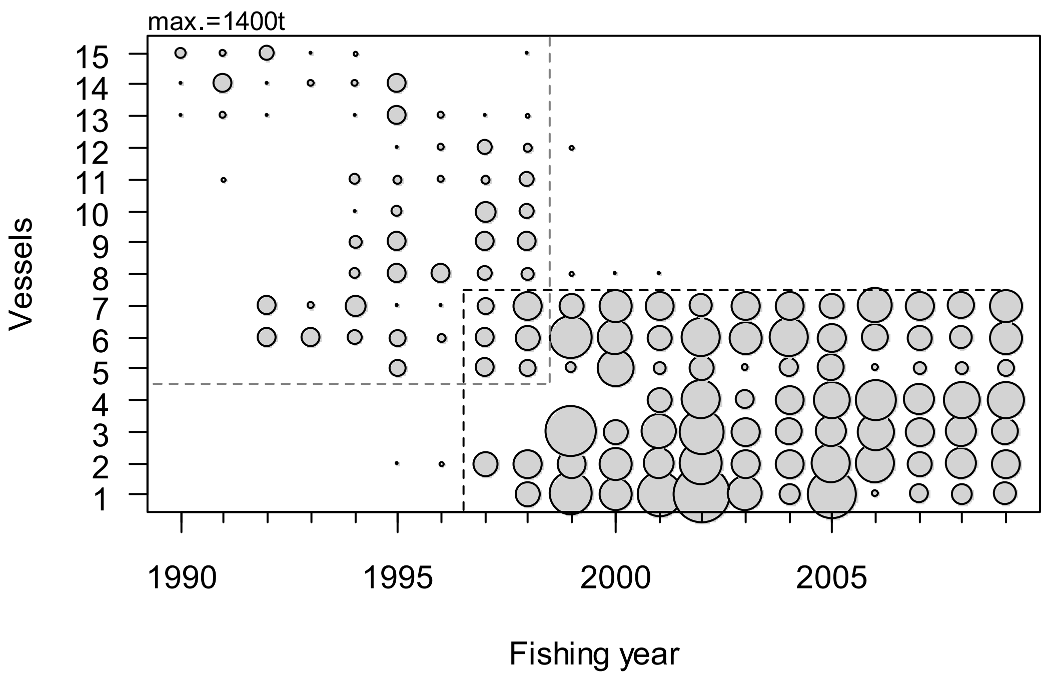

Figure 31: Relative catch of blue mackerel for core fishers included in the catch per unit effort analyses fishing for the merged data. The area of the circle is proportional to the catch. The core vessel datasets are split into an early series comprising vessels 5–15 for fishing years 1989–90 to 1997–98, and a late series comprising vessels 1–7 for fishing years 1996–97 to 2008–09 for the standardisation analyses. Vessel numbers are arbitrary numbers.

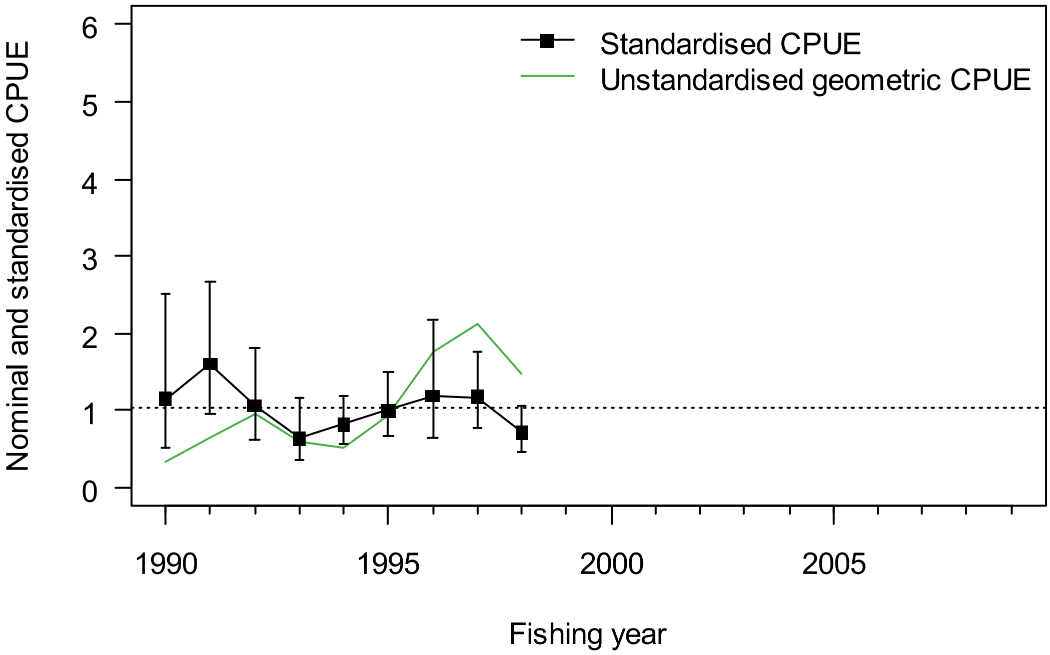

Figure 32: Standardised and unstandardised CPUE indices from 1989–90 to 1997–98 for Model 1 (merged dataset). Vertical bars indicate the 95% confidence interval of the standardised indices.

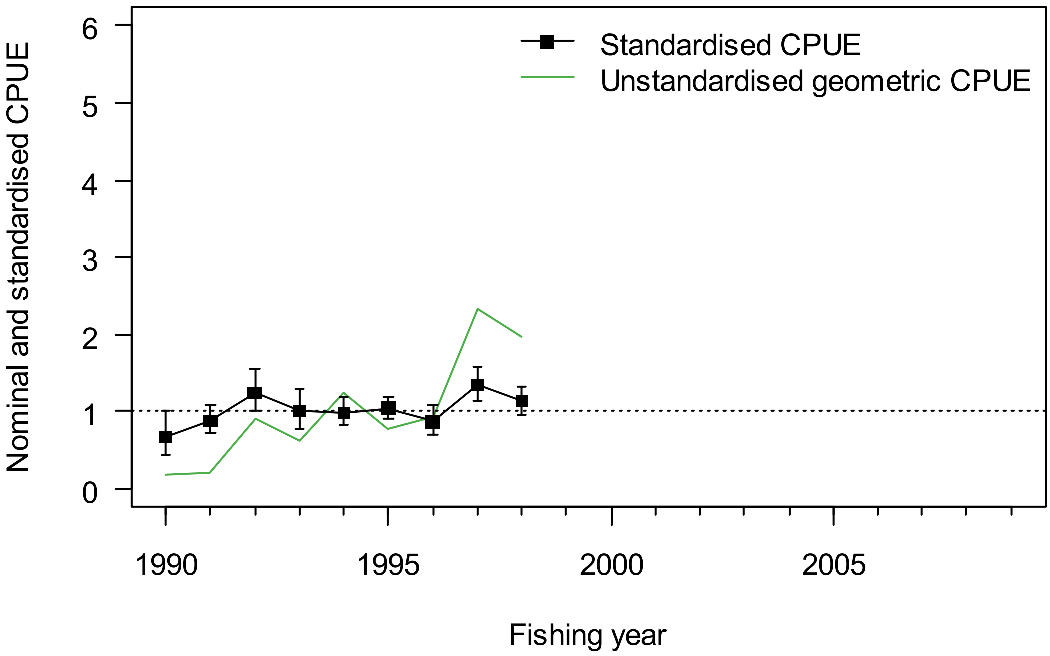

Figure 33: Standardised and unstandardised CPUE indices from 1989–90 to 1997–98 for Model 2 (tow-level dataset). Vertical bars indicate the 95% confidence interval of the standardised indices.

