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An update of longline Catch-Per-Unit-Effort indices for snapper in SNA 1

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TABLE OF CONTENTS

Executive Summary

Langley, A.D. (2016). An update of longline Catch-Per-Unit-Effort indices for snapper in SNA 1.

***New Zealand Fisheries Assessment Report 2016/59.* 71 p.**

The SNA 1 fishstock is considered to be comprised of three stock units: east Northland, Hauraki Gulf and Bay of Plenty. Accordingly, the assessment of SNA 1 is structured to accommodate the spatial structure of the constituent stock units. Standardised CPUE indices have been derived for the snapper bottom longline fisheries operating in each of the three areas. The annual snapper longline CPUE indices were an important input in the most recent (2013) stock assessment for SNA 1, providing an index of relative stock abundance during 1989/90–2011/12.

The purpose of the current study was to update the standardised CPUE indices (including 2012/13–2013/14) and investigate the main factors influencing the trends in the nominal and standardised CPUE from the SNA 1 longline fisheries.

The current study was able to closely approximate the area specific longline CPUE indices derived in the previous study. For each of the three fishery areas, the most recent CPUE indices (2012/13–2013/14) were broadly comparable to the CPUE indices from the preceding five years (i.e., 2007/08–2011/12).

The trends in the standardised CPUE indices were relatively robust to the range of model configurations investigated in the study. However, the recent Hauraki Gulf CPUE indices were sensitive to the treatment of the individual core vessels in the CPUE model. There is an indication that the efficiency of some of the long established vessels in the fleet has increased over time and this may introduce a positive bias in the CPUE indices in the latter period.

For each fishery area, there was an indication of a degree of spatial variation in the recent trends in stock abundance. These observations were apparent at the relatively coarse spatial resolution of the daily CPUE data set (i.e. Statistical Area). The diverging trends in CPUE among Statistical Areas may reflect differential exploitation rates among the areas in concert with relatively limited movement between the areas. Alternatively, different trends in the CPUE from the constituent Statistical Areas may be related to changes in the distribution of snapper in response to prevailing oceanographic conditions. An analysis of the location based data from the Hauraki Gulf fishery revealed considerable variation in the spatial distribution of snapper CPUE during 2007/08–2013/14. The results suggest that snapper were concentrated in the western area of the inner Gulf during 2009/10–2011/12 and dispersing from the area in 2012/13–2013/14. These trends indicated that a change in fish distribution may have been a cause of the divergent trends in the area-specific CPUE during 2008/09–2013/14.

The availability of the location based catch and effort data enabled mesoscale (5–30 km) changes in the distribution of fishing effort to be investigated for the Hauraki Gulf fishery. The study indicated that fishing vessels generally remained in areas supporting higher catch rates of snapper and would relocate to a new area if catch rates were low. This observation is consistent with the target operation of the fishery. There was no indication that the operation of the fishery had changed over the recent period (2007/08–2014/15).

It is proposed that the CPUE analyses be updated in 2018 (including data from 2015/16–2016/17). Further investigation is recommended to determine the best approach to derive annual CPUE indices that account for the sub-regional distribution of biomass rather than simply reflecting the distribution of fishing effort (effort records).

INTRODUCTION

The target longline fishery for snapper (*Pagrus auratus*) represents one of the main commercial fisheries in SNA 1, accounting for approximately 35% of the total catch during 2005/06–2009/10 (McKenzie & Parsons 2012).

The SNA 1 fishstock is considered to be comprised of three stock units: east Northland, Hauraki Gulf and Bay of Plenty (Ministry for Primary Industries 2016). Accordingly, the assessment of SNA 1 is structured to accommodate the spatial structure of the constituent stock units (Francis & McKenzie 2015).

For each stock unit, standardised CPUE indices have been derived for the snapper bottom longline fisheries operating in each of the three areas (McKenzie & Parsons 2012). The initial analysis derived CPUE indices for 1989/90–2009/10 (McKenzie & Parsons 2012) and the indices were subsequently updated to include data from 2010/11–2011/12 (Francis & McKenzie 2015). The resulting CPUE indices were incorporated in the most recent (2013) stock assessment of SNA 1, representing the main relative abundance indices in each of the three stock units. Consequently, the CPUE indices were highly influential in the estimation of recent trends in stock abundance for SNA 1 (Francis & McKenzie 2015, Ministry for Primary Industries 2016).

For the east Northland and Hauraki Gulf longline fisheries, the trends in the standardised CPUE indices differed considerably from the large increases in the nominal CPUE from the two fisheries (Francis & McKenzie 2015). One objective of the current study was to investigate the influence of the main variables incorporated in the standardised CPUE models to account for the differences between the standardised and unstandardised (nominal) CPUE indices. A second objective of the study was to update the time series of CPUE indices to include data from the most recent years (2012/13–2014/15) and, thereby, provide an indication of recent trends in stock abundance. The study was funded by the SNA 1 Commercial stakeholder group.

DATA SETS

Commercial catch and effort data from the SNA 1 bottom longline (BLL) fishery were sourced from the Ministry for Primary Industries (MPI) database *warehou*. The data extract was specified to include all fishing trips that conducted BLL fishing effort within the area of the SNA 1 fishstock (Statistical Areas 001–010) during 1989/90–2014/15. The selection of fishing effort was constrained to include BLL target fishing effort that could be expected to catch snapper (target species SNA, KAH, TRE, TAR, GUR, SCH, KIN and RSN).

For the qualifying fishing trips, all effort data records were obtained regardless of whether or not snapper was reported to have been caught or landed. The estimated catch and landed catch records of all finfish species were sourced for the qualifying fishing trips.

For 1989/90–2006/07, BLL fishing vessels reported catch and effort data using the Catch Effort Landing Return (CELR), which records aggregated fishing effort and the estimated catch of the top five species. Typically, only one CELR record is completed for each BLL fishing day. The verified landed greenweight that is obtained at the end of the trip was recorded on the Landings section of the CELR form.

In 2007/08, the Lining Trip Catch Effort Return (LTCER) was introduced specifically for the inshore line fisheries, including the BLL method. The LTCER form records detailed fishing activity, including start location and depth of the set, the number of hooks set, start and end time of the set and the associated (estimated) catches from individual sets. The LTCER form enables the estimated catch of the eight main species (by weight) to be recorded for each set. The landed catches associated with trips reported on the LTCER form are reported at the end of a trip on the Catch Landing Return (CLR).

1.1 Data processing

Two data sets were configured for the CPUE analyses: 1) a daily aggregated data set that included fishing effort records from the CELR and LTCER formats and aggregated fishing activity and catches by fishing vessel and fishing day (1989/90–2014/15) and 2) a LTCER data set that was comprised of fishing event and catch data from the more recent years (2007/08–2014/15).

1.1.1 Daily aggregated data set

The daily aggregated data set initially included all fishing trips specified in the data extract. The initial set of snapper landed catch records was restricted to those records that represented the final destination of the snapper catch (destination codes L, A, C, E, and O). This resulted in a trivial reduction in the total SNA 1 landed catch included in the landings data set (Table 1).

Table 1: Total SNA 1 reported landed catch included in the daily aggregated data set at each step of the catch grooming process.

Criterion	Reported catch (t)	Percent of total reported catch
All landing records	51 213.4	100.0%
Destination codes (L, A, C, E, O)	50 731.5	99.1%
Exclude landed catch outliers	50 470.7	98.5%
Associated effort records	50 460.0	98.5%
Target SNA or GUR	49 764.8	97.2%

Potential landed catch outliers were examined by comparing the corresponding landed catches and aggregated estimated catches from individual fishing trips. In most cases, the ratio of the trip landed catch to the estimated catch approximated 1.0 (median 1.04) indicating a good correspondence between the landed catch and estimated catch (Figure 2). A small number of trips (n = 2) with exceptionally large landings (exceeding 20 t SNA 1) were excluded.

The data set was refined to include only bottom longline trips that targeted either snapper or red gurnard. These target species accounted for most of the SNA 1 bottom longline catch (Table 1).

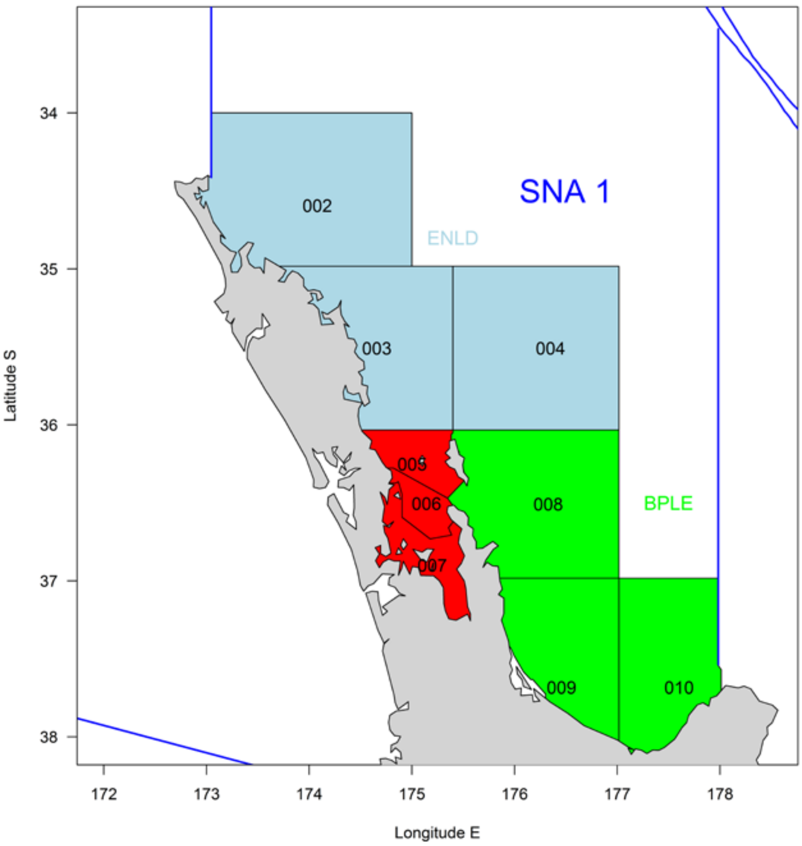

Figure 1: Map of SNA 1 fishery areas defined based on Statistical Areas. The area of the Hauraki Gulf fishery is shaded in red.

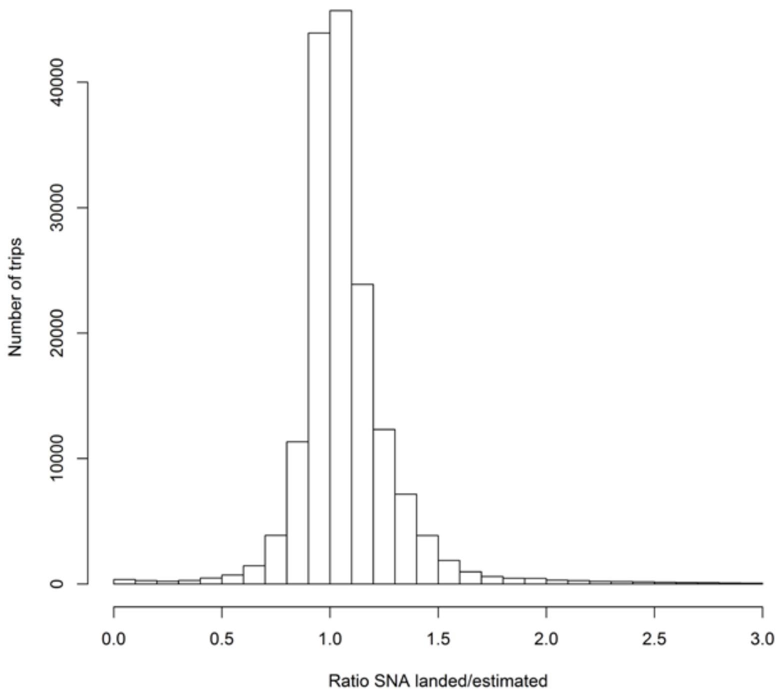

Figure 2: Frequency histogram of the ratio of the SNA 1 landed catch and the sum of snapper estimated catches from individual bottom longline fishing trips.

Catch and effort data from the LTCER fishing trips were aggregated in a manner that approximates the daily aggregate format of the CELR, following the approach of Langley (2014). The approach aggregates longline fishing effort (number of sets and total number of hooks set) for each fishing vessel and fishing day. The resulting records are assigned a statistical area and target species based on the predominant statistical area and declared target species from the day of fishing.

Following the aggregation of the fishing effort data by vessel fishing day, there was no indication of change in the number of sets or the number of hooks set corresponding to the introduction of the LTCER form in 2007/08 (Figure 3).

For the LTCER fishing trips, the estimated species catches were also aggregated by vessel fishing day and the aggregate catches were ranked based on species catch weight. The five species with the largest estimated catches were retained, replicating the recording of the top five species estimated catches in the CELR format. The estimated catches of the remainder of the species (non top five) were not included in the daily aggregate data set. For almost all of the daily aggregated LTCER fishing records (96%), snapper was recorded as the dominant species caught (by weight). Consequently, excluding daily snapper estimated catches beyond the top five ranked species did not result in an appreciable reduction in the total snapper estimated catch included in the LTCER data set.

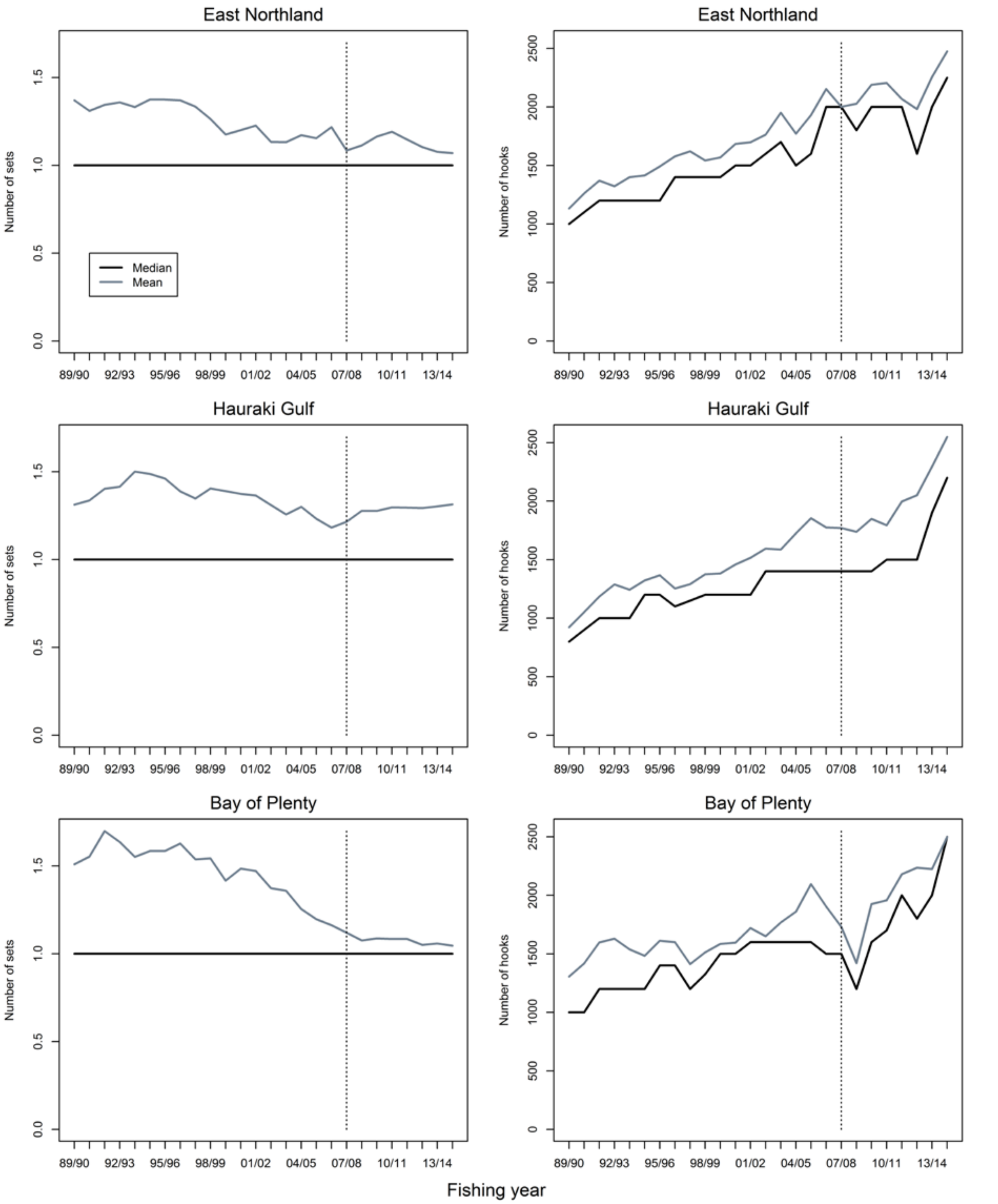

Figure 3: A summary of daily aggregated fishing effort (total number of sets and total number of hooks set per day) for the snapper bottom longline fishery by area and fishing year. The vertical line indicates the year that the LTCER reporting form was introduced (2007/08).

The landed catches of SNA 1 from each fishing trip were apportioned to the daily aggregate fishing effort records following the approach developed by Starr (2007). For fishing trips that recorded at least one top five estimated catch of snapper, the SNA 1 landed catch was allocated to the individual fishing effort records in proportion to the individual estimated catches (represented 97.7% of total landed catch). For fishing trips with no associated top five estimated catches, the landed catches were assigned to the daily fishing records in proportion to the number of sets per day (represented 2.3% of total landed catch).

The daily aggregate data set was subdivided following the spatial stratification of SNA 1 adopted by McKenzie & Parsons (2012); i.e., east Northland (ENLD), Statistical Areas 002–004; Hauraki Gulf (HG), Statistical Areas 005–007; Bay of Plenty (BPLE) Statistical Areas 008–010 (Figure 1).

The variables included in the data set are presented in Table 2.

Table 2: The variables included in the daily BLL CPUE data set for the three fishery areas and the acceptable range for each variable.

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric	
FishingYear	Fishing year	Categoric (26)	1989/90–2014/15
Month	Month	Categoric (12)	1–12, 1=January
Target	SNA target or non target set	Categoric (2)	
StatArea	Statistical area	Categoric (3)	002–004 (ENLD) 005–007 (HG) 008–010 (BPLE)
StatArea:Month		Interaction	
NumHooks	Natural logarithm of number of hooks	Continuous	ln(200–6000)
SNAcatch	Scaled estimated SNA catch (kg).	Continuous	0–8000 kg

1.1.2 Individual LTCER fishing event data set

The fishing event based LTCER data were available for 2007/08–2014/15 fishing years. For the LTCER data set, the fishing event format was retained. The landed snapper catch from each fishing trip was apportioned amongst the individual fishing event records in a similar manner to the processing of the daily aggregated data set (previous section); i.e. the total landed SNA 1 catch from the trip was apportioned amongst fishing events in proportion to the estimated snapper catch from each set. For the LTCER records, estimated catches of snapper were recorded for almost all (99.8%) qualifying fishing events. On that basis, there was no secondary allocation of snapper catches in proportion to fishing effort (numbers of sets).

The resulting LTCER data set was subdivided into the three fishery areas defined in the previous section.

CPUE Analyses

1.2 Update of previous analysis

McKenzie & Parsons (2012) applied a Generalised Linear Modelling (GLM) approach to derive standardised CPUE indices for each of the three SNA 1 fishery areas. The analysis was subsequently updated to extend the time series of CPUE indices to 1989/90–2011/12 (Francis & McKenzie 2015).

The previous analyses were based on BLL catch and effort data sets that were formulated in a similar manner to the daily aggregate data set described in Section 1.1.1. Nonetheless, there were minor differences in both the data selection criteria and data processing between the previous and current analysis and, hence, the comparative data sets are not identical.

The current study attempted to replicate the fishery area BLL CPUE indices derived by Francis & McKenzie (2015). Each fishery area data set was limited to a subset of "core" vessels based on four vessel selection criteria (see Francis & McKenzie 2015). For the current study, similar criteria were applied to each fishery area data set to approximate the data sets used in the previous study. It is assumed that the resulting data sets are comparable to the previous study although direct comparisons were not possible as summary details of the fishery area data sets were not presented in Francis & McKenzie (2015).

The current fishery data sets included a small proportion of records with no associated snapper landed catch (zero catch records) (Appendix 3 Tables A2–4). These records were excluded from the final data sets.

For each fishery area, the current study configured log-linear regression models that were equivalent in formulation to the models derived by Francis & McKenzie (2015). For each model, the dependent variable was the natural logarithm of the daily catch (kg) of snapper. In the previous analysis, a set of explanatory variables was selected for each fishery area model. For the current analysis, each model was refitted using the explanatory variables that were selected in the previous study (Table 3). The variable *NumHooks* is the natural logarithm of the total number of hooks set per day and was parameterised as a third order polynomial. The other explanatory variables were included in the model as categoric variables.

Table 3: Explanatory variables included in the BLL CPUE models derived by Francis & McKenzie (2015).

Model variable	Fishery area		
	East Northland	Hauraki Gulf	Bay of Plenty
1	*FishingYear*	*FishingYear*	*FishingYear*
2	*NumHooks*	*NumHooks*	*Vessel*
3	*Vessel*	*Vessel*	*NumHooks*
4	*Month*	*Month*	*Target*
5	*Target*		

The annual CPUE indices derived for each fishery area are presented in Appendix 2. For each fishery area, the current analysis was able to approximate the CPUE indices derived by Francis & McKenzie (2015). The annual indices were very similar for both the Hauraki Gulf and Bay of Plenty fishery area (Figures A2 and A3). For the East Northland fishery area, the general trend in the CPUE indices was very similar for the previous and current analyses, although there were some differences in the magnitude of the indices for the years with the highest CPUE (Figure A1).

For each fishery area, the CPUE indices were also updated to include data from the subsequent three years (2012/13–2014/15), while retaining the equivalent subset of core vessels. The inclusion of the additional years' data did not influence the annual indices from the original data period (Figures A1–3). For each fishery area, the most recent CPUE indices tended to fluctuate about the level of the indices from the preceding five years (2007/08–2011/12).

1.3 Revised analysis

For the current study, the standardised CPUE models formulated by Francis & McKenzie (2015) were also refitted with the entire data set (1989/90–2014/15). For each fishery area, the subset of core vessels was defined to account for approximately 70% of the total snapper catch from the BLL fishery (Table 4). For the Bay of Plenty fishery area this required a relatively low threshold for inclusion in the core vessel subset.

Table 4: Summary statistics for the daily core vessel data sets for each fishery area.

	Fishery area		
	East Northland	Hauraki Gulf	Bay of Plenty
Minimum trips per year	35	35	5
Minimum years	6	7	5
Number core vessels	40	45	46
Proportion SNA catch	67.6%	68.1%	74.1%

For each fishery area, a Generalised Linear Modelling (GLM) approach was applied to model the magnitude of the non zero snapper catches. The dependent variable was the natural logarithm of catch and a lognormal error structure was assumed. The data sets included a small number of zero catch records that were excluded from the model data sets. The potential explanatory variables available for inclusion in each CPUE model are presented in Table 2. The small number of records for non snapper target fishing were excluded from the model data sets and, hence, the *Target* variable was excluded from the set of potential explanatory variables.

A step-wise fitting procedure was implemented to configure each of the CPUE models. The procedure included all of the potential explanatory variables (Table 2) with the continuous variable (*NumHooks*) parameterised as a third order polynomial function. The categoric variable *FishingYear* was included in the initial model and subsequent variables were included in the model based on the improvement in the Akaike Information Criterion (AIC).

For each of the CPUE models, annual CPUE indices were derived from the *FishingYear* coefficients. The influence of the main variables on the annual indices was investigated using the approach of Bentley et al. (2012). The robustness of the individual models was also evaluated by a detailed examination of the model residuals relative to the key variables included in the model.

For the three fishery areas, a separate standardised CPUE analysis was conducted using the LTCER fishing event data set from 2007/08–2014/15 (Section 1.1.2). The individual fishing locations were categorised by assigning the records to a grid of 0.2 degree latitude/longitude cells based on the start position of the set (*Loc2* variable). The spatial resolution of the 0.2 degree grid represented a compromise between maintaining the location of the fishing activity, given the spatial scale of individual fishing operations (longline sets), while ensuring that there were sufficient records at individual locations. Data records from *Loc2* cells with fewer than 20 records were excluded from the data set (Table 5). Fishing effort records were also restricted to depths less than 100 m, encompassing the main distribution of the snapper longline catch in each fishery area; the depth range accounted for 87%, 99.7% and 93% of the snapper catch from East Northland, the Hauraki Gulf and Bay of Plenty, respectively.

The LTCER data set was stratified by fishery area. For the three fishery areas, the data set was further limited to a set of (core) vessels that completed a minimum of 35 fishing trips in a minimum of five years (within the specific area).

The standardised CPUE analysis of the LTCER data sets applied the GLM approach used for formulating the daily CPUE models (described above). The potential explanatory variables available for inclusion in each of the LTCER CPUE models are presented in Table 5.

Table 5: Variables included in the LTCER fishing event data set.

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric	
FishingYear	Fishing year	Categoric (8)	2007/08–2014/15
Month	Month	Categoric (12)	1–12
Loc2	Start location of set categorised by 0.2 degree latitude/longitude cell.	Categoric	
TargetSpecies	Declared target species for set	Categoric (2)	SNA,GUR
Duration	Natural logarithm of set duration	Continuous	Ln(1–12)
Depth	Fishing depth (m)	Continuous	< 100 (BPLE) < 100 (HG) < 100 (BPLE)
StartTime	Hour at the start of set	Continuous	0–23
NumHooks	Natural logarithm of number of hooks set	Continuous	Ln(200–6000)
SNAcatch	Scaled estimated SNA set catch (kg).	Continuous	0–1000 kg

1.4 East Northland

1.4.1 Longline fishery characterisation

Annual snapper catches from the East Northland BLL fishery increased from about 500 t in the early 1990s to a peak of approximately 900 t in 1996/97 (Figure 4). Annual catches declined during the late 1990s and during 2003/04–2014/15 were maintained at about 500–600 t per annum.

The East Northland BLL fishery primarily operates within Statistical Areas 002 and 003. Annual catches are relatively evenly distributed between the two areas, although in recent years there has been an increase in the proportion of the catch taken from the southern area (003) (Figure 4). A very small proportion of the annual catch is taken from Statistical Area 004, representing only 1–2% of the total annual catch during the last decade.

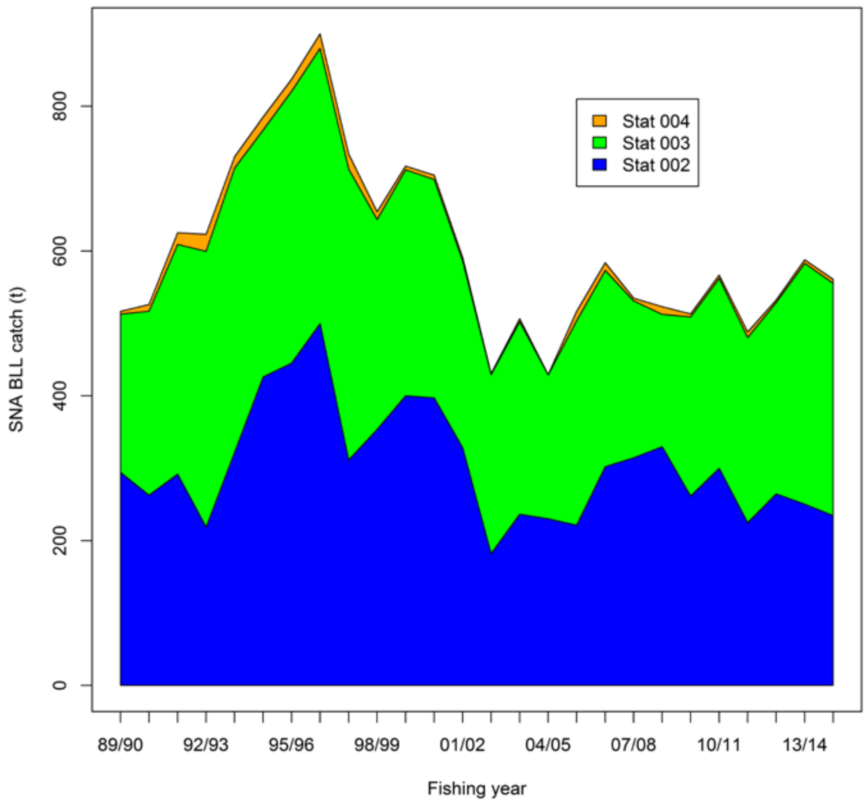

Figure 4: Annual total BLL snapper catch by Statistical Area for the East Northland fishery area.

A relatively large number of BLL vessels operated in the fishery during the early 1990s but there was considerable rationalisation of the fleet during the mid–late 1990s and the size of the fleet declined considerably during the period (Figure 5).

The core fleet selection criteria excluded many of the vessels that operated in the fishery during the early 1990s and, correspondingly, the core fleet accounted for a relatively low proportion (approximately 50%) of the total snapper catch during that period (Figure 5). In contrast, during 1994/95–2010/11, the core fleet accounted for 68–85% of the total annual catch.

In the more recent years, the core fleet has comprised 7–9 vessels and the overall proportion of snapper catch included in the core vessel data set has declined (to 41% in 2014/15) (Figure 5). This decline is a function of the turn-over of the BLL fleet with a number of vessels retiring in recent years (Figure 6) and a number of new entrants in the fishery during the last five years. Nonetheless, some of the remaining vessels in the fleet have operated in the fishery for a considerable period; eight of the nine core vessels that operated in the fishery in 2014/15 had participated in the fishery for at least 15 years (Figure 6).

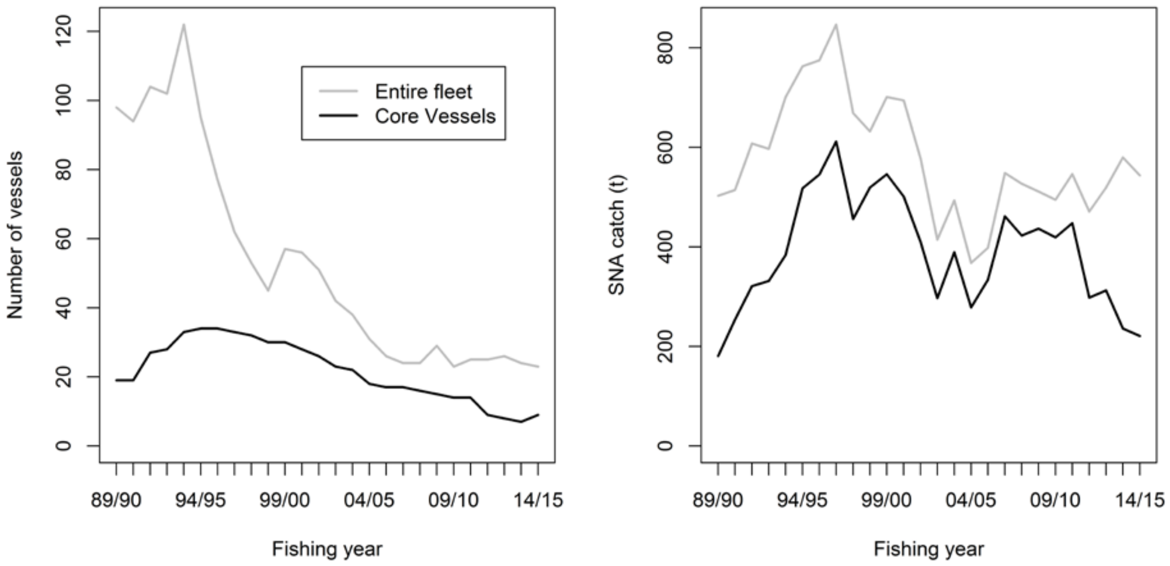

Figure 5: A comparison of the number of vessels and the annual snapper catch included in the total data set and the core vessel data set for the East Northland BLL fishery.

