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Fishery characterisation and Catch-Per-Unit-Effort analysis for blue moki in MOK 1 and MOK 3

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Blue moki (*Latridopsis ciliaris*) in MOK 1 and MOK 3 is caught in inshore set-net fisheries while a substantial proportion of the catch from MOK 1 is also taken as a bycatch of inshore trawl fisheries. Most of the catch is taken from the along the central east coast of the North and South Islands encompassing East Cape, Wairarapa, Cook Strait and Kaikoura.

Three main fisheries were selected based on the magnitude and continuity of blue moki catch during the period 1989–90 to 2015–16, specifically:

1. The tarakihi bottom-trawl fishery operating within the Gisborne–Mahia area (Statistical Area 013) throughout the year (BT-TAR2-North).
2. The target blue moki set-net fishery operating between East Cape and Wairarapa (Statistical Areas 014–016) primarily during May–October (SN-MOK1).
3. The Kaikoura set-net fishery (Statistical Area 018) operating during May–June and October (SN-MOK3).

For each fishery, a standardised CPUE analysis was conducted using a Generalised Linear Modelling (GLM) approach. The CPUE analyses of the Kaikoura set-net (SN-MOK3) and MOK 1 target set-net (SN-MOK1) fisheries modelled the positive catch of blue moki assuming a lognormal error structure, while the CPUE analysis of the tarakihi bottom-trawl fishery (BT-TAR2-North) also modelled the presence/absence of blue moki in the catch and derived a delta-lognormal CPUE series.

The fishery characterisation summarised the spatio-temporal trends in blue moki catch and catch rate. These trends suggested that the stock structure of blue moki may include three components based on the distribution of blue moki outside of the spawning period, as indicated by the magnitude of catch during the summer period or inferred from apparent seasonal movements of fish. The three areas are East Cape (Statistical Area 013), Cook Strait (016) and an undefined area south of Kaikoura.

The SINSWG rejected the SN-MOK1 and SN-MOK3 CPUE indices as monitoring tools that could be used to determine stock status against Harvest Standard reference points, for the following reasons:

1. High inter-annual variation in the CPUE indices due to the low precision of CPUE indices derived from limited catch/effort datasets from these small fisheries and/or inter-annual variation in the catchability (availability) of migrating fish.
2. Possible hyperstability as a result of fishing directed at dense schools of migrating fish.

The WG nevertheless agreed that the SN-MOK1 and SN-MOK3 CPUE indices were likely to be broadly indicative of trends in abundance.

The two sets of SN CPUE indices are considered to represent the component (or components) of the blue moki stock migrating northward prior to spawning and then returning southward following spawning. These CPUE indices indicate that there has been a general increase in the abundance of adult blue moki within MOK 3 and the southern area of MOK 1 from the late 1990s. This is consistent with the estimates of total mortality derived from the population age structure in 2005–06 that indicated that fishing mortality on the adult population was less than natural mortality (M).

The BT-TAR2-North CPUE indices contrast the trend in the CPUE indices from the two set-net fisheries. The BT-TAR2-North CPUE indices declined from 1996–97 to 2002–03 and remained at a relatively low level during 2002–03 to 2008–09. The index increased in 2009–10 and remained at about that level during 2010–11 to 2015–16. These recent indices are at a level considerably lower than the indices from 1989–90 to 1996–97 (with the exception of the low 1992–93 index).

The BT-TAR2-North CPUE indices are considered to be predominantly comprised of a component of the blue moki stock that remains in the Gisborne–Mahia area throughout the year. The trawl catch is probably comprised of both immature and mature blue moki, although limited sampling of this component of the stock was conducted during the previous catch sampling programme. The SINSWG considered that the BT-TAR2-North CPUE series potentially provides an index of abundance for the resident portion of the population, but did not provide a monitoring tool for the entire population.

The contrasting trends in the CPUE indices (SN-MOK1 and SN-MOK3 versus BT-TAR-North) are indicative of differences in the stock dynamics (recruitment and/or exploitation) in the two components of the stock (resident and migrating). It was not considered feasible to amalgamate the three sets of CPUE indices to derive a composite set of abundance indices for the MOK 1&3 stock as the relative proportion of the stock biomass monitored by each CPUE series is unknown. Thus, the utility of the CPUE series is limited to the monitoring each component of the stock separately.

1 INTRODUCTION

Blue moki (*Latridopsis ciliaris*) in MOK 1 and MOK 3 is caught in inshore set-net fisheries while a substantial proportion of the catch from MOK 1 is also taken as a bycatch of inshore trawl fisheries. Most of the catch is taken from the along the central east coast of the North and South Islands from East Cape, Wairarapa, Cook Strait and Kaikoura (Figure 1). For MOK 1, annual catches were maintained at about the level of the current TACC of 402 t from the mid-1990s (Figure 2).

For MOK 3, annual catches were considerably less than the TACC of about 125 t during 1993–94 to 2006–07 (Figure 3). Catches increased steadily in the following years and exceeded the TACC during 2009–10 to 2013–14. The TACC was increased to 160 t in 2014–15 although catches increased further in 2015–16 (182 t).

Francis (1981) analysed seasonal trends in blue moki catch and gonad maturity data from the main fishery areas along the east coast of the North and South Island, supported by recoveries of blue moki tagged off Kaikoura. The study concluded that blue moki make an annual spawning migration, swimming north from Kaikoura in May–June, reaching Gisborne to spawn in August–September, and then swimming south, passing Kaikoura again in October. This suggested the existence of a single stock of blue moki on the east coast of New Zealand (Francis 1981).

While the distribution of blue moki during summer was unknown, Francis (1981) postulated that the main spawning migration did not begin south of Banks Peninsula. It was proposed that the fish may move into deep water or on to the Mernoo Bank or Chatham Rise (Francis 1981). In the subsequent years, there has been no appreciable catch of blue moki from the Chatham Rise (MOK 4) (Ministry for Primary Industries 2016) and blue moki have not been sampled from research trawl stations across the Chatham Rise, with the exception of a small number of trawls in the vicinity of the Mernoo Bank (Anderson et al. 1998).

A preliminary analysis of catch and effort data from the MOK 1 and MOK 3 fisheries was conducted by Langley & Walker (2004). Standardised CPUE indices were derived for four main fisheries from 1989–90 to 2002–03. The trends in the CPUE indices differed considerably between the four fisheries and, consequently, the indices were not considered sufficiently reliable to monitor trends in stock abundance.

Subsequently, the CPUE analyses from the blue moki fisheries within Fishery Management Area (FMA) 2 were updated to the 2009–10 fishing year (Bentley & Kendrick in prep). The CPUE indices from the main set-net (targeting blue moki or blue warehou) and trawl (targeting tarakihi) fisheries exhibit considerably different trends over the time series. The tarakihi trawl fishery is concentrated in the East Cape area and catches blue moki throughout the year, although catch rates are highest during June–July and September. It is considered that the FMA 2 set-net fishery intercepts blue moki during the seasonal migration of fish northwards to the spawning grounds and southwards following spawning. The differences in the CPUE trends from the two fisheries (trawl and set net) may indicate that the stock structure of blue moki along the eastern coast is more complex than previously considered.

Sampling of the length and age compositions of the MOK 1 catch from the target tarakihi trawl fishery and blue moki set-net fishery were conducted in 2004–05 and 2005–06 (Manning et al. 2010). The age compositions were generally comparable between the two fisheries although seasonal differences were apparent in the age structure of the catch from the trawl fishery. The age compositions were used to derive estimates of fishing mortality rates using a catch curve analysis. The analysis indicated fishing mortality rates were low in the preceding period (prior to 2004–05 and 2005–06) (Ministry for Primary Industries 2016).

The purpose of the current study is to characterise recent trends in the MOK 1 and MOK 3 fisheries and update the CPUE indices from the main fisheries to the 2015–16 fishing year. The study was funded by the Southern Inshore Fisheries Management Company Ltd and Area 2 stakeholders of Fisheries Inshore New Zealand.

2 DATASETS

Commercial catch and effort data from the MOK 1 and MOK 3 fishstocks were sourced from the Ministry for Primary Industries (MPI) database *warehou*. The data extract was specified to include all fishing trips during 1989–90 to 2015–16 that either landed blue moki and/or participated in a fishery that was likely to catch blue moki. The specific criteria are as follows:

i. landed MOK 1 and/or MOK 3; and/or
ii. targeted or caught blue moki (MOK) by single trawl (BT) within Statistical Areas 010–018, 020, 022 and 024–026 (Figure 1); and/or
iii. targeted TAR, GUR, TRE, SNA, WAR, ELE, RCO, FLA, and/or BAR by single trawl (BT) within Statistical Areas 010–018, 020, 022 and 024–026; or
iv. targeted or caught blue moki (MOK) by set net (SN) within Statistical Areas 010–018, 020, 022 and 024–026; or
v. targeted TAR, WAR, ELE, SPO, and/or SCH by set net (SN) within Statistical Areas 010–018, 020, 022 and 024–026.

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

From 1989–90, most inshore fishing vessels reported catch and effort data via the Catch Effort Landing Return (CELR), which records aggregated fishing effort and the estimated catch of the top five species. Fishing effort and catch was required to be recorded for each target species and statistical area fished during each day, although, typically, catch and effort data were aggregated by fishing day (Langley 2014). The verified greenweight of the landed catch, determined at the end of the fishing trip, was recorded on the Landings section of the CELR form.

In 2007–08, the Trawl, Catch and Effort Return (TCER) was introduced specifically for the inshore trawl fisheries and was adopted by most of the inshore trawl vessels operating in the fisheries catching MOK 1 and MOK 3. The TCER form records detailed fishing activity, including trawl start location and depth, and associated catches from individual trawls. Landed catches associated with trips reported on TCER forms is reported at the end of a trip on the Catch Landing Return (CLR).

In 2006–07, a new method-specific reporting form was also introduced for the set-net fishery (Netting Catch Effort Return). The NCER form records detailed fishing activity, including start location, the number and length of net set, start time of the set, set duration and the associated (estimated) catches from individual sets. The NCER form enables the estimated catch of the eight main species (by weight) to be recorded for each set. The landed catches from each trip are reported on the Landings section of the NCER form.

The Quota Management System (QMS) totals are collected from fishing permit holders on a monthly basis (Monthly Harvest Return, MHR) and are subjected to a different regime of storage and checking.

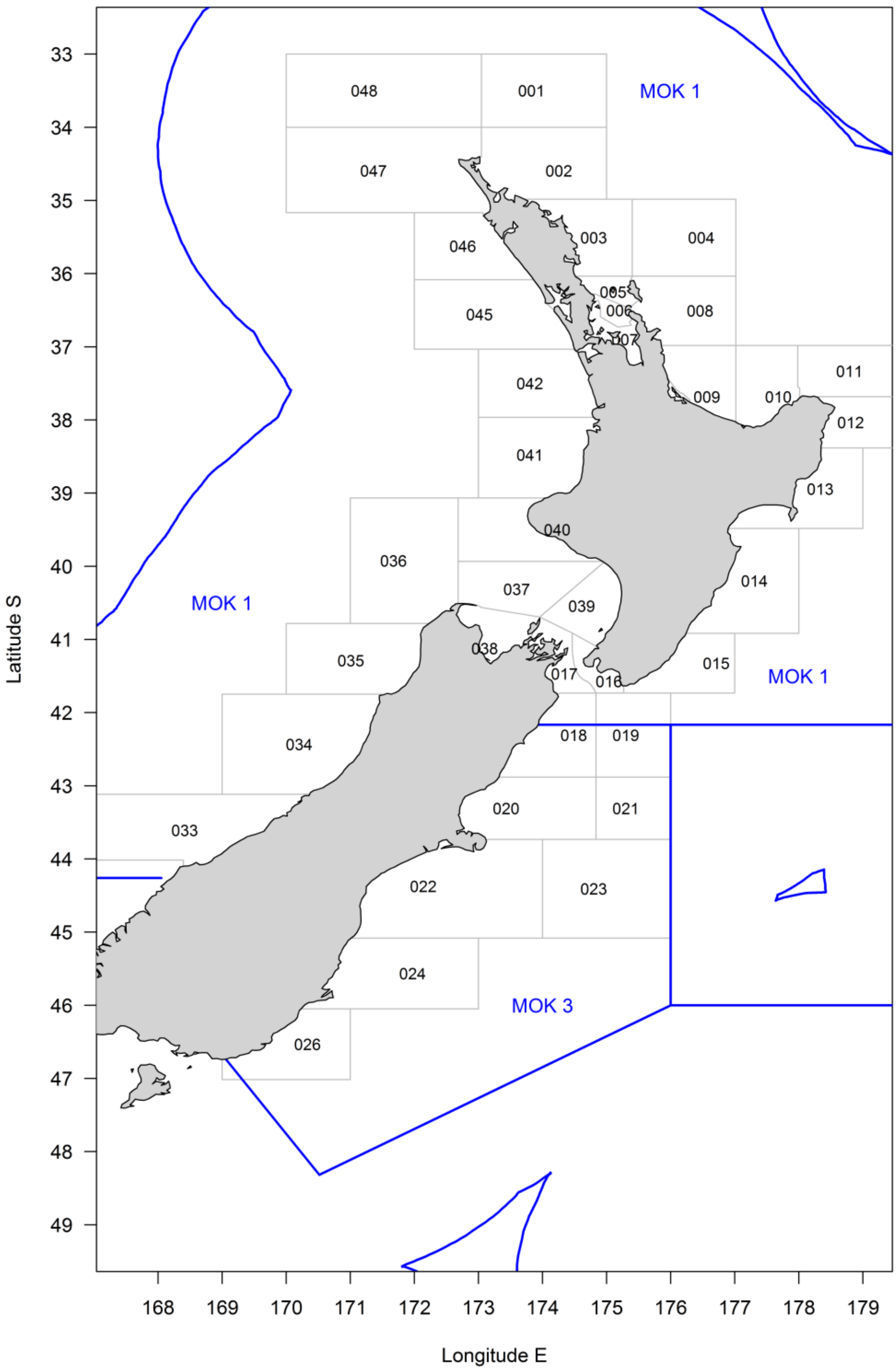

Figure 1: Map of MOK 1 and MOK 3 fishstocks and constituent Statistical Areas.