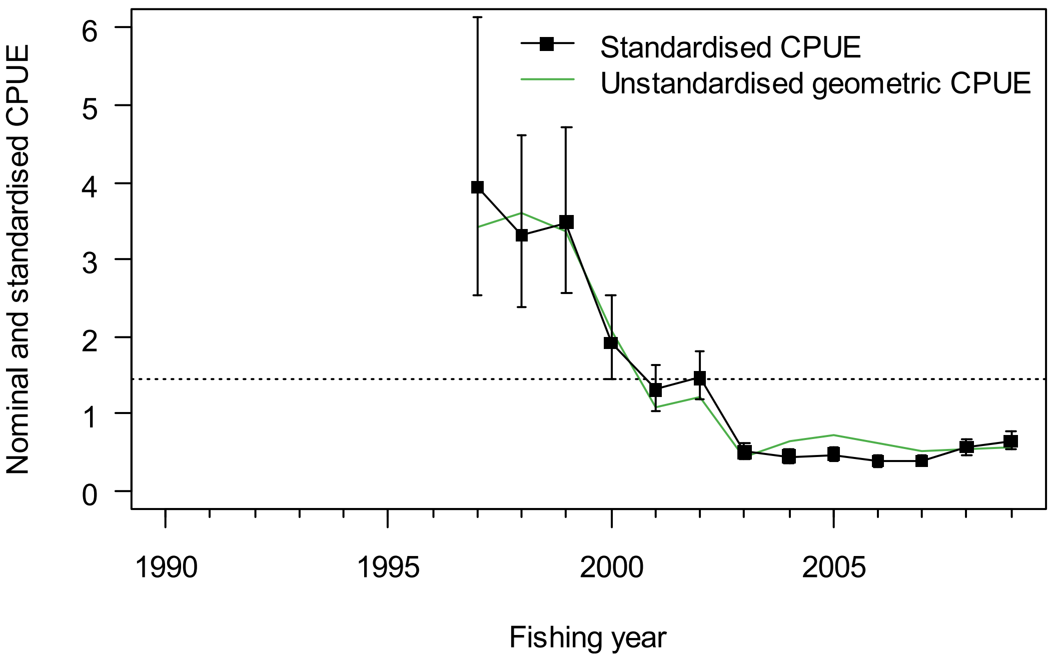

Figure 34: Standardised and unstandardised CPUE indices from 1996–97 to 2008–09 for Model 3 (merged dataset). Vertical bars indicate the 95% confidence interval of the standardised indices.

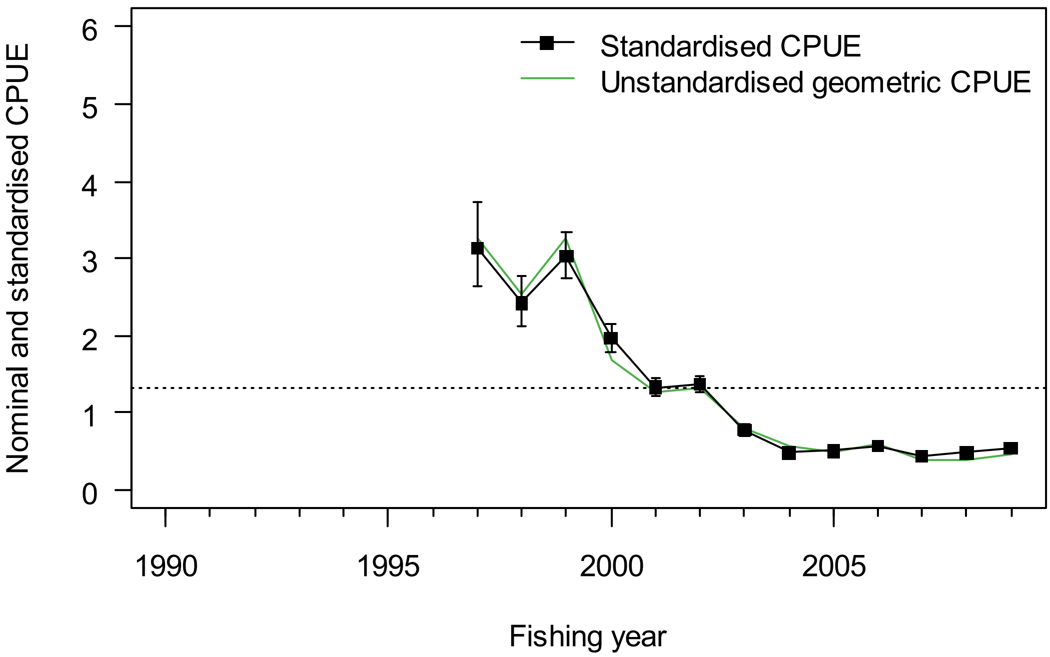

Figure 35: Standardised and unstandardised CPUE indices for from 1996–97 to 2008–09 for Model 4 (tow-level dataset). Vertical bars indicate the 95% confidence interval of the standardised indices.

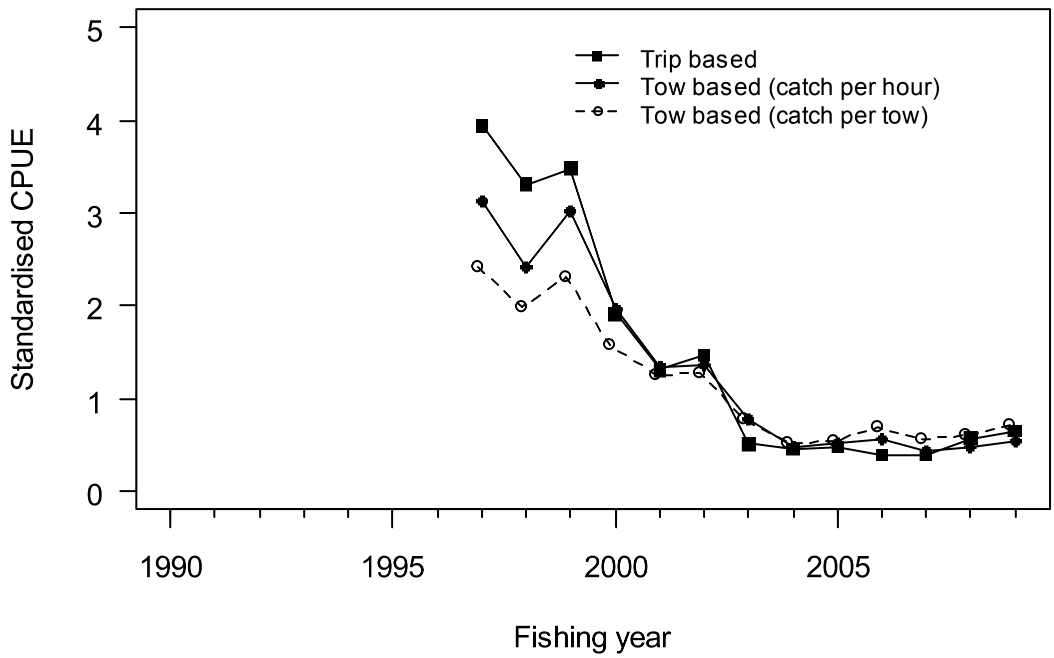

Figure 36: A comparison of standardised CPUE indices from three models: Model 3 (merged data), Model 4 (tow level data), and a variation of Model 4 in which catch per tow was used as the response variable instead of catch per hour.