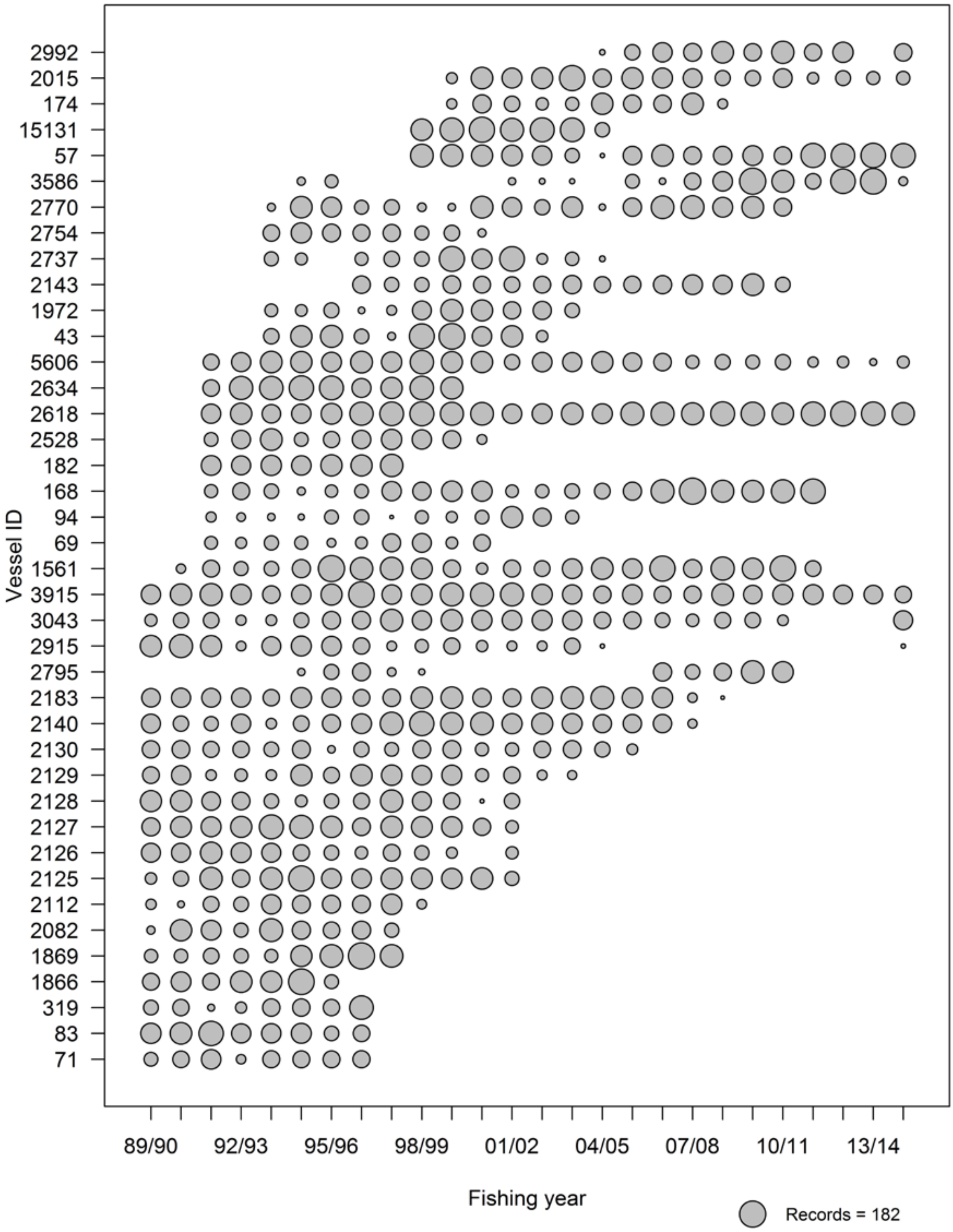

Figure 6: Distribution of East Northland data records by fishing year and vessel for the core fleet included in the final daily aggregated CPUE data set.

The distribution of fishing effort records between the two main Statistical Areas was broadly comparable between the total data set and the core vessel set, although during 1993/94–2008/09 the core vessel data set included a higher proportion of fishing effort from Statistical Area 002 compared to the overall data set. Fishing effort from Statistical Area 002 dominated the core vessel data set during 1994/95–2001/02 (Figure 7).

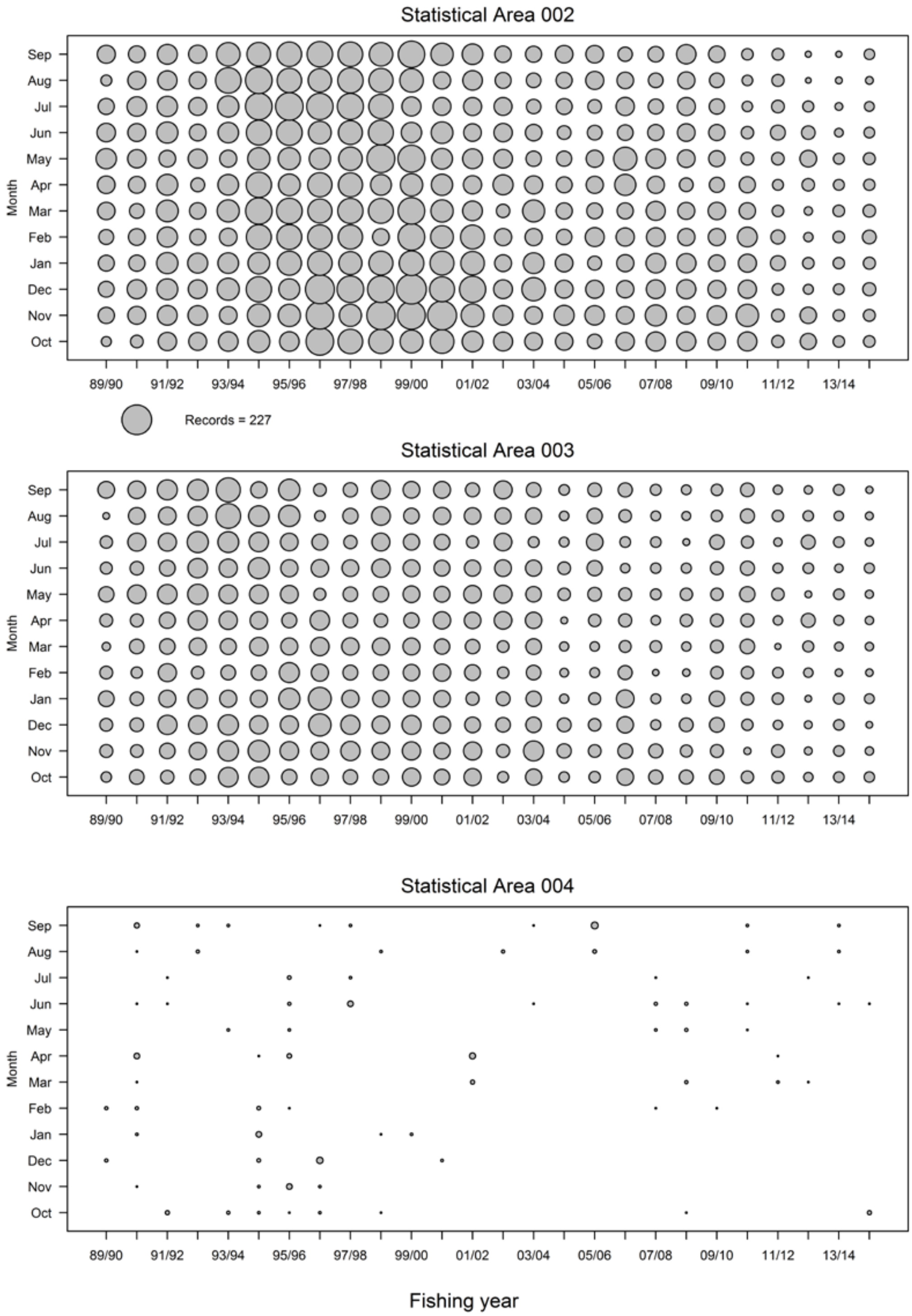

Figure 7: Annual distribution of daily aggregate data records by Statistical Area and month for the East Northland core vessel CPUE data set.

For the core fleet, fishing effort was relatively evenly distributed throughout the fishing year although effort tended to be slightly higher during the first quarter of the fishing year (October–December) compared to July–September (Figure 7). There was no appreciable difference in the seasonal distribution of fishing effort between the core fleet and the total fleet.

There was considerable variation amongst the core fleet in the number of hooks set per vessel (Figure 8). From the late 2000s, two main modes of fishing operation have emerged with one set of vessels setting 700–1000 hooks per day and another set of vessels setting more than 2000 hooks per day (Figure 8). Overall, there was a general increase in the number of hooks set per vessel since the late 1990s. The average daily catch of snapper also tended to increase during the 2000s (Figure 8).

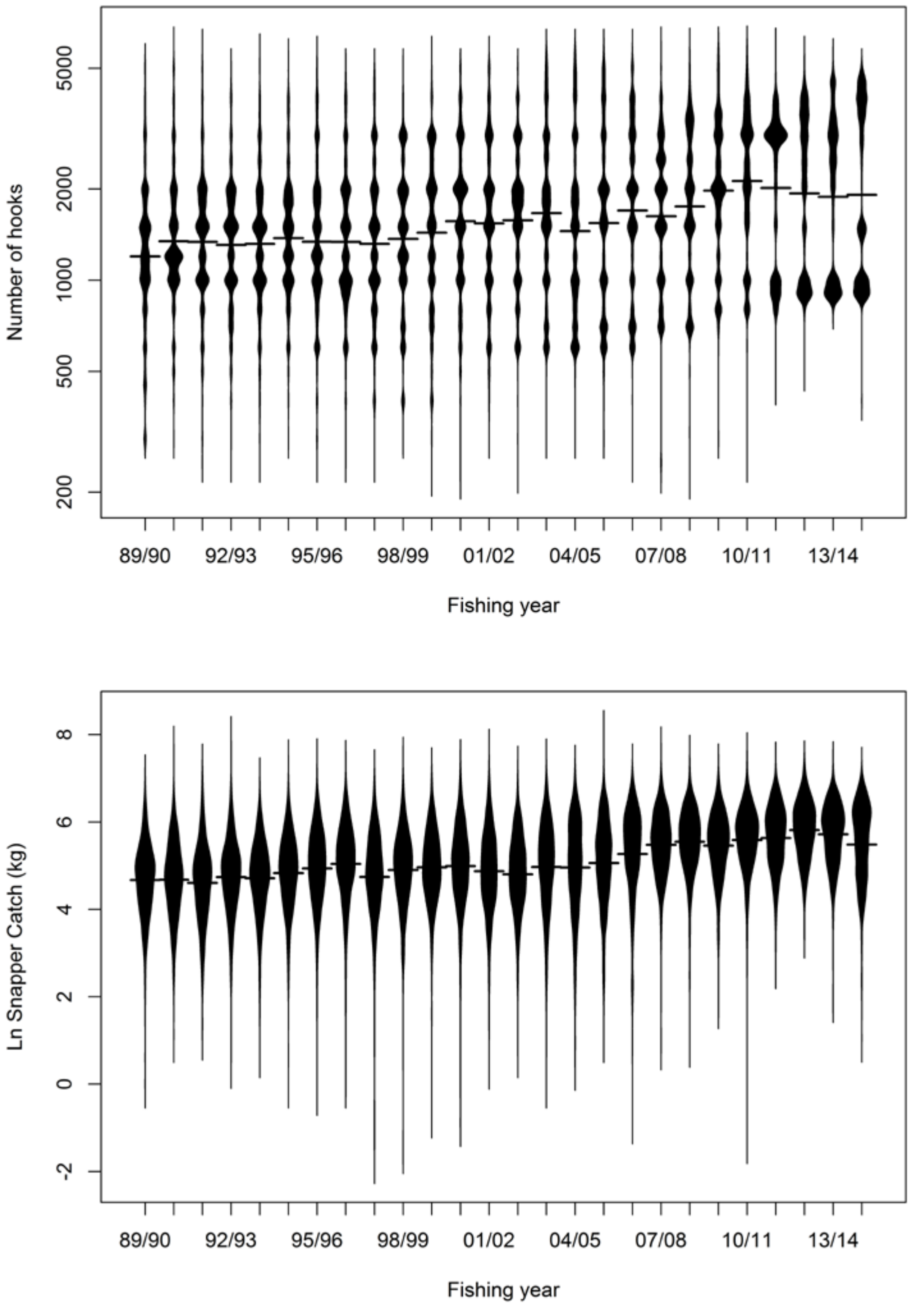

Figure 8: Beanplots of the daily number of hooks set (top panel) and the logarithm of snapper catch (kg) (bottom panel) for the East Northland CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the mean value.

For the core fleet, snapper was the dominant species caught; snapper accounted for at least 70% of the total trip catch weight from 75.2% of trips. The main associated species caught were red gurnard and tarakihi although both species generally represented a small proportion of the catch (relative to the snapper catch) (Figure 9). There is no indication that the species catch composition changed substantially over the study period.

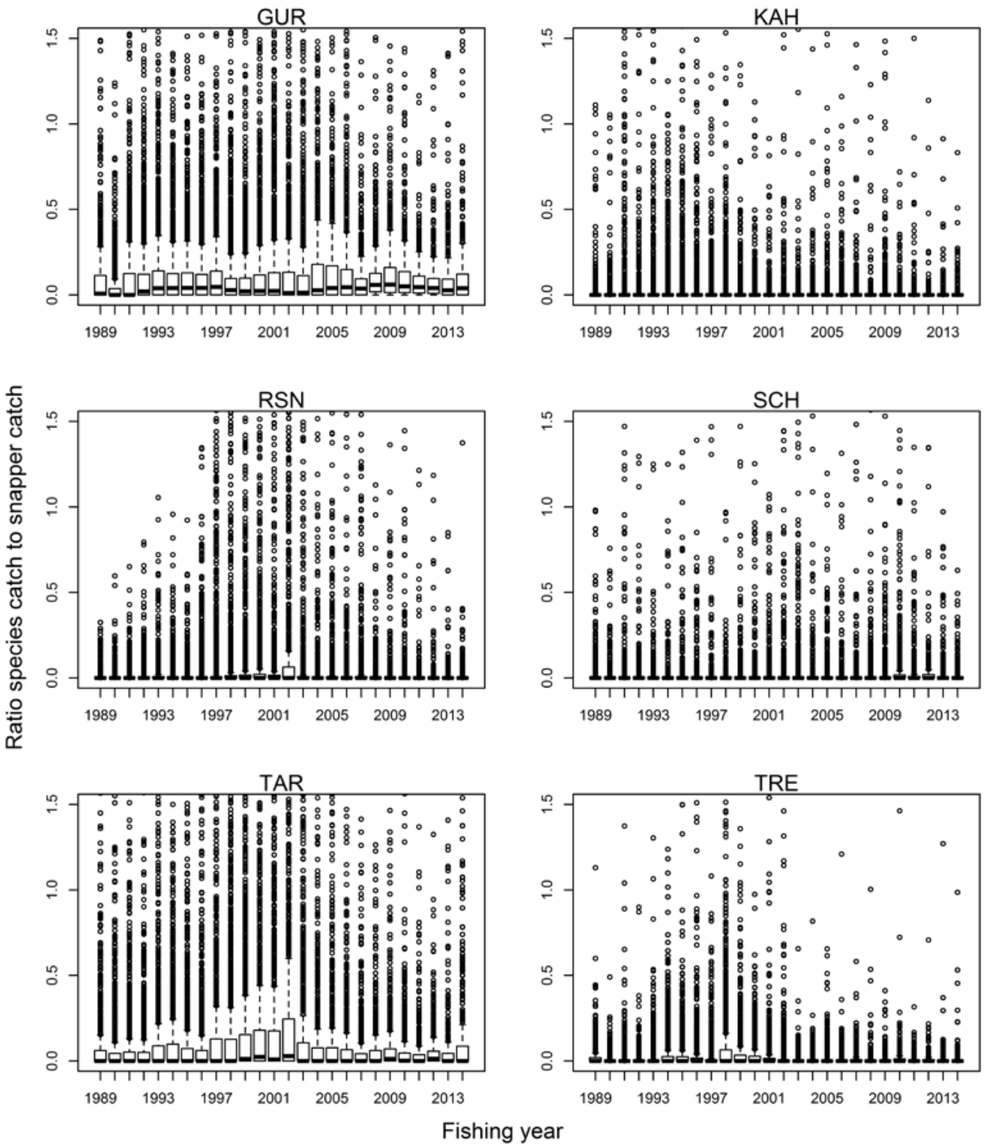

Figure 9. Boxplots of the ratio of the species catch to the snapper catch from each fishing trip for the main associated species caught by the East Northland BLL fishery (core vessel data set).

1.4.2 CPUE indices

The CPUE regression model for the East Northland fishery included all the potential explanatory variables in the final model (Table 6). The effort variable (*NumHooks*) accounted for the highest proportion of the explained variation in snapper catch followed by *FishingYear*, *Vessel* and *Month*. The *StatArea* variable accounted for a minor proportion of the total explained deviance. Overall, the model accounted for 41.6% of the total variation.

The residual diagnostics indicate that the model generally approximates the assumption of a normally distributed error structure (Figure 10). However, there is a long tail of negative residuals that skew the distribution of the model residuals. These residuals correspond to observations of small catches of snapper (less than 10 kg) that are not predicted by the CPUE model (Figure 10).

Table 6: Summary of stepwise selection of variables in the East Northland CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			46 584	42 708		
1	*FishingYear*	25	4 308.3	46 559	38 400	0.101	123 254.9
2	*NumHooks*	3	9 492.1	46 556	28 908	0.323	110 033.3
3	*Vessel*	39	1 934.5	46 517	26 973	0.368	106 884.6
4	*Month*	11	1 641.4	46 506	25 332	0.407	103 981.9
5	*StatArea*	2	261.9	46 504	25 070	0.413	103 501.8
6	*StatArea:Month*	22	108.2	46 482	24 962	0.416	103 344.2

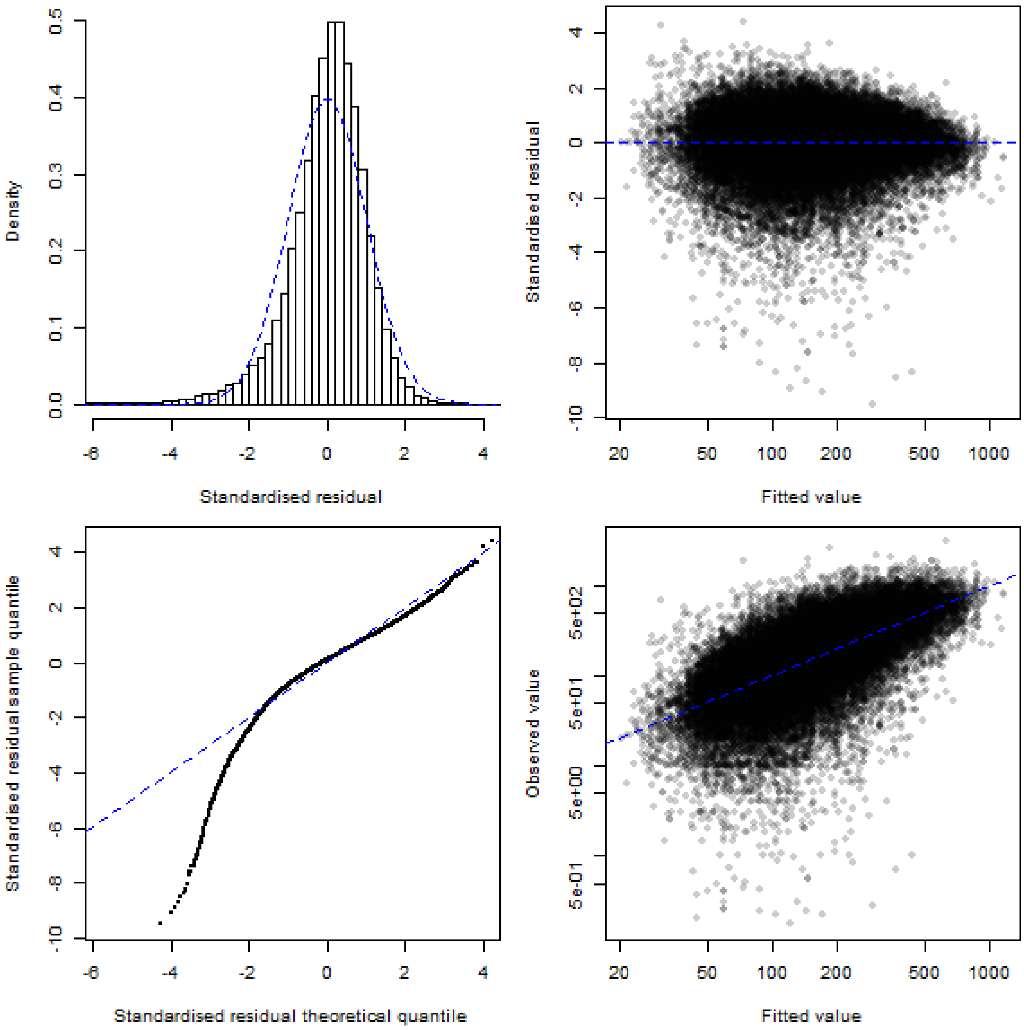

Figure 10: Residual diagnostics for the CPUE model for the East Northland fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the CPUE model fluctuate over the study period. The indices increased during the early 1990s, reaching a peak in 1996/97, and then declined to a lower level in the early 2000s (Figure 11). During the mid 2000s, the indices increase to a relatively high level in 2007/08–2008/09, declined in 2009/10, increased to a peak in 2012/13 and then declined during the next two years (to 2014/15).

There is a marked difference in the recent trends between the standardised CPUE indices and the unstandardised CPUE indices (Figure 11). The smaller increase in the standardised indices during 2002/03–2012/13 is primarily attributed to the inclusion of the effort variable (*NumHooks*) in the CPUE model (Figure 12), adjusting for the overall increase in the number of hooks set in the fishery during the period (Appendix 3, Figure A4).

The *Vessel* variable was also influential in the CPUE model, further moderating the increase in the CPUE indices in the last decade. This indicates that the more efficient vessels have remained in the fishery during the recent period (Figure 12), while some of the less efficient vessels were no longer operating in the fishery (Appendix 3, Figure A5).

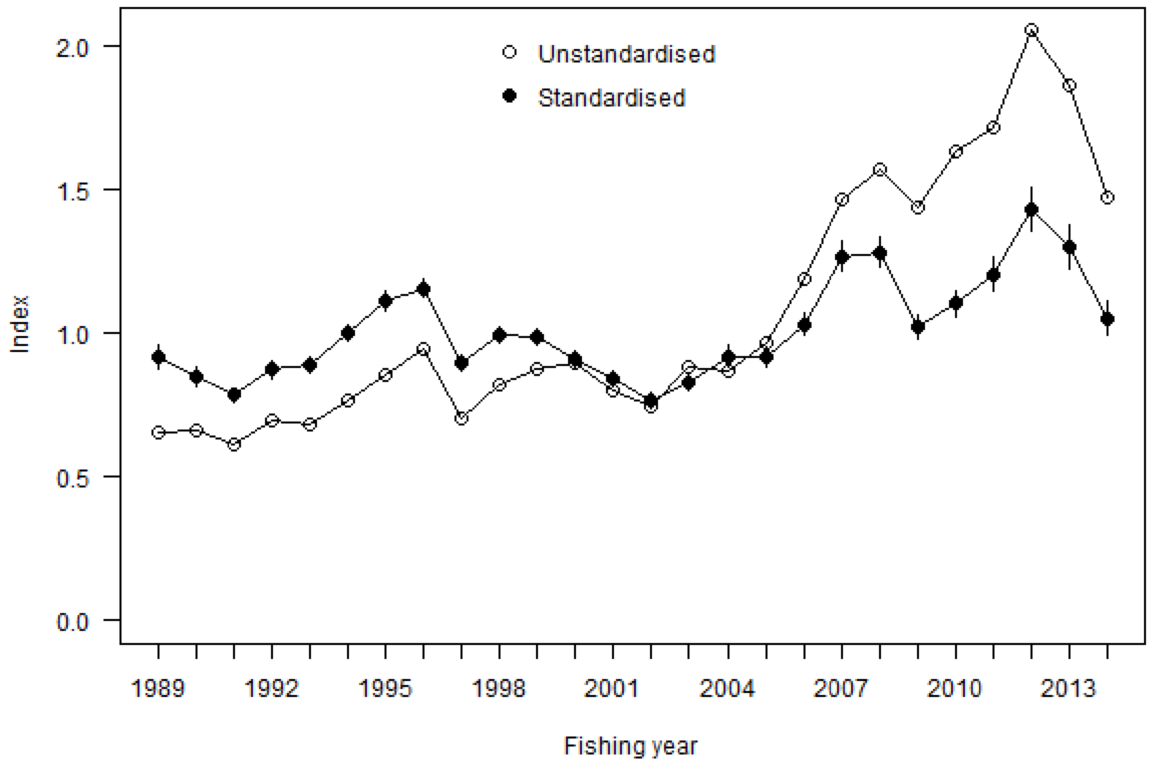

Figure 11: A comparison between the unstandardised and standardised CPUE indices for the East Northland fishery. The unstandardised indices represent the geometric mean of the snapper catch per fishing day. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

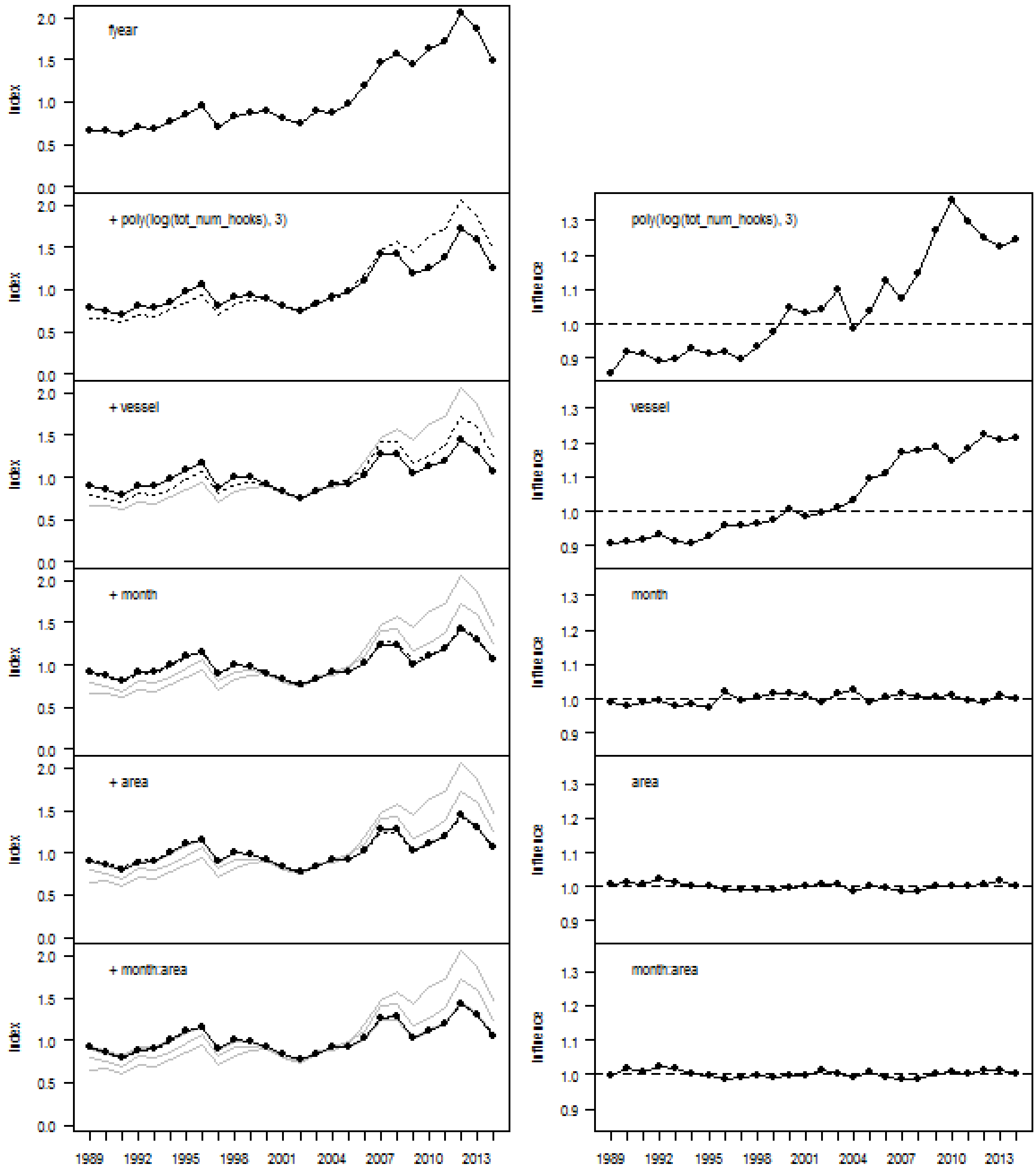

Figure 12: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the CPUE model for the East Northland fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

Annual trends in the model residuals were examined for a number of the variables included within the CPUE model. The *NumHook* variable was partitioned into three categories that approximate groupings within the data set: fewer than 1200 hooks, 1200–2200 hooks, and more than 2200 hooks (Figure 8). For each year, the average of the residuals was determined for each hook category (Figure 13). During the 1990/91–1996/97, the CPUE model generally over-estimated the snapper catches for the lowest hook category as is evident in the negative average annual residual pattern (Figure 13). Conversely, during 2008/09–2013/14, the CPUE model generally under-estimated the snapper catches for the same hook category resulting in a period of positive average annual residuals.