2.1 Data processing

The landed catch records were restricted to those records that represented the final destination of the blue moki (MOK 1 or MOK 3) catch (i.e., destination codes L, A, C, E and O). This resulted in an approximately 10% reduction in the total landed catch included in the landings dataset (Table 1 and Table 2). The reduction in the landed catch was attributable to catch assigned to two main destination codes. For MOK 1, most reduced landed catch was associated with a small number of records with the transshipped (T) destination code. These records are very likely to have been catches from HOK 1 that were incorrectly transcribed as MOK 1. Additional large landings of MOK 1 were examined and crossreferenced with the fishing effort data. Trips that targeted hoki (HOK) were identified and the corresponding MOK 1 landings were deleted.

For MOK 3, most of the landed catch that was excluded was associated with catches placed in a holding receptacle on land (destination code Q). Most of these records were related to one vessel operating in the set-net fishery within Statistical Area 018 in the 2008–09 to 2015–16 fishing years. An examination of the individual landing records from the corresponding trips revealed separate 'L' and 'Q' landing records for the MOK 3 catch. Deleting the records attributed to destination code 'Q' avoided duplication of the catch from the individual trip.

Table 1: Total MOK 1 reported landed catch included in the daily aggregated dataset at each step of the catch grooming process.

Criterion	Reported catch (t)	Percent of total reported catch
All landing records	12 393.7	100.0%
Destination codes (L, A, C, E, O)	11 350.9	91.6%
Exclude HOK trips	9 918.0	80.0%
Associated effort records	9 700.7	78.3%

Table 2: Total MOK 3 reported landed catch included in the daily aggregated dataset at each step of the catch grooming process.

Criterion	Reported catch (t)	Percent of total reported catch
All landing records	2 993.8	100.0%
Destination codes (L, A, C, E, O)	2 670.5	89.2%
Exclude HOK trips	2 645.2	88.4%
Associated effort records	2 571.0	85.9%

Potential landed catch outliers were examined by comparing the corresponding landed catches and aggregated estimated catches from individual fishing trips. There was a good correspondence between the landed catch and estimated catch from individual trips (Figure 4), although there was a large number of trips with small landed catches (less than 10 kg) with no associated estimated catch. Overall estimated catches represented 70–80% of the landed catch. A small number of trips with exceptionally large landings (exceeding 20 t MOK 1) were excluded.

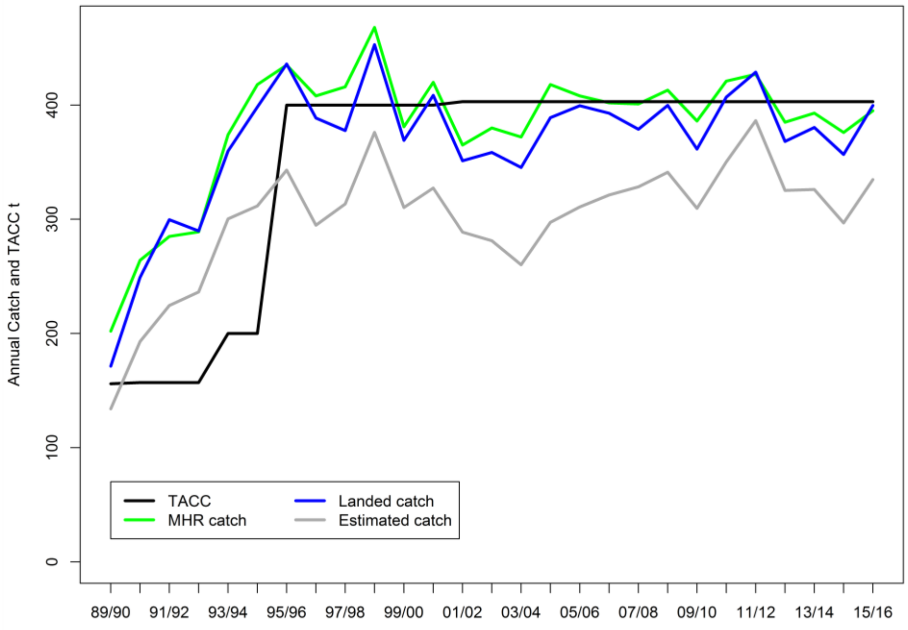

Figure 2: Comparison of total annual MOK 1 TACC and estimated and landed catches (t) by fishing year from vessel trip landing returns and the total reported landings (t) to the QMS (MHR).

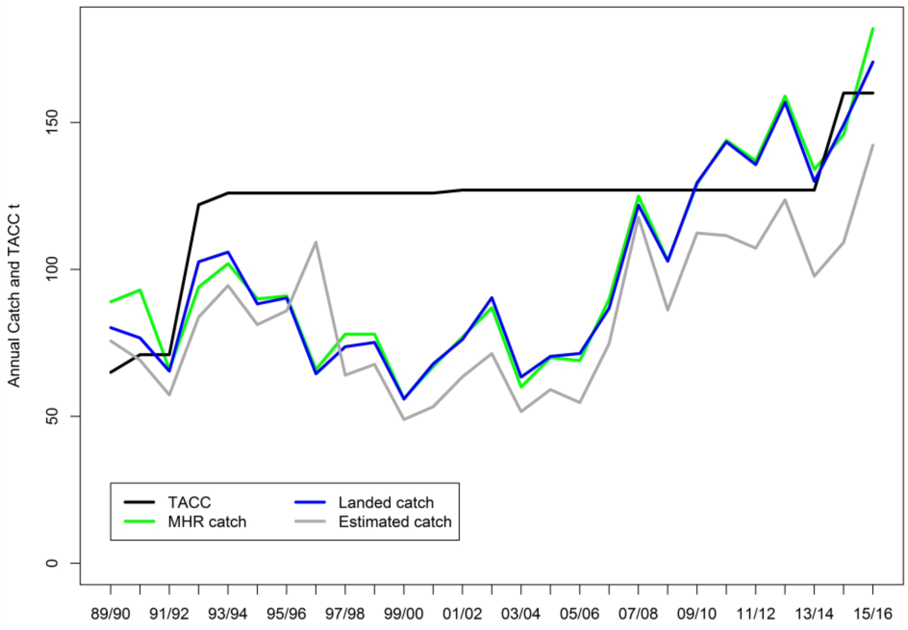

Figure 3: Comparison of total annual MOK 3 TACC and estimated and landed catches (t) by fishing year from vessel trip landing returns and the total reported landings (t) to the QMS (MHR).

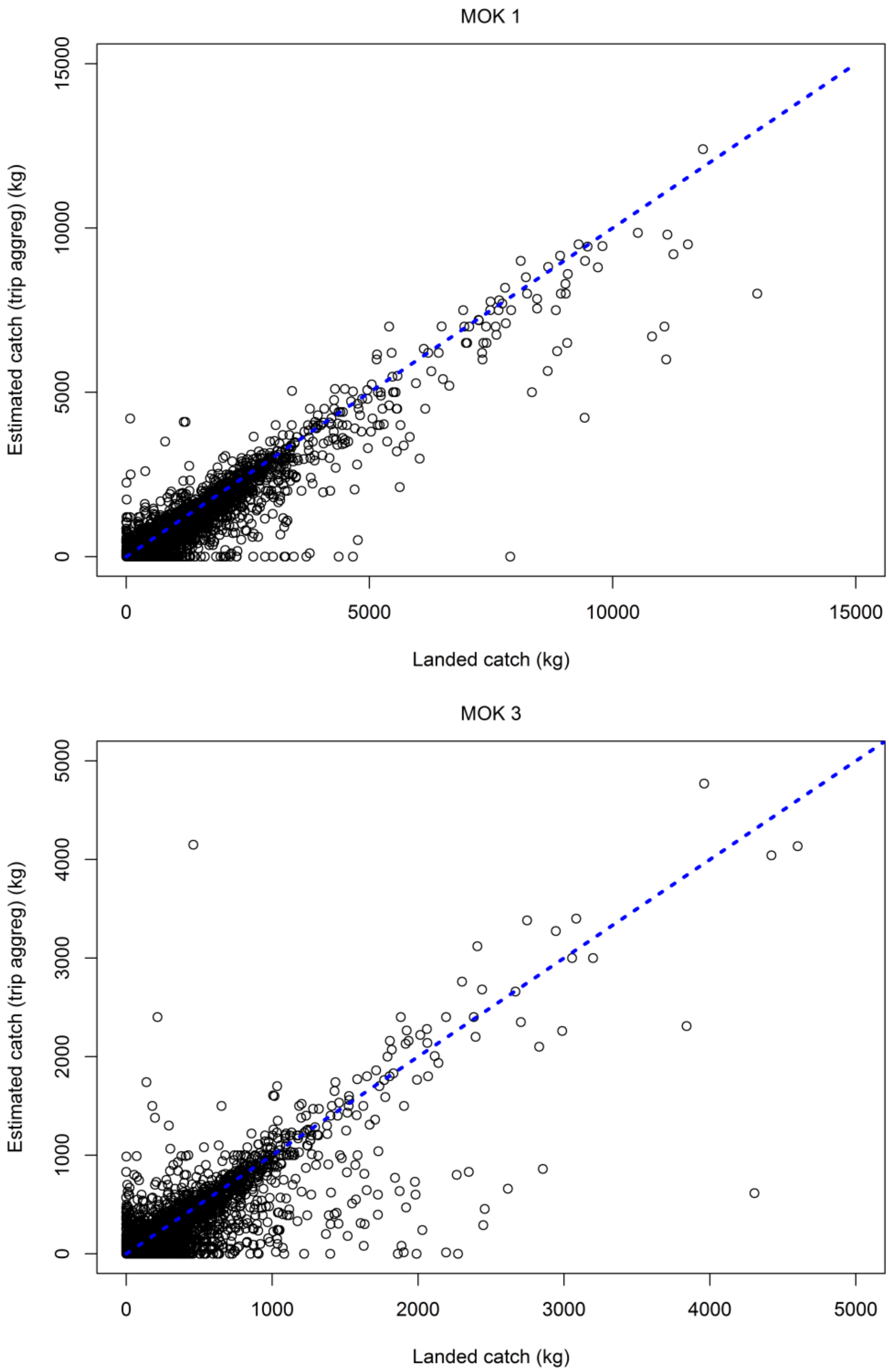

Figure 4: Comparison of blue moki landed catch and the sum of blue moki estimated catches for MOK 1 (top) and MOK 3 (bottom) from individual fishing trips.

The estimated catch and effort data were aggregated in a manner that approximates the daily aggregate format of the CELR following the approach of Langley (2014). The approach aggregates method (gear type) specific fishing effort 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. The estimated species catches are also aggregated by the vessel, gear, fishing day and the aggregate catches are ranked based on species catch weight. The five species with the largest estimated catches are retained, replicating the recording of the top five species estimated catches from the CELR. The estimated catches of the remainder of the species (non-top five) are not included in the subsequent analysis. This aggregation approach reduces the potential for the catch and effort dataset to be influenced by the changes in reporting formats (e.g., from CELR to TCER).