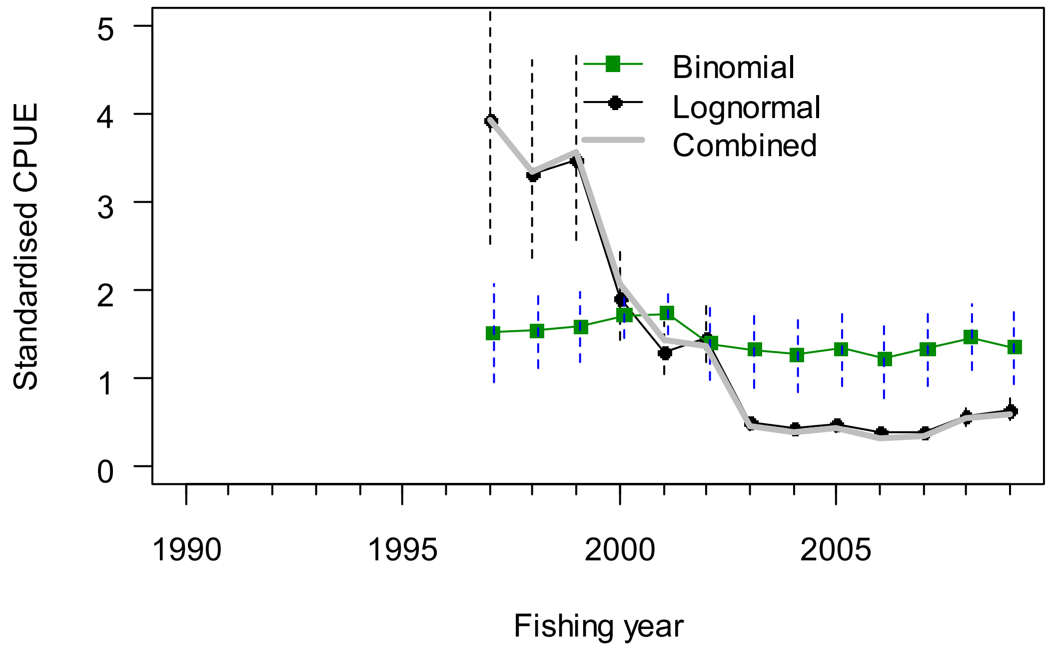

Figure 37: Standardised CPUE indices from a binomial-lognormal model fitted to the merged dataset from 1996–97 to 2008–09.

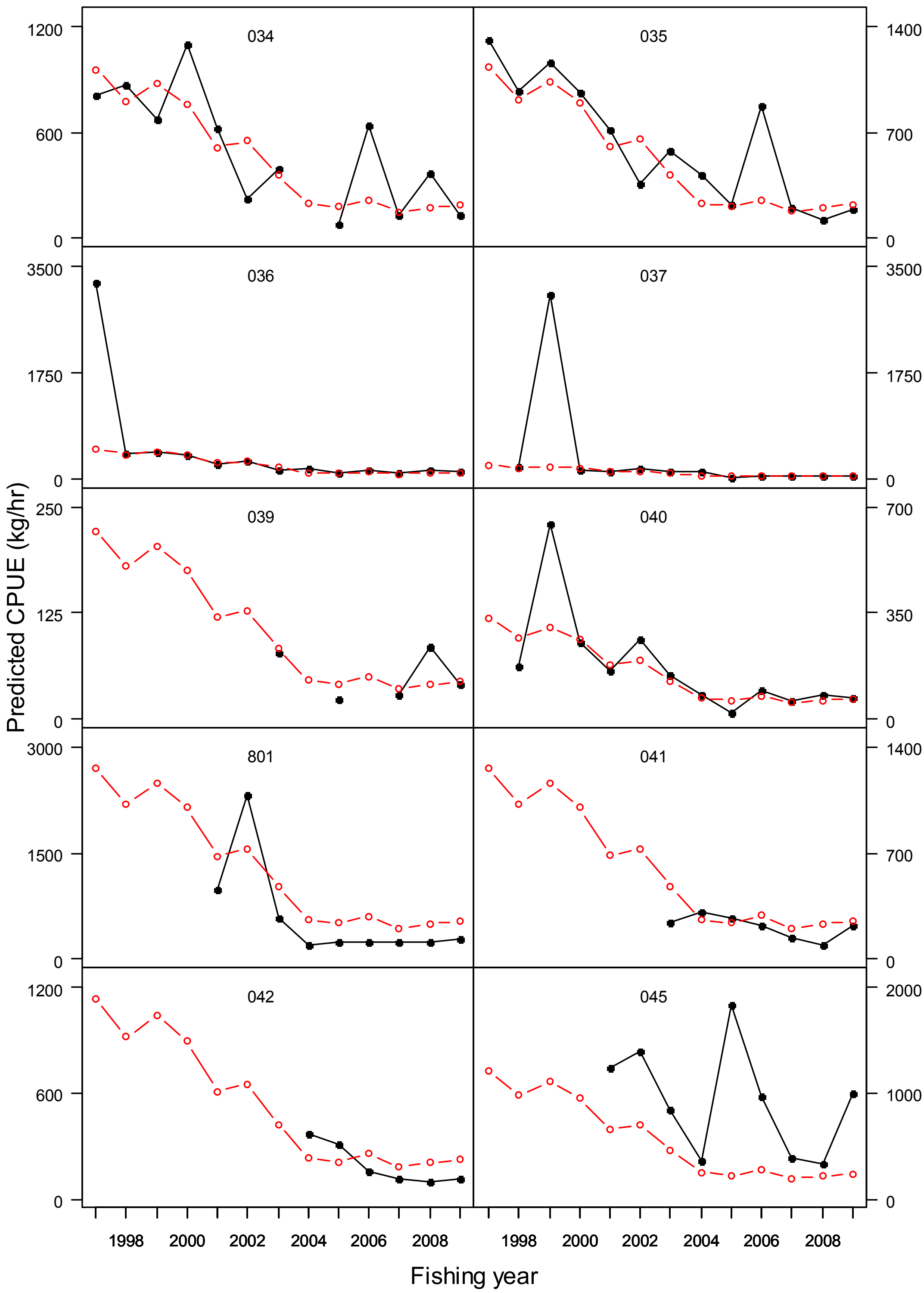

Figure 38: Predicted catch rates (red lines and open circles) for each statistical area from a variation of model 4 (tow-level data) in which statistical area was offered as an explanatory variable, overlaid with predicted catch rates from the model fitted to the same data but with a year * statistical area interaction.