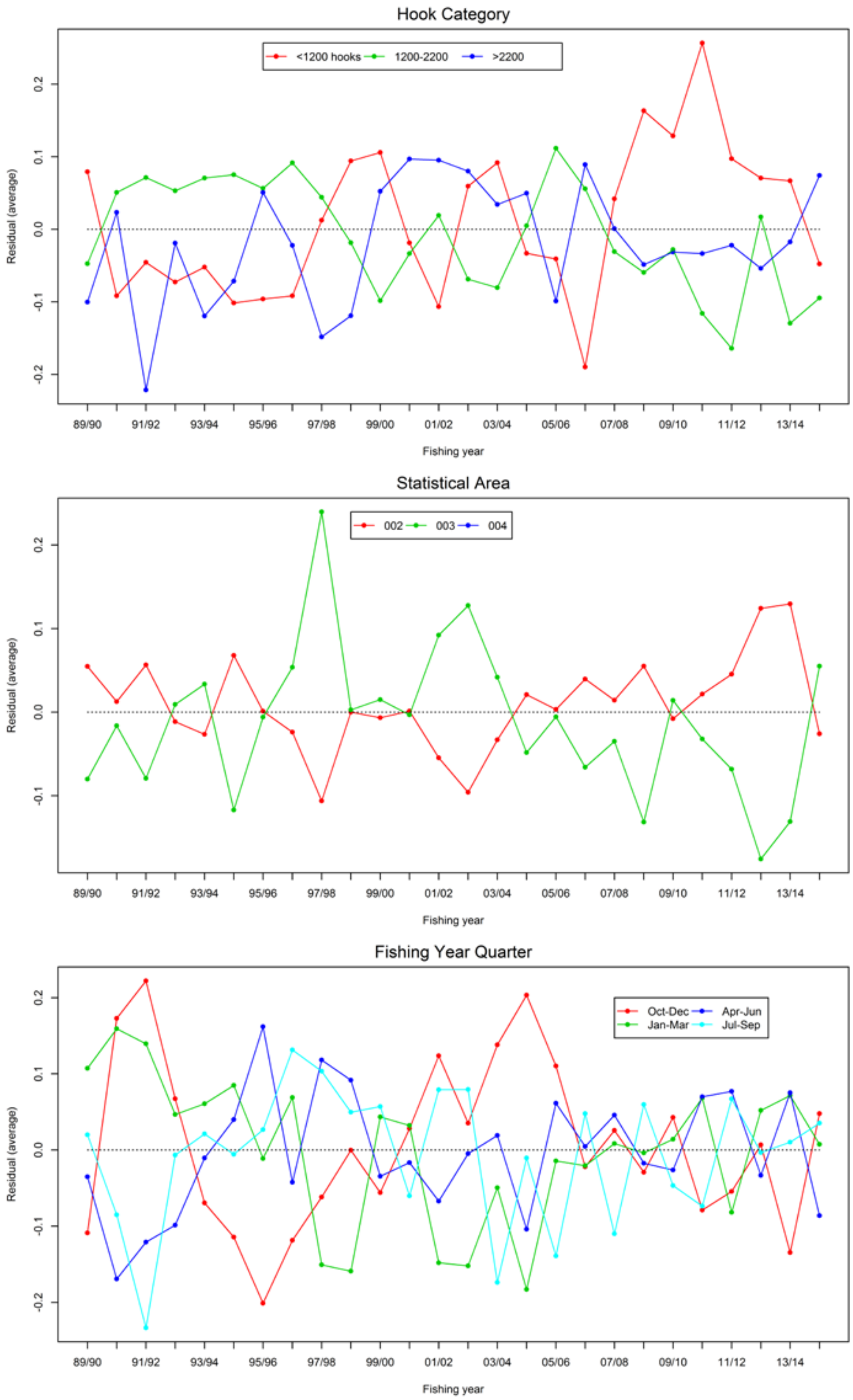

Figure 13: Average annual residuals from the East Northland CPUE model by category for three variables included in the model. The variables are: total number of hooks (*NumHooks*) classified in three size categories (top panel), Statistical Area (middle panel) and *Month* classified in quarterly periods (bottom panel).

Trends in the annual average residuals were also evident for the two main Statistical Areas (002 and 003) during 2004/05–2014/15 (Figure 13). During this period, the average annual residuals from Statistical Area 002 were generally positive, while the annual average residuals from Statistical Area 003 were generally negative. These patterns may indicate divergent trends in snapper CPUE between the two areas. The spatial trends in CPUE are examined in more detail in Section 1.7.

The *Month* variable was categorised into the four quarters of the fishing year: October–December, January–March, April–June and July–September. The residuals for the first quarter fluctuated considerably over the time period; the annual average residuals were relatively high in 1990/91–1991/92, low during 1993/94–1997/98 and high in 2001/02–2005/06 (Figure 13). There were inverse trends in the residuals from the other three quarters.

The trend in the residuals by hook category may indicate that the parameterisation of the relationship between snapper catch and number of hooks set was not constant over the study period. This may potentially result in a bias in the CPUE indices given that there was a steady increase in the proportion of CPUE records within the largest hook category (Figure 14). The sensitivity of the CPUE indices to these changes was investigated by refitting the CPUE model with data from the lowest hook category only (i.e., excluding data records with *NumHooks* greater than 1200). The resulting annual indices from the CPUE model sensitivity differed somewhat from the base CPUE model although the general trend in the two sets of CPUE indices was very similar (Figure 15).

Similarly, the CPUE model was rerun with a data set that excluded records from the first quarter of the fishing year. The resulting CPUE indices were very similar to the base CPUE model (Figure 15).

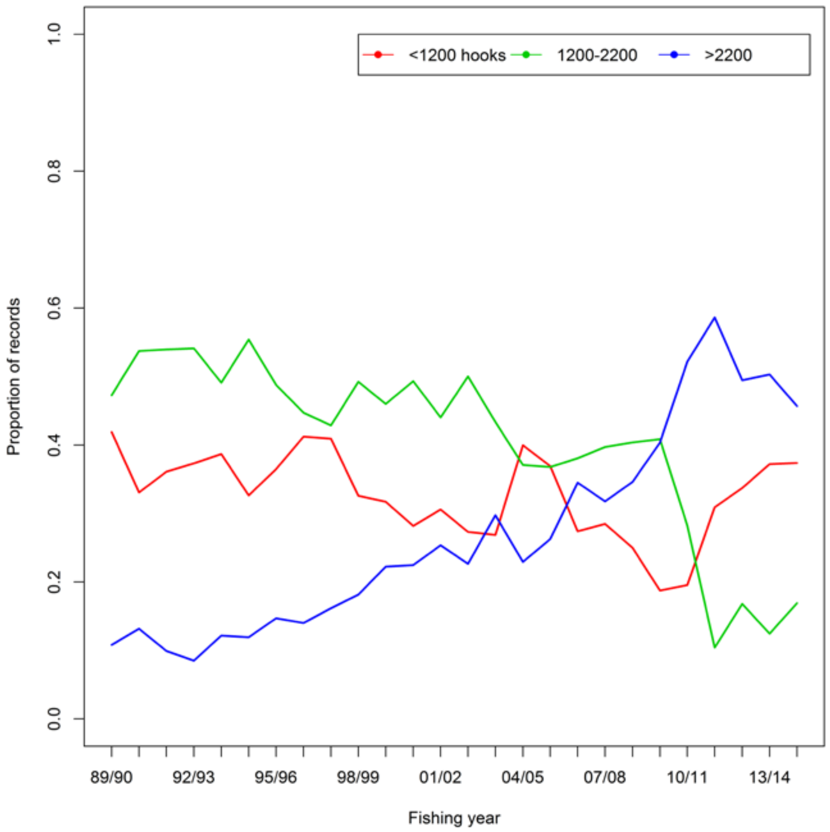

Figure 14: Proportional distribution of records by notional category of the *NumHooks* variable and fishing year for the East Northland core vessel data set.

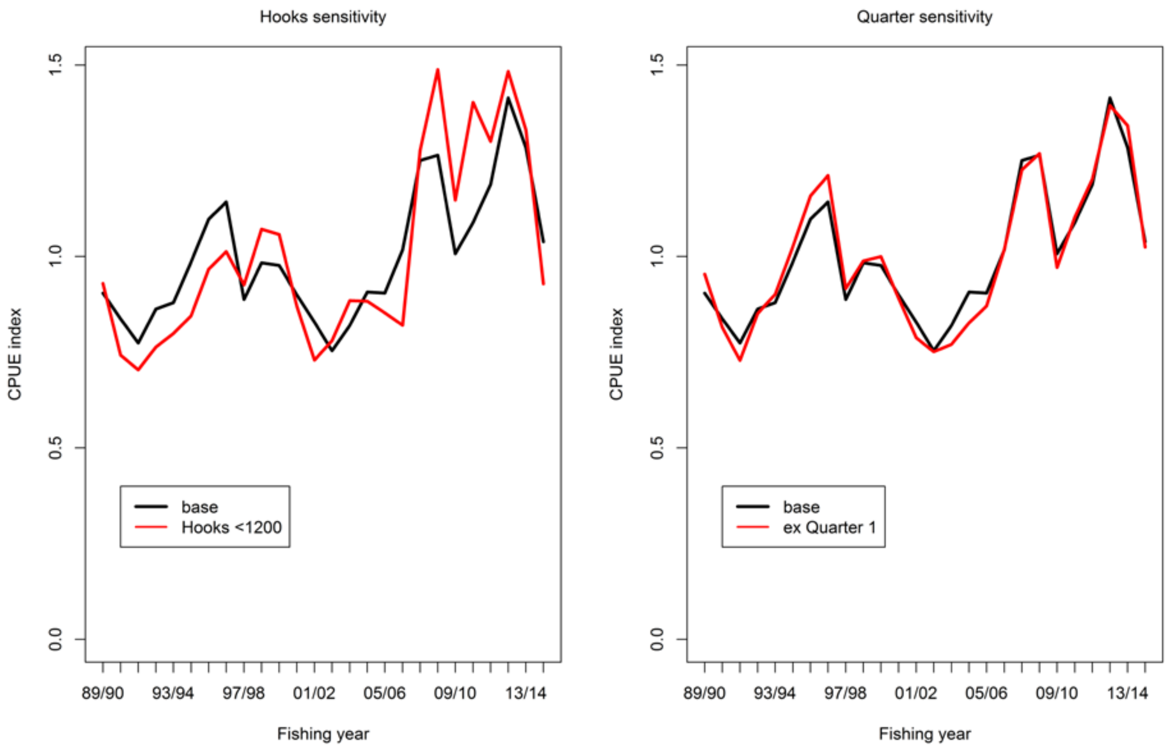

Figure 15: A comparison of the annual CPUE indices from the East Northland CPUE model (base) and CPUE indices derived from an alternative model derived from the subset of data records with *NumHooks* fewer than 1200 (left panel) and an alternative model that excluded data from the first quarter of the fishing year (right panel).

There are no marked differences between the annual CPUE indices derived from the LTCER data set and the daily CPUE indices from the corresponding years (2007/08–2014/15) (Appendix 5 Figure A13).

1.5 Hauraki Gulf

1.5.1 Longline fishery characterisation

Annual snapper catches from the Hauraki Gulf BLL fishery increased from about 930 t in 1989/90 to a peak of approximately 1400 t in 1992/93 (Figure 16). In the subsequent years, annual catches declined sharply and then stabilised at about 1000 t during 1995/96–2002/03. Since then, annual catches generally declined and reached the lowest level in 2014/15 at about 490 t.

The distribution of catch from the fishery among the three constituent Statistical Areas varied during the study period (Figure 16). The larger annual catches in the early 1990s were primarily attributable to higher catches from the inner Hauraki Gulf (Statistical Area 007). During the 1990s, the outer Hauraki Gulf area (Statistical Area 005) accounted for a substantial proportion of the total catch. The catch from this area declined over the subsequent years and since 2001/02 the annual catches were relatively evenly distributed amongst the three Statistical Areas (Figure 16).

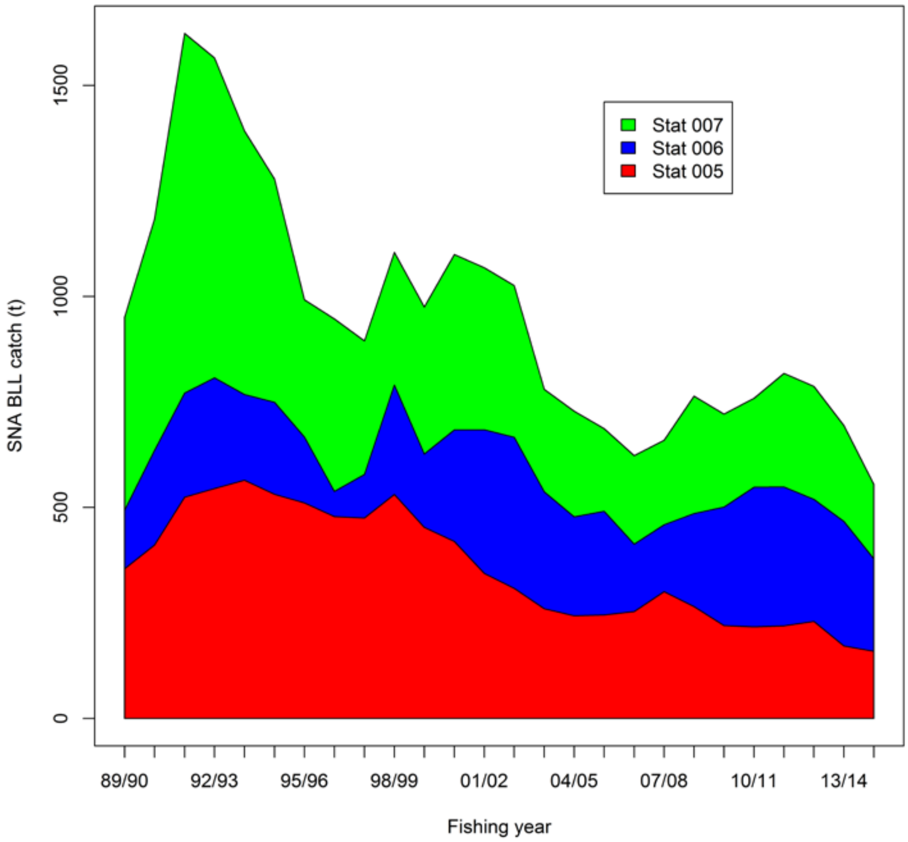

Figure 16: Annual total BLL snapper catch by Statistical Area for the Hauraki Gulf fishery area.

A relatively large number of BLL vessels operated in the fishery during the early 1990s. There was considerable rationalisation of the fleet during the mid–late 1990s and the size of the fleet declined considerably during the period (Figure 17).

The core fleet selection criteria excluded many of the vessels that operated in the fishery during the early 1990s and, correspondingly, the core fleet accounted for a relatively low proportion (36–53%) of the total snapper catch during that period (Figure 17). In contrast, during 1995/96–2014/15, the core fleet accounted for 68–95% of the total annual catch.

In the more recent years, the BLL fleet was relatively stable and included 11–15 core vessels. Most of these vessels have operated in the fishery for a considerable period; six of the 11 core vessels that operated in the fishery in 2014/15 had participated in the fishery for at least 20 years (Figure 18).

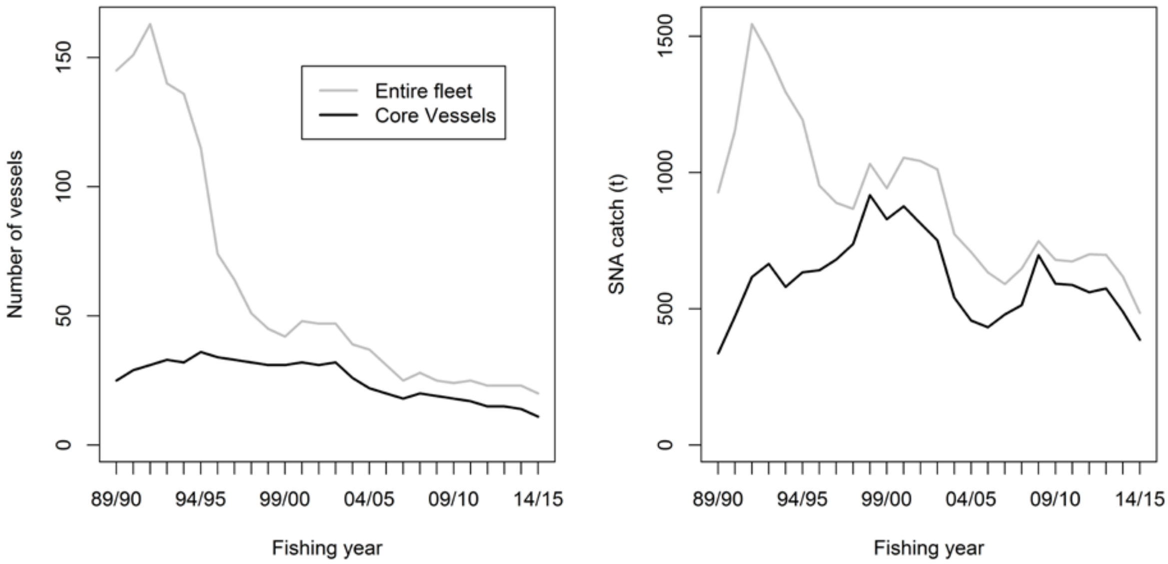

Figure 17: A comparison of the number of vessels and the annual snapper catch included in the total data set and the core vessel data set for the Hauraki Gulf BLL fishery.

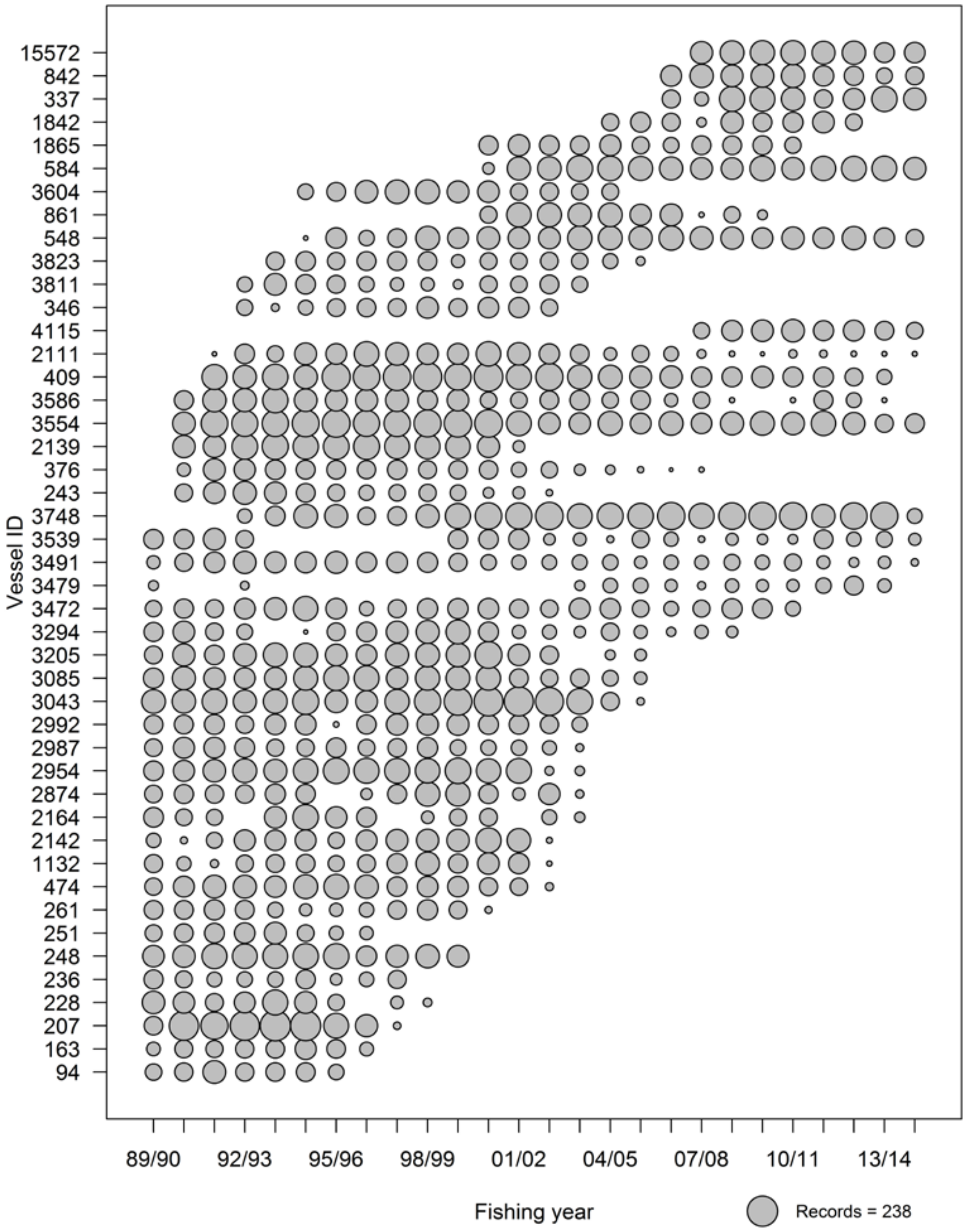

Figure 18: Distribution of Hauraki Gulf data records by fishing year and vessel for the core fleet included in the final daily aggregated CPUE data set.

During 1989/90–2000/01, the records included in the core vessel data set were dominated by fishing effort within Statistical Area 005, while in the subsequent period fishing effort was more evenly distributed between the three areas (Figure 19). Prior to 1998/99, there was a marked difference in the spatial distribution of the core and non-core BLL fleet; in contrast to the core fleet, fishing effort by the non-core fleet was concentrated within the inner Hauraki Gulf (007), and a relatively low proportion of the total fishing effort was conducted in the outer Hauraki Gulf (005).

For the core fleet, fishing effort was relatively evenly distributed throughout the fishing year, although effort tended to be slightly higher during the first quarter of the fishing year (October–December) compared to July–September (Figure 19). There was no appreciable difference in the seasonal distribution of fishing effort between the core fleet and the total fleet.

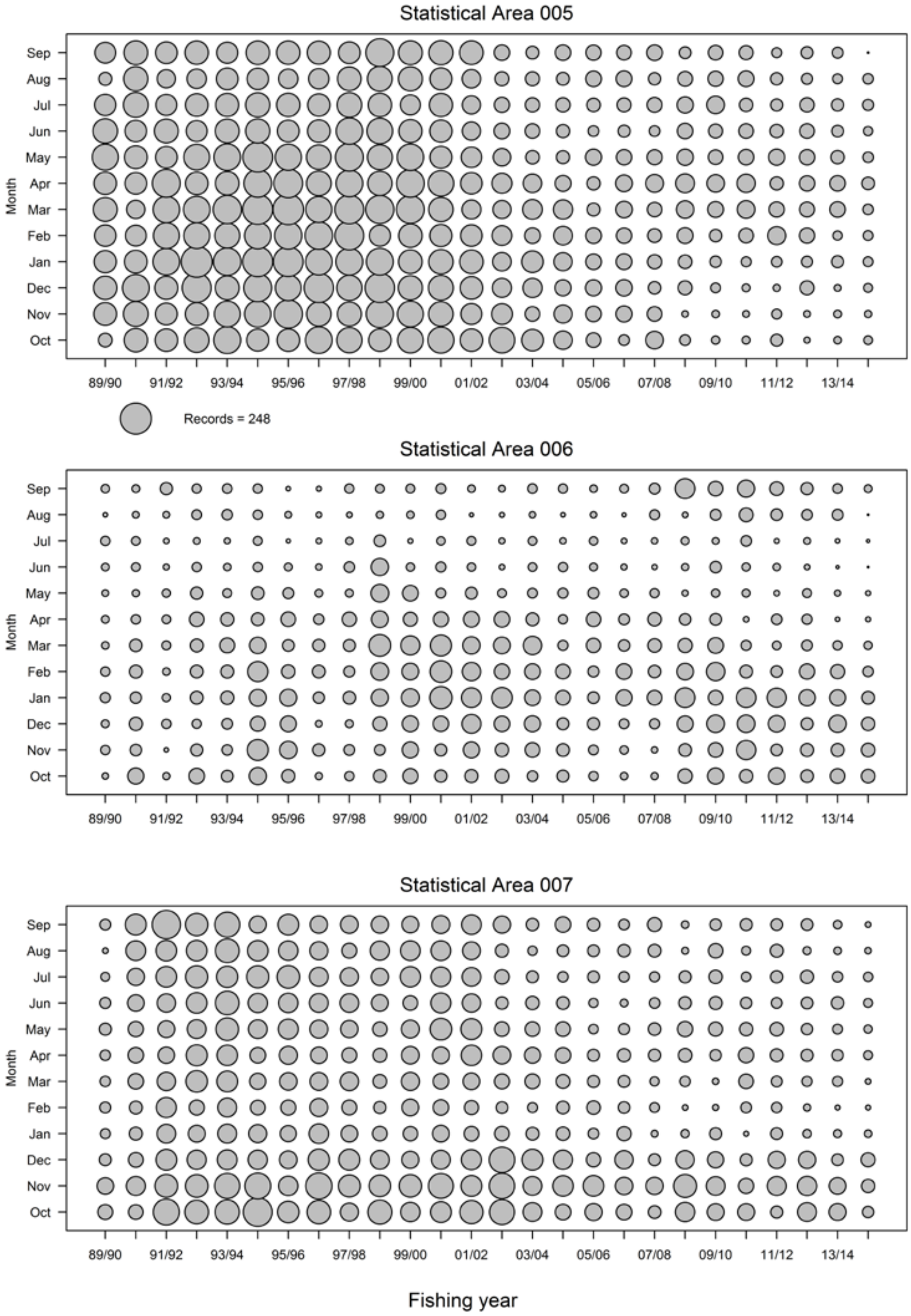

Figure 19: Annual distribution of daily aggregate data records by Statistical Area and month for the Hauraki Gulf core vessel CPUE data set.

Fishing effort in the inner Hauraki Gulf (007) was generally higher during October–December. From 2008/09, there was a strong seasonal pattern in the distribution of fishing effort by the core fleet: fishing in the inner Hauraki Gulf was concentrated in October–December, fishing in the central Hauraki Gulf (006) occurred primarily during September–February and, correspondingly, limited fishing effort occurred in the outer Hauraki Gulf (005) during October–January (Figure 19).

There was considerable variation amongst the core fleet in the number of hooks set per vessel (Figure 20). From the mid-2000s, there was a general increase in the number of hooks set per vessel and the increase in effort was more pronounced in the more recent years, with an increase in the number of fishing days setting in excess of 2000 hooks. The average daily catch of snapper tended to increase from the early 2000s (Figure 20).

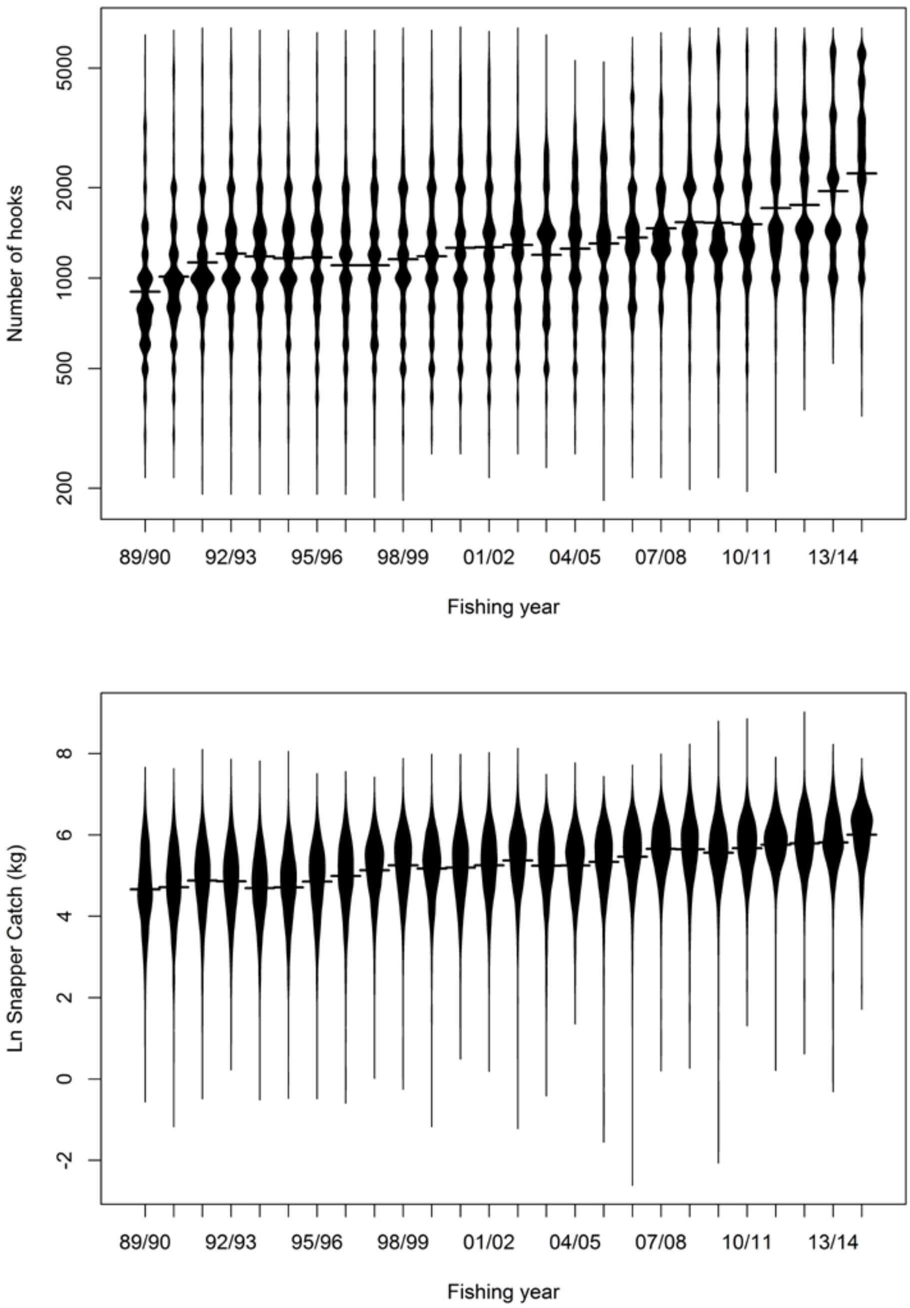

Figure 20: Beanplots of the daily number of hooks set (top panel) and the logarithm of snapper catch (kg) (bottom panel) for the Hauraki Gulf CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the mean value.

For the core fleet, snapper was the dominant species caught; snapper accounted for at least 90% of the total trip catch weight from 80% of trips. The main associated species caught was red gurnard although this species generally represented a very minor proportion of the catch (relative to the snapper catch) (Figure 21). There is no indication that the species catch composition changed substantially over the study period.