Most of the trips with a landed catch of blue moki were successfully linked to the aggregated fishing effort records. However, the number of trips was reduced by the exclusion of effort records for fishing methods that would not be expected to catch blue moki (e.g., surface longline and troll) and/or target species that are unlikely to be associated with blue moki (e.g., ORH, SSO and BOE). There were also fishing effort records that were missing the data fields required to generate the aggregated effort records. The reduction in the number of fishing trips included in the final dataset resulted in a small reduction in the overall quantity of MOK 1 and MOK 3 landed catch (Table 1 and Table 2).

For 1989–90 to 2016–17, the MOK 1 and MOK 3 landed catches included in the aggregated dataset approximated the annual MOK 1 and MOK 3 catches reported by the Ministry for Primary Industries (Ministry for Primary Industries 2016).

The landed catches of blue moki 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 blue moki, the landed catch was allocated to the individual fishing effort records in proportion to the individual estimated catches. 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 fishing events per day.

3 FISHERY CHARACTERISATION

3.1 MOK 1

The annual catches of blue moki from MOK 1 increased from 202 t in 1989–90 to 435 t in 1995–96. During the subsequent years, annual catches were maintained at about the level of the current TACC of 403 t (Figure 2).

Most of the MOK 1 catch was taken by either the target set-net fishery or as a bycatch of the tarakihi trawl fishery (Figure 5). Prior to 2001–02, blue moki was also taken as a bycatch of the set-net fishery targeting blue warehou. During 2009–10 to 2014–15, the trawl method accounted for 55–70% of the annual catch and the remainder of the catch was taken by set-net fishery. The relative importance of the set-net fishery was greater during the early 2000s (Figure 5).

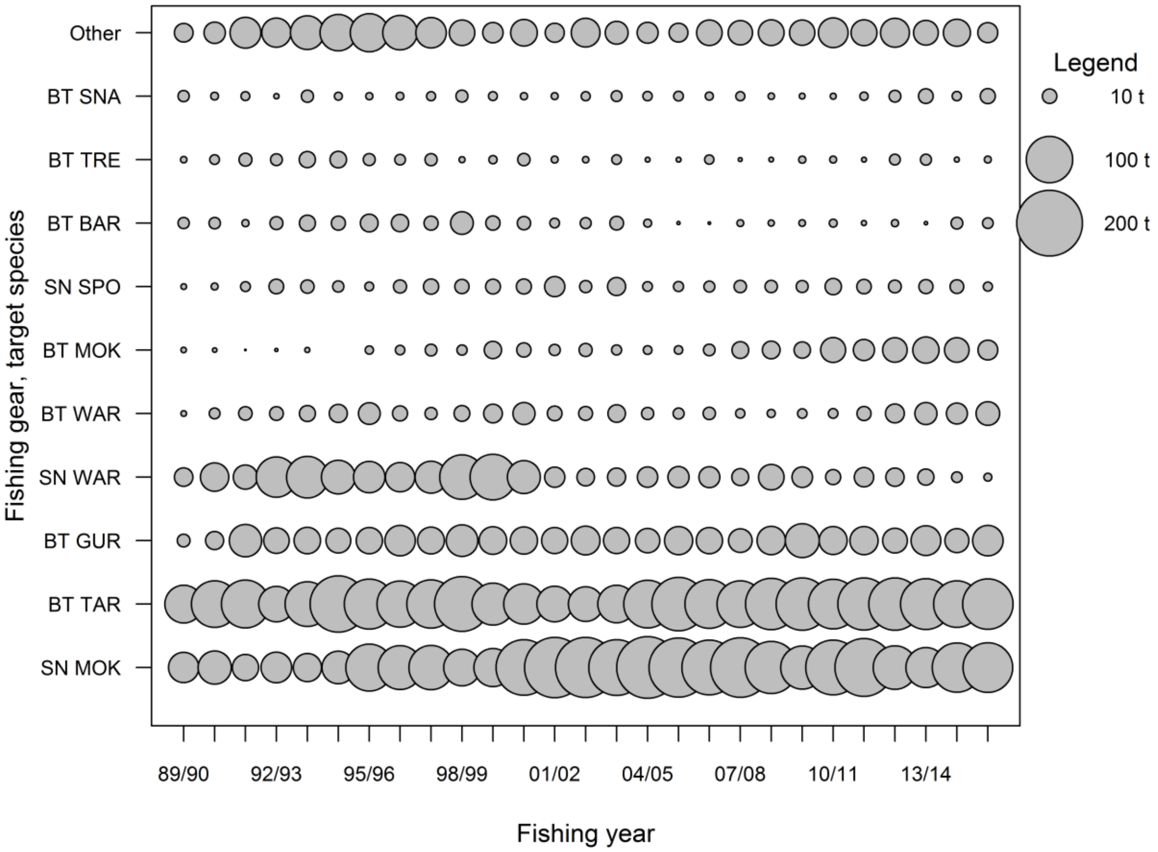

Figure 5: Annual MOK 1 catch by fishing method and target species. The area of the circle is proportional to the magnitude of the catch.

The largest proportion of the trawl catch was taken from Statistical Area 013 between Gisborne and Mahia Peninsula (Figure 6 and Figure 7), while significant trawl catch is also taken from Cook Strait (Statistical Areas 016 and 017) and along the Wairarapa coast (014 and 015).

The largest catches from the MOK 1 trawl fishery generally occur during September–December (Figure 9). The seasonal distribution of catch differs amongst the main areas of the fishery. The larger catches in September were dominated by catches from Statistical Areas 013 and 014 (Figure 10). This peak in catch was preceded by high catches from Statistical Area 014 in July. Catches from both areas were relatively low in August. Unstandardised catch rates in Statistical Areas 012, 013 and 014 generally peaked in September and were low during November–April (Figure 11).

Catches and catch rates from the trawl fishery in Statistical Areas 016 and 017 tended to be highest during November–December and low during July–September (Figure 10 and Figure 11).

Most of the MOK 1 set-net catch was taken off the east coast of the North Island from Wairarapa to East Cape (Statistical Areas 012–015) (Figure 6 and Figure 8). The spatial distribution of catch varied considerably over the study period. From 2007–08, there was a general decline in the catch taken from along the Wairarapa coast (014 and 015), while the set-net catch from East Cape (012) and the Wellington coast (016) increased.

Most of the MOK 1 set-net catch was taken in May–September (Figure 9). In recent years, the highest seasonal catches were taken from Statistical Area 012 during August and from Statistical Area 014 during September (Figure 12). Unstandardised catch rates of MOK 1 from the set-net fishery have a similar seasonal trend in these areas (Figure 13).

Set-net catches and catch rates from Statistical Area 016 were generally highest during May–July (Figure 12 and Figure 13), while there was no strong seasonal trend in MOK 1 catch from Statistical Area 017.

During the early 2000s, a considerable proportion of the set-net catch was taken from Statistical Area 015. Catches and catch rates for the fishery were highest in June–July with a secondary peak in September–October.

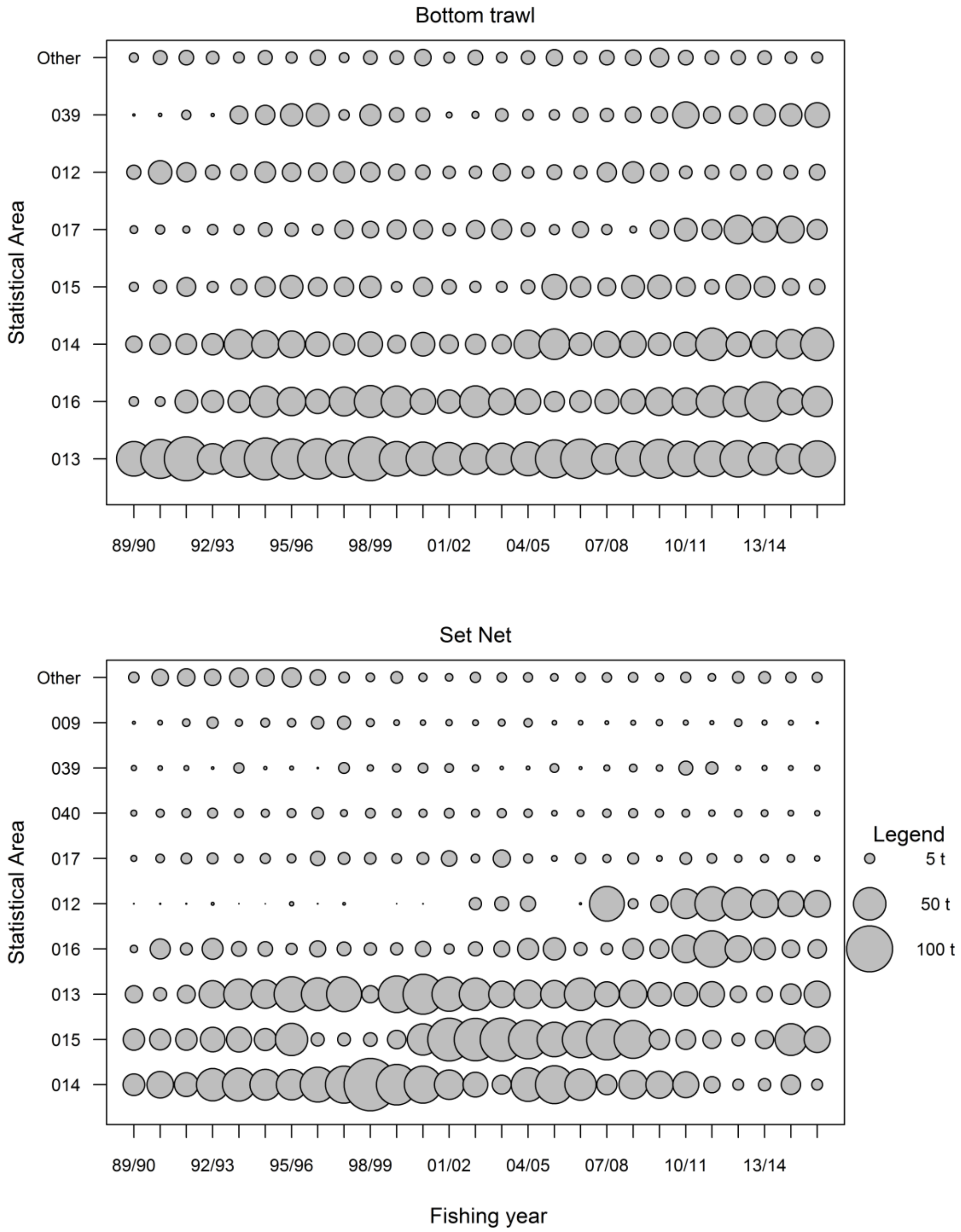

Figure 6: Annual MOK 1 catch by Statistical Area for the trawl (top) and set-net (bottom) fisheries. The area of the circle is proportional to the magnitude of the catch.