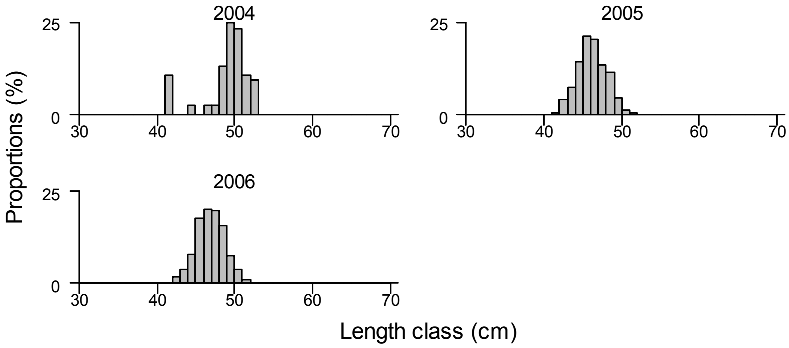

Figure 39: Scaled length frequencies of blue mackerel from market sampling from 2003–04 to 2005–06 fishing years.

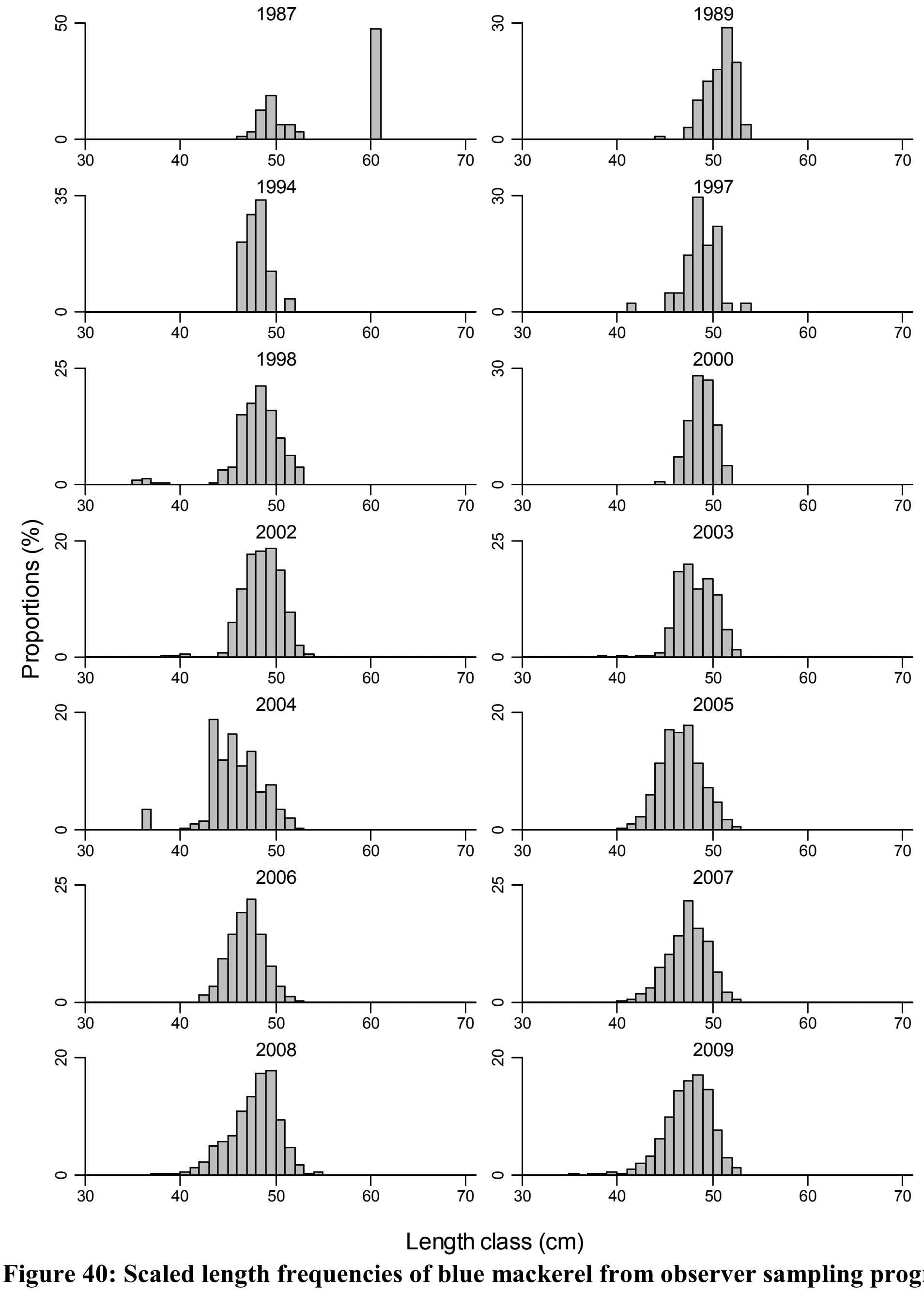

Figure 40: Scaled length frequencies of blue mackerel from observer sampling program, 1986–87 to 2008–09 fishing years.

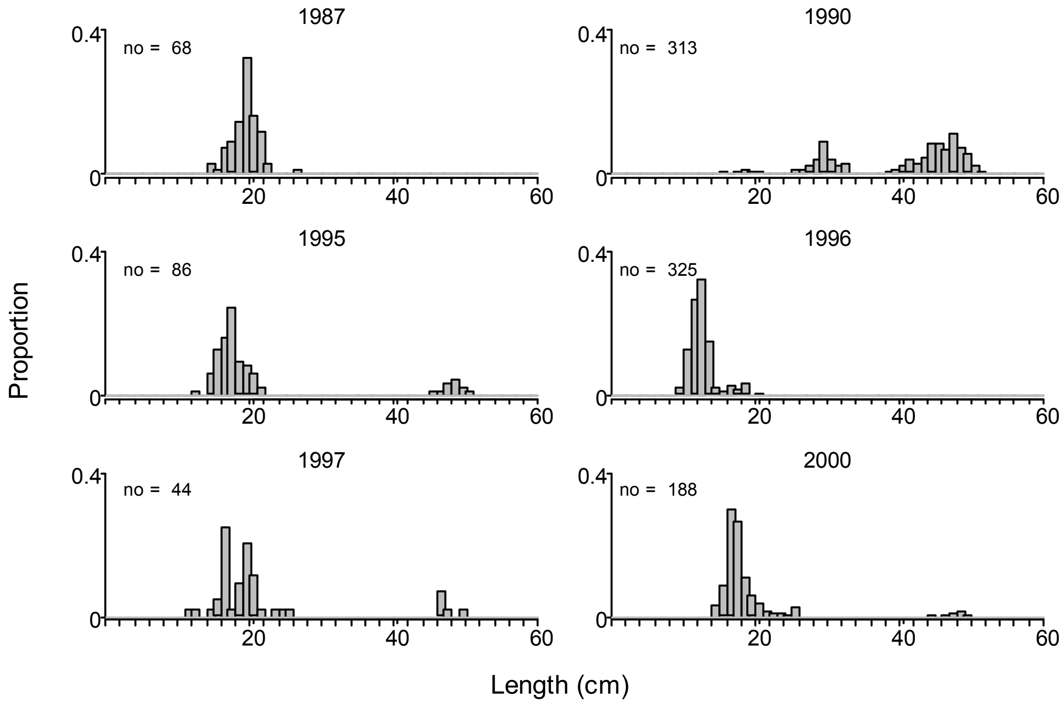

Figure 41: Unscaled length frequencies of blue mackerel from research trawl in EMA 7, 1981–82 to 2004–05 fishing year. Years where sample size was less than 10 were excluded.