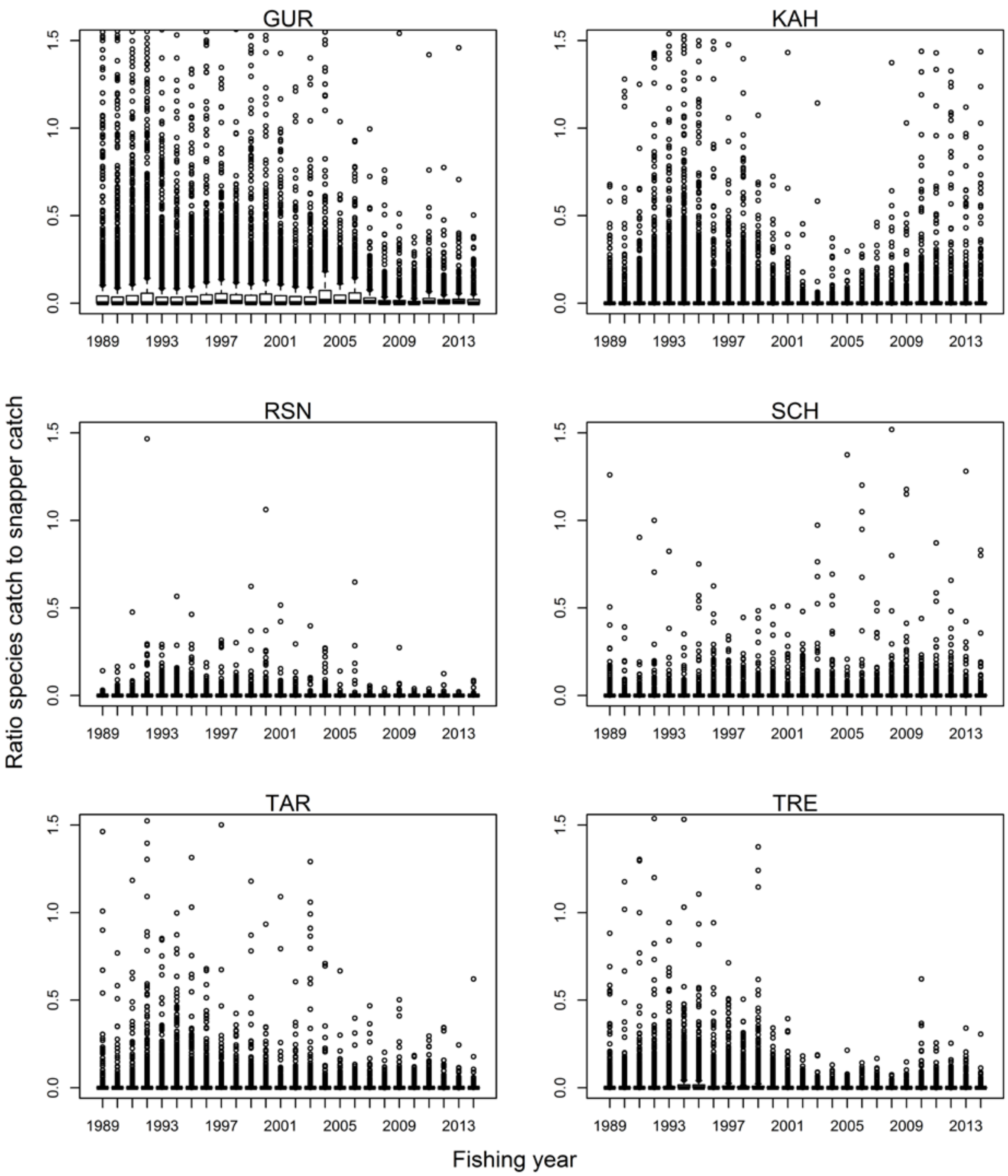

Figure 21: Boxplots of the ratio of the species catch to the snapper catch from each fishing trip for the main associated species caught by the Hauraki Gulf BLL fishery (core vessel data set).

1.5.2 CPUE indices

The CPUE regression model for the Hauraki Gulf fishery incorporated all the potential explanatory variables in the final model (Table 7). The effort variable (*NumHooks*) accounted for the highest proportion of the explained variation in snapper catch followed by *FishingYear*, *Vessel* and *Month*. The *StatArea* variable accounted for a minor proportion of the total explained deviance. Overall, the model accounted for 53.3% of the total variation.

Table 7: Summary of stepwise selection of variables in the Hauraki Gulf CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			64 568	56 004		
1	*FishingYear*	25	7 698.9	64 543	48 305	0.137	164 555.0
2	*NumHooks*	3	14 506.0	64 540	33 799	0.396	141 503.1
3	*Vessel*	44	4 345.7	64 496	29 453	0.474	132 704.7
4	*Month*	11	2 976.5	64 485	26 477	0.527	125 847.6
5	*StatArea*	2	21.6	64 483	26 455	0.528	125 798.9
6	*StatArea:Month*	22	279.8	64 461	26 175	0.533	125 156.4

The residual diagnostics indicate that the model residuals closely approximate the assumption of a normally distributed error structure (Figure 22). However, there are a relatively small number of observations with large negative residuals that skew the lower tail of the distribution of the model residuals. These residuals correspond to observations of small catches of snapper (less than 5 kg) that are not predicted by the CPUE model (Figure 22).

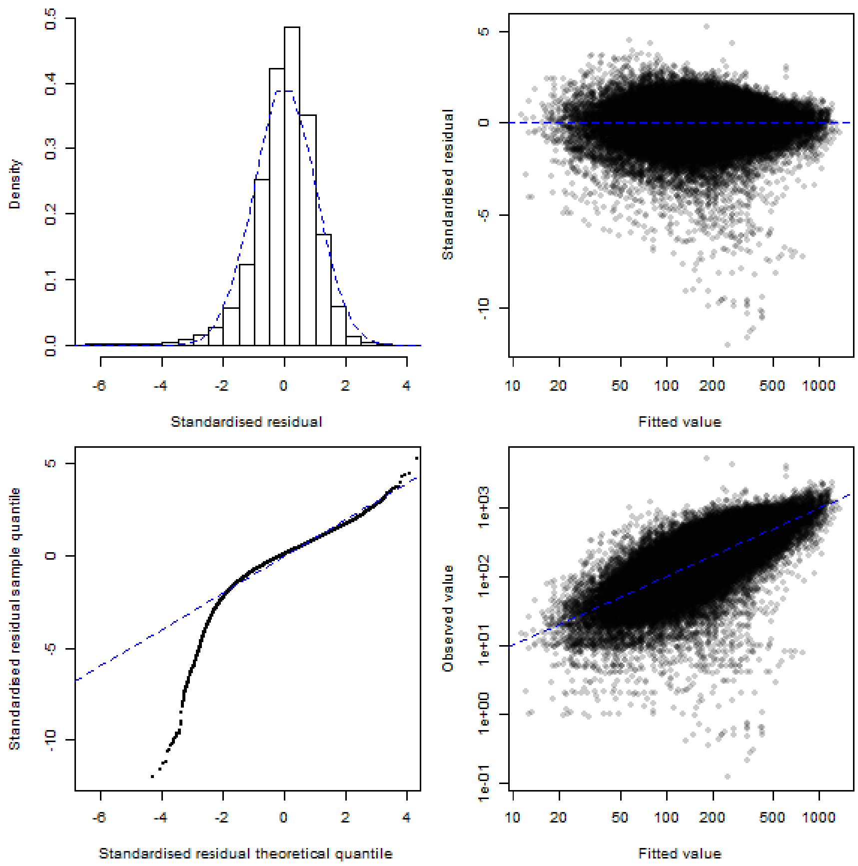

Figure 22: Residual diagnostics for the CPUE model for the Hauraki Gulf fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the CPUE model increased during 1994/95–1998/99 and then remained relatively stable during 1999/00–2005/06 (Figure 23). The indices increased in the two subsequent years and during 2007/08–2012/13 the CPUE indices fluctuated about the higher level. The CPUE indices declined in 2013/14 and remained at that level in 2014/15 (Figure 23).

There is a marked difference in the trends in the standardised CPUE indices compared to the unstandardised CPUE (Figure 23). The large increase in the unstandardised indices during 2004/05–2014/15 is moderated by the inclusion of the effort variable (*NumHooks*) in the CPUE model (Figure 24) which counters the overall increase in the number of hooks set during the period (Appendix 3 Figure A7). The increase in the unstandardised indices was also moderated, to a lesser extent, by the inclusion of the *Vessel* variable (Figure 24 and Appendix 3 Figure A8). The inclusion of the other variables in the CPUE model had very little influence on the annual CPUE indices.

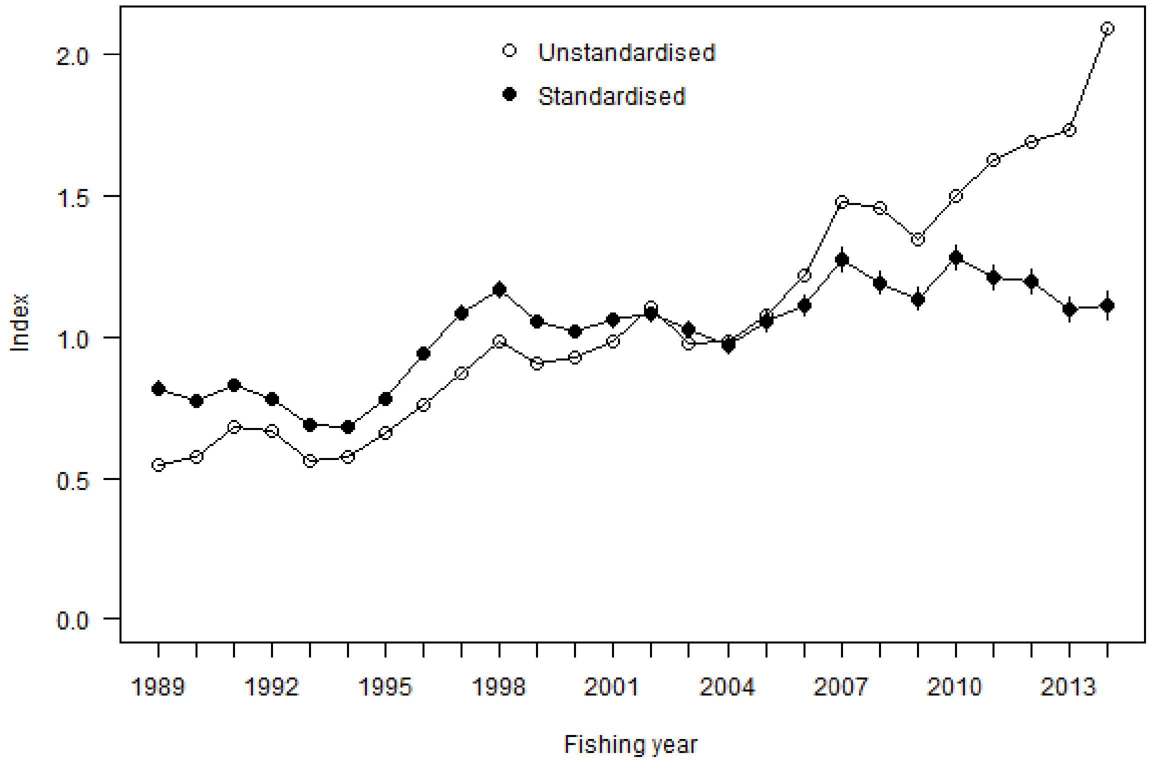

Figure 23: A comparison between the unstandardised and standardised CPUE indices for the Hauraki Gulf fishery. The unstandardised indices represent the geometric mean of the snapper catch per fishing day. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

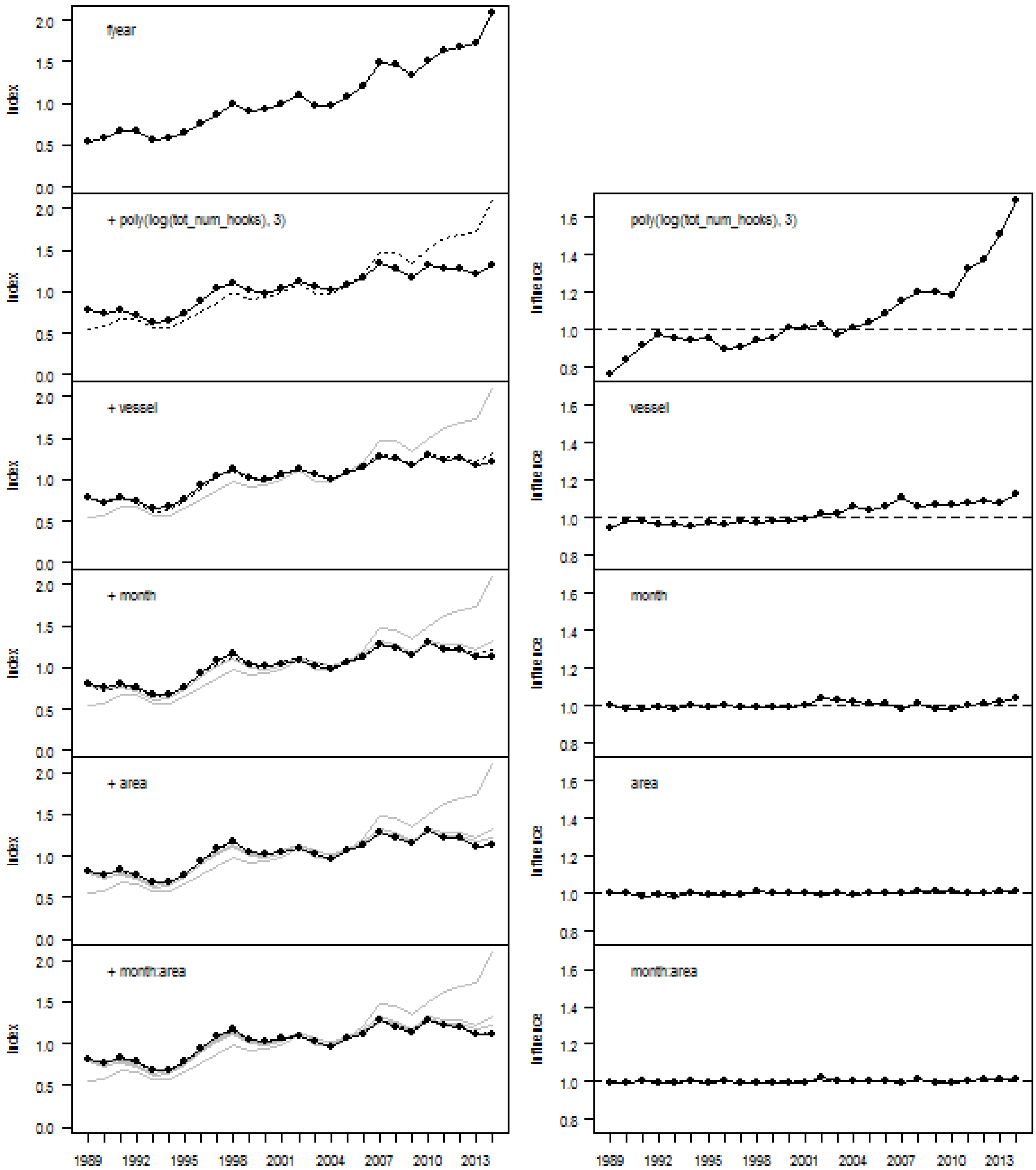

Figure 24: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the CPUE model for the Hauraki Gulf fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

Annual trends in the model residuals were examined for a number of the variables included within the CPUE model. The *NumHook* variable was partitioned into three categories that approximate groupings within the data set: less than 900 hooks, 900–1700 hooks, and more than 1700 hooks (Figure 20). For each year, the average of the residuals was determined for each hook category. No strong annual trend was apparent in the residuals by hook category (Figure 25), indicating that the trends in the CPUE indices are generally comparable amongst the hook categories. This was also evident when the CPUE model was refitted using the subset of records with *NumHooks* less than 900 hooks. The resulting annual CPUE indices from alternative data sets were virtually identical to the CPUE indices from the base model.

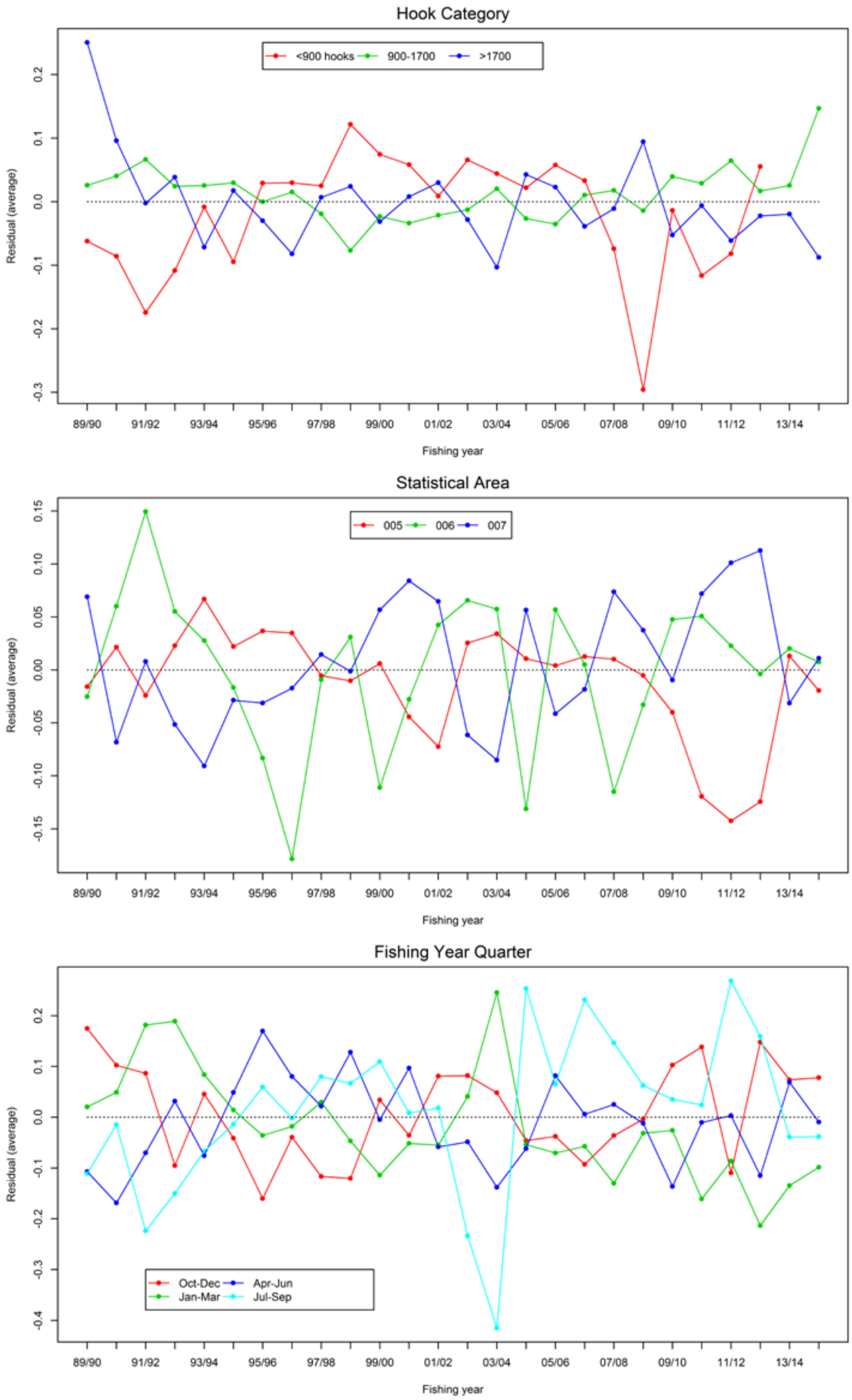

Figure 25: Average annual residuals from the Hauraki Gulf CPUE model by category for three variables included in the model. The variables are: total number of hooks (*NumHooks*) classified in three size categories (top panel), Statistical Area (middle panel) and *Month* classified in quarterly periods (bottom panel).

There are a considerable number of vessels in the core fleet that have operated in the fishery for many years (Figure 18). The CPUE model estimates an individual coefficient for each vessel and the coefficients are assumed to be temporally invariant. Thus, the CPUE model does not have the flexibility to account for changes in the efficiency of a vessel over the time period. For a longline vessel, efficiency may be expected to change if there is a change in vessel skipper, vessel operator, fishing gear technology, or operational constraints (e.g. access to ACE for key species).

To investigate the sensitivity of the CPUE model to the assumptions of stationarity of the vessel coefficients, the CPUE model data set was reconfigured by partitioning the individual vessel data into two time blocks partitioned by the median fishing year that the vessel operated in the fishery. Then, the CPUE model was refitted estimating independent vessel coefficients for each vessel time block (doubling the number of vessel coefficients estimated).

Amongst the core fleet, there was considerable variation in the ratio of the vessel coefficients from the two time blocks (Figure 26), particularly for the group of vessels that operated during the 1990s–early 2000s. For vessels that operated in the fishery over a longer time period (at least 20 years) the ratios of the coefficients from the two time blocks generally approximated 1.0 (no change) or were greater than 1.0, indicating a higher level of efficiency during the latter period (Figure 26).

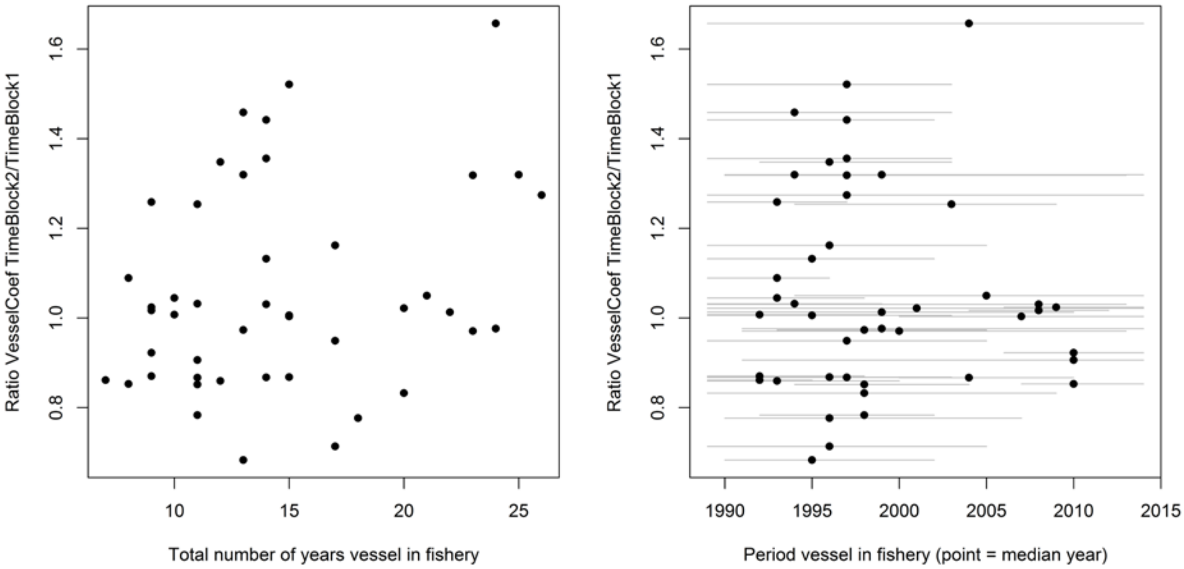

Figure 26: The ratio of individual core vessel coefficients estimated for two time blocks in a CPUE regression model to investigate the sensitivity of the assumption of constant vessel efficiency for the Hauraki Gulf fishery. The left panel compares the ratio to the total number of years the vessel participated in the fishery. The right panel plots the ratio for each vessel over the time period the vessel participated in the fishery.

The annual CPUE indices were sensitive to the inclusion of the vessel time blocks in the CPUE model resulting in a reduction in the CPUE indices during 2007/08–2014/15 (Figure 27).

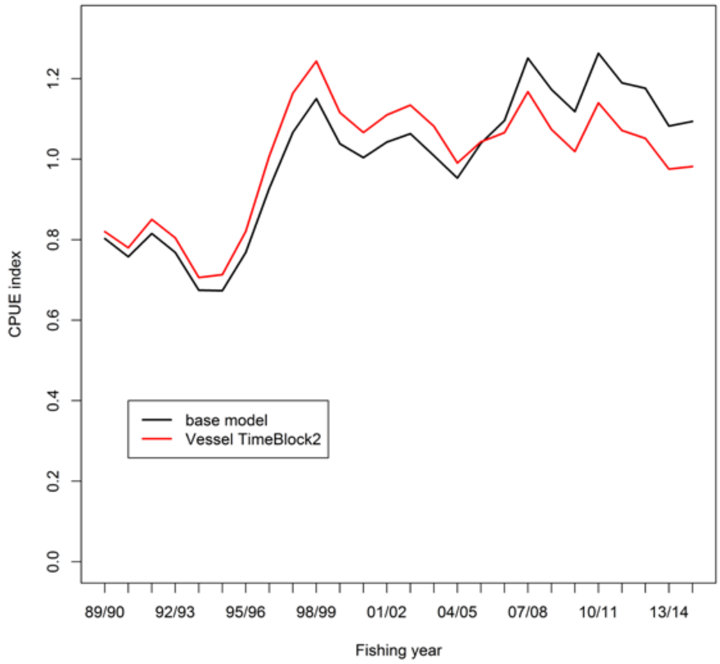

Figure 27: A comparison of Hauraki Gulf CPUE indices from the base model and a CPUE regression model that incorporated two time blocks for estimation of the vessel coefficients.

There are no marked differences between the annual CPUE indices derived from the LTCER data set and the daily CPUE indices from the corresponding years (2007/08–2014/15) (Appendix 5 Figure A14).

1.5.3 Spatial effects

For the base CPUE model, there are temporal trends in the average annual residuals calculated for the individual Statistical Areas (005–007) (Figure 25). The residual patterns from Statistical Areas 005 and 007 tend to be negatively correlated with the greatest contrast apparent during 2010/11–2012/13 when catch rates from Statistical Area 007 were higher than predicted by the model (positive residuals) and catch rates from Statistical Area were lower than predicted (negative residuals) (Figure 25).

To further examine spatial trends in CPUE within the Hauraki Gulf, the residuals from the LTCER data CPUE model were examined. The CPUE model had the configuration:

log(*SNAcatch*) ~ *FishingYear* + poly(*NumHooks*,3) + *Month* + *Vessel* + *Loc2* + poly(*StartTime*,3) + poly(*Depth*,3)

The variable *Loc2* represented individual 0.2 degree latitude/longitude cells. For each fishing year, the average of the model residuals from each *Loc2* cell was determined (Figure 28). The sequence of annual plots reveals the following temporal trend in the spatial pattern of the model residuals:

- In 2008/09, the residuals are generally positive in the outer Hauraki Gulf and negative in the inner Gulf.
- The central Gulf is characterised by positive residuals in 2009/10.
- In 2010/11 and 2011/12, the inner Gulf is dominated by positive residuals. Correspondingly, the outer Gulf is dominated by negative residuals.
- The western area of the inner Gulf is dominated by negative residuals in 2013/14 and 2014/15. There are weak positive residuals in the eastern area of the inner Gulf.

These observations are relatively consistent with the pattern in the Statistical Area residuals from the main CPUE model (Figure 25). The results may indicate a shift in the distribution of snapper over the period with fish being concentrated in the western area of the inner Gulf during 2009/10–2011/12 and dispersing from the area in the subsequent years.

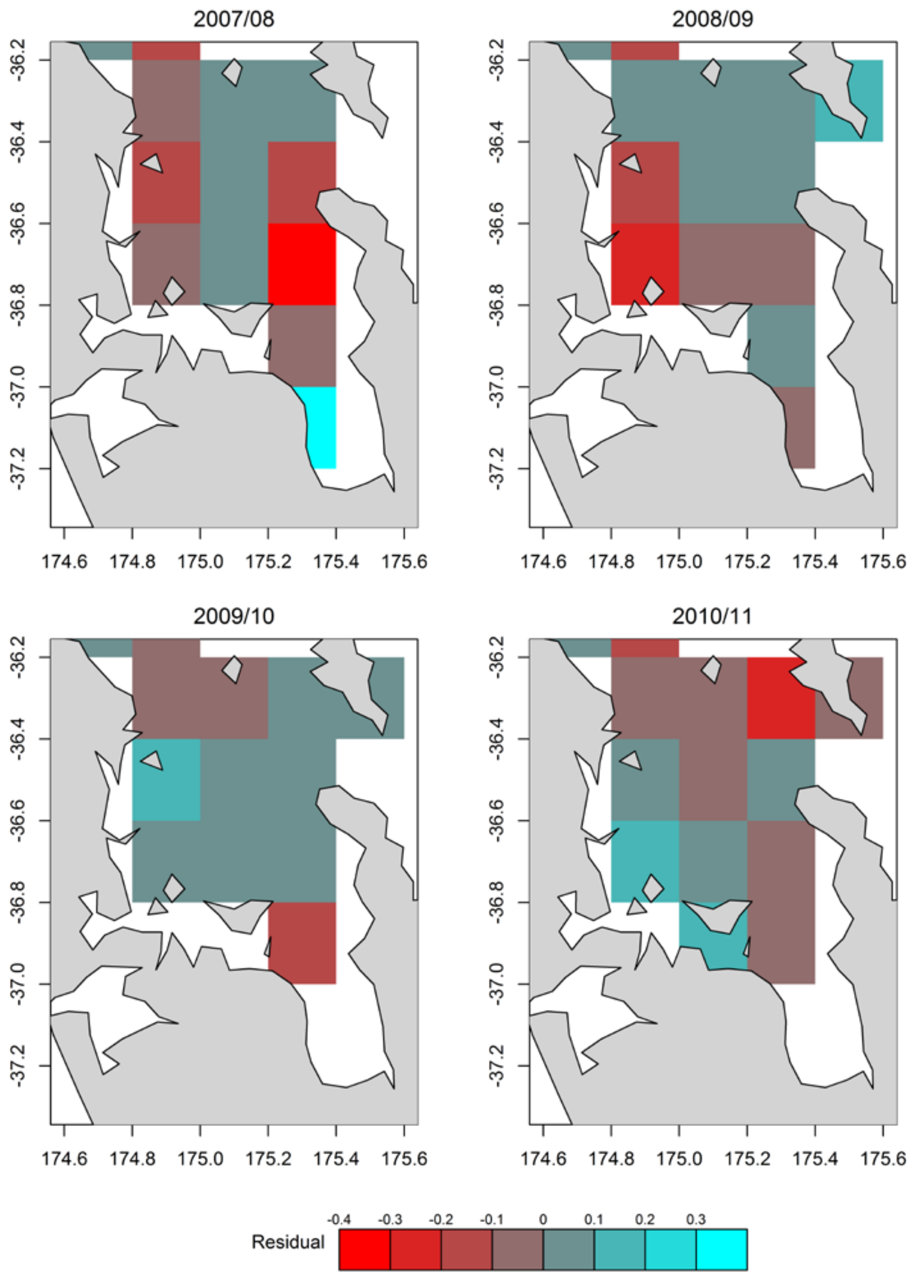

Figure 28: Annual average residuals by 0.2 degree cells from a regression model of the Hauraki Gulf LTCER data set. Only annual *Loc2* cells with a minimum of 40 observations are plotted.