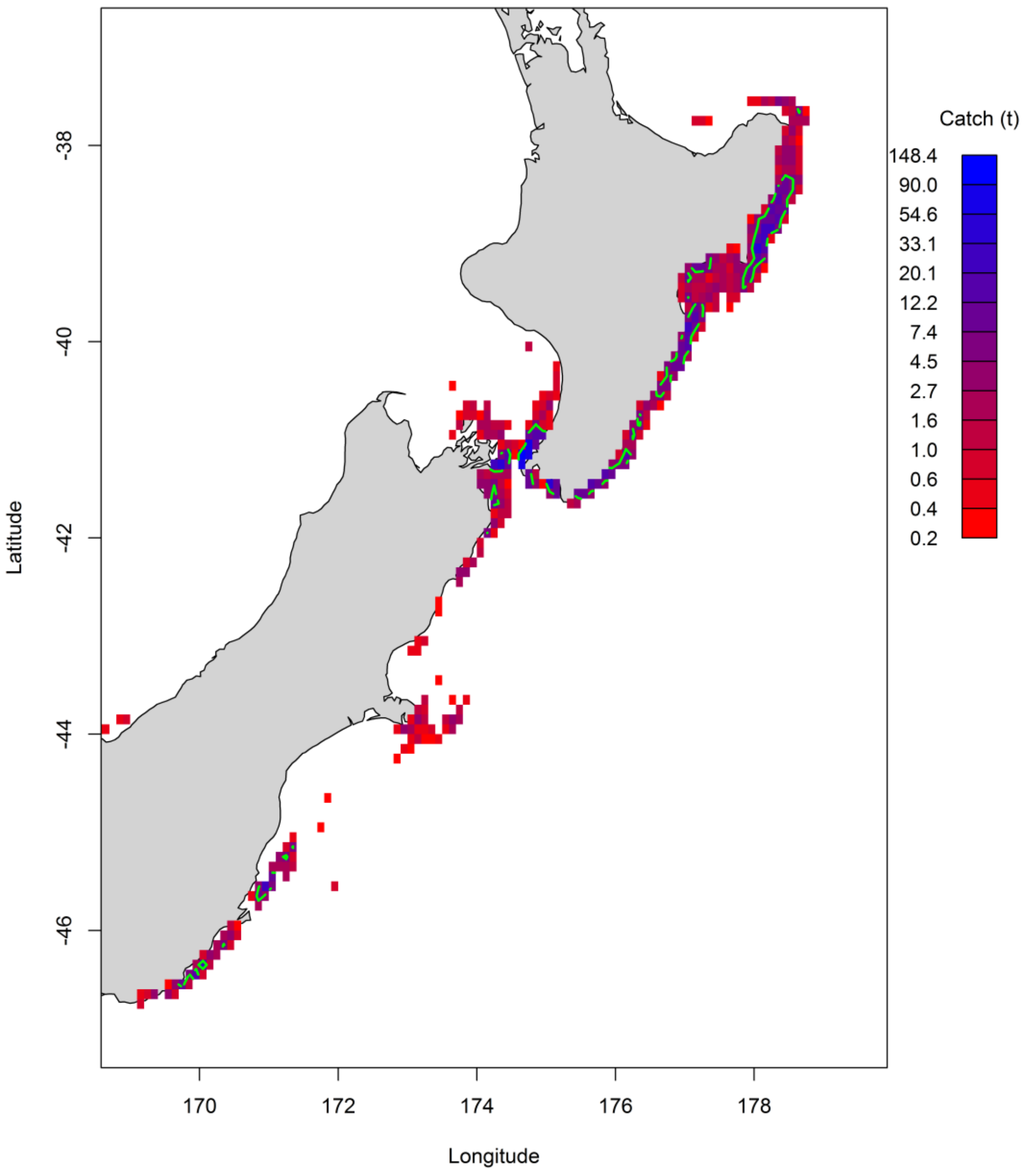

Figure 7: Blue moki catches (t) from the trawl fishery in MOK 1 and MOK 3 aggregated by 0.1 degree of latitude and longitude from 2007–08 to 2015–16. There is a minimum threshold of 250 kg per lat/long cell. The green contour line represents an aggregate catch of 5 t.

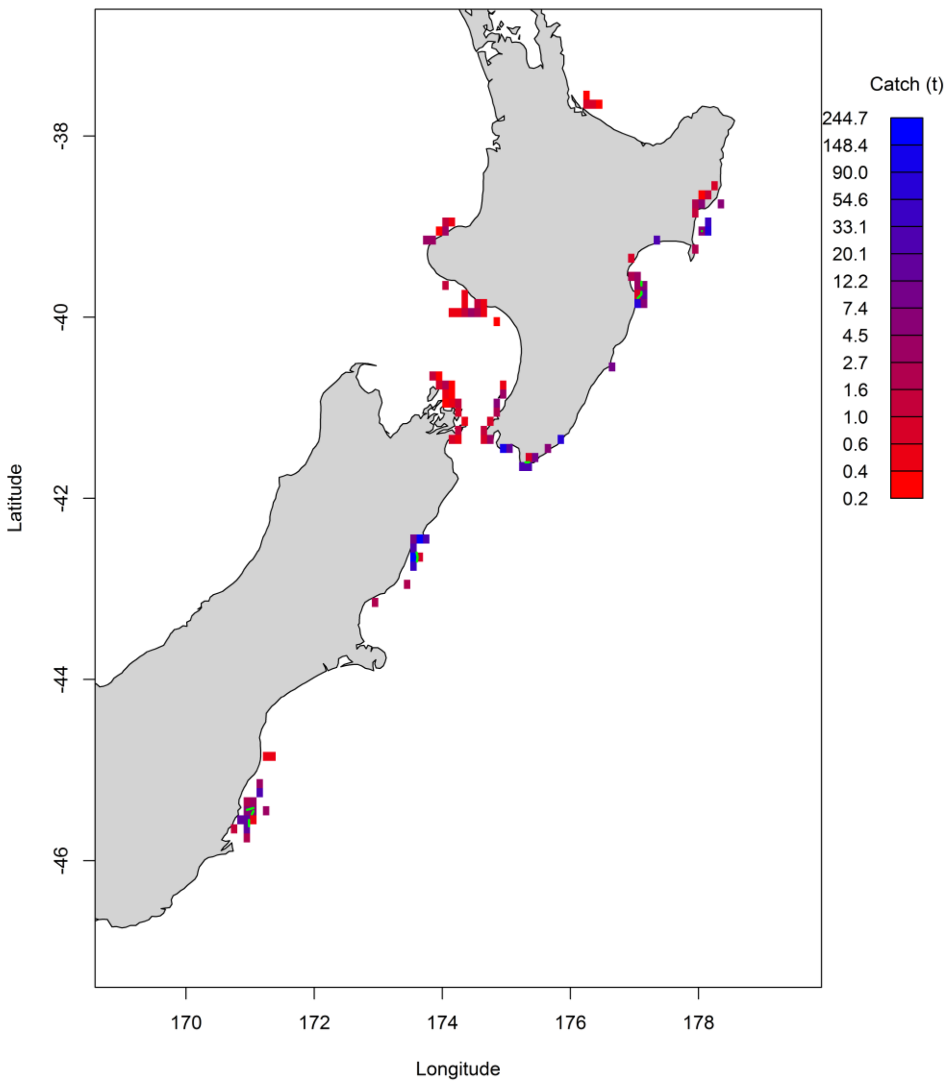

Figure 8: Blue moki catches (t) from the set-net fishery in MOK 1 and MOK 3 aggregated by 0.1 degree of latitude and longitude from 2006–07 to 2015–16. There is a minimum threshold of 250 kg and a minimum of three set-net vessels per lat/long cell. The green contour line represents an aggregate catch of 5 t.

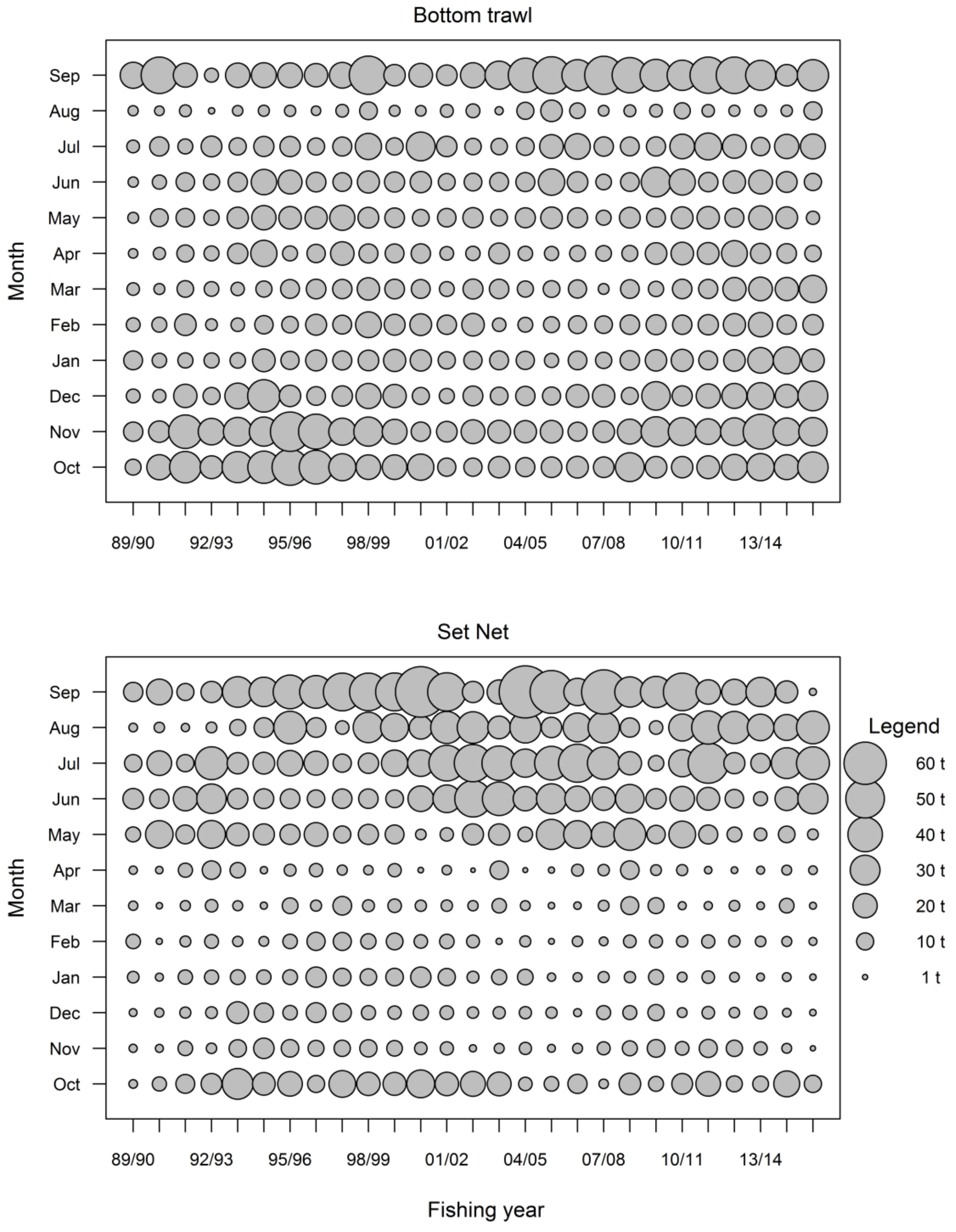

Figure 9: Annual MOK 1 catch by month for the trawl (top) and set-net (bottom) fisheries. The area of the circle is proportional to the magnitude of the catch.

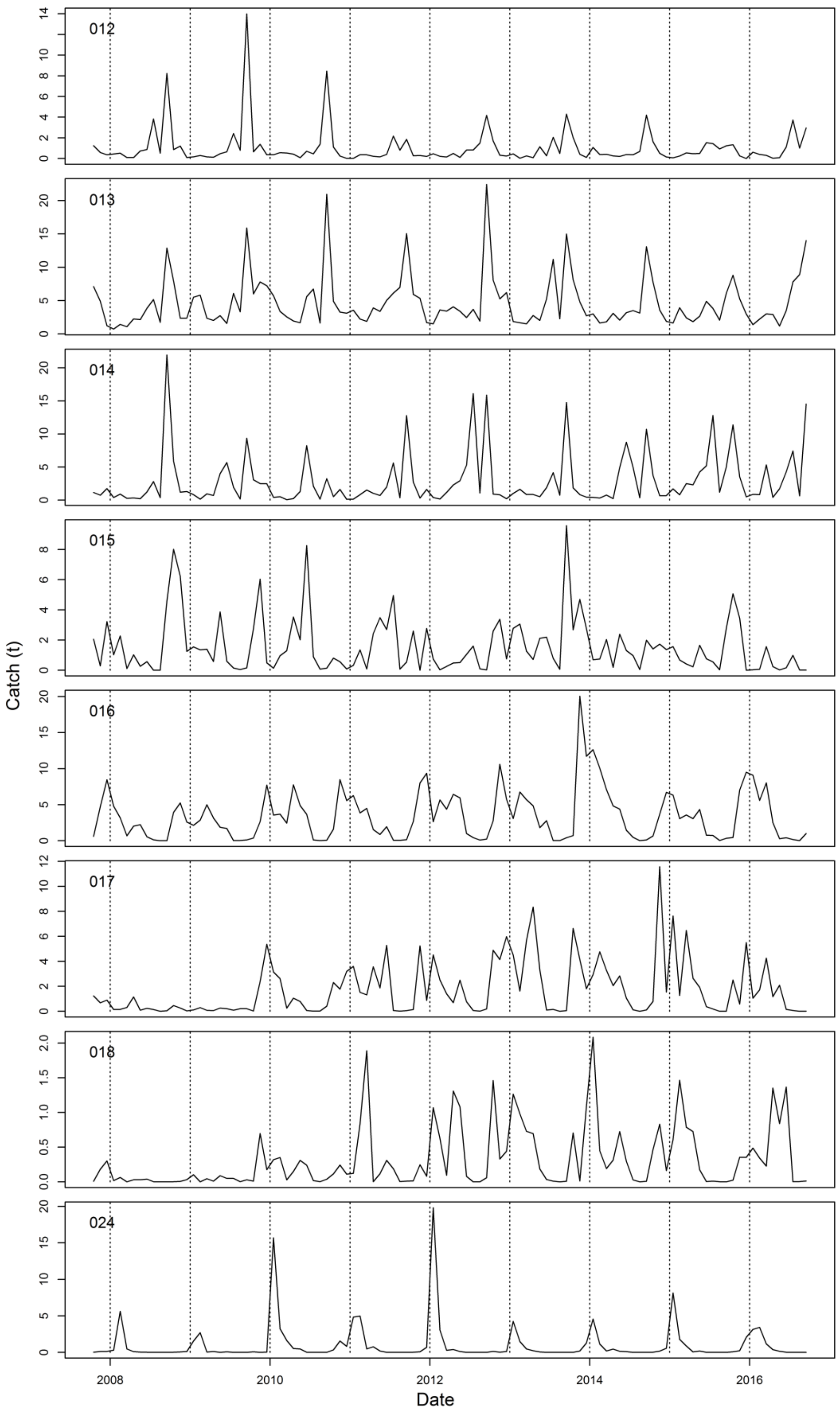

Figure 10: Monthly trawl catch (t) of blue moki (MOK 1 and MOK 3) from October 2007 to September 2016 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