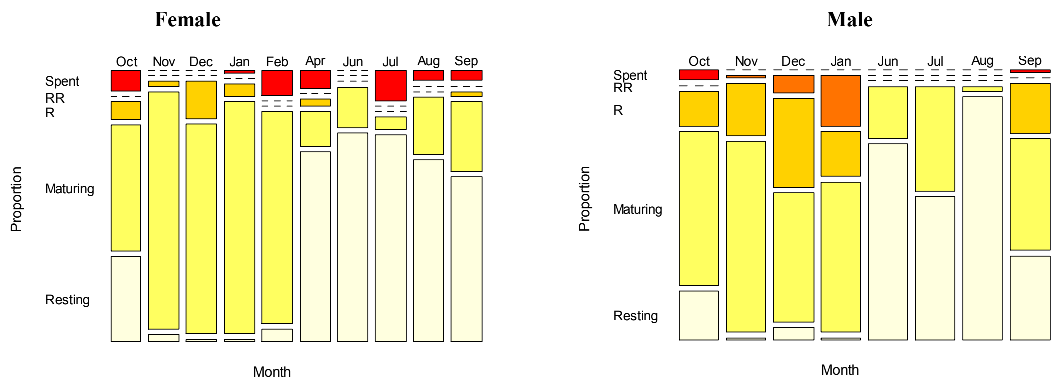

Figure 42: Monthly proportions of female (left) and male (right) blue mackerel gonad developmental stages collected by the Observer Programme in EMA 7, 1994–95 to 2008–09 fishing years combined. Reproductive stages are coloured Resting: pale yellow, Maturing: yellow, Ripe: gold, Running ripe: orange, and Spent: red.

APPENDIX A: CATCH EFFORT DATA EXTRACTS AND GROOMING

Table A1. List of tables and fields requested in the Ministry of Fisheries extract 7378.

Fishing_events table

Event_Key
Version_seqno
DCF_key
Start_datetime
End_datetime
Primary_method
Target_species
Fishing_duration
Catch_weight
Effort_depth
Effort_height
Effort_num
Effort_num_2
Effort_seqno
Effort_total_num
Effort_width
Effort_speed
Total_net_length
Total_hook_num
Set_end_datetime
Haul_start_datetime
Start_latitude (full accuracy)
Start_longitude (full accuracy)
End_latitude (full accuracy)
End_longitude (full accuracy)
Pair_trawl_yn
Bottom_depth
Column_a
Column_b
Column_c
Column_d
Display_fishyear
Start_stats_area_code
Vessel_key
Form_type
Trip
Literal_yn
Interp_yn
Resrch_yn

Landing_events table

Event_Key
Version_seqno
DCF_key
Landing_datetime
Landing_name
Species_code
Species_name
Fishstock_code (ALL fish stocks)
State_code
Destination_type
Unit_type
Unit_num
Unit_weight
Conv_factor
Green_weight
Green_weight_type
Processed_weight
Processed_weight_type
Form_type
Trip_key
Trip_start_datetime
Trip_end_datetime
Vessel_key
Form_type
Literal_yn
Interp_yn
Resrch_yn

Estimated subcatch table

Event_Key
Version_seqno
DCF_key
Species_code (ALL species for each fishing event)
Catch_weight
Literal_yn
Interp_yn
Resrch_yn

Vessel_history table

Vessel_key
Flag_nationality_code
Built_year
Engine_kilowatts
Gross_tonnes
Overall_length_metres

Table A2: Details of data corrections by imputation and invalid record removal during the grooming process.

Imputations made	Records	Before	After	Difference	percentage
Invalid start date	116 198	77	10	67	0.06%
Invalid primary method	115 763	62	0	62	0.05%
Invalid target species	115 763	38	0	38	0.03%
Invalid stat area	115 763	684	0	684	0.59%
Invalid latitude or longitude	108 991	939	94	845	0.78%
Invalid effort depth (TCPER)	114 253	928	0	928	0.81%
Invalid bottom depth (TCEPR)	114 253	1739	310	1429	1.25%
Transpose bottom-effort depth	114 253	3931	0	3931	3.44%
Invalid BT effort number	36 423	7	0	7	0.02%
Invalid BT effort width	36 423	656	46	610	1.67%
Invalid BT effort height	36 423	1515	86	1429	3.92%
Invalid BT effort speed for TCPER	35 776	70	0	70	0.20%
Invalid BT fishing duration	35 776	704	0	704	1.97%
Invalid MW effort number for TCPER	71 374	620	0	620	0.87%
Invalid MW effort width for TCPER	71 374	2273	0	2273	3.18%
Invalid MW effort height for TCPER	71 374	24	0	24	0.03%
Invalid MW effort speed for TCPER	71 374	60	0	60	0.08%
Invalid MW fishing duration for TCPER	71 374	591	0	591	0.83%

	Effort			Landings		
Records removed	Records	Trips	Catch	Records	Trips	Catch
Original extract	116 468	4 465	56 515	6 607	4 493	64 485
Duplicate form number	116198	4414	56383	6487	4405	64268
Invalid start date	115763	4405	56383	6487	4405	64268
Invalid primary method	115763	4405	56383	6487	4405	64268
Invalid target	115763	4405	56383	6416	4361	63429
Invalid stats area	114253	4361	55575	6416	4361	63429
Re-stratify by stat area, trip, target, method	15113	4361	55575	6416	4361	63429
Remove interim landing codes	14443	4102	55329	5871	4102	61237
Invalid green weight landings	14442	4101	54143	5805	4101	61058
Drop straddling stats area	14354	4086	53617	5805	4101	61058

APPENDIX B: CPUE MODEL DIGNOSTICS AND STANDARDISED INDICES

Table B1: Predictor variables and R^2 values from GLM stepwise regression analysis for selected models. Variables are shown in order of acceptance by the model with associated cumulative R^2 value. Only variables entered into the model are shown.

Early series (1989–90 to 1997–98)

M1 (trip-level)		M2 (tow-level)	
Variable	R^2	Variable	R^2
fishing year	0.070	fishing year	0.166
vessel	0.266	vessel	0.372
fishing duration	0.408	start latitude	0.386
month	0.494		
stat area	0.563		

Late series (1996–97 to 2008–09)

M3 (trip-level)		M4 (tow-level)	
Variable	R^2	Variable	R^2
fishing year	0.035	fishing year	0.118
fishing duration	0.188	effort height	0.191
stat area	0.330	vessel	0.241
month	0.434	start latitude	0.259
vessel	0.445		

Table B2: Standardised CPUE indices for selected models.