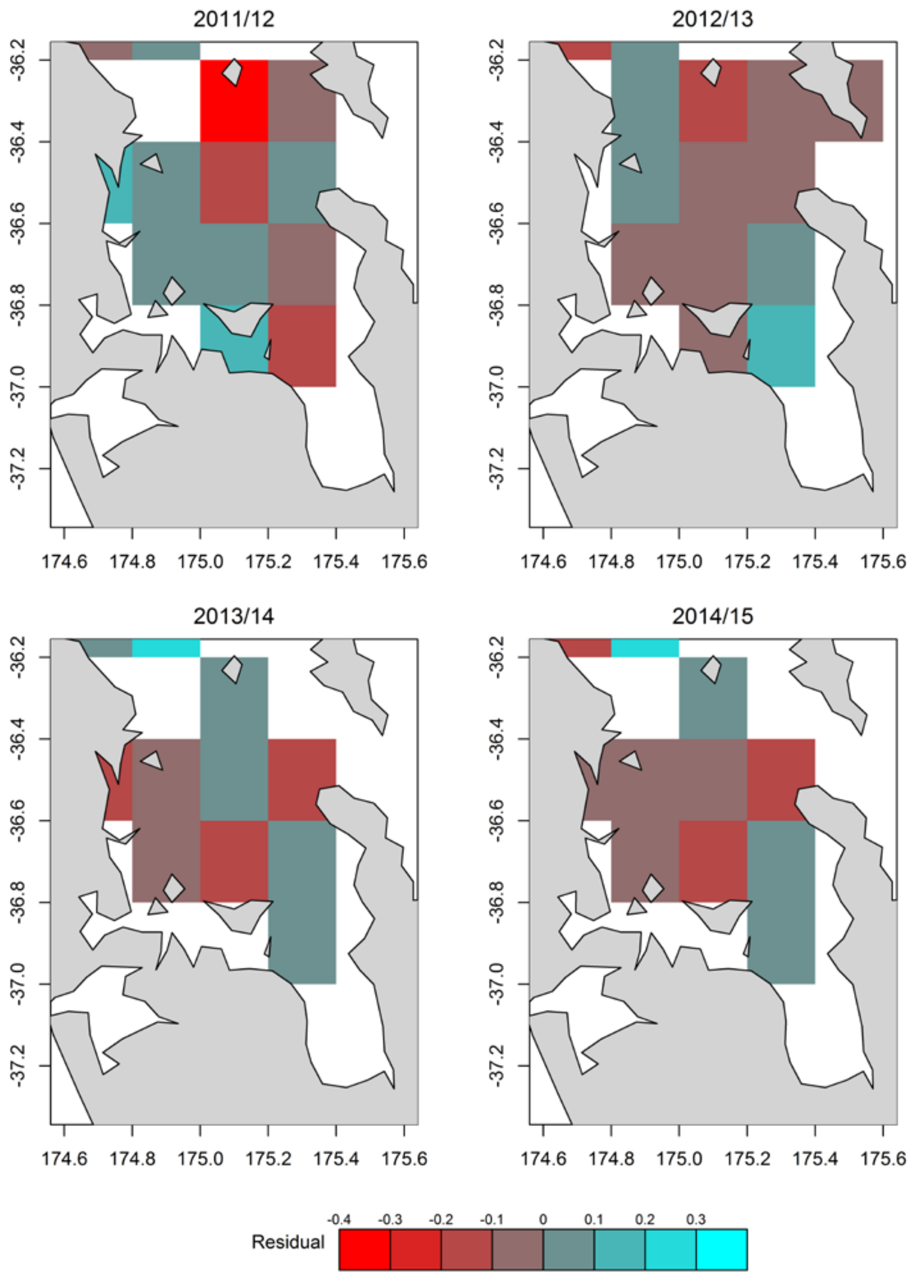

Figure 28 continued.

1.5.4 Interdependence of fishing effort

The commercial sector has expressed concern regarding the reliability of the BLL CPUE indices as an index of relative stock abundance. A primary reason for the concern is that it is considered that commercial fishermen were increasingly avoiding areas of higher snapper abundance. The LTCER data set was examined to determine whether there was any evidence to support this assertion.

The LTCER data set was limited to vessels that fished at least 150 sets in the Hauraki Gulf fishery in a specific year during 2007/08–2014/15. This limited the data set to 30 vessel/fishing year combinations and six unique vessels representing a total of 7589 longline sets. For each set, the following metrics were determined from the previous set conducted by the vessel:

- Number of days since the previous set,
- Snapper catch rate (kg per hook) of the previous set,

- Distance from the start position of the previous set, and
- Depth of the previous set.

The distance from the previous set was derived from the start positions of the successive sets. The available data included start position (latitude and longitude) at a resolution of 0.1 degree. Thus, the location data will only be of a resolution that may not detect all movements that are less than about 12 km along either axis, although a considerable proportion of the shorter movements will be evident at that spatial resolution. Overall, it was considered that the resolution of the current data set was sufficient to undertake an exploratory analysis of the interdependence of subsequent longline sets.

The data set was further restricted to include only sets that occurred within one or two days of the previous set (3685 records). Each set was assigned to a location based on a 0.1 degree lat/long grid. A set was then characterised as whether it had continued to fish at the same location (*moveNY* = "No") or conducted the next set at a different location (*moveNY* = "Yes"). The probability of moving to a new location was estimated using a binomial regression model with the potential explanatory variables *FishingYear*, *Month*, *Loc2*, and *FishingYear* (Table 5) and the CPUE of the previous set (*cpuePrev*). The final model had the formulation:

moveNY ~ poly(*cpuePrev*, 3) + *Loc2* + *FishingYear*

The model accounted for a small proportion of the total variance (R^2= 5.7%) with most (69%) of the explained variance attributable to the *cpuePrev* variable. The parameterisation of the variable predicts that there is a high probability of moving to a new location if the snapper catch rate from the preceding set was very low (Figure 29). The probability of moving decreases with increasing catch rates from the previous set; however, there is still a relatively high probability (approx. 50%) of moving following a set with relatively high catch rates (above 0.25 kg per hook) (Figure 29). There is no indication that vessels are more likely to move following a set with very high catch rates, although the relationship is poorly determined at the higher levels of snapper catch rate. There were a limited number of records (146) with (preceding) catch rates exceeding 0.4 kg per hook.

There was limited contrast in the individual *FishingYear* coefficients suggesting that there was no significant change in the frequency of the movement response by the fleet over the time period (8 years).

The interdependence of longline sets was further examined by categorising the vessel behaviour for the fishing events that immediately followed a set with a high snapper catch rate (defined as sets above the 90% quantile of snapper catch rate kg/hook i.e. 0.303 kg). These sets predominantly occurred during the main spawning period (October–December). A relatively high proportion (55%) of the subsequent sets occurred within the same location (0.1 degree cell) and in the same depth range (within 5 metres). These sets frequently achieved catch rates that were comparable to the preceding set (median ratio CPUE/*cpuePrev* 82%). Most of the remainder of the sets moved to an adjacent 0.1 degree cell, fished in a similar depth and achieved catch rates that were comparable to the sets that remained in the same location (median ratio CPUE/*cpuePrev* 74%).

The close proximity and the similar performance of these sets to the proceeding set may indicate that the set has been conducted along a reciprocal path; i.e., the start position of the second set may have been close to the end position of the first set and the line set back towards the start position of the first set. The end location of the set is not recorded in the LTCEPR data and, therefore, it is not possible to determine the frequency of such a fishing strategy. This fishing strategy would be likely to result in an over-estimation in the probability of vessel movement in response to higher snapper catch rates (Figure 29).

In general, the extent of vessel movement was higher following a set with a lower snapper catch rate compared to following a set with a higher snapper catch rate. There was also a greater change in the fishing depth between successive sets following a lower catch rate.

Overall, the results of these analyses indicate that the longline fleet will generally direct fishing effort to endeavour to achieve higher snapper catch rates or maintain high snapper catch rates. There was no strong evidence from the analysis to indicate that the fleet is actively avoiding (or successfully able to avoid) areas of high snapper catch rates, especially during the main spawning period.

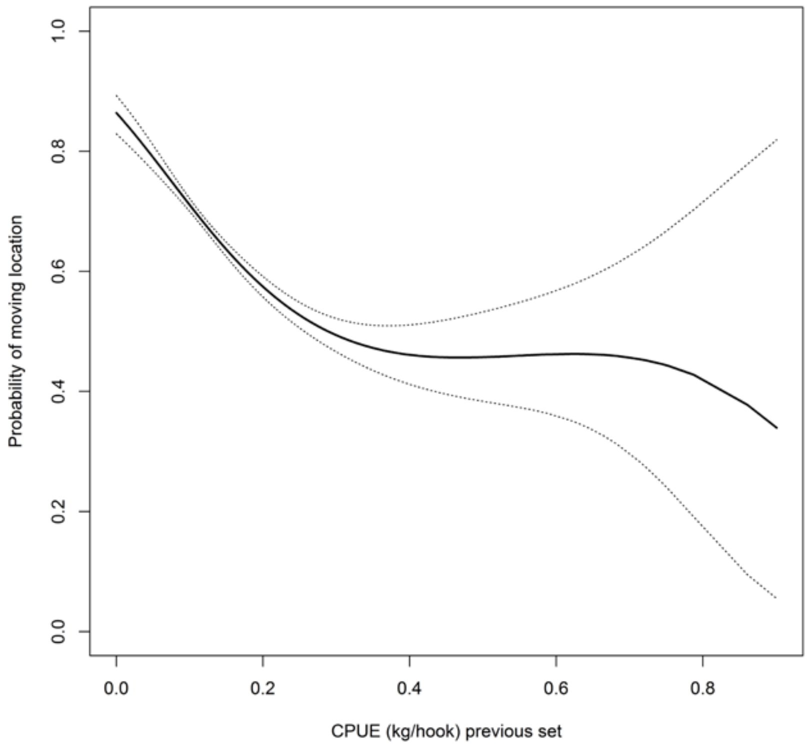

Figure 29: Predicted probability of conducting the next set at a new location in response to the snapper catch rate from the preceding set derived from the Hauraki Gulf binomial movement model.

1.6 Bay of Plenty

1.6.1 Longline fishery characterisation

Annual snapper catches from the Bay of Plenty BLL fishery fluctuated between about 200–350 t over the study period (Figure 30), although, in the most recent years, annual catches have increased and approached 400 t in 2014/15.

The annual catch from the Bay of Plenty BLL fishery has been dominated by catches from the north-western Bay of Plenty (Statistical Area 008) (Figure 30). Annual catches from this area increased in 2009/10 and were maintained at the higher level in the subsequent years. Most of the remainder of the longline catch was taken from Statistical Area 009, although there was considerable inter-annual variability in the magnitude of the catch from this area. Catches from the area were relatively high in recent years (2013/14 and 2014/15) (Figure 30). Limited catches were taken from the eastern Bay of Plenty (Statistical Area 010), primarily during 2000/01–2006/07, and catches from the area were negligible in the subsequent years (Figure 30).

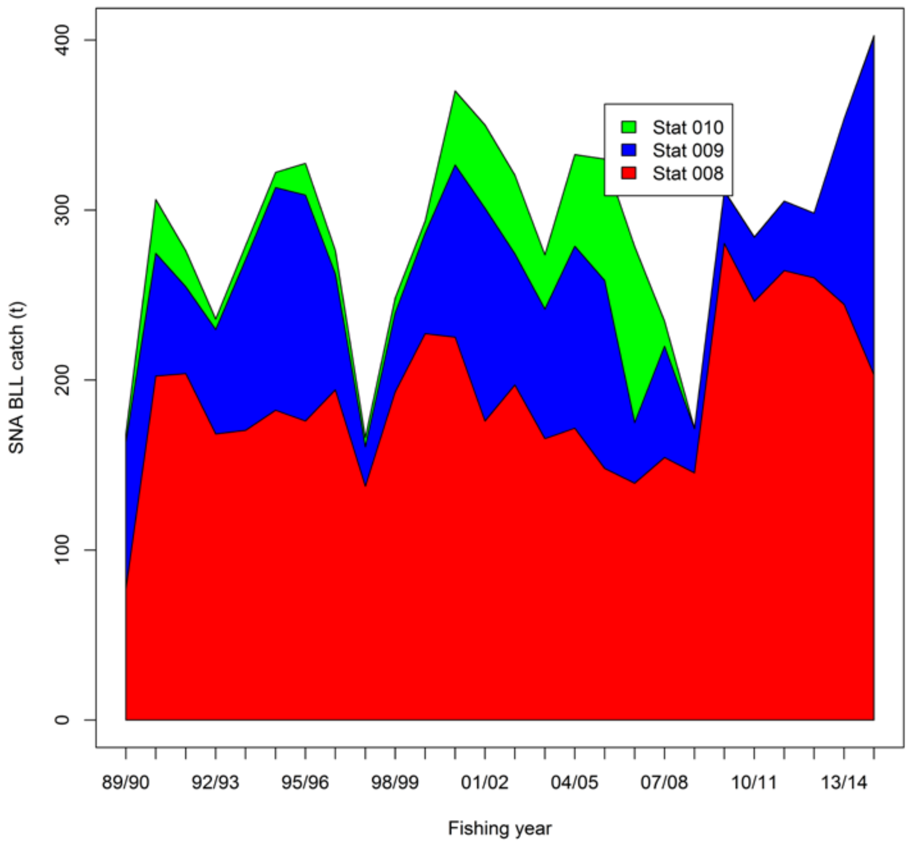

Figure 30: Annual total BLL snapper catch by Statistical Area for the Bay of Plenty fishery area.

A relatively large number of BLL vessels operated in the fishery during the early 1990s although there was considerable rationalisation of the fleet during the mid–late 1990s and the size of the fleet declined considerably during the period (Figure 31).

The core fleet selection criteria excluded many of the vessels that operated in the fishery during the early 1990s and, correspondingly, the core fleet accounted for a relatively low proportion (30–40%) of the total snapper catch during 1989/90–1991/92 (Figure 31). In contrast, during 1995/96–2007/08 the core fleet accounted for 70–80% of the total catch, while during 2008/09–2014/15 the proportion of catch by the core fleet exceeded 90%.

In the more recent years, the core fleet has comprised 13–16 vessels, representing almost the entire fleet (Figure 31). This is partly due to the relatively low threshold for individual vessels to achieve the core fleet criteria, although it also indicates that the BLL fleet has been relatively stable over the last five years; five of the 13 core vessels that participated in the fleet in the most recent year (2014/15) operated in the fishery for at least 15 years (Figure 32).

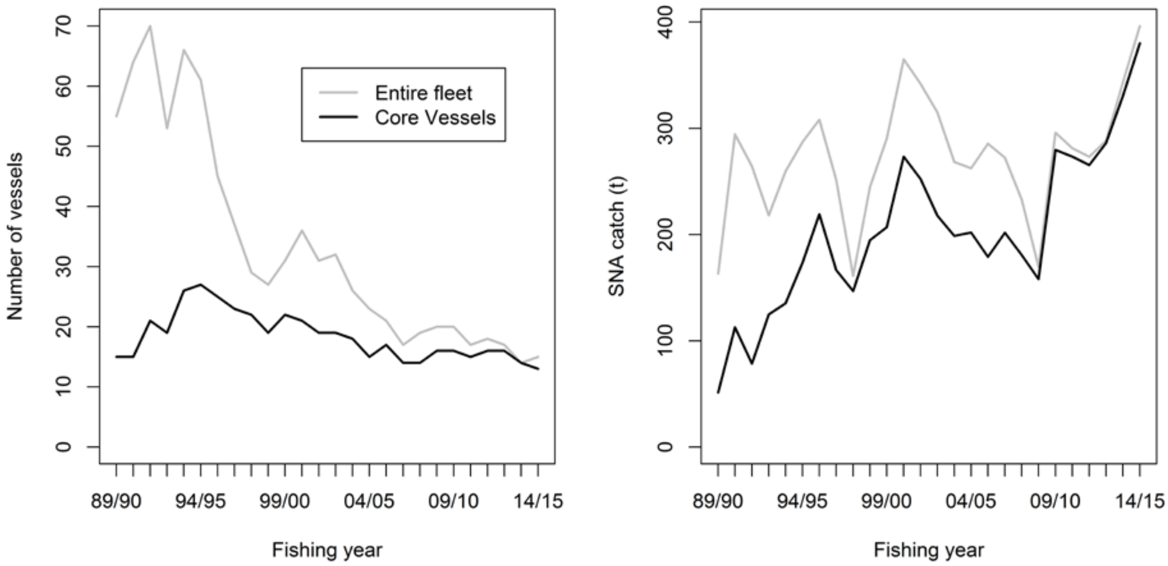

Figure 31: A comparison of the number of vessels and the annual snapper catch included in the total data set and the core vessel data set for the Bay of Plenty BLL fishery.

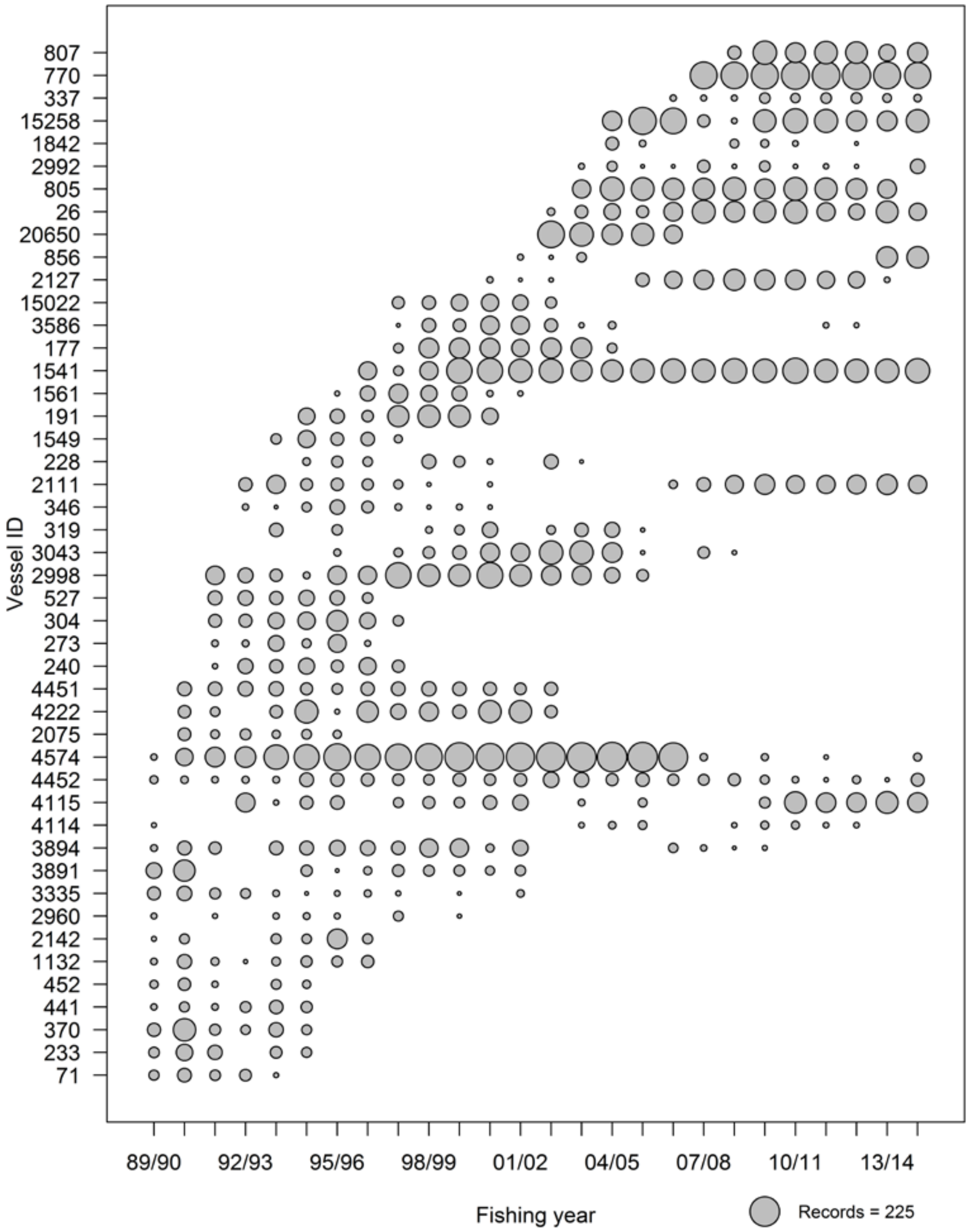

Figure 32: Distribution of Bay of Plenty data records by fishing year and vessel for the core fleet included in the final daily aggregated CPUE data set.

The core vessel data set is dominated by fishing effort records from the western Bay of Plenty (Statistical Area 008 and, to a lesser extent, Statistical Area 009) (Figure 33). The data set also included fishing effort records from the eastern Bay of Plenty (010), primarily during 2002/03–2006/07. The spatial distribution of the fishing effort by the remainder of the fleet (non core vessels) was generally comparable to the core vessel data set.

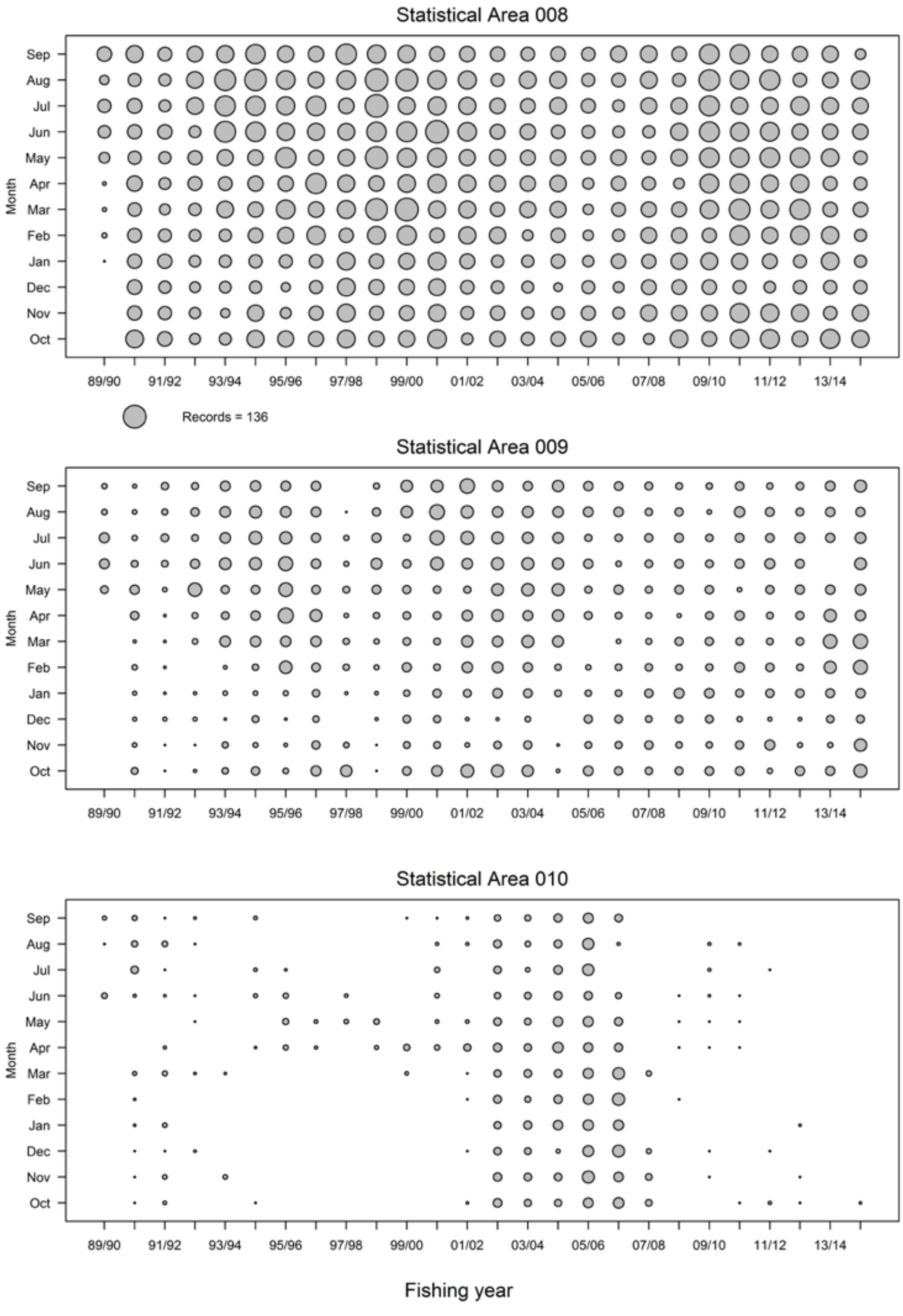

Figure 33: Annual distribution of daily aggregate data records by Statistical Area and month for the Bay of Plenty core vessel CPUE data set.

Prior to 2004/05, fishing effort by the core fleet tended to be higher during the second half of the fishing year (May–September) although in the more recent years fishing effort was relatively evenly distributed throughout the fishing year (Figure 33). There was no appreciable difference in the seasonal distribution of fishing effort between the core fleet and the remainder of the Bay of Plenty BLL fleet.

There was considerable variation amongst the core fleet in the number of hooks set per vessel (Figure 34). From the late 2000s, two main modes of fishing operation emerged with one group of vessels setting 800–1000 hooks per day and another group setting more than 1500 hooks per day (Figure 34). Overall, there was a general increase in the number of hooks set per vessel from the late 2000s. The average daily catch of snapper also tended to increase from the mid 2000s (Figure 34).

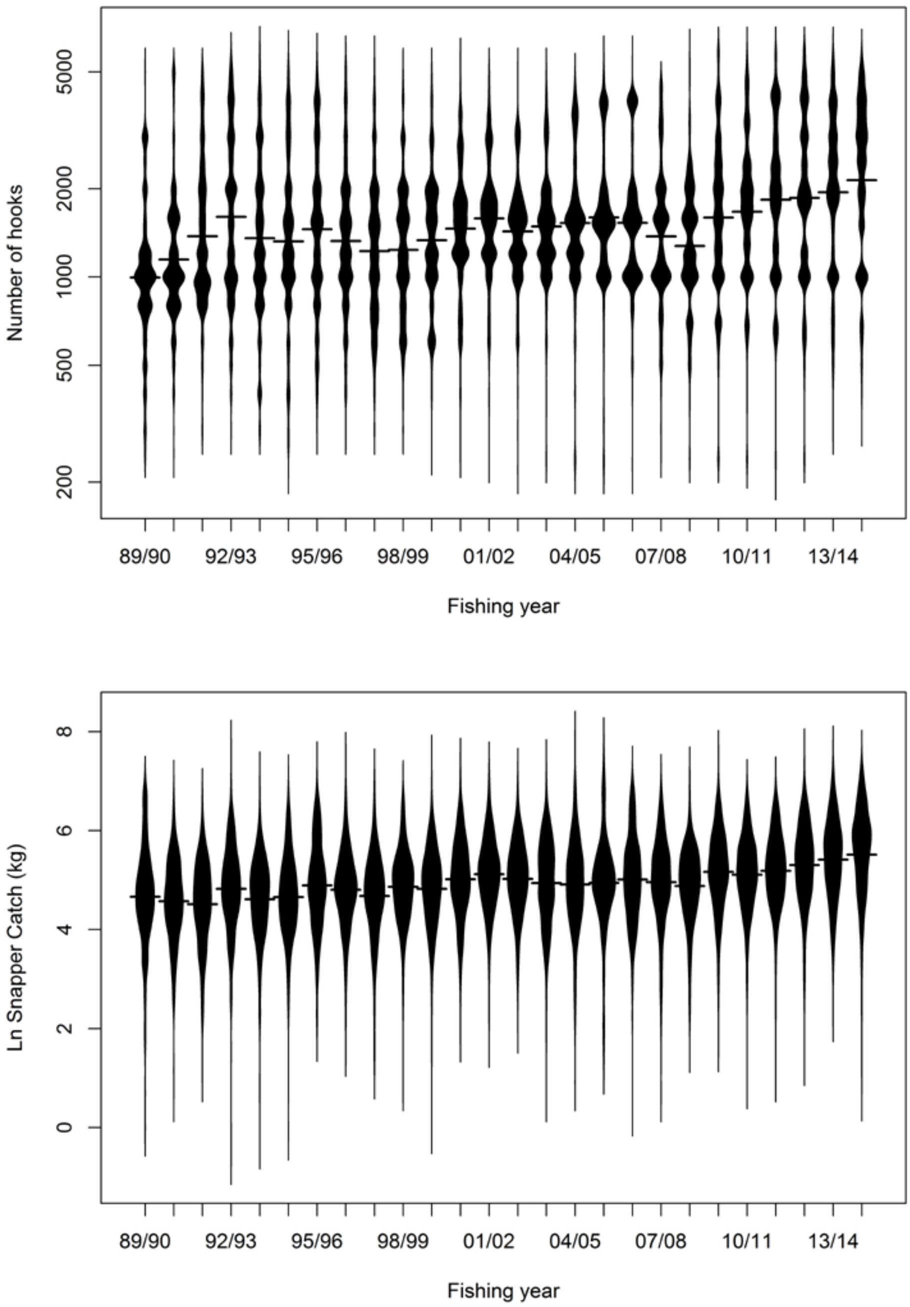

Figure 34: Beanplots of the daily number of hooks set (top panel) and the logarithm of snapper catch (kg) (bottom panel) for the Bay of Plenty CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the mean value.

For the core fleet, snapper was the dominant species caught; snapper accounted for at least 70% of the total trip catch weight from 80% of trips. The main associated species caught were red gurnard and tarakihi although both species generally represented a small proportion of the catch (relative to the snapper catch) (Figure 35). There is no indication that the species catch composition changed substantially over the study period.

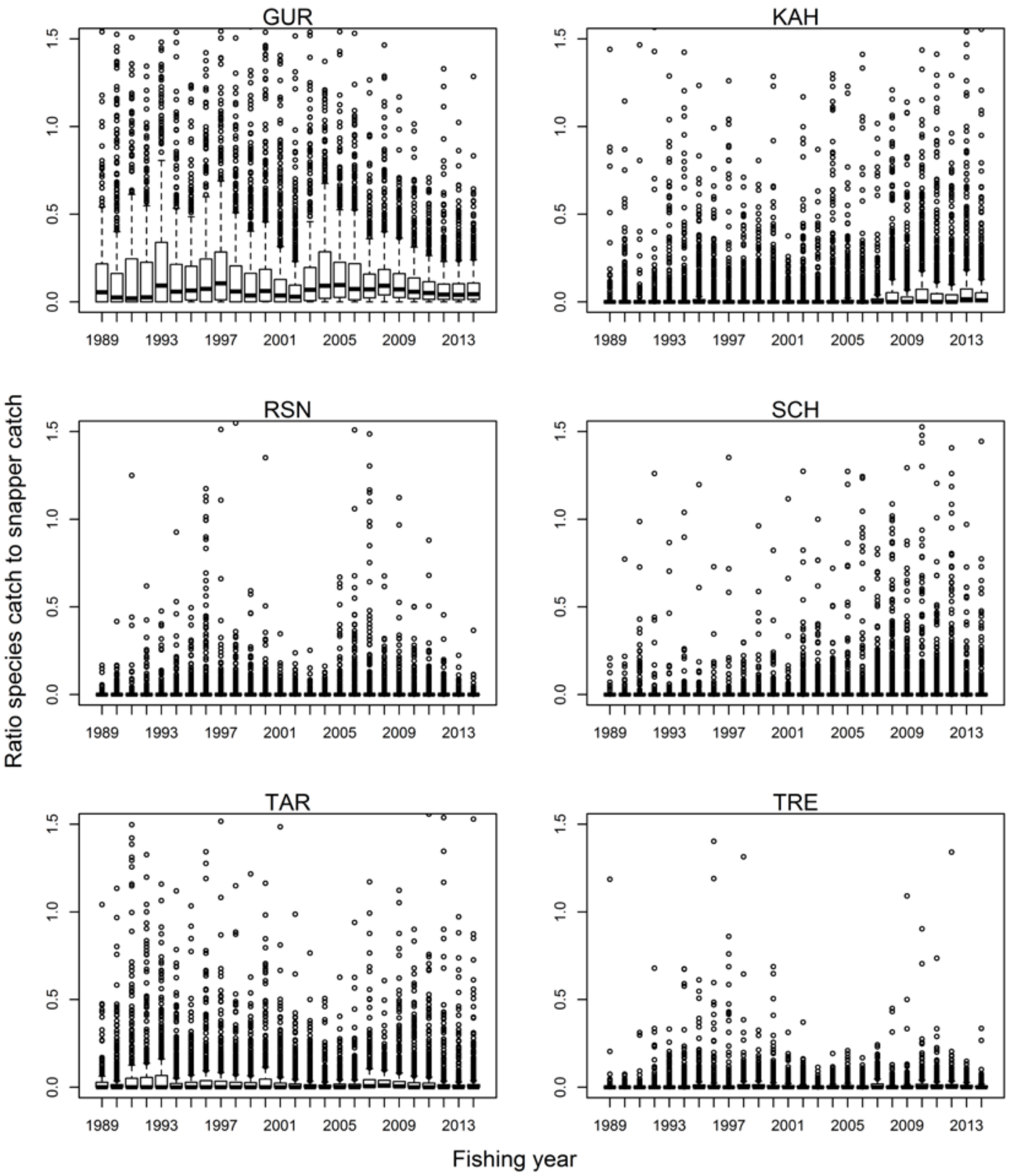

Figure 35: Boxplots of the ratio of the species catch to the snapper catch from each fishing trip for the main associated species caught by the Bay of Plenty BLL fishery (core vessel data set).