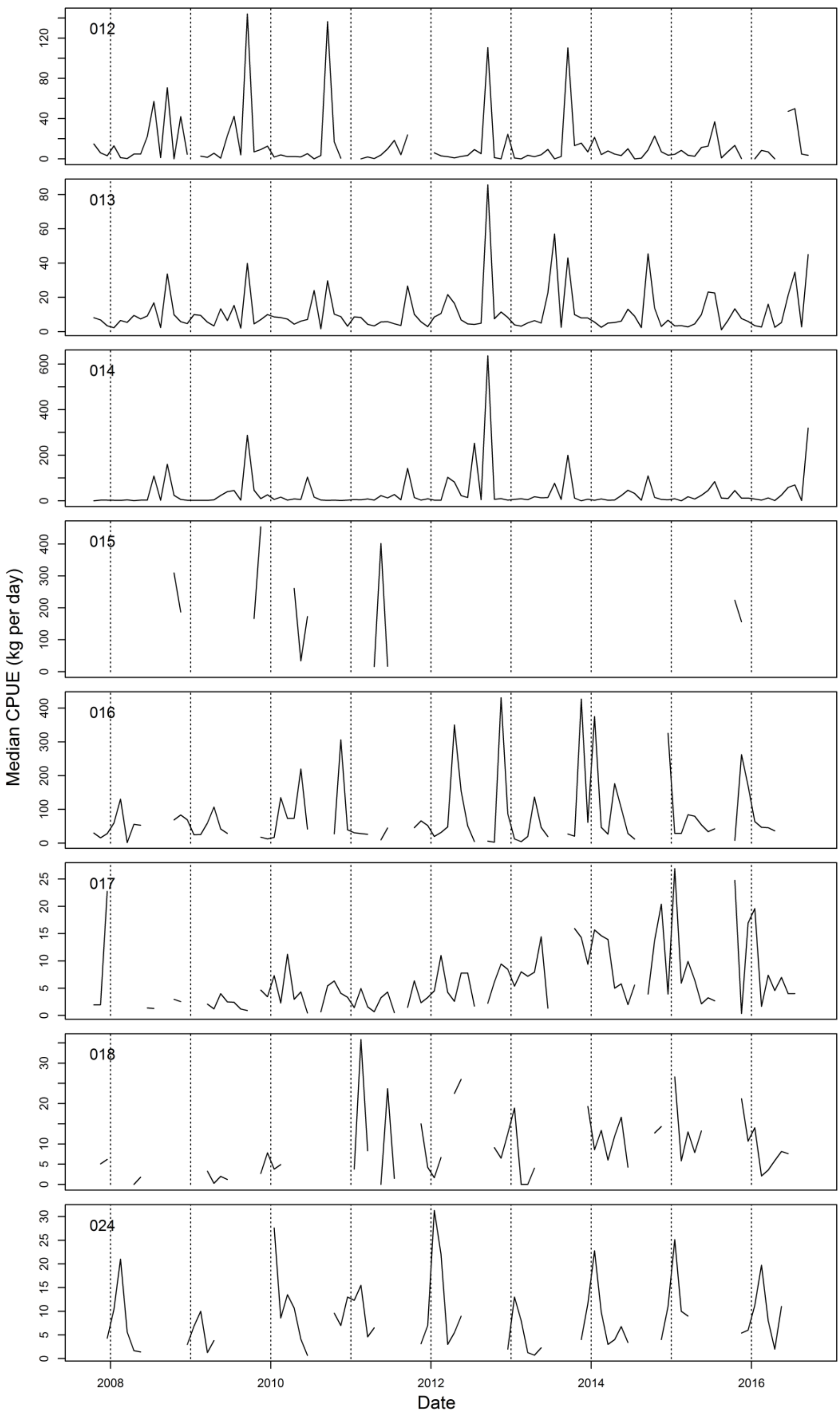

Figure 11: Median monthly trawl catch rate (kg per day) of blue moki (MOK 1 and MOK 3) from October 2007 to September 2016 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

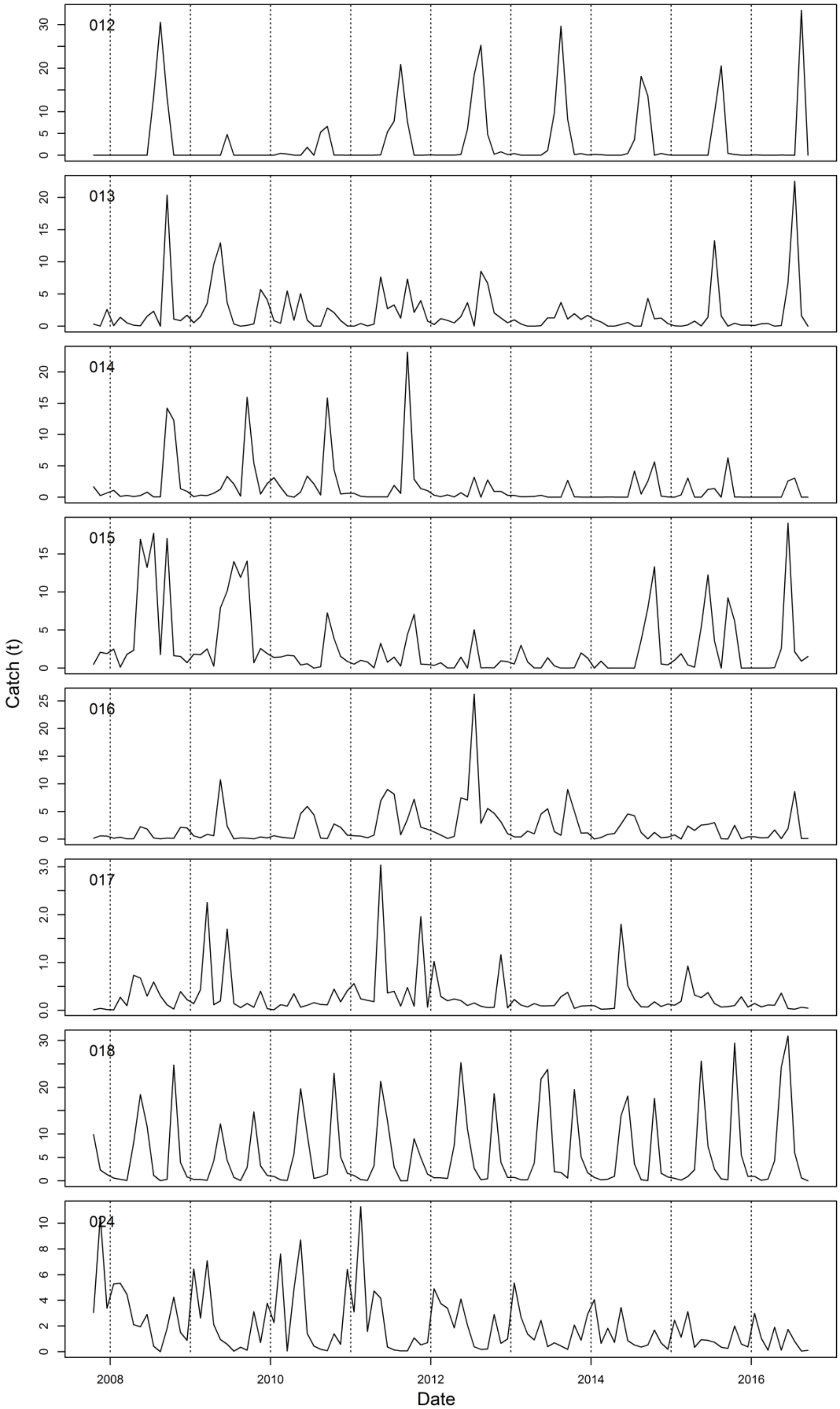

Figure 12a: Monthly set-net catch (t) of blue moki (MOK 1 and MOK 3) from October 2007 to September 2016 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

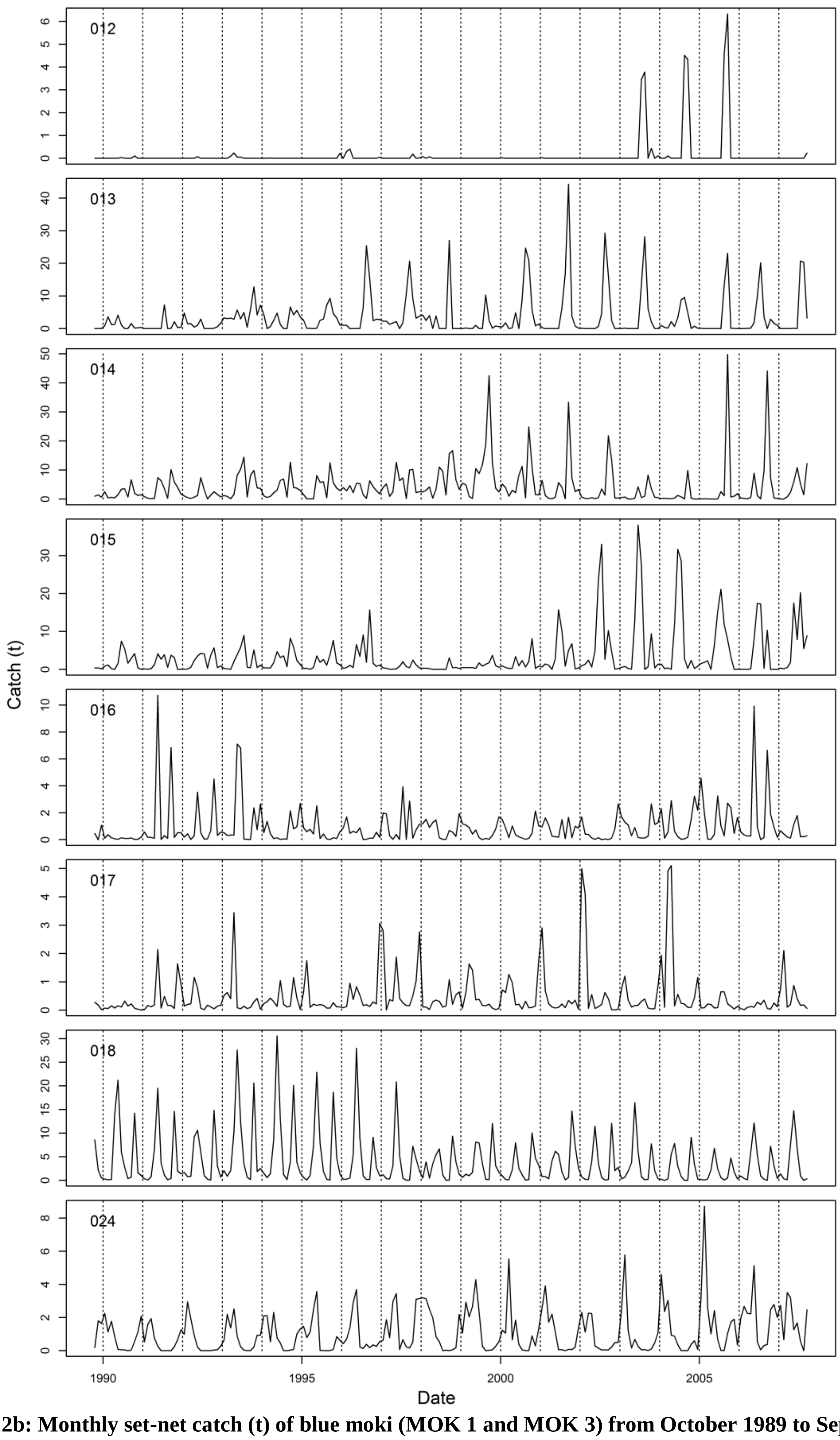

Figure 12b: Monthly set-net catch (t) of blue moki (MOK 1 and MOK 3) from October 1989 to September 2007 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