	M1 (trip-level)		M2 (tow-level)		M3 (trip-level)		M4 (tow-level)	
Fishing Year	Indices	c.v.	Indices	c.v.	Indices	c.v.	Indices	c.v.
1990	1.15	0.41	0.70	0.21				
1991	1.60	0.26	1.00	0.10				
1992	1.06	0.28	1.24	0.11				
1993	0.64	0.31	1.06	0.13				
1994	0.82	0.18	0.91	0.09				
1995	1.00	0.20	1.05	0.07				
1996	1.19	0.31	0.95	0.11				
1997	1.17	0.21	1.24	0.08	3.94	0.22	3.15	0.09
1998	0.71	0.21	0.98	0.08	3.31	0.17	2.07	0.07
1999					3.48	0.15	2.80	0.05
2000					1.91	0.14	1.89	0.05
2001					1.31	0.11	1.30	0.04
2002					1.46	0.11	1.25	0.04
2003					0.51	0.09	0.80	0.05
2004					0.45	0.10	0.49	0.04
2005					0.48	0.10	0.51	0.04
2006					0.39	0.10	0.63	0.04
2007					0.39	0.09	0.46	0.04
2008					0.57	0.09	0.52	0.04
2009					0.65	0.09	0.59	0.04

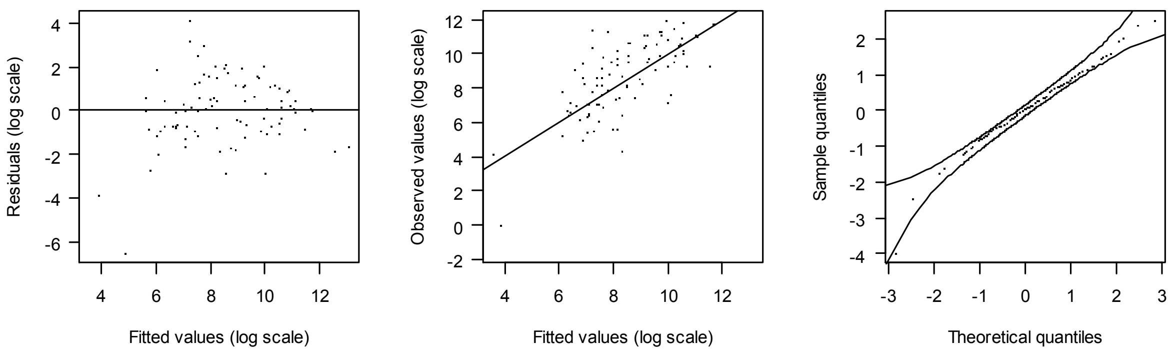

Figure B1: Residual diagnostic plots for CPUE model 1.

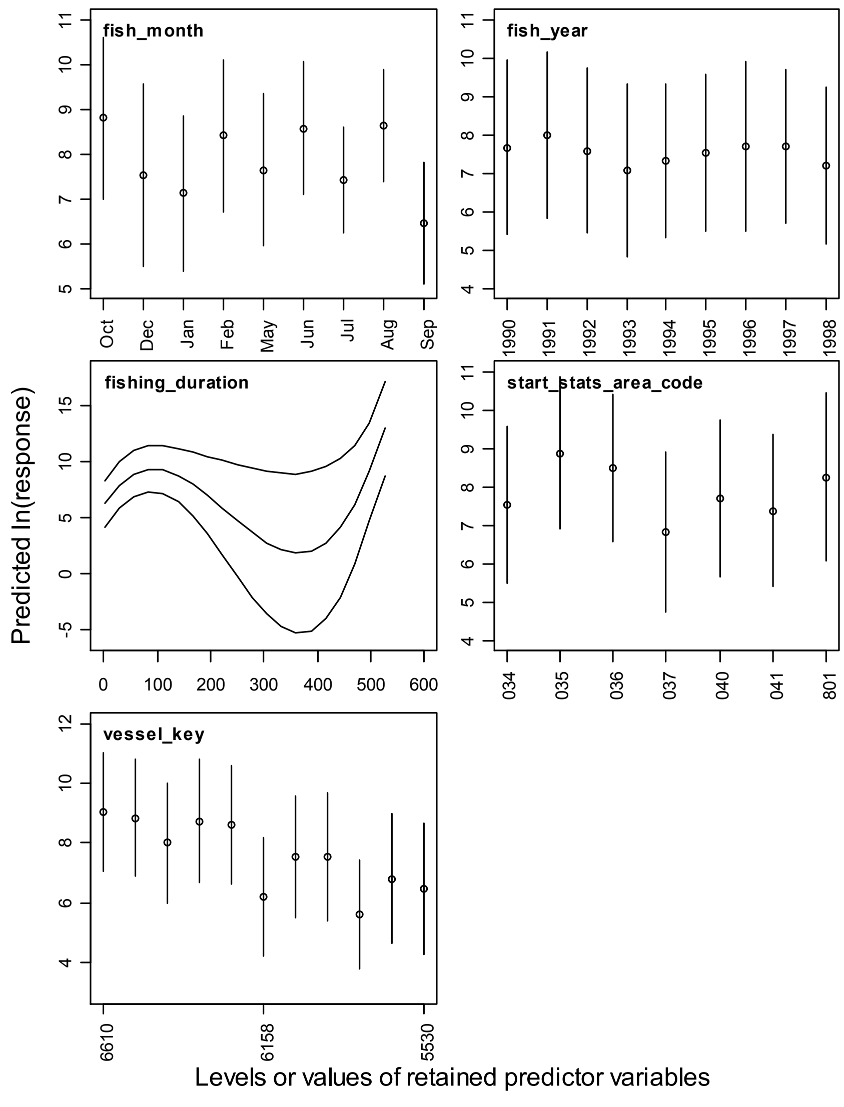

Figure B2: Predicted CPUE for variables *month, fishing year, fishing duration, statistical area, and vessel key* for CPUE model 1. Bounds show the expected values ± 2 standard deviations

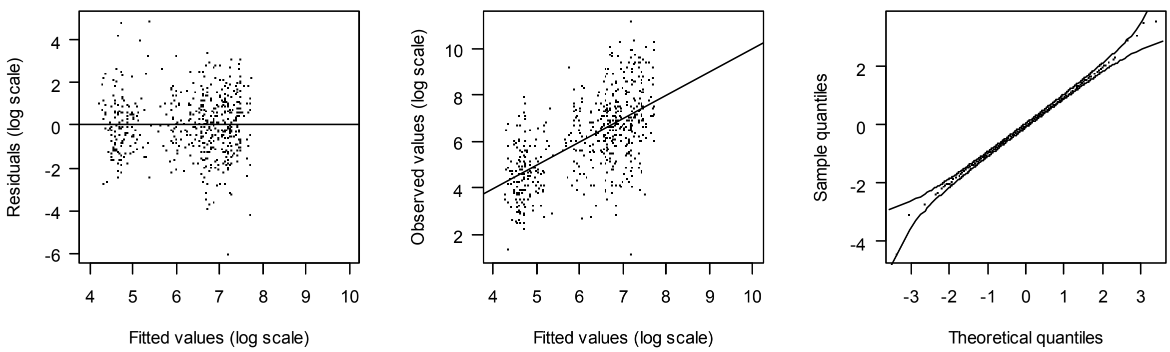

Figure B3: Residual diagnostic plots for CPUE model 2.