1.6.2 CPUE indices

The CPUE regression model for the Bay of Plenty fishery incorporated all the potential explanatory variables in the final model (Table 8). The effort variable (*NumHooks*) accounted for the highest proportion of the explained variation in snapper catch followed by *FishingYear*, *Vessel* and *Month*. The *StatArea* variable accounted for a minor proportion of the total explained deviance. Overall, the model accounted for 59.0% of the total variation.

The residual diagnostics indicate that the model residuals closely approximate the assumption of a normally distributed error structure (Figure 36). However, there are a relatively small number of observations with large negative residuals that skew the lower tail of the distribution of the model residuals. These residuals correspond to observations of small catches of snapper (less than 5 kg) that are not predicted by the CPUE model (Figure 36).

Table 8: Summary of stepwise selection of variables in the Bay of Plenty CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			26 101	20 185		
1	*FishingYear*	25	1 509.2	26 076	18 676	0.075	65 390.1
2	*NumHooks*	3	8 342.4	26 073	10 334	0.488	49 948.0
3	*Vessel*	45	1 692.0	26 028	8 642	0.572	45 370.7
4	*Month*	11	150.3	26 017	8 491	0.579	44 934.8
5	*StatArea*	2	43.9	26 015	8 447	0.581	44 803.4
6	*StatArea:Month*	22	172.8	25 993	8 275	0.590	44 307.9

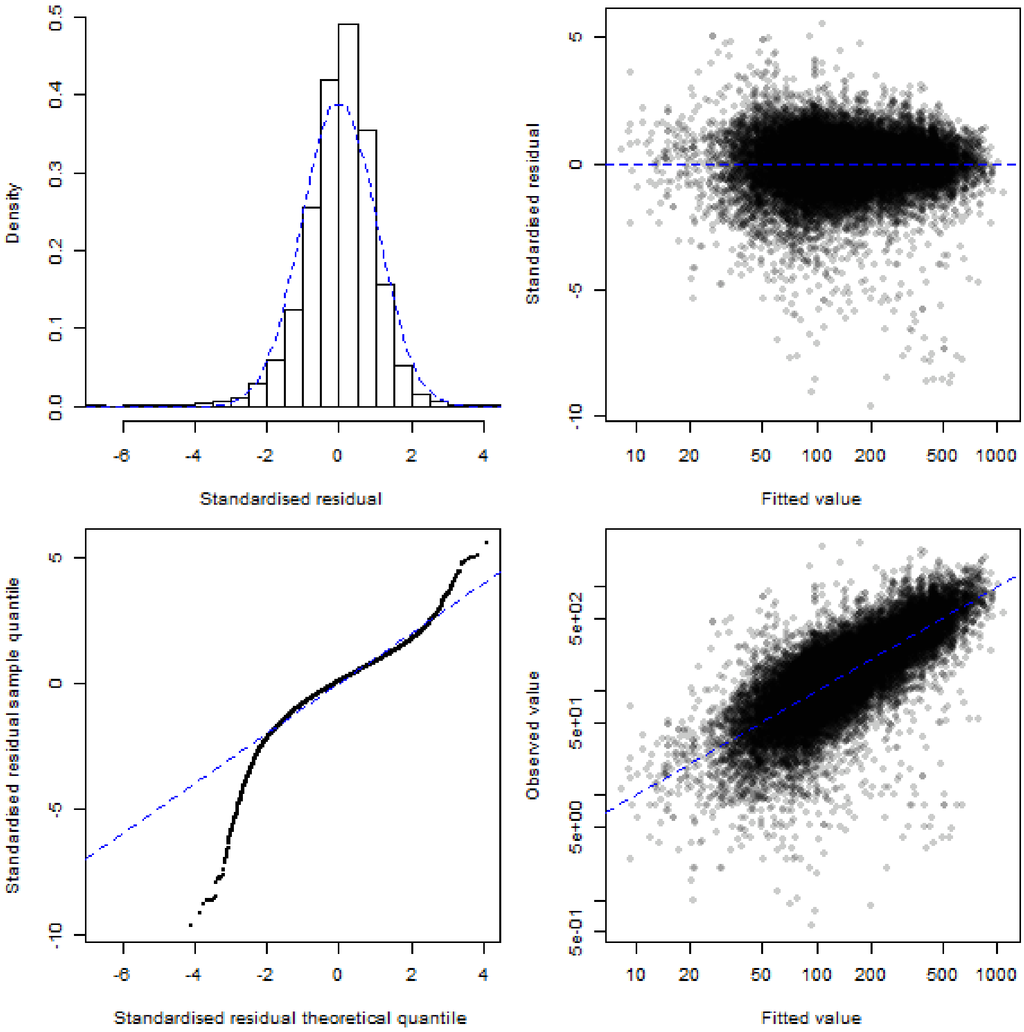

Figure 36: Residual diagnostics for the CPUE model for the Bay of Plenty fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the CPUE model increased during 1991/92–1996/97, remained relatively stable during 1996/97–2004/05 (Figure 37). The indices increased from 2004/05–2007/08 and fluctuated about the higher level during the subsequent years (2008/09–2014/15) (Figure 37).

There are considerable differences in the trends from the standardised CPUE indices compared to the unstandardised CPUE indices, particularly during 2007/08–2014/15 (Figure 37). The large increase in the unstandardised indices in recent years is moderated by the inclusion of the effort variable (*NumHooks*) in the CPUE model (Figure 38) which accounted for the overall increase in the number of hooks set in the fishery during the period (Appendix 3 Figure A10). The inclusion of the *NumHooks* variable was somewhat countered by the *Vessel* variable which accounted for a reduction in fishing effort by some of the more efficient vessels during 2002/03–2008/09 (Figure 38 and Appendix 3 Figure A11). The inclusion of the other variables in the CPUE model had very little influence on the annual CPUE indices.

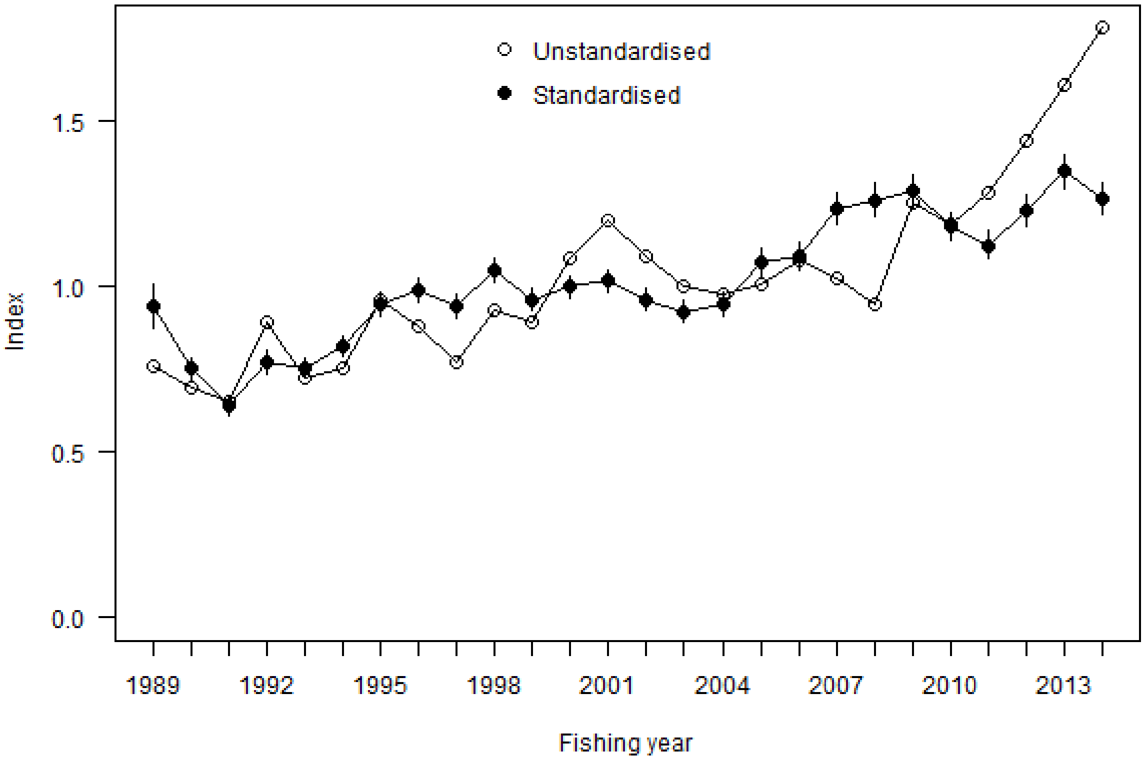

Figure 37: A comparison between the unstandardised and standardised CPUE indices for the Bay of Plenty fishery. The unstandardised indices represent the geometric mean of the snapper catch per fishing day. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

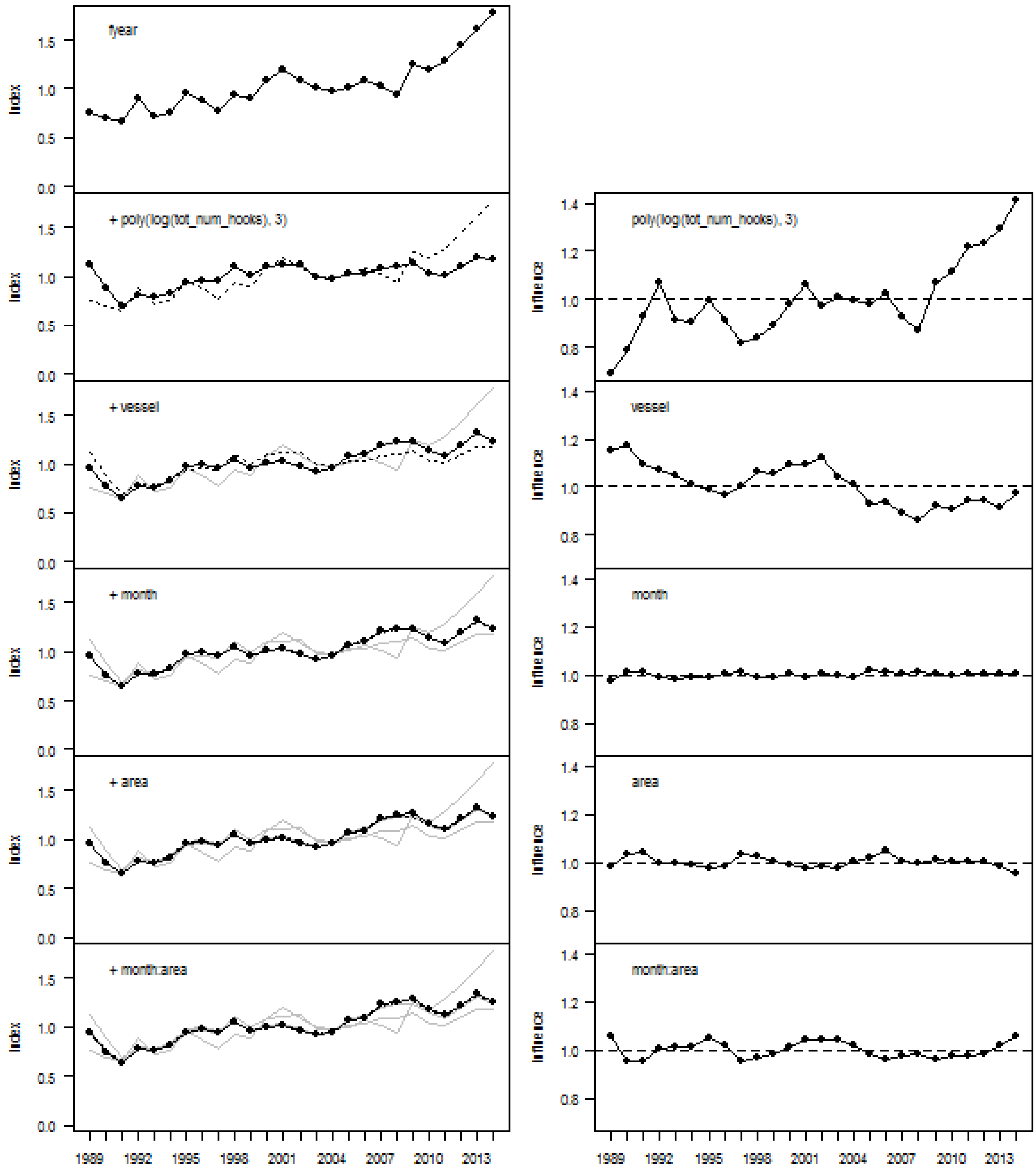

Figure 38: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the CPUE model for the Bay of Plenty fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1989 denotes the 1989/90 fishing year).

Annual trends in the model residuals were examined for a number of the variables included in the CPUE model. The *NumHook* variable was partitioned into three categories that approximate groupings within the data set: less than 1200 hooks, 1200–2200 hooks, and more than 2200 hooks (Figure 34). For each year, the average of the residuals was determined for each hook category. No strong annual trend was apparent in the residuals by hook category (Figure 39), indicating that the trends in the CPUE indices are generally comparable amongst the hook categories.

There was no strong temporal trend in the model residuals summarised by season (quarter), with the exception of the first quarter of the fishing year (October–December) (Figure 39). During 1999/2000–

2003/04, the residuals from the first quarter were generally positive, while during 2007/2008–2012/13 the residuals from the first quarter were negative (Figure 39). The sensitivity of the CPUE indices to the data from the first quarter was assessed by refitting the CPUE model with the records excluded from the data set. There was no appreciable difference between the resulting CPUE indices and the CPUE indices from the base CPUE model.

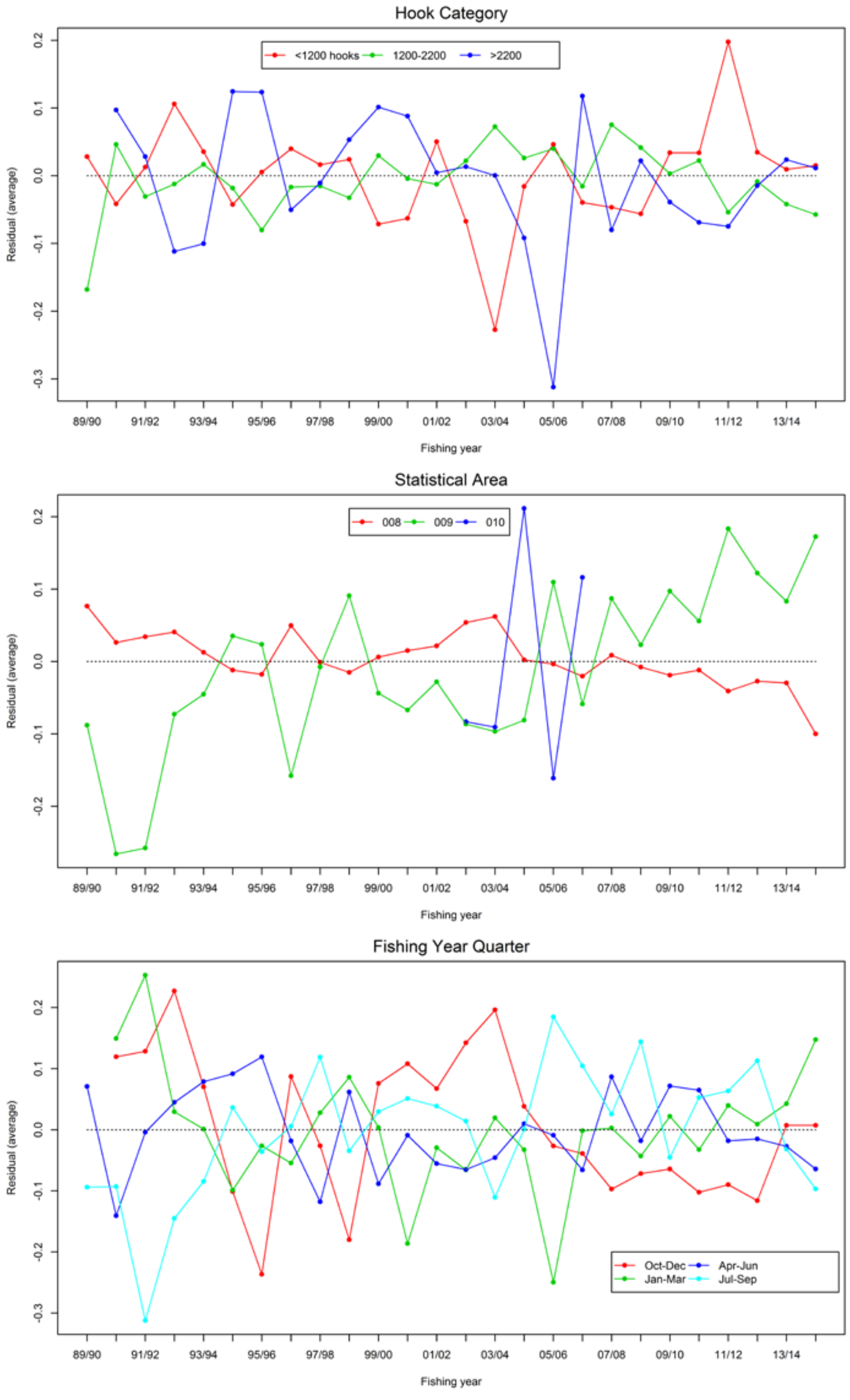

Figure 39: Average annual residuals from the Bay of Plenty CPUE model by category for three variables included in the model. The variables are: total number of hooks (*NumHooks*) classified in three size categories (top panel), Statistical Area (middle panel) and *Month* classified in quarterly periods (bottom panel).

Different trends in the CPUE model residuals were apparent when the residuals were summarised by Statistical Area (Figure 39). From 2002/03, there was a general increase in the average residuals from Statistical Area 009, while the residuals from 008 did not reveal a strong trend (Figure 39). Very limited data were available from Statistical Area 010.

There are no marked differences between the annual CPUE indices derived from the LTCER data set and the daily CPUE indices from the corresponding years (2007/08–2014/15) (Appendix 5 Figure A15).

1.7 Spatial indices

To investigate the longer term spatial patterns in the CPUE indices, each of the regional daily CPUE models was refitted with the inclusion of an interaction term between the *FishingYear* and *StatArea* variables. For each region, the resulting annual CPUE indices derived for the individual Statistical Areas (Figure 40) were consistent with the temporal trends apparent in the Statistical Area residuals from the base CPUE model.

For East Northland, the CPUE trends from Statistical Areas 002 and 003 were comparable prior to the mid 2000s but deviated in the subsequent years, with the CPUE in Statistical Area 002 increasing considerably more than Statistical Area 003 (Figure 40). The base CPUE indices for the region mediated the trends from the two areas, reflecting the relatively even distribution of effort from the two areas (Figure 41).

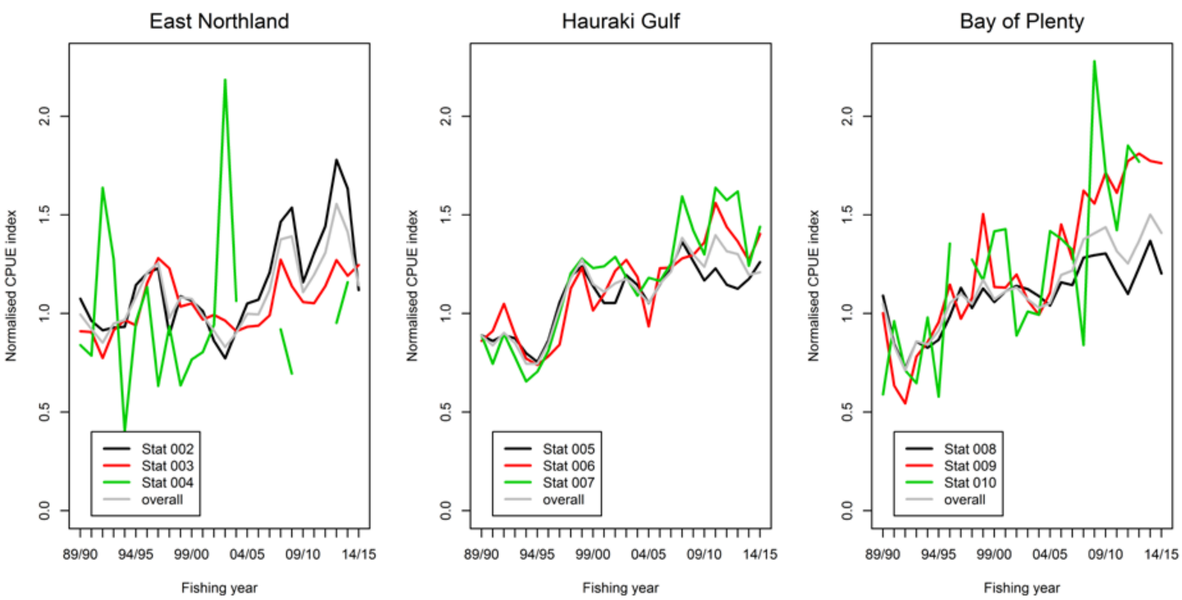

Figure 40: A comparison of the Statistical Area CPUE indices derived from regional CPUE models including a *FishingYear, StatArea* interaction term. The regional CPUE indices ("overall") from the base CPUE models are also presented for each region.

For the Hauraki Gulf region, the CPUE trends from the three Statistical Areas were comparable during 1989/90–2006/07. During the subsequent years, the indices from Statistical Areas 006 and 007 were generally higher than from Statistical Area 005, especially during 2010/11–2012/13 (Figure 40). The base CPUE indices for the region are at an intermediate level between the indices from Statistical Areas 006 and 007 and Statistical Area 005 (Figure 41).

For the Bay of Plenty, the CPUE indices from Statistical Areas 008 and 009 deviated from about 2004/05 with the indices from the latter area increasing considerably, while the indices from Statistical Area 008 remained relatively stable (Figure 40). There were limited data from Statistical Area 010 (Figure 41) and, hence, the corresponding indices are poorly determined. Nonetheless, the indices from this area exhibit a trend that is more consistent with the indices from 009 (Figure 40). The regional indices for the Bay of Plenty are skewed towards the indices derived from Statistical Area 008, reflecting the dominance of the data from this area within the overall data set (Figure 41).

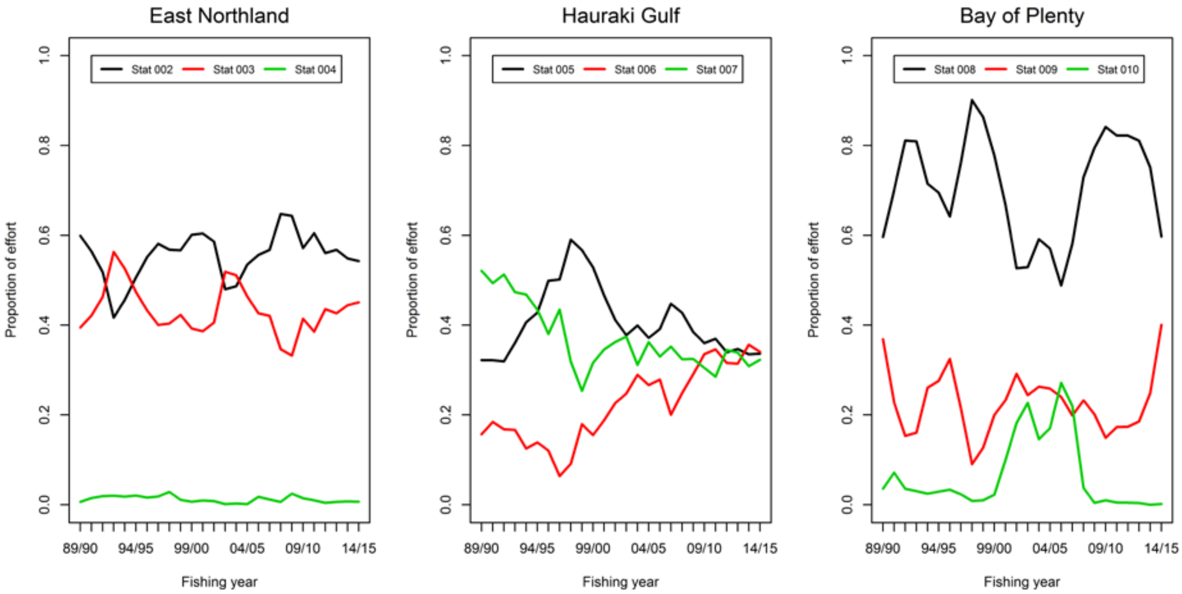

Figure 41: The distribution of the annual number of CPUE records by Statistical Area for each region (core vessel, daily CPUE data sets).

DISCUSSION

The current study was able to closely approximate the area specific longline CPUE indices presented in Francis & McKenzie (2015). As in the previous study, the standardised CPUE models moderated the increase in the nominal CPUE in the East Northland and Hauraki Gulf areas by accounting for the general increase in the average number of hooks set per day.

The trends in the standardised CPUE indices were relatively robust to the range of model configurations investigated in the study. However, the recent Hauraki Gulf CPUE indices were sensitive to the treatment of the individual core vessels in the CPUE model. There is an indication that the efficiency of some of the long established vessels in the fleet has increased over time and this may introduce a positive bias in the CPUE indices in the latter period.

For each fishery area, there was an indication of a degree of spatial variation in the recent trends in stock abundance. These observations were apparent at the relatively coarse spatial resolution of the daily CPUE data set (i.e. Statistical Area). The diverging trends in CPUE among Statistical Areas may reflect differential patterns in exploitation between the areas in concert with relatively limited movement between the areas. For example, the BLL catch from Statistical Area 009 was relatively low during 2006/07–2013/14 and the snapper catch rates from the area increased considerably more than from Statistical Area 008 where longline catch rates were substantially higher.

Alternatively, different trends in the CPUE from the constituent Statistical Areas may be related to changes in the distribution of snapper in response to prevailing oceanographic conditions. An analysis of the location based data from the Hauraki Gulf fishery indicated that a change in fish distribution may have been a cause of the divergent trends in area-specific CPUE during 2008/09–2013/14.

A more detailed spatially structured model is required to more thoroughly investigate a range of alternative hypotheses that could account for sub regional differences in BLL CPUE. Further consideration is also required to determine the best approach to derive annual CPUE indices that account for the sub-regional distribution of biomass rather than simply reflecting the distribution of fishing effort (effort records). This is likely to be problematic in the Bay of Plenty area where there appear to be considerable sub-regional differences in CPUE and limited BLL CPUE data available from beyond the north-western area of the Bay of Plenty (i.e. from Statistical Areas 009 and 010).

Changes in the spatial operation of the longline fisheries may impact the overall CPUE indices. Since October 1995, fishing within an area of the inner Hauraki Gulf (within Statistical Area 007) has been restricted by seasonal closure of commercial fishery during 1 October–31 March. The impact of the closure on the Hauraki Gulf BLL CPUE indices is difficult to evaluate as the closure predates the collection of detailed, location-based catch and effort data. However, there is no indication that snapper BLL CPUE from the overall area of Statistical Area 007 declined immediately following the introduction of the seasonal closure.

There are limited data available to corroborate the trends in the BLL CPUE indices and appraise the reliability of the CPUE indices as indices of stock abundance. Some corroboration is available from comparing the CPUE indices with the time-series of age composition data available from the area-specific longline fisheries (Walsh et al. 2014). In general, marked changes in the age structure of the longline catch following the recruitment of strong year classes tend to coincide with an increase in BLL CPUE, specifically:

- For the Hauraki Gulf, the large increase in the CPUE indices in late 1990s appears to correspond to recruitment of the very strong 1989 year class.
- For the Bay of Plenty, the age compositions of the longline catch indicate strong year classes entering fishery in 1993/94–1995/96 (1989 year class) and 2003/04–2004/05 (1999 year class) (Walsh et al. 2014). There was a corresponding increase in the CPUE indices during these periods and during following years.
- For east Northland, the periods of higher CPUE during 1995/96–1998/99 and 2005/06–2008/09 tended to follow strong recruitment in 1995/96–1996/97 (1989–1991 year classes) and 2003/04–2007/08 (1999–2003 year classes) (Walsh et al. 2014).

These comparisons provide some support for the general trends observed in the annual CPUE indices. However, they do not provide information regarding the strength of the relationship between the CPUE indices and stock abundance.

The commercial sector has expressed concerns regarding the reliability of BLL CPUE as an index of stock abundance. The sector has stated that the operation of the fleet is constrained by the availability of SNA 1 ACE and some processors restrict individual boats to weekly snapper catch limits, especially during the summer period. This may result in some vessels fishing in less productive areas to increase the catch of other species relative to the catch of snapper. However, any such change in fleet operation was not evident from the current study that indicated that the species catch composition had remained relatively consistent in each of the fishery areas.

The availability of the LTCER catch and effort data enabled mesoscale (5–30 km) changes in the distribution of fishing effort to be investigated for the Hauraki Gulf fishery. The study indicated that fishing vessels generally remained in areas supporting higher catch rates of snapper and would relocate to a new area if catch rates were low. This observation is consistent with the target operation of the fishery and there has been no indication of a change in the operation of the fishery over the recent period (2007/08–2014/15). The persistent targeting of higher snapper catch rate areas may moderate the trends in BLL CPUE relative to trends in stock abundance, i.e. resulting in “hyperstability” in the BLL CPUE indices. This effect could be exaggerated if fishing vessels actively avoided areas of very high snapper abundance or remained in areas that yielded moderate (i.e. satisfactory) catch rates, rather than actively searching for areas that would yield higher catch rates.