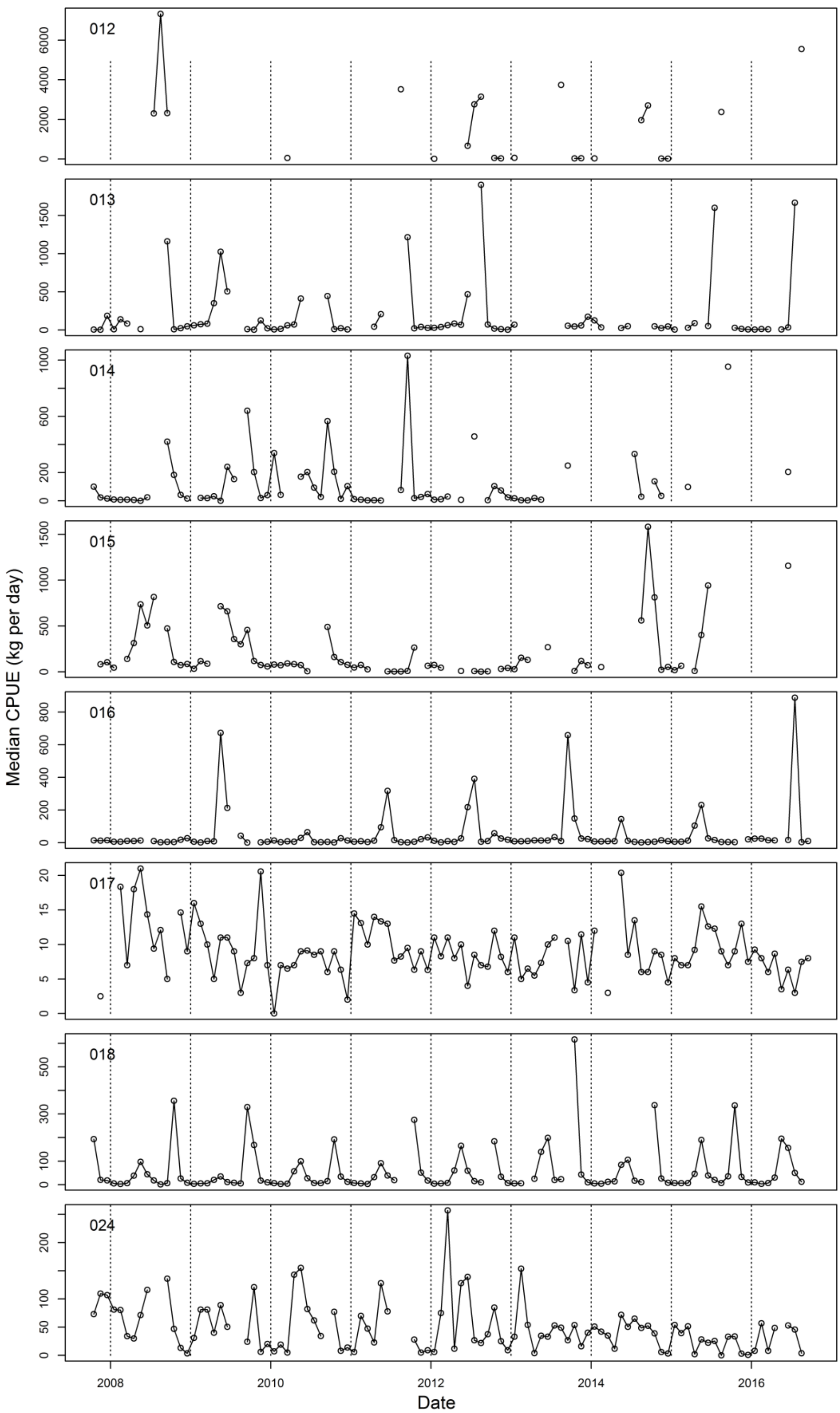

Figure 13a: Median monthly set-net catch rate (kg per day) of blue moki (MOK 1 and MOK 3) from October 2007 to September 2016 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

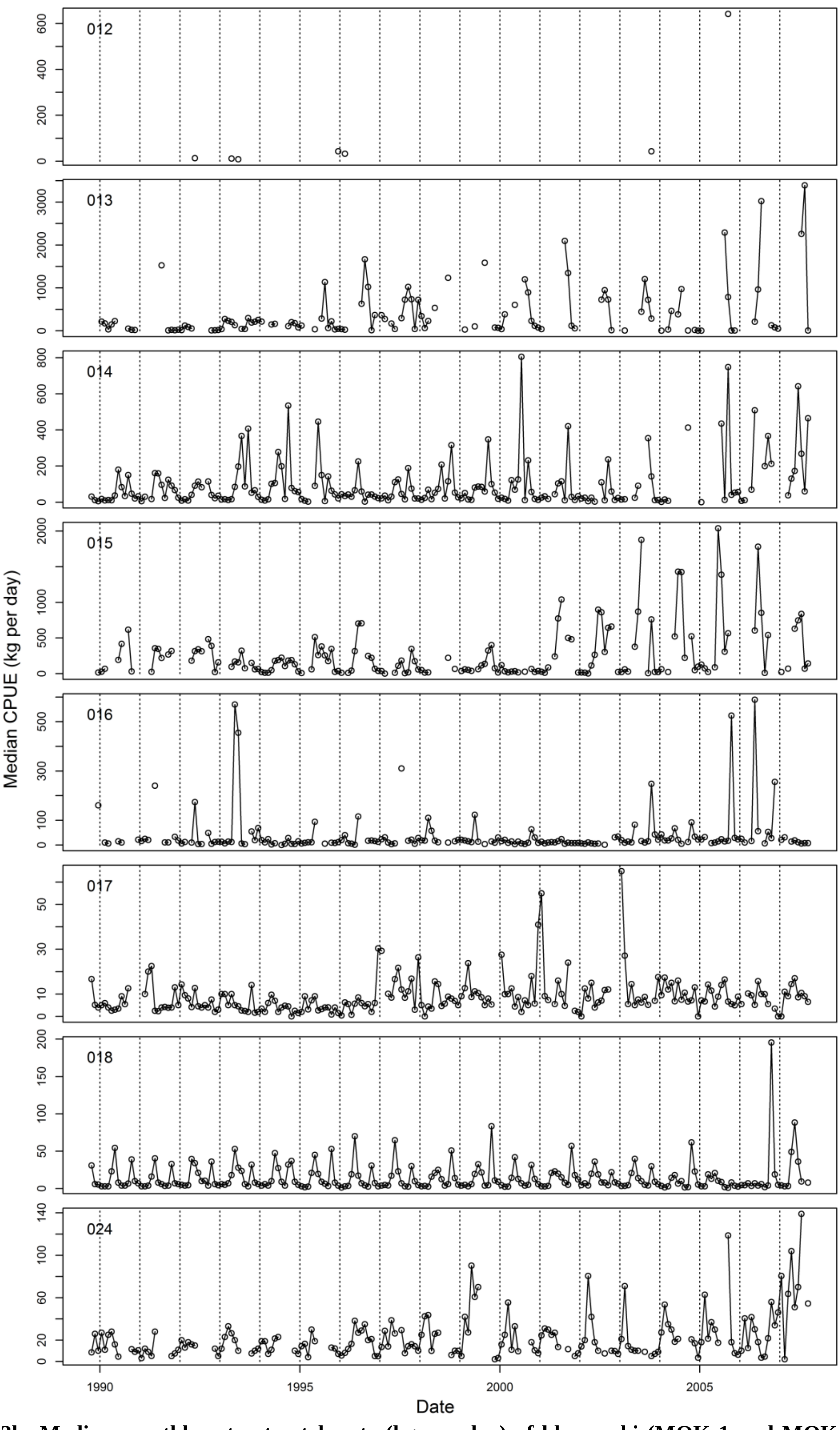

Figure 13b: Median monthly set-net catch rate (kg per day) of blue moki (MOK 1 and MOK 3) from October 1989 to September 2007 for each of the main Statistical Areas of the fishery. The vertical line represents 1 January.

3.2 MOK 3

During 1989–90 to 2006–07, annual catches fluctuated at about 70–90 t per annum, considerably below the level of the TACC, which was maintained at a level of about 120–130 t from 1992–93 to 2013–14 (Figure 3). Annual catches increased steadily from 2005–06 to reach a peak of 159 t in 2012–13. The TACC was subsequently increased to 160 t in 2014–15 and catches have remained at the higher level (182 t in 2015–16).

Most of the MOK 3 catch was taken by the set-net fisheries targeting blue moki, rig or tarakihi. From 2009–10, there was an increase in the proportion of the catch taken as a bycatch from the target flatfish and tarakihi trawl fisheries (Figure 14).

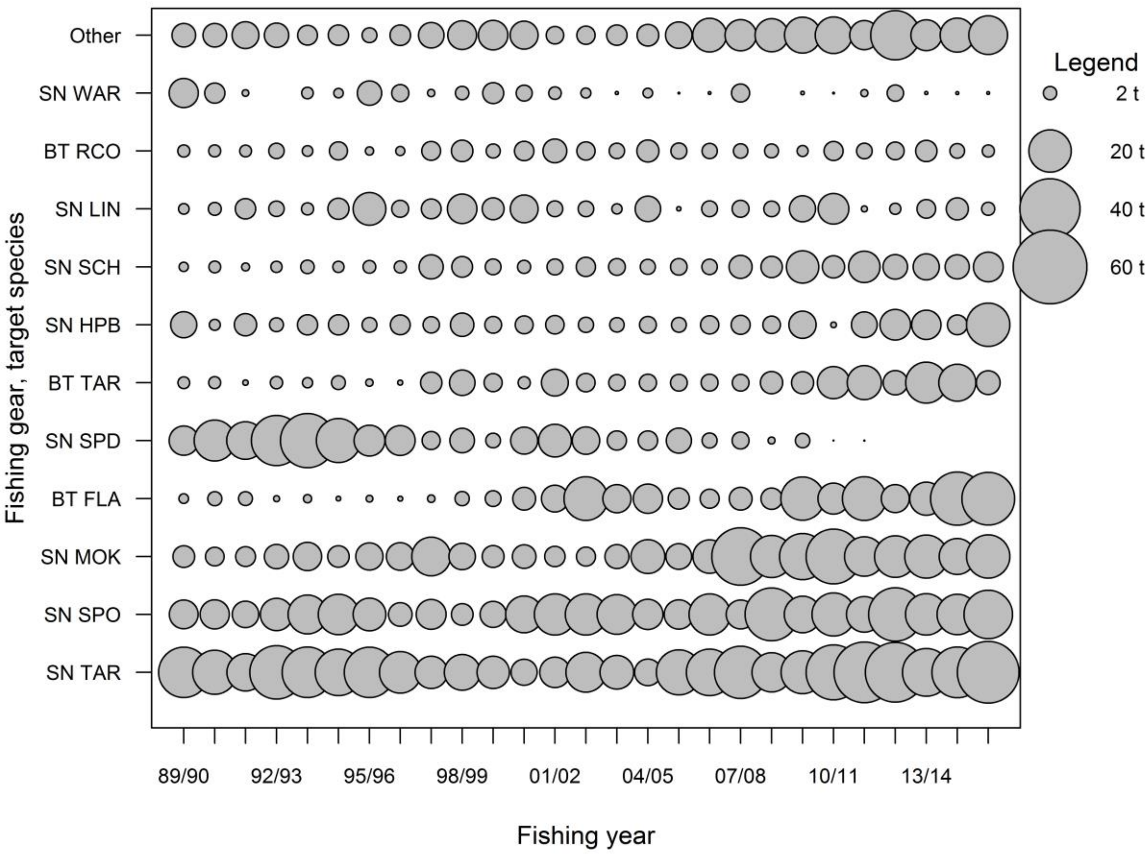

Figure 14: Annual MOK 3 catch by fishing method and target species. The area of the circle is proportional to the magnitude of the catch.