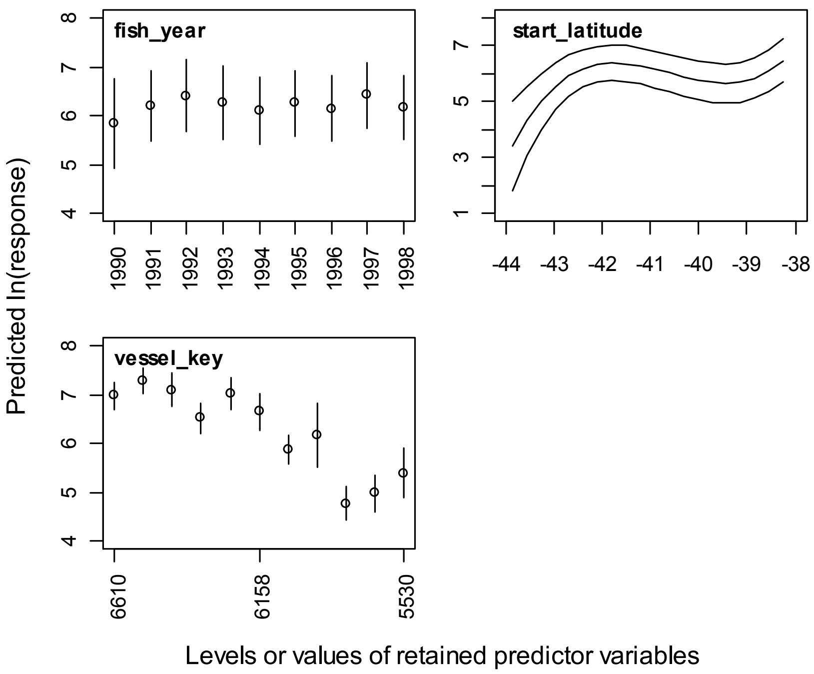

Figure B4: Predicted CPUE for variables *start latitude, fishing year, and vessel key* for CPUE model 2. Bounds show the expected values ± 2 standard deviations.

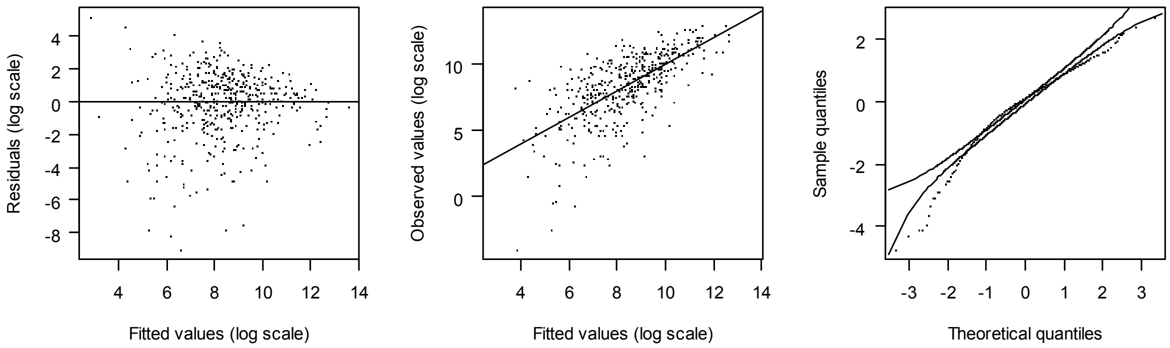

Figure B5: Residual diagnostic plots for CPUE model 3.

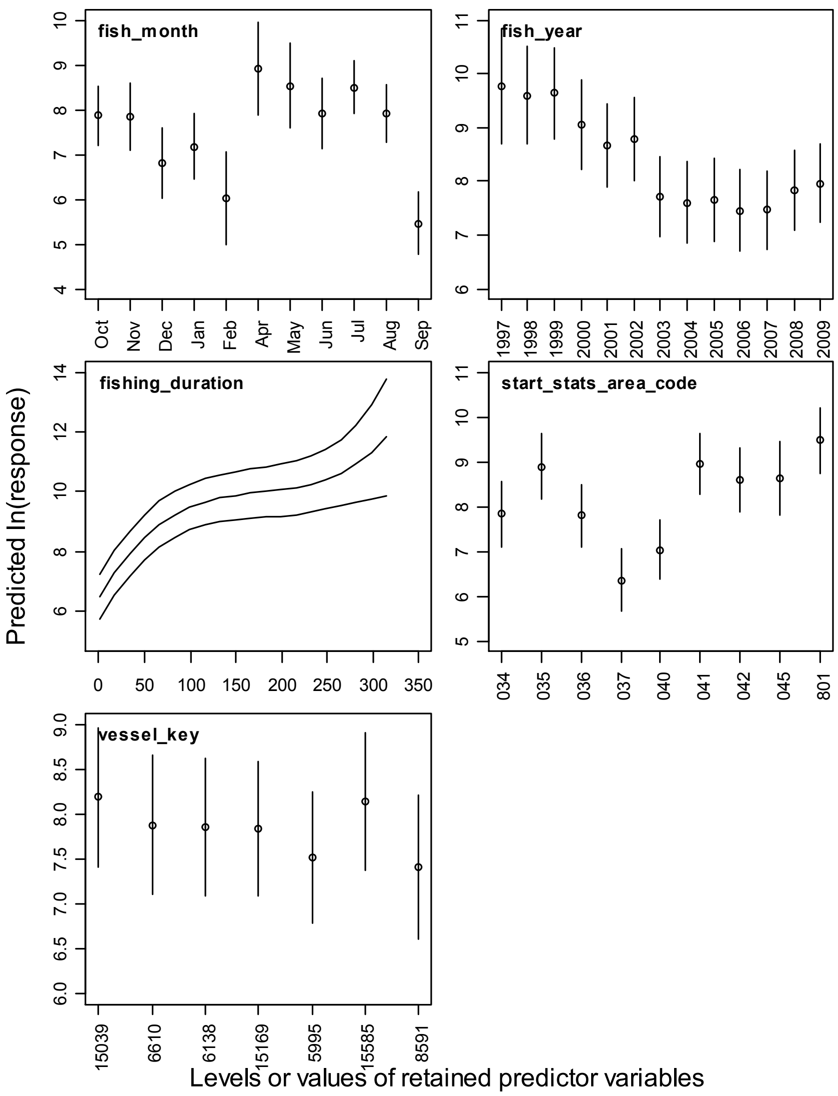

Figure B6: Predicted CPUE for variables *month, fishing year*, *fishing duration, statistical area, and vessel key* for CPUE model 4. Bounds show the expected values ± 2 standard deviations

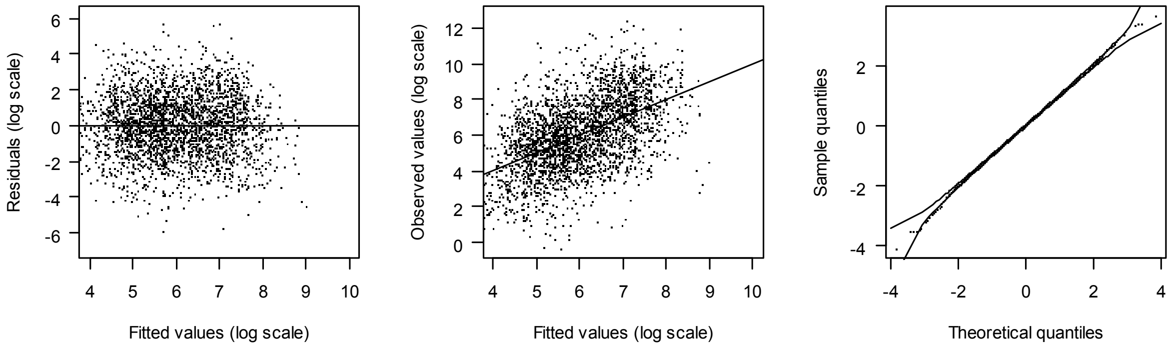

Figure B7: Residual diagnostic plots for CPUE model 4.