Further analysis of the location based catch and effort data is likely to increase our understanding of the operation of the fleet and, thereby, provide greater insights into the reliability of the BLL CPUE indices. In addition, the corresponding time-series of BLL CPUE indices and age composition data may enable the estimation of the CPUE-abundance relationship in the framework of an age-structured population model, especially with the inclusion of additional population abundance data (i.e. from tagging studies).

MANAGEMENT IMPLICATIONS

The BLL annual CPUE indices were an important input in the most recent (2013) stock assessment for SNA 1, providing an index of relative stock abundance during 1989/90–2011/12. A similar, updated series of BLL CPUE indices are also likely to be available for inclusion in the next stock assessment of SNA 1.

The schedule for conducting the next SNA 1 stock assessment is yet to be determined. In the interim, the update of the BLL CPUE indices provides an opportunity to monitor recent trends in relative abundance of SNA 1 in the three stock units. More importantly, it provides the opportunity to further refine the analysis of BLL catch and effort data to evaluate the reliability of the resulting CPUE indices as indices of stock abundance. The three current sets of daily CPUE indices were accepted by the Northern Inshore Fishery Assessment Working Group (8 April 2016). However, the Working Group did not have the opportunity to review a number of the auxiliary analysis presented in this report, specifically the detailed analysis of the Hauraki Gulf LTCER data set. These relatively novel approaches provide an opportunity to more thoroughly evaluate the utility of the CPUE data and should be developed further during the next update of the SNA 1 BLL CPUE indices. It is proposed that the CPUE analyses be updated in 2018 (including data from 2015/16–2016/17).

ACKNOWLEDGMENTS

This study was funded by the SNA 1 Commercial stakeholder group. Commercial fishermen, quota managers and processors operators provided insights into the operation of the SNA 1 longline fishery. Members of the Northern Inshore Fishery Assessment Working Group reviewed the updated standardised CPUE indices. David Middleton provided comments on the manuscript. Software developed by Nokome Bentley was utilised for the presentation of CPUE model diagnostics.

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APPENDIX 1. SUMMARY OF ANNUAL LONGLINE CATCHES BY AREA

Table A1: Annual catches (tonnes) of SNA 1 from the bottom longline fishery by fishery area (daily aggregated data set).

Fishing year	Fishery area				Total
	ENLD	HG	BPLE	Other	
1989/90	517.6	951.9	172.2	48.3	1 690.0
1990/91	528.4	1 183.8	320.5	97.2	2 129.9
1991/92	631.2	1 627.5	295.9	72.9	2 627.5
1992/93	628.1	1 584.1	287.0	57.9	2 557.1
1993/94	736.5	1 398.2	308.7	34.7	2 478.1
1994/95	787.4	1 281.6	353.8	27.2	2 450.0
1995/96	839.5	992.6	331.4	12.6	2 176.1
1996/97	902.3	947.2	281.1	28.4	2 159.0
1997/98	736.0	895.7	176.7	17.8	1 826.2
1998/99	654.5	1 104.4	258.1	17.1	2 034.1
1999/2000	717.7	975.3	294.8	35.6	2 023.4
2000/01	706.3	1 099.8	374.8	23.6	2 204.5
2001/02	592.0	1 068.3	353.9	17.5	2 031.7
2002/03	431.0	1 026.7	321.2	19.6	1 798.5
2003/04	513.3	780.6	276.7	19.1	1 589.7
2004/05	443.0	729.6	335.3	2.2	1 510.1
2005/06	527.7	686.8	331.0	2.4	1 547.9
2006/07	589.8	623.6	281.6	0.8	1 495.8
2007/08	538.0	659.4	236.4	5.9	1 439.7
2008/09	528.8	763.7	172.3	5.8	1 470.6
2009/10	515.6	722.3	321.1	6.8	1 565.8
2010/11	568.5	758.8	296.6	3.1	1 627.0
2011/12	491.8	818.0	314.0	1.1	1 624.9
2012/13	544.6	787.2	305.9	0.8	1 638.5
2013/14	599.7	694.4	361.0	5.2	1 660.3
2014/15	586.2	554.9	411.0	3.0	1 555.1

APPENDIX 2. COMPARATIVE CPUE INDICES

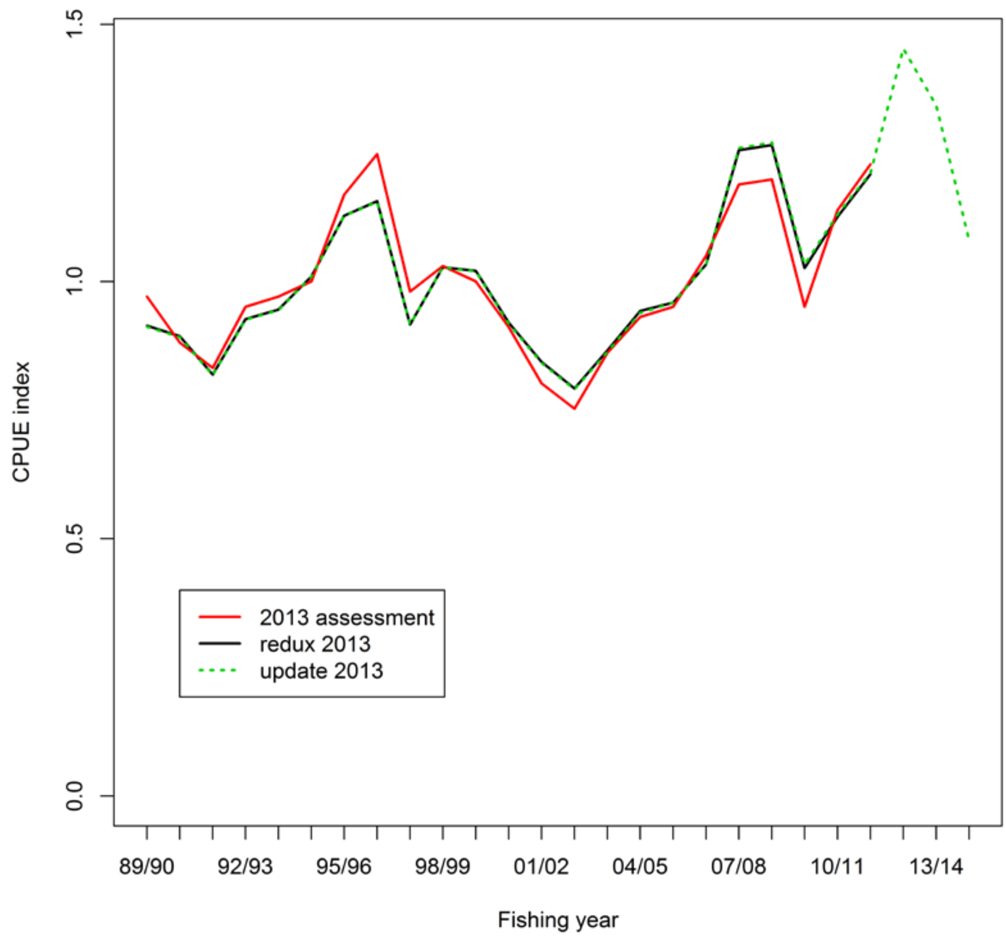

Figure A1: A comparison of BLL CPUE indices for the East Northland fishery area from the previous analysis by Francis & McKenzie (2015) (2013 assessment) and a repeat of the previous analysis (redux 2013). The previous model was also updated to include catch and effort data from three subsequent years (2012/13–2014/15) (update 2013).

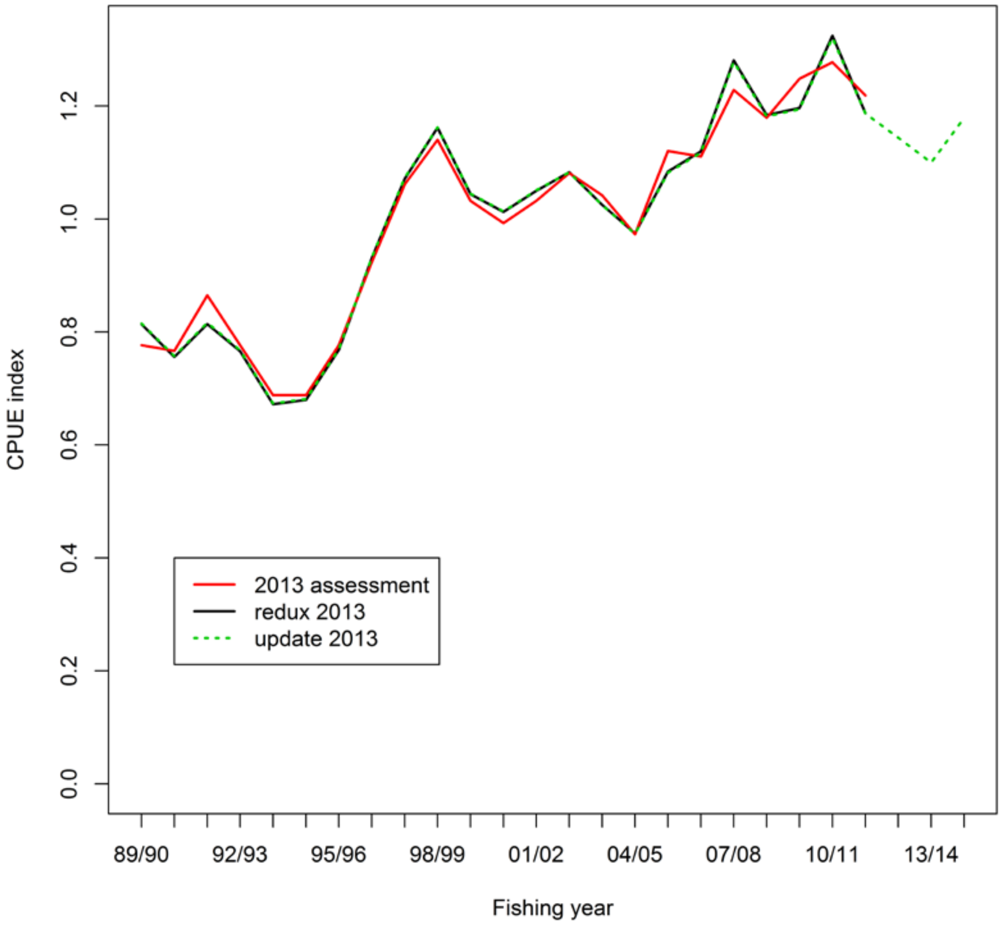

Figure A2: A comparison of BLL CPUE indices for the Hauraki Gulf fishery area from the previous analysis by Francis & McKenzie (2015) (2013 assessment) and a repeat of the previous analysis (redux 2013). The previous model was also updated to include catch and effort data from three subsequent years (2012/13–2014/15) (update 2013).

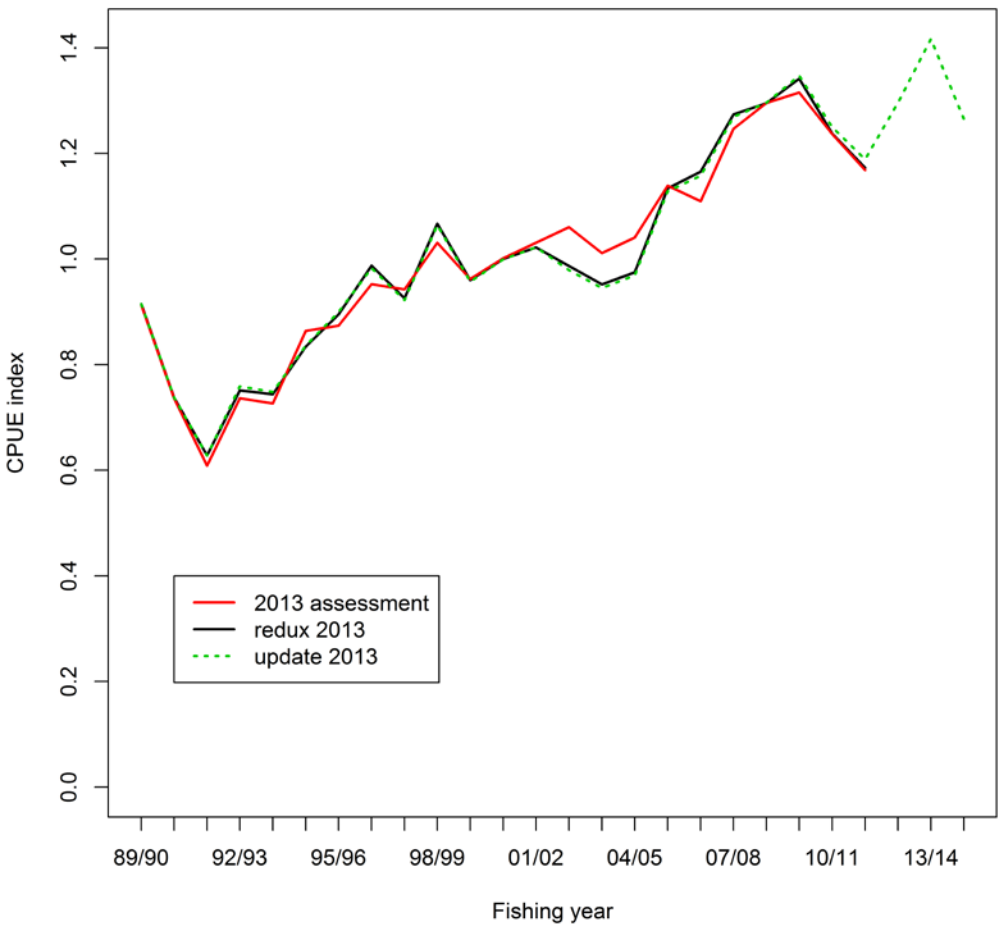

Figure A3: A comparison of BLL CPUE indices for the Bay of Plenty fishery area from the previous analysis by Francis & McKenzie (2015) (2013 assessment) and a repeat of the previous analysis (redux 2013). The previous model was also updated to include catch and effort data from three subsequent years (2012/13–2014/15) (update 2013).

APPENDIX 3. CPUE DATA SETS

Table A2: Summary of the catch and effort data from the East Northland (ENLD) BLL CPUE data set (core vessels only).

Fishing year	Number vessels	Number trips	SNA catch (t)	Number sets	Hooks (1000s)	Percent zero catch
1989/90	19	1 018	180.7	1 805	1 842	9.3
1990/91	19	1 191	253.8	2 095	2 492	1.7
1991/92	27	1 541	321.1	2 994	3 265	1.8
1992/93	28	1 565	331.4	2 952	2 963	1.1
1993/94	33	1 857	383.4	3 484	3 743	1.0
1994/95	34	2 170	517.8	4 227	4 547	0.6
1995/96	34	2 139	545.4	3 857	4 352	1.6
1996/97	33	2 200	611.6	3 899	4 421	2.3
1997/98	32	2 011	455.8	3 555	4 075	2.2
1998/99	30	2 127	519.1	3 512	4 303	1.0
1999/2000	30	2 122	546.0	3 285	4 708	1.9
2000/01	28	1 881	501.0	2 826	4 332	3.0
2001/02	26	1 718	410.1	2 580	3 895	3.4
2002/03	23	1 446	296.9	1 867	3 044	0.8
2003/04	22	1 419	389.4	2 017	3 510	0.7
2004/05	18	1 006	278.5	1 444	2 203	1.5
2005/06	17	1 075	333.9	1 636	2 695	0.7
2006/07	17	1 240	461.6	1 957	3 253	0.6
2007/08	16	1 029	422.8	1 479	2 586	0.7
2008/09	15	1 031	436.7	1 478	2 756	0.7
2009/10	14	1 091	419.1	1 626	3 158	0.8
2010/11	14	987	447.5	1 604	3 229	0.7
2011/12	9	688	298.1	978	1 960	0.0
2012/13	8	654	312.5	827	1 739	0.0
2013/14	7	554	236.1	671	1 405	0.2
2014/15	9	570	220.9	667	1 529	0.3

Table A3: Summary of the catch and effort data from the Hauraki Gulf (HG) BLL CPUE data set (core vessels only).

Fishing year	Number vessels	Number trips	SNA catch (t)	Number sets	Hooks (1000s)	Percent zero catch
1989/90	25	1 395	336.7	2 610	2 128	0.9
1990/91	29	2 009	472.0	3 734	3 353	1.0
1991/92	31	2 315	616.7	4 145	4 145	0.8
1992/93	33	2 494	665.2	4 636	4 988	1.2
1993/94	32	2 612	580.5	5 112	5 041	1.1
1994/95	36	2 598	634.1	5 599	5 333	0.7
1995/96	34	2 360	641.4	4 947	4 911	1.3
1996/97	33	2 266	680.5	4 548	4 315	1.4
1997/98	32	2 356	737.9	4 569	4 367	1.8
1998/99	31	2 550	917.3	5 226	4 958	1.4
1999/2000	31	2 440	828.7	4 977	4 847	0.1
2000/01	32	2 262	876.5	4 982	5 324	0.4
2001/02	31	2 005	812.7	4 382	4 669	0.3
2002/03	32	1 717	751.6	3 405	3 766	0.4
2003/04	26	1 390	541.2	2 676	2 801	1.0
2004/05	22	1 167	457.1	2 441	2 634	0.6
2005/06	20	1 035	432.3	1 954	2 286	0.6
2006/07	18	1 110	479.2	1 875	2 447	2.2
2007/08	20	1 021	513.5	1 760	2 368	1.7
2008/09	19	1 201	697.1	2 348	3 244	1.7
2009/10	18	1 116	592.3	2 251	3 088	2.0
2010/11	17	1 066	587.8	2 187	2 885	2.1
2011/12	15	1 046	560.8	1 992	2 931	4.3
2012/13	15	983	574.9	1 946	2 937	5.0
2013/14	14	814	489.3	1 615	2 729	5.8
2014/15	11	548	386.2	1 108	2 133	5.4

Table A4: Summary of the catch and effort data from the Bay of Plenty (BPLE) BLL CPUE data set (core vessels only).

Fishing year	Number vessels	Number trips	SNA catch (t)	Number sets	Hooks (1000s)	Percent zero catch
1989/90	15	189	51.3	487	365	6.6
1990/91	15	493	112.7	1 414	1 114	1.2
1991/92	21	391	78.6	1 350	1 037	3.6
1992/93	19	400	124.8	1 369	1 399	1.5
1993/94	26	584	135.3	1 725	1 641	0.8
1994/95	27	703	173.6	2 082	1 910	1.9
1995/96	25	664	219.2	2 015	2 096	6.0
1996/97	23	664	166.7	1 842	1 699	7.7
1997/98	22	661	146.8	1 649	1 504	8.1
1998/99	19	811	194.7	1 893	1 729	7.4
1999/2000	22	835	206.9	1 868	1 962	4.9
2000/01	21	898	273.3	2 008	2 193	1.0
2001/02	19	811	252.3	1 631	2 033	0.4
2002/03	19	909	217.9	1 731	1 876	8.9
2003/04	18	816	198.8	1 565	1 797	8.3
2004/05	15	850	201.9	1 417	1 965	11.2
2005/06	17	882	179.0	1 246	1 910	20.6
2006/07	14	755	201.7	1 173	1 739	7.7
2007/08	14	666	180.7	1 007	1 432	0.2
2008/09	16	714	158.1	995	1 308	0.0
2009/10	16	854	279.7	1 304	2 265	0.2
2010/11	15	912	273.3	1 371	2 469	0.1
2011/12	16	826	265.4	1 241	2 482	0.2
2012/13	16	740	286.1	1 128	2 406	0.9
2013/14	14	718	330.5	1 157	2 489	0.5
2014/15	13	690	380.1	1 110	2 715	2.4

APPENDIX 4. CPUE MODEL INFLUENCE PLOTS

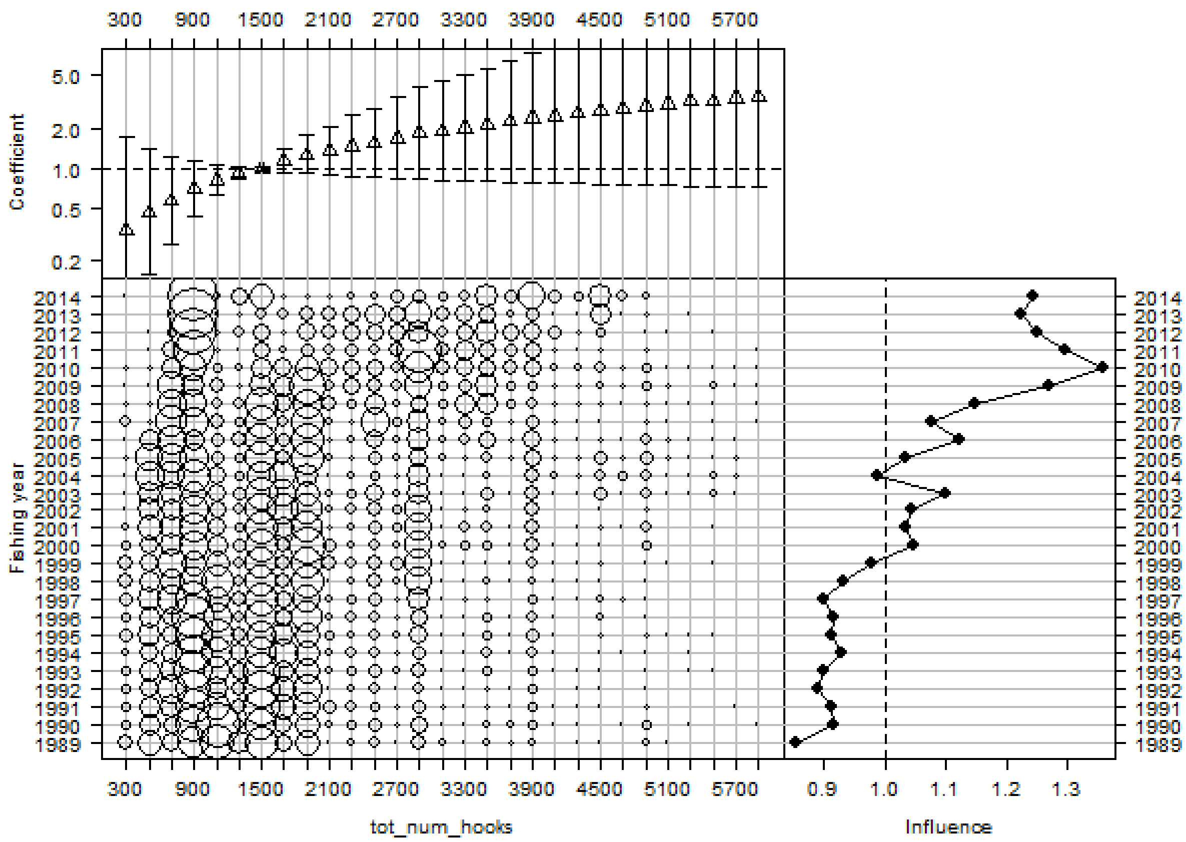

Figure A4: Influence plot for the *NumHooks* variable in the East Northland CPUE model.

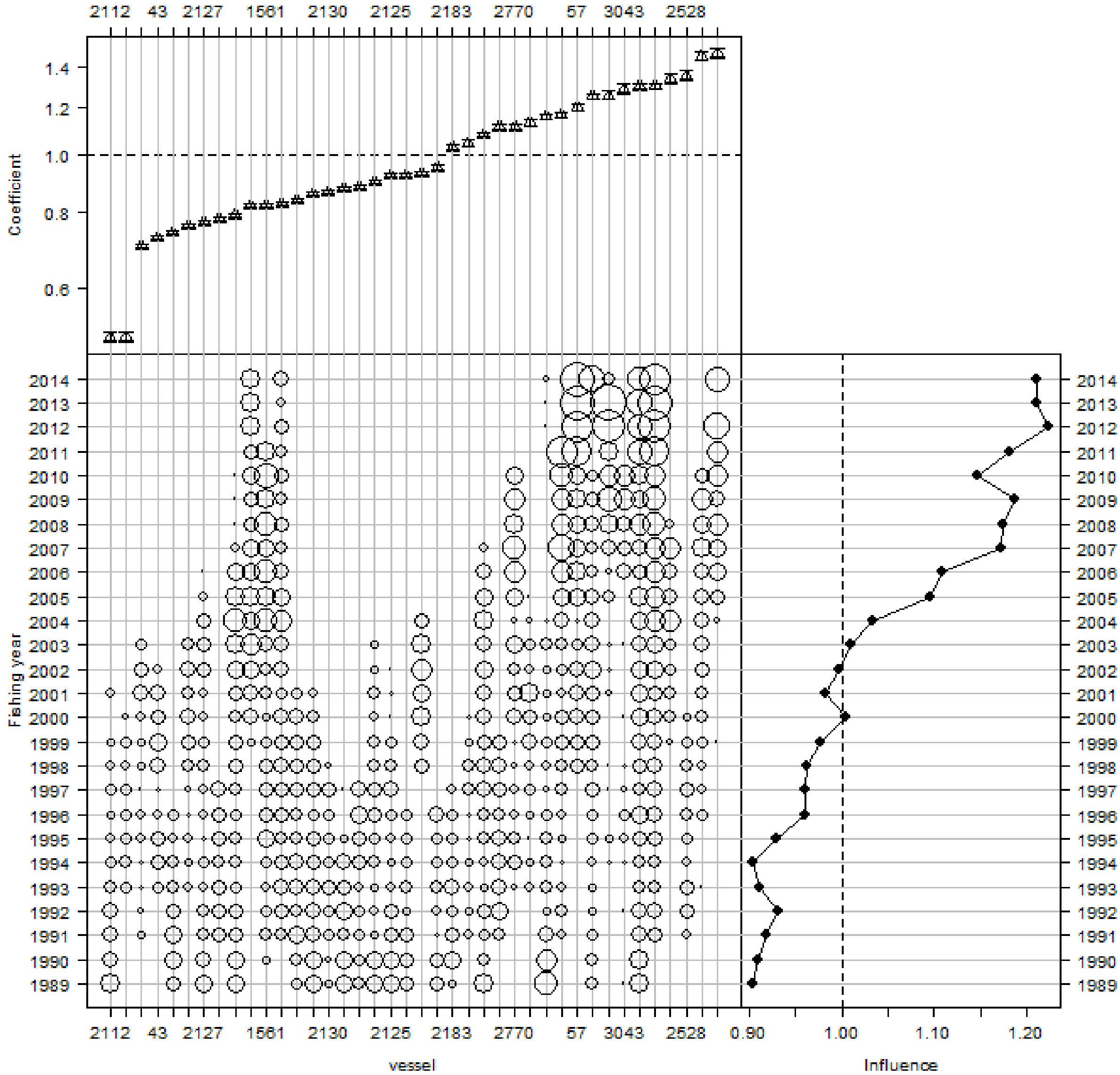

Figure A5: Influence plot for the *Vessel* variable in the East Northland CPUE model.

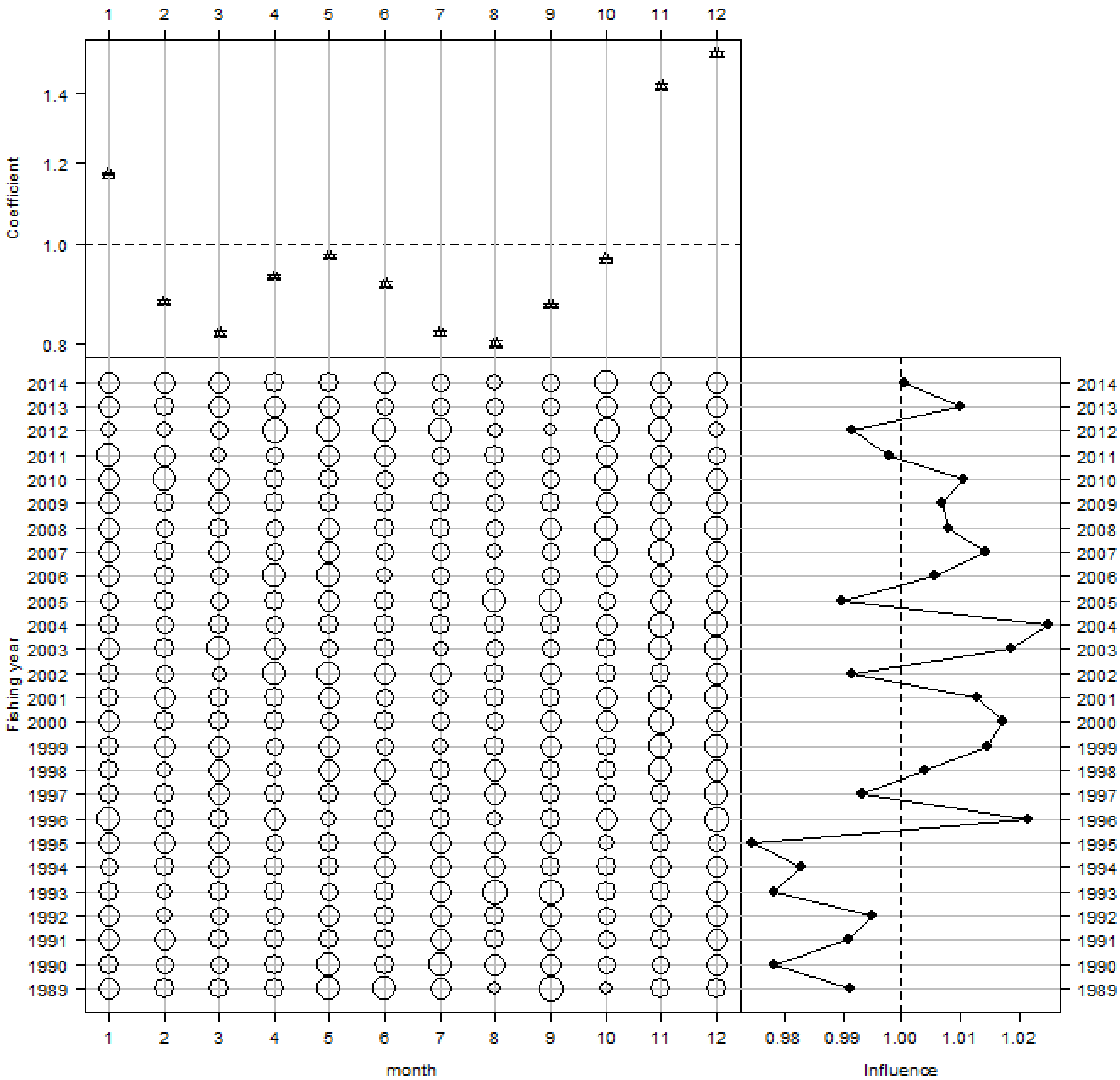

Figure A6: Influence plot for the *Month* variable in the East Northland CPUE model model (month 1 = January).