Most of the trawl catch was taken in the southern area of MOK 3 in Statistical Areas 024 and 026, while the set-net fisheries operated primarily within Statistical Area 018 (Figure 15).

The set-net catch was predominantly taken during April–June and in October (Figure 16). This seasonal trend in catch is dominated by the fisheries in Statistical Area 018 (Figure 12) and there is a similar seasonal trend in the unstandardised catch rates for these fisheries (Figure 13). Catches and catch rates are low during the intervening months (July–September and November–March).

Set-net catches from Statistical Area 024 were generally higher from December–May and low during June–September (Figure 12) although there is no corresponding seasonal trend in unstandardised catch rates (Figure 13). Annual trawl catches and catch rates from the area peaked during January–February (Figure 10 and Figure 11), while there was limited fishing effort during June–August.

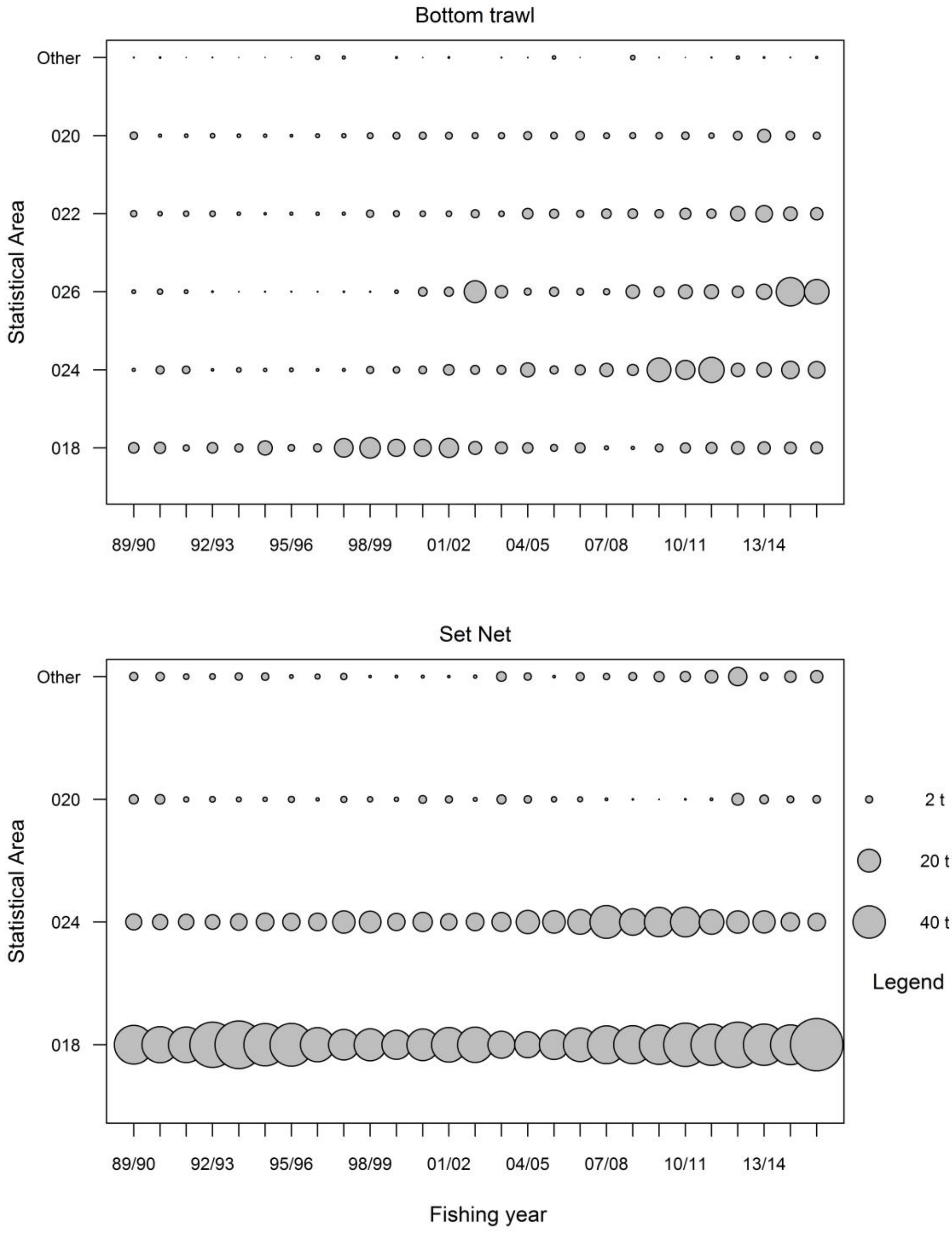

Figure 15: Annual MOK 3 catch by Statistical Area for the trawl (top) and set-net (bottom) fisheries. The area of the circle is proportional to the magnitude of the catch.

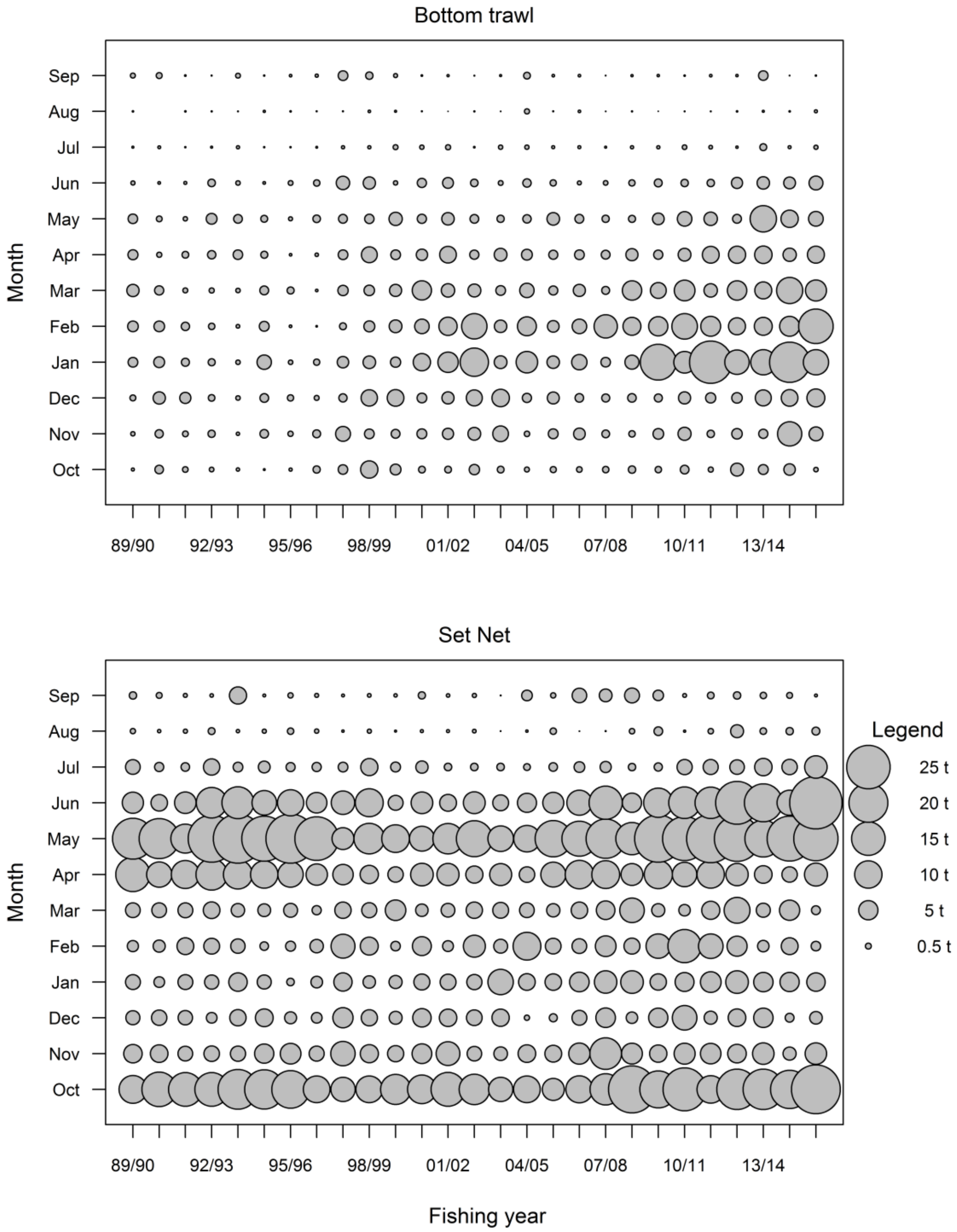

Figure 16: Annual MOK 3 catch by month for the trawl (top) and set-net (bottom) fisheries. The area of the circle is proportional to the magnitude of the catch.

3.3 Summary

Catch rates of blue moki by month and fishing method reveal seasonal trends that are consistent with the spawning migrations described by Francis (1981). Catch rates from the trawl fishery around the Wellington coast (016) decline during May–August, corresponding to an increase in catch rates along the southern Wairarapa (015) (Figure 17), followed by an increase in catch rates in June–July in Statistical Area 014. Similar seasonal trends are also evident in the catch rates of the set-net fisheries in these areas (Figure 17).

Catch rates in these areas (014–016) are considerably lower in August, which corresponds to a peak in catch rates from the set-net fisheries around East Cape (012 and 013) during July–September (Figure 17). The catch rates from the trawl fisheries in Statistical Areas 012 and 013 also decline in August.

The catch rates from the set-net fishery in 013 decline in September and drop to a relatively low level by October (Figure 17). During September–October, there is a secondary peak in the catch rates from the trawl and set-net fisheries in Statistical Areas 013–015. The catch rates in these areas returned to relatively low levels during November–December, while catch rates in the trawl fishery in Statistical Area 016 increased in October and remained at a relatively high level during October–April.

These seasonal trends in catch rate are indicative of a northwards migration of blue moki from Cook Strait in June–August to spawn in areas off East Cape during August. Fish then return southwards returning to the Cook Strait area in October.

The relatively high catch rates in the Cook Strait area (016) throughout spring and summer indicate a significant proportion of the population resides in this area. However, the seasonal peak in the set-net catch rates from Kaikoura (018) during October also indicates that a component of the stock moves further southwards. Catch rates remain low in the Kaikoura set-net fishery during the summer months (December–March). During May–July, there is another seasonal peak in catch rates from the Kaikoura set-net fishery corresponding to the northward movement of fish prior to spawning.

The distribution of this component of the stock during the spring–summer period is unknown. There is an increase in the trawl catch rates of blue moki off the Otago coast (024) during December–February, which may indicate the return of a proportion of the fish to the southern extreme of the range of blue moki.

Blue moki are generally caught in relatively low quantities from the trawl fisheries in Pegasus Bay (020) and Canterbury Bight (022). Annual catches of blue moki from the Canterbury Bight increased from about 2005–06, primarily as a bycatch of the target tarakihi trawl fishery.

The seasonal patterns in catch rate were used to categorise the peak fishing season(s) for blue moki in each Statistical Area (Table 3). The annual catches of blue moki from each Statistical Area were partitioned by season: peak and non-peak. The annual catches from Statistical Areas 012, 014, 015 and 018 were dominated by the catch during the peak season (Figure 18). This indicates that these fisheries are primarily focused on the component of the stock that was migrating to spawn. Whereas, the fisheries in Statistical Areas 013 and 016 caught blue moki throughout the year, with the annual catches distributed between the peak and non-peak periods. In Statistical Areas 013 and 014, there was a general decline in the catch taken during the off-peak period from the mid-1990s (Figure 18).