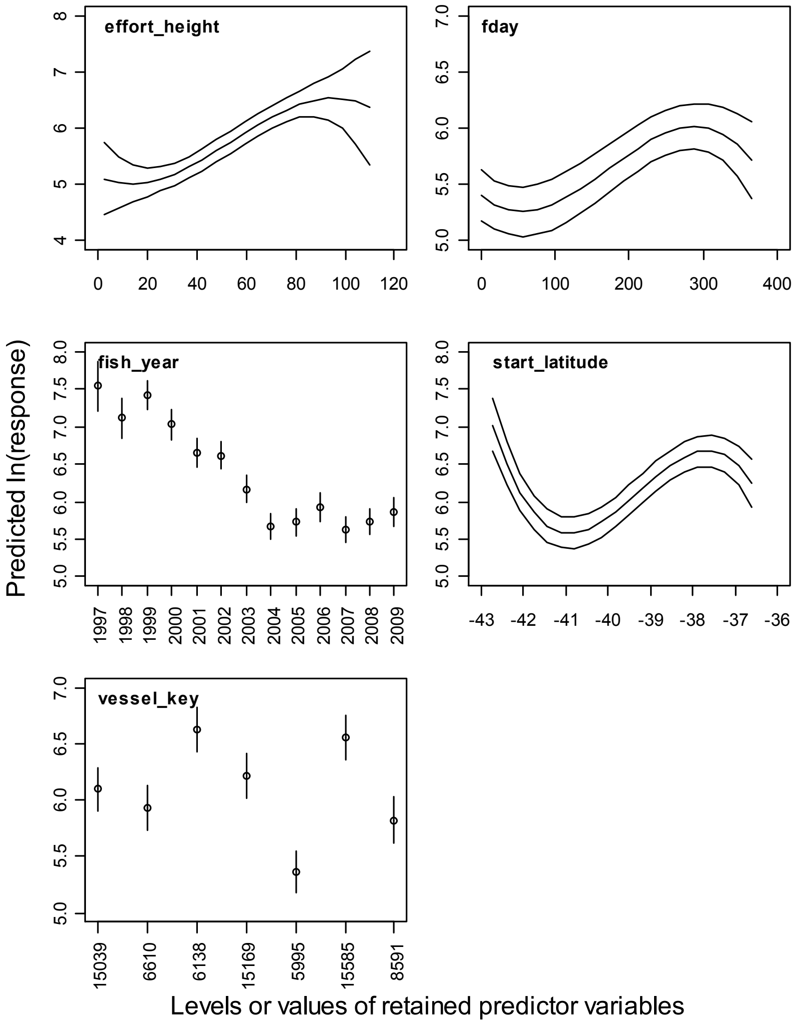

Figure B8: Predicted CPUE for variables *fishing day, fishing year*, *start latitude, effort height and vessel key* for CPUE model 4.

APPENDIX C: TRAWL DATABASE EXTRACTS.

Table C1: Sources of fish length data blue mackerel collected from research trawl voyages since 1981–82.

Year	Trip code	Vessel	length (cm)		No of fish measured		
			Min	Max	Total	female	male
1981-82	kah8203	Kaharoa	9	43	55		
	kah8205	Kaharoa	16	30	6		
	kah8211	Kaharoa	51	53	2		
1982-83	jco8306	James Cook	46	51	5	3	2
	kah8216	Kaharoa	17	18	2		
	kah8303	Kaharoa	8	15	233		
	kah8313	Kaharoa	51	51	1		
1983-84	jco8415	James Cook	47	51	6	0	6
	kah8413	Kaharoa	13	22	22		
1984-85	jco8420	James Cook	53	53	1	1	0
	kah8421	Kaharoa	23	23	1		
	kah8506	Kaharoa	11	43	101		
	kai8501	Kaiyo Maru	51	52	2		
1985-86	kah8517	Kaharoa	19	46	15		
	kah8609	Kaharoa	8	23	384		
1986-87	kah8612	Kaharoa	15	27	68		
	kah8613	Kaharoa	16	24	28		
	kah8711	Kaharoa	7	26	74		
1987-88	kah8715	Kaharoa	20	20	2		
	kah8716	Kaharoa	15	42	109		
1988-89	kah8810	Kaharoa	17	47	50		
1989-90	cor9001	Cordella	15	53	313	100	189
	kah8917	Kaharoa	17	28	99		
	kah8918	Kaharoa	11	52	18		
	kah9004	Kaharoa	15	15	1		
1990-91	kah9016	Kaharoa	17	35	27		
	kah9017	Kaharoa	24	43	2		
	kah9105	Kaharoa	51	51	2	2	0
1991-92	kah9111	Kaharoa	48	51	2		
	kah9202	Kaharoa	6	11	73		
	kah9204	Kaharoa	46	49	2	1	0
	kah9205	Kaharoa	52	56	3	1	2
	tan9106	Tangaroa	43	43	1	0	1
1992-93	kah9212	Kaharoa	14	35	95	0	1
	kah9302	Kaharoa	9	75	153	0	2
	kah9304	Kaharoa	35	35	1	0	1
	kah9306	Kaharoa	51	53	4	2	2
	tan9301	Tangaroa	46	46	1	0	1
1993-94	kah9311	Kaharoa	12	36	568	0	1
	kah9402	Kaharoa	5	47	131	0	2
	kah9406	Kaharoa	51	51	1	1	0
	tan9401	Tangaroa	41	41	1	1	0
	tan9402	Tangaroa	44	44	1	1	0
1994-95	kah9410	Kaharoa	13	22	73	0	13
	kah9411	Kaharoa	19	44	25	0	0
	kah9502	Kaharoa	32	53	2	1	0
	kah9504	Kaharoa	46	51	12	3	8
	kah9507	Kaharoa	18	18	1		
	tan9502	Tangaroa	45	45	1		

Table C1-continued

1995-96	kah9601	Kaharoa	9	10	2		
	kah9602	Kaharoa	10	47	11		
	kah9606	Kaharoa	49	52	2	1	1
	kah9608	Kaharoa	10	21	325	0	0
	tan9601	Tangaroa	48	48	1	0	1
1996-97	kah9615	Kaharoa	12	26	39	0	0
	kah9701	Kaharoa	47	50	5	3	2
	tan9701	Tangaroa	48	48	1	0	1
1997-98	kah9720	Kaharoa	14	28	97	0	0
	tan9801	Tangaroa	47	48	2	1	1
1998-99	kah9902	Kaharoa	11	42	17	0	0
1999-00	kah0004	Kaharoa	48	50	5	2	3
	kah9915	Kaharoa	15	48	183	3	2
2000-01	kah0012	Kaharoa	10	30	75		
	tan0111	Tangaroa	52	53	2		
2001-02	kah0209	Kaharoa	49	49	1		
	tan0201	Tangaroa	49	49	1	1	0
2002-03	kah0304	Kaharoa	47	49	3	0	1
	tan0301	Tangaroa	39	50	12	4	8
2004-05	kah0503	Kaharoa	49	49	3	0	2
	kah0506	Kaharoa	54	54	1		
	tan0501	Tangaroa	42	48	5	5	0
2005-06	kah0611	Kaharoa	45	53	2	1	1
	tan0601	Tangaroa	35	37	3	1	2
2006-07	kah0704	Kaharoa	49	49	1	0	1
	kah0705	Kaharoa	53	53	1	1	0
2007-08	kah0806	Kaharoa	53	53	1	0	1
	tan0801	Tangaroa	40	51	3	2	1
2008-09	kah0905	Kaharoa	52	52	1	1	0
2009-10	tan1001	Tangaroa	43	47	11	4	7