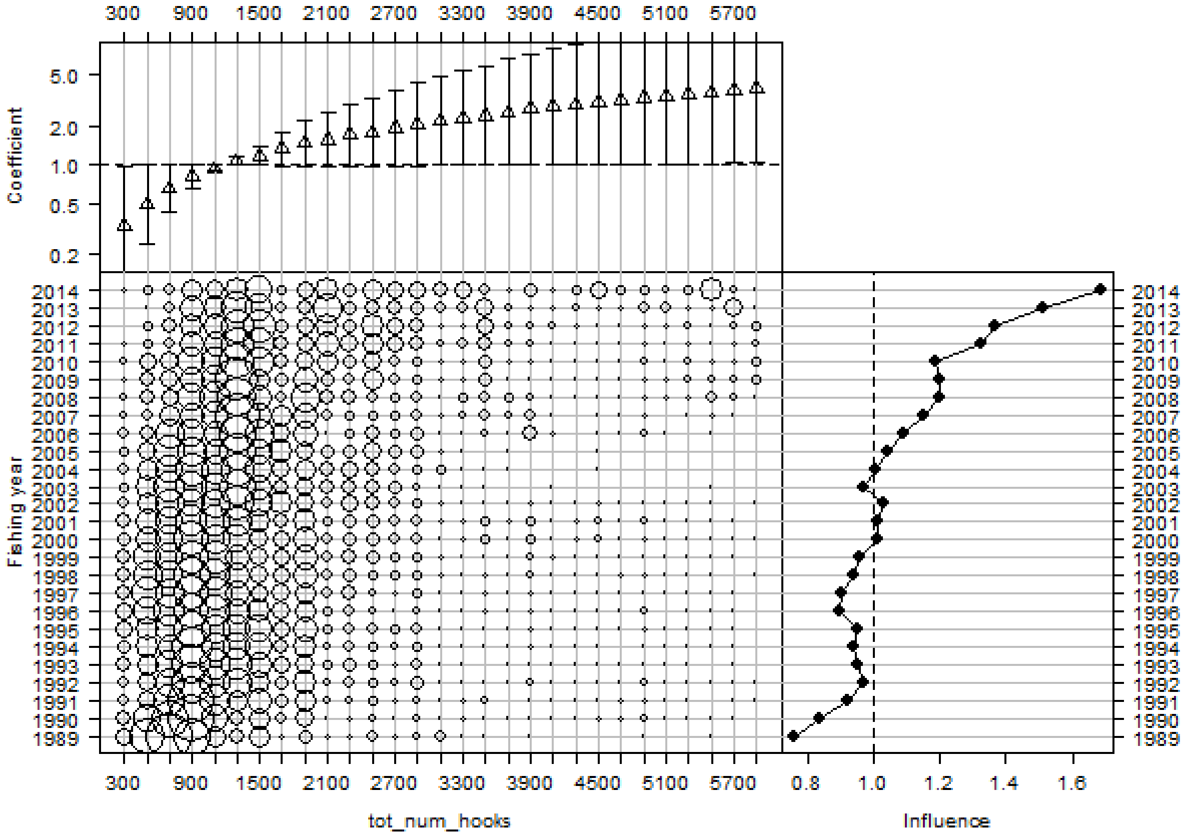

Figure A7: Influence plot for the *NumHooks* variable in the Hauraki Gulf CPUE model.

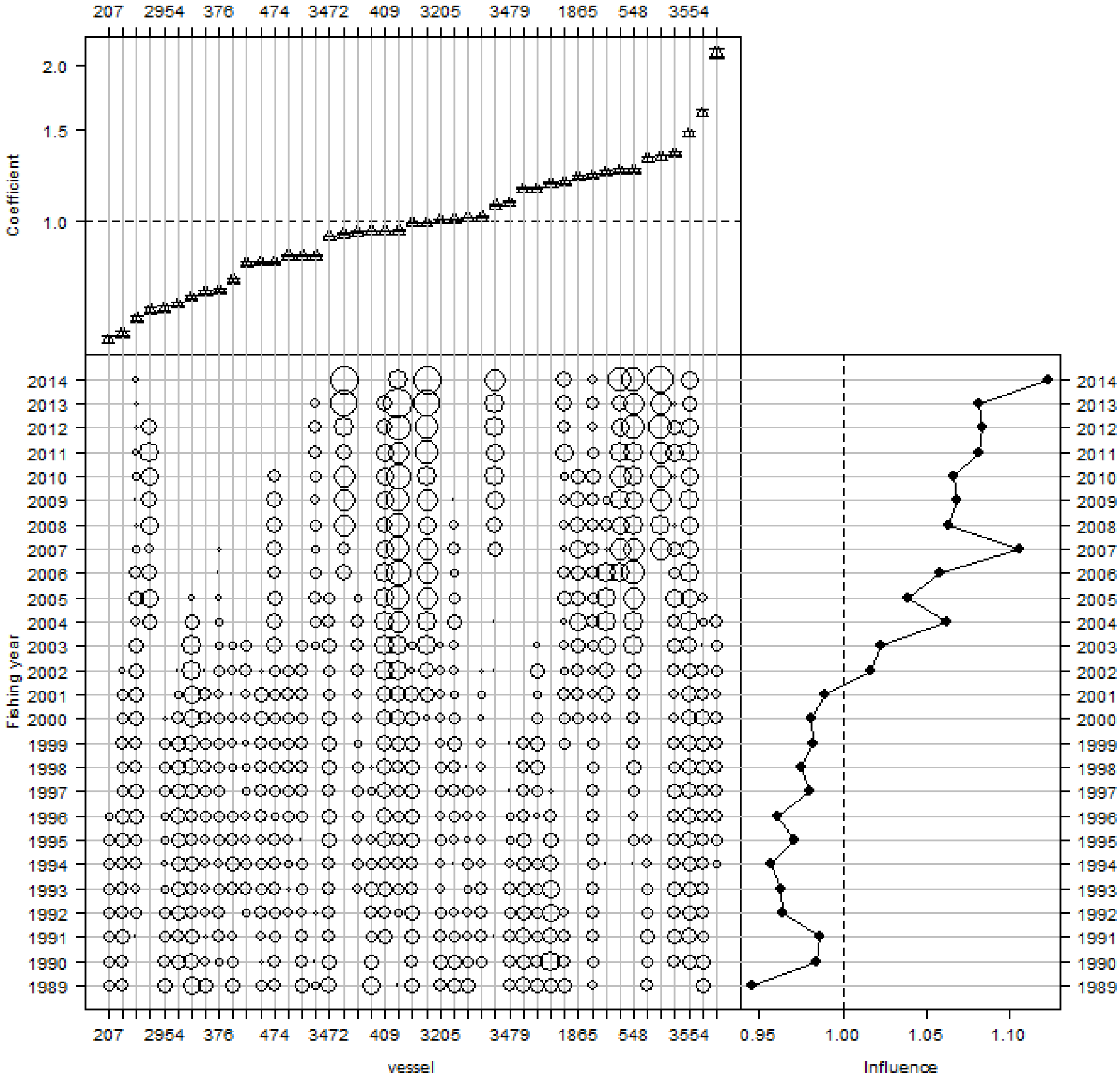

Figure A8: Influence plot for the *Vessel* variable in the Hauraki Gulf CPUE model.

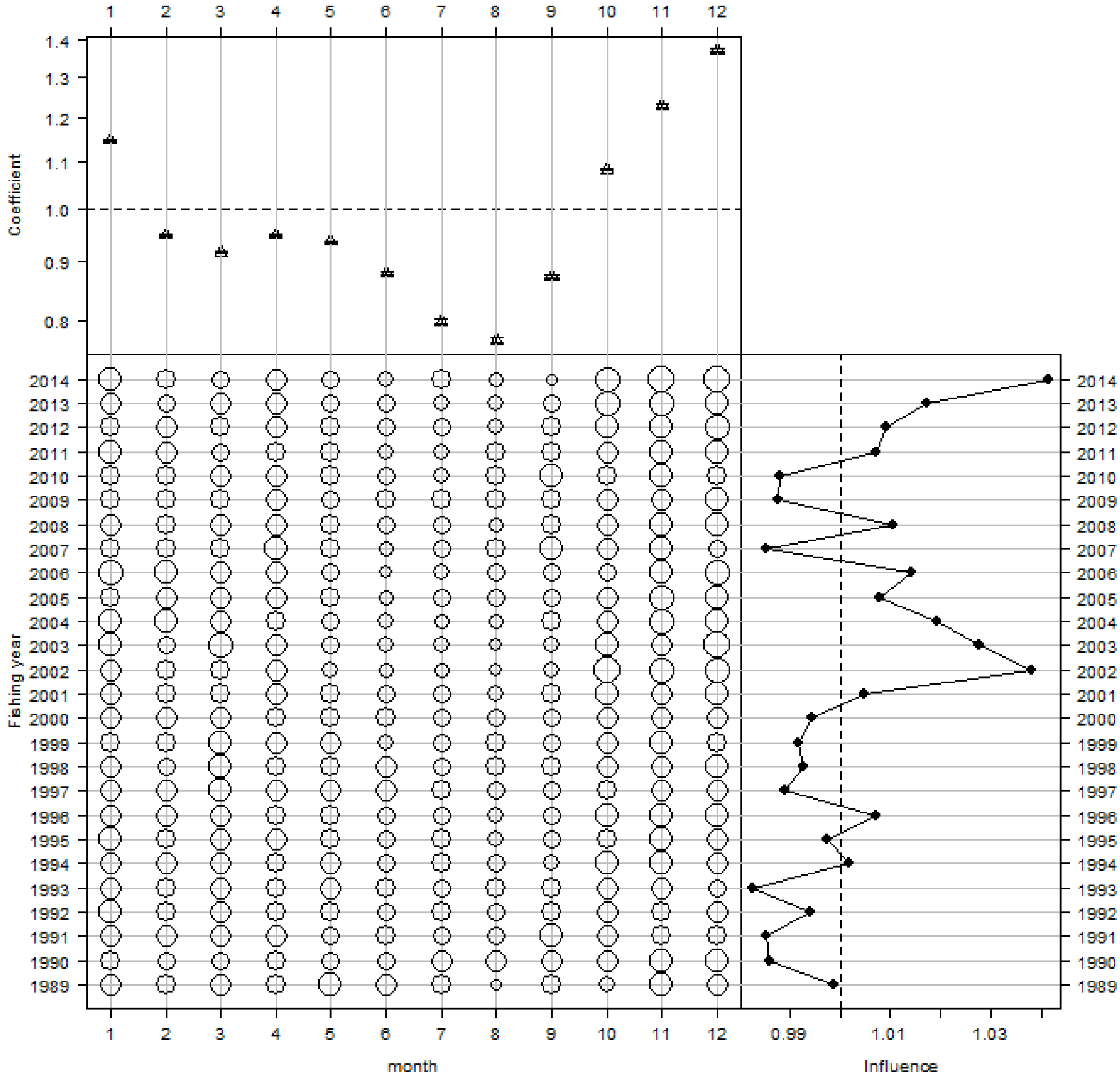

Figure A9: Influence plot for the *Month* variable in the Hauraki Gulf CPUE model (month 1 = January).

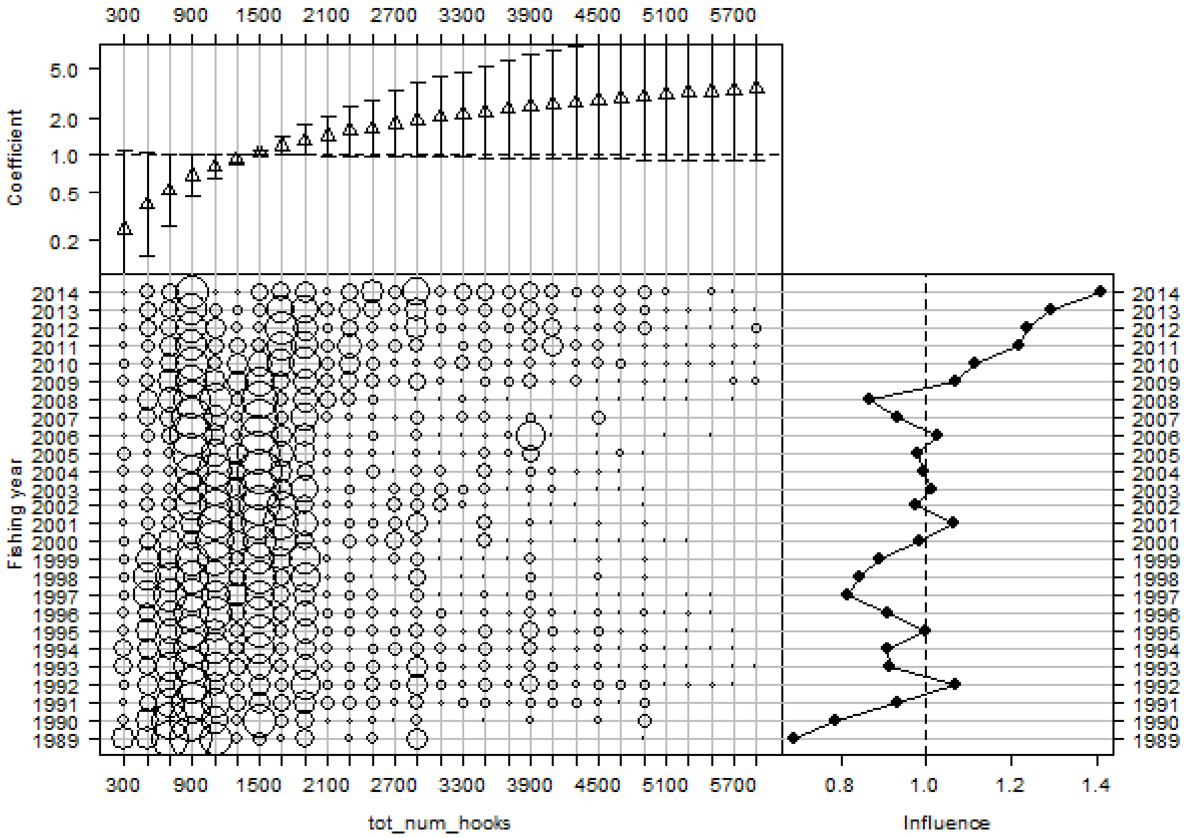

Figure A10: Influence plot for the *NumHooks* variable in the Bay of Plenty CPUE model.

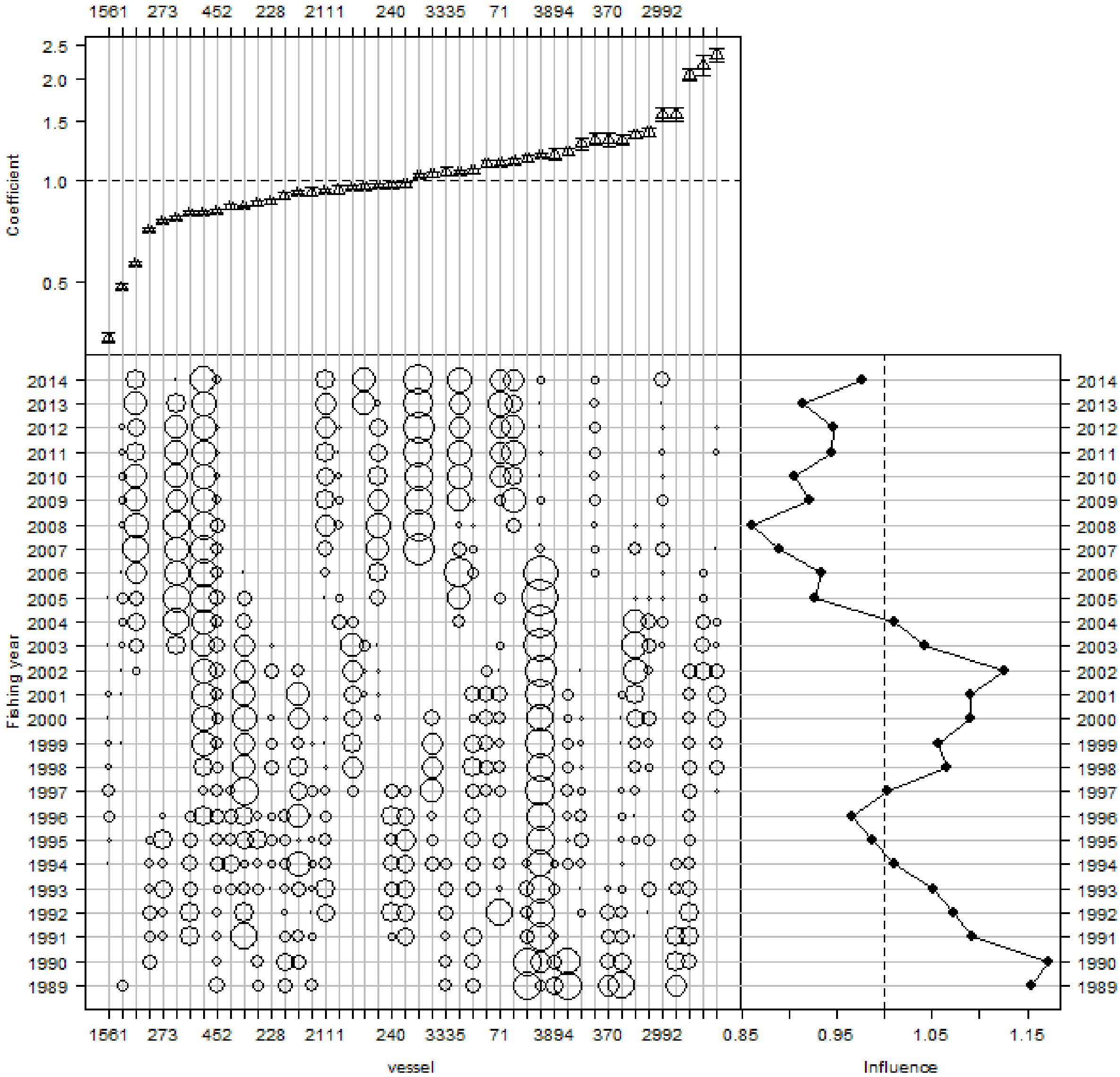

Figure A11: Influence plot for the *Vessel* variable in the Bay of Plenty CPUE model.

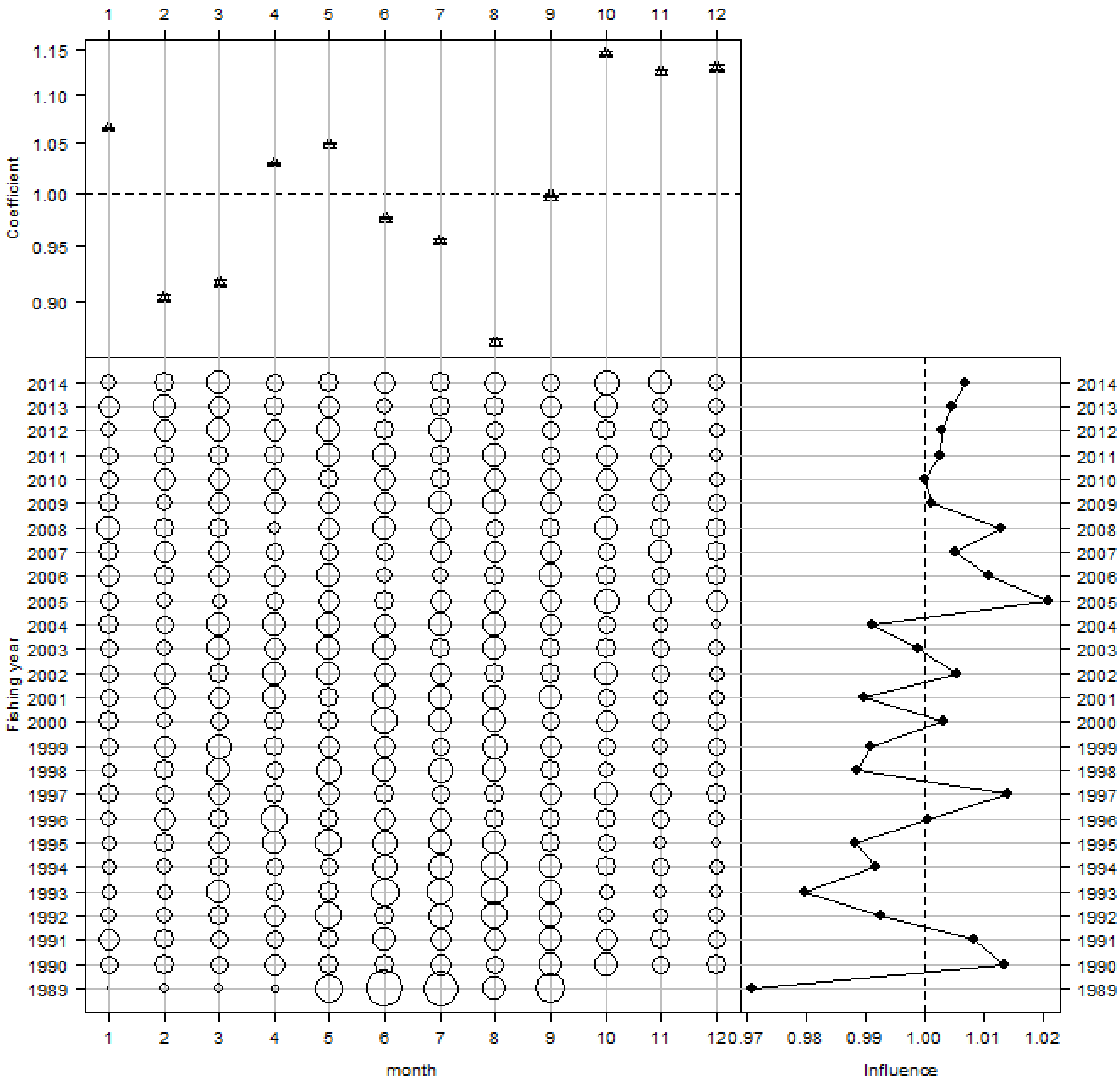

Figure A12: Influence plot for the *Month* variable in the Bay of Plenty CPUE model model (month 1 = January).

APPENDIX 5. TABULATED CPUE INDICES

Table A5: Annual SNA 1 BLL CPUE indices for each Fishery Area and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	East Northland			Hauraki Gulf			Bay of Plenty		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89/90	0.904	0.856	0.956	0.803	0.803	0.803	0.923	0.923	0.923
90/91	0.837	0.792	0.884	0.758	0.730	0.786	0.737	0.683	0.796
91/92	0.774	0.735	0.816	0.815	0.787	0.845	0.626	0.577	0.680
92/93	0.863	0.818	0.910	0.768	0.742	0.796	0.757	0.697	0.821
93/94	0.880	0.836	0.926	0.674	0.651	0.698	0.742	0.687	0.802
94/95	0.986	0.938	1.037	0.673	0.650	0.697	0.803	0.743	0.867
95/96	1.098	1.043	1.155	0.768	0.742	0.796	0.927	0.857	1.003
96/97	1.142	1.086	1.202	0.928	0.895	0.962	0.968	0.894	1.047
97/98	0.888	0.843	0.934	1.067	1.029	1.105	0.923	0.852	0.999
98/99	0.984	0.934	1.035	1.150	1.110	1.192	1.030	0.952	1.115
99/00	0.977	0.928	1.028	1.038	1.002	1.076	0.943	0.872	1.020
00/01	0.899	0.853	0.949	1.004	0.969	1.041	0.979	0.905	1.059
01/02	0.828	0.785	0.875	1.043	1.005	1.082	0.997	0.921	1.079
02/03	0.754	0.713	0.798	1.063	1.023	1.105	0.943	0.870	1.022
03/04	0.820	0.775	0.867	1.009	0.969	1.050	0.906	0.835	0.982
04/05	0.907	0.854	0.964	0.953	0.914	0.994	0.928	0.855	1.006
05/06	0.905	0.853	0.960	1.040	0.995	1.086	1.052	0.969	1.144
06/07	1.018	0.960	1.078	1.096	1.048	1.146	1.072	0.987	1.164
07/08	1.251	1.178	1.328	1.251	1.195	1.310	1.211	1.114	1.317
08/09	1.265	1.191	1.343	1.173	1.123	1.226	1.239	1.139	1.347
09/10	1.007	0.948	1.070	1.118	1.070	1.169	1.266	1.166	1.374
10/11	1.089	1.024	1.157	1.263	1.207	1.321	1.158	1.067	1.257
11/12	1.188	1.110	1.272	1.190	1.136	1.246	1.103	1.016	1.198
12/13	1.415	1.318	1.518	1.176	1.123	1.233	1.205	1.109	1.309
13/14	1.284	1.192	1.384	1.082	1.030	1.138	1.322	1.216	1.437
14/15	1.038	0.965	1.118	1.094	1.033	1.158	1.240	1.140	1.348

APPENDIX 5. A COMPARISON WITH LTCER CPUE INDICES

Table A6: Summary of stepwise selection of variables in the East Northland LTCER CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			7 148	4 359		
1	*FishingYear*	7	197.3	7 141	4 161	0.045	16 437.5
2	*NumHooks*	3	1125.6	7 138	3 036	0.304	14 188.9
3	*Vessel*	13	461.5	7 125	2 574	0.409	13 036.0
4	*Month*	11	124.1	7 114	2 450	0.438	12 704.7
5	*Loc2*	28	76.1	7 086	2 374	0.455	12 535.0
6	*StartTime*	3	42.4	7 083	2 332	0.465	12 412.0
7	*Depth*	3	11.8	7 080	2 320	0.468	12 381.8

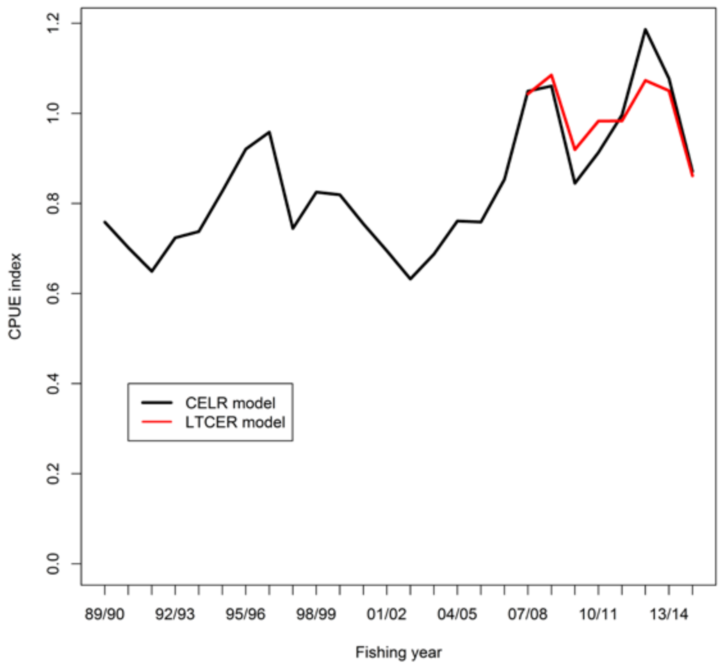

Figure A13: A comparison of the east Northland long term (CELR format) CPUE indices and the CPUE indices derived from LTCER data.

Table A7: Summary of stepwise selection of variables in the Hauraki Gulf LTCER CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			12 862	8 255		
1	*FishingYear*	7	68.5	12 855	8 186	0.008	30 708.5
2	*NumHooks*	3	2500.5	12 852	5 686	0.311	26 025.9
3	*Month*	11	776.1	12 841	4 909	0.405	24 160.1
4	*Vessel*	11	435.6	12 830	4 474	0.458	22 987.0
5	*Loc2*	23	88.6	12 807	4 385	0.469	22 775.6
6	*StartTime*	3	41.0	12 804	4 344	0.474	22 660.7
7	*Depth*	3	8.2	12 801	4 336	0.475	22 642.4

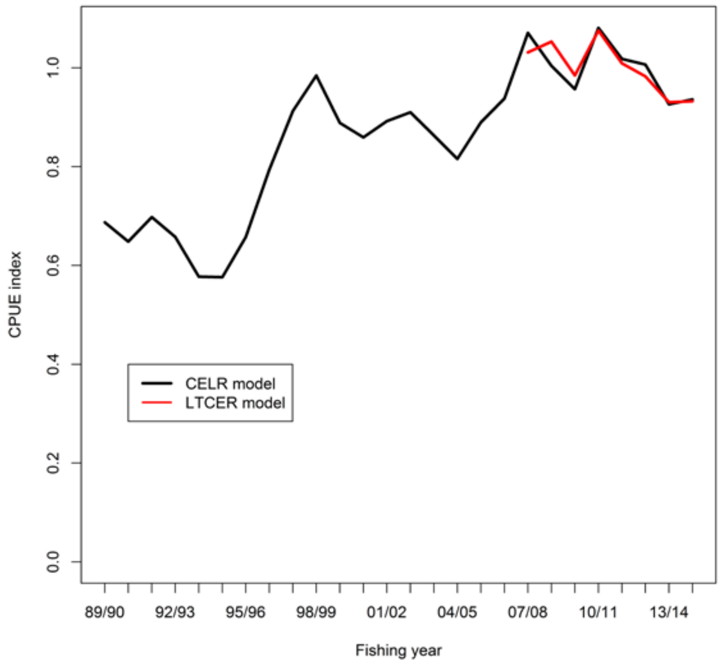

Figure A14: A comparison of the Hauraki Gulf long term (CELR format) CPUE indices and the CPUE indices derived from LTCER data.

Table A8: Summary of stepwise selection of variables in the Bay of Plenty LTCER CPUE model. Model terms are listed in the order of acceptance to the model. All variables were selected in the final model. AIC: Akaike Information Criterion.

Step	Variable	Df	Deviance	Resid Df	Residual Deviance	R^2	AIC
	Null			7 418	5 522		
1	*FishingYear*	7	383.1	7 411	5 139	0.069	18 347.9
2	*NumHooks*	3	3004.9	7 408	2 134	0.614	11 833.8
3	*Vessel*	11	332.2	7 397	1 802	0.674	10 600.4
4	*Loc2*	21	69.1	7 376	1 733	0.686	10 352.3
5	*Month*	11	34.1	7 365	1 699	0.692	10 226.7
6	*StartTime*	3	24.4	7 362	1 674	0.697	10 125.5
7	*Depth*	3	5.0	7 359	1 669	0.698	10 109.4

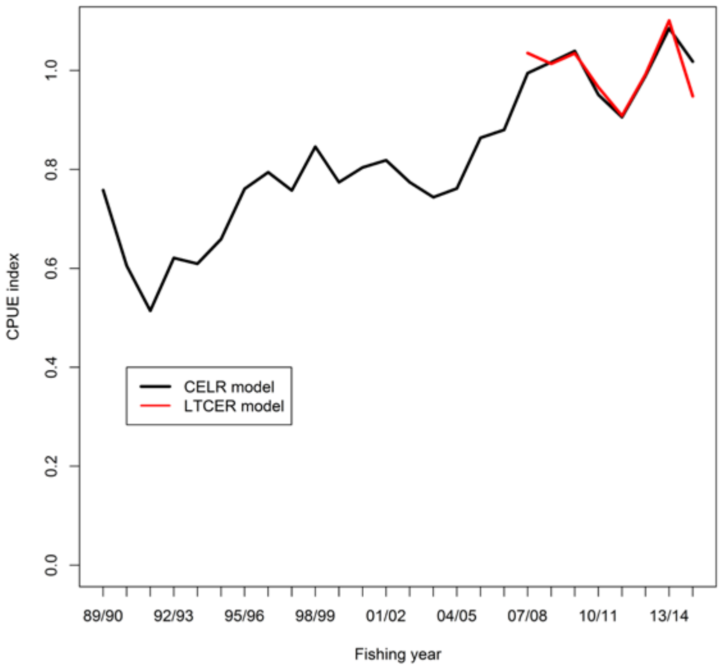

Figure A15: A comparison of the Bay of Plenty long term (CELR format) CPUE indices and the CPUE indices derived from LTCER data.