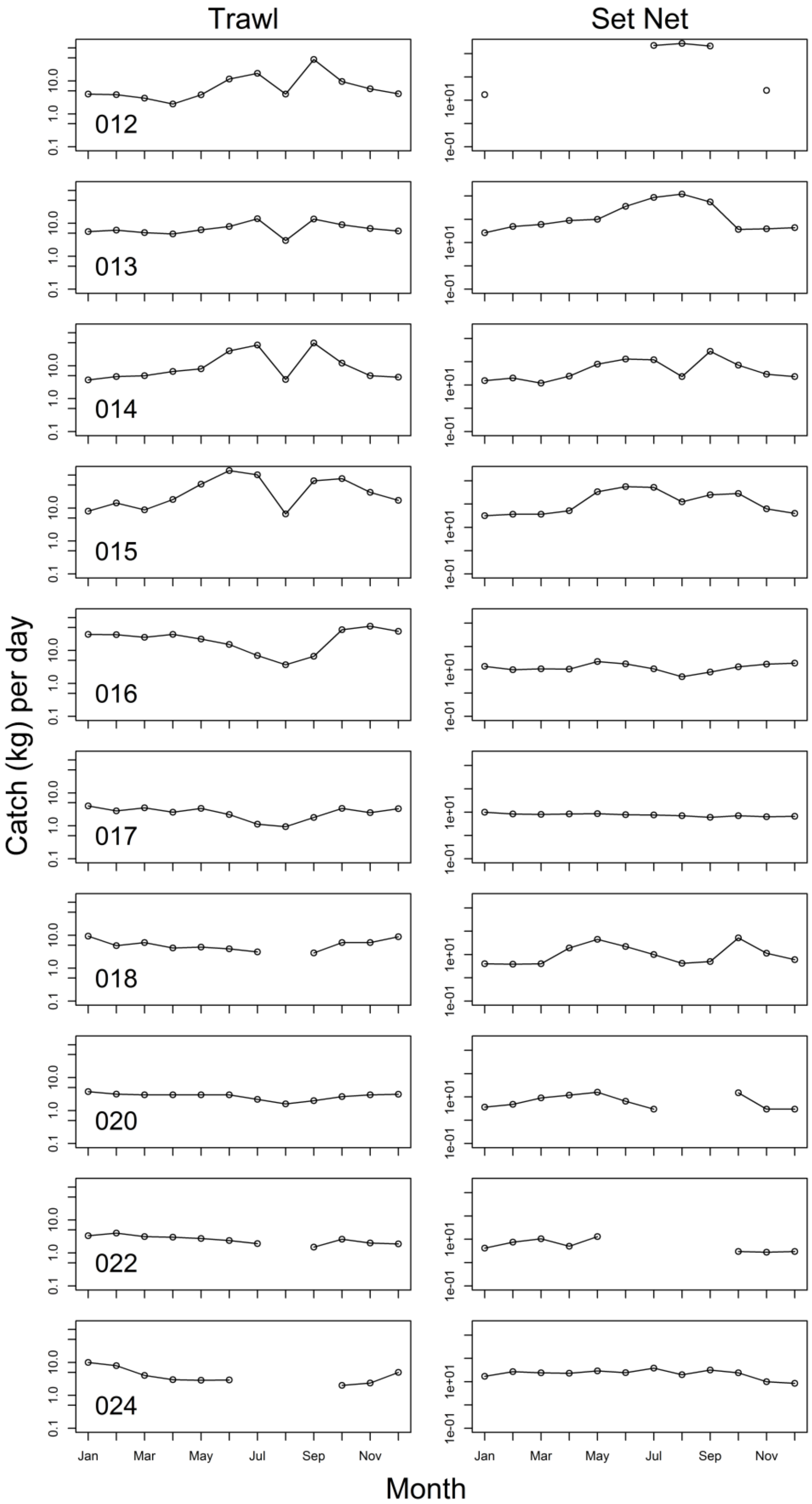

Figure 17: Median monthly catch rates (kg per day) of blue moki for inshore trawl fisheries (left) and set-net fisheries (right) by Statistical Area from 1989–90 to 2015–16 (all years combined). A logarithmic scale is used for the y-axis.

Table 3: Generalised catch rate by month and fishing method for each of the Statistical Areas that accounted for most of the blue moki catch from 1989–90 to 2015–16. Each month was categorised as having a high (H), moderate (M) or low (L) relative catch rate based on the aggregated unstandardised monthly median catch rates for each Statistical Area. The dash indicates insufficient data available. BT = bottom trawl; SN = set net.

Stat Area	Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
012	BT	L	L	L	L	L	L	H	L	H	L	L	L
	SN	L	L	L	L	-	-	H	H	H	-	L	-
013	BT	L	L	L	L	L	M	H	L	H	M	L	L
	SN	L	L	L	L	L	M	H	H	M	L	L	L
014	BT	L	L	L	L	L	H	H	L	H	L	L	L
	SN	L	L	L	L	M	H	H	L	H	M	L	L
015	BT	L	L	L	L	M	H	H	L	M	M	L	L
	SN	L	L	L	L	H	H	H	L	M	M	L	L
016	BT	M	M	M	M	M	L	L	L	L	H	H	H
	SN	M	M	M	M	H	H	M	L	L	M	H	H
017	BT	L	L	L	L	L	L	L	L	L	L	L	L
	SN	L	L	L	L	L	L	L	L	L	L	L	L
018	BT	L	L	L	L	L	L	L	-	L	L	L	L
	SN	L	L	L	H	H	H	L	L	L	H	L	L
024	BT	H	H	L	L	L	L	-	-	-	L	L	M
	SN	M	M	M	M	M	M	M	M	M	M	L	L

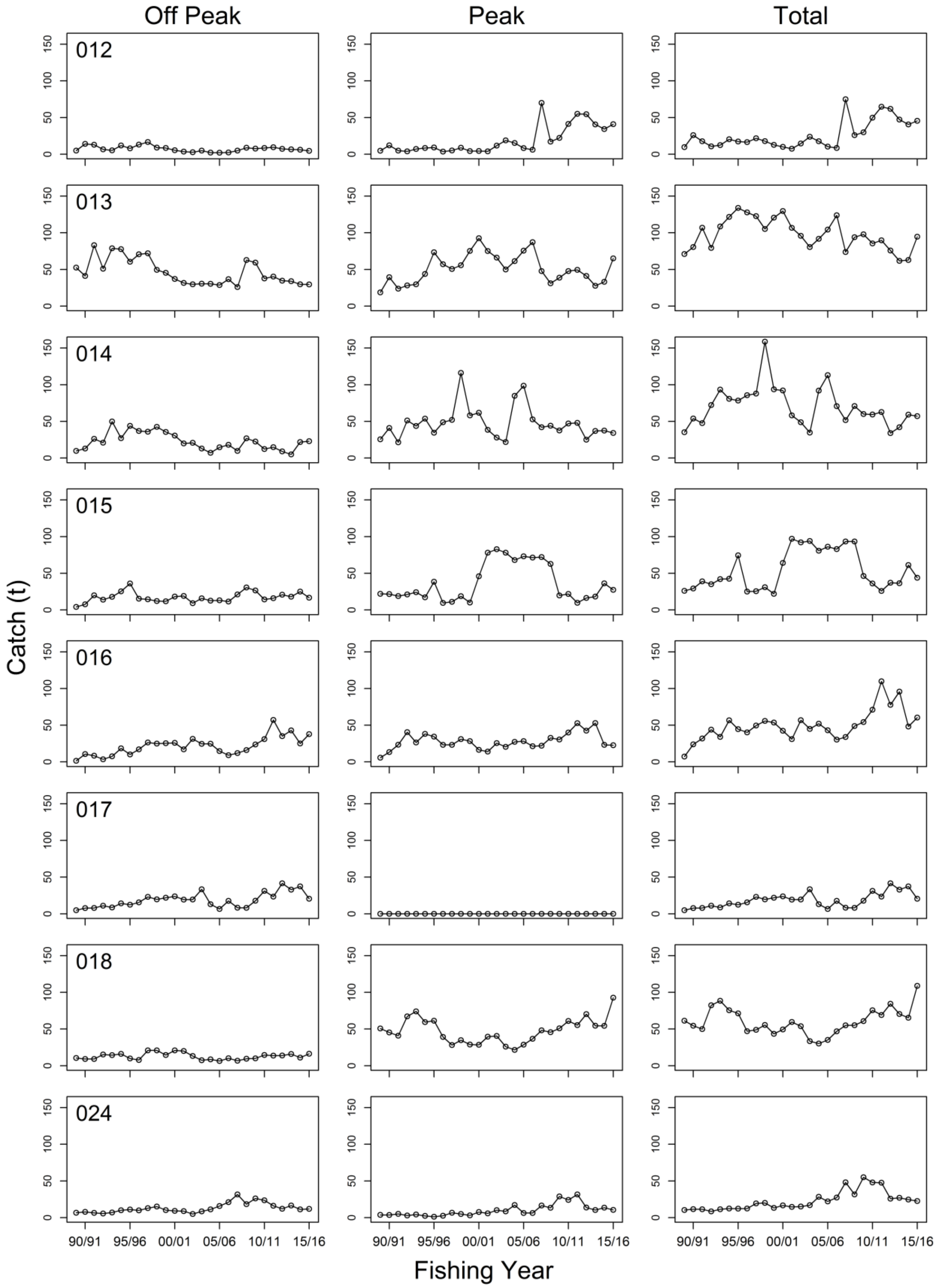

Figure 18: Annual catches of blue moki from the main Statistical Areas within MOK 1 and MOK 3 by season and the entire year (total, right). Season is defined as 'non-peak' (left) and peak (centre) based on the period of high catch rates in each Statistical Area (see Table 3).

4 CPUE ANALYSES

The results of the fishery characterisation were used to define three main fisheries for inclusion in the CPUE analysis based on the magnitude and continuity of catch throughout the study period, specifically:

1. The tarakihi bottom-trawl fishery operating within the Gisborne–Mahia area (Statistical Area 013) throughout the year (BT-TAR2-North).
2. The target blue moki set-net fishery operating between East Cape and Wairarapa (Statistical Areas 014–016) primarily during May–October (SN-MOK1).
3. The Kaikoura set-net fishery (Statistical Area 018) operating during May–June and October (SN-MOK3).

For each fishery, a standardised CPUE analysis was conducted using a Generalised Linear Modelling (GLM) approach. The CPUE analyses of the Kaikoura set-net (SN-MOK3) and MOK 1 target set-net (SN-MOK1) fisheries modelled the positive catch of blue moki assuming a lognormal error structure, while the CPUE analysis of the tarakihi bottom-trawl fishery (BT-TAR2-North) also modelled the presence/absence of blue moki in the catch and derived delta-lognormal CPUE indices. Details of the individual CPUE analyses are presented in the following sections.

A preliminary analysis was also conducted for a separate trawl fishery within Statistical Areas 015 and 016. The preliminary results indicated that the CPUE trends from this fishery (BT-TAR2-South) differed considerably from the BT-TAR2-North CPUE indices. However, annual catches from the BT-TAR2-South fishery were low (about 20–30 t per annum) and there was limited continuity in the participation of vessels in the trawl fleet. Consequently, the resulting CPUE indices were poorly determined and were not considered to represent a reliable index of stock abundance.

4.1 BT-TAR2-North CPUE

The BT-TAR2-North CPUE dataset comprised daily aggregate catch and effort data from the trawl fishery targeting tarakihi in Statistical Area 013 (Table 4). The dataset was limited to vessels that caught a minimum of 1000 kg of blue moki in at least five years. The core vessel dataset accounted for 77% of the blue moki catch included in the overall dataset. The core fleet included a total of 20 vessels of which two participated in the fishery in each of the 27 years of the time series. In most years, the fleet was comprised of a minimum of 9 vessels with at least 12 vessels operating during 2003–04 to 2011–12 (Figure 19).

Table 4: Variables included in the BT-TAR2-North daily aggregated dataset and range associated with each variable.

Variable	Description	Variable type	Range
FishingYear	Fishing year	Categorical	1990–2016
Month	Month	Categorical	1–12
Vessel	Vessel identifier	Categorical	
StatArea	Statistical Area	Categorical	013
TargetSpecies	Target species	Categorical	TAR
Catch	Blue moki catch (kg)	Continuous	0–2 500
NumTrawls	Number of trawls	Continuous	1–8
Duration	Total fishing duration (hr)	Continuous	1–18

There was a steady increase in the number of fishing days included in the core vessel set during 1989–90 to 2006–07. This trend reversed during 2010–11 to 2015–16 (Figure 19).

Almost all of the blue moki catch was allocated to the daily aggregated fishing effort records based on the distribution of the estimated catch within individual fishing trips (Figure 19). These records represented approximately 60% of the daily records with an allocated catch of blue moki. The remainder of the positive catch records (approximately 40%) were from trips with no estimated catches of blue moki and the landed catch was allocated amongst all corresponding fishing events from the corresponding trips. The blue moki catches allocated based on the effort distribution were generally small (median 10 kg).

The annual catches of blue moki by the core fleet fluctuated over the study period with higher catches during 1994–95 to 1998–99 and 2005–06 to 2010–11 (Figure 19). There was a relatively constant proportion of records (generally 20–25%) with no catch of blue moki (Figure 19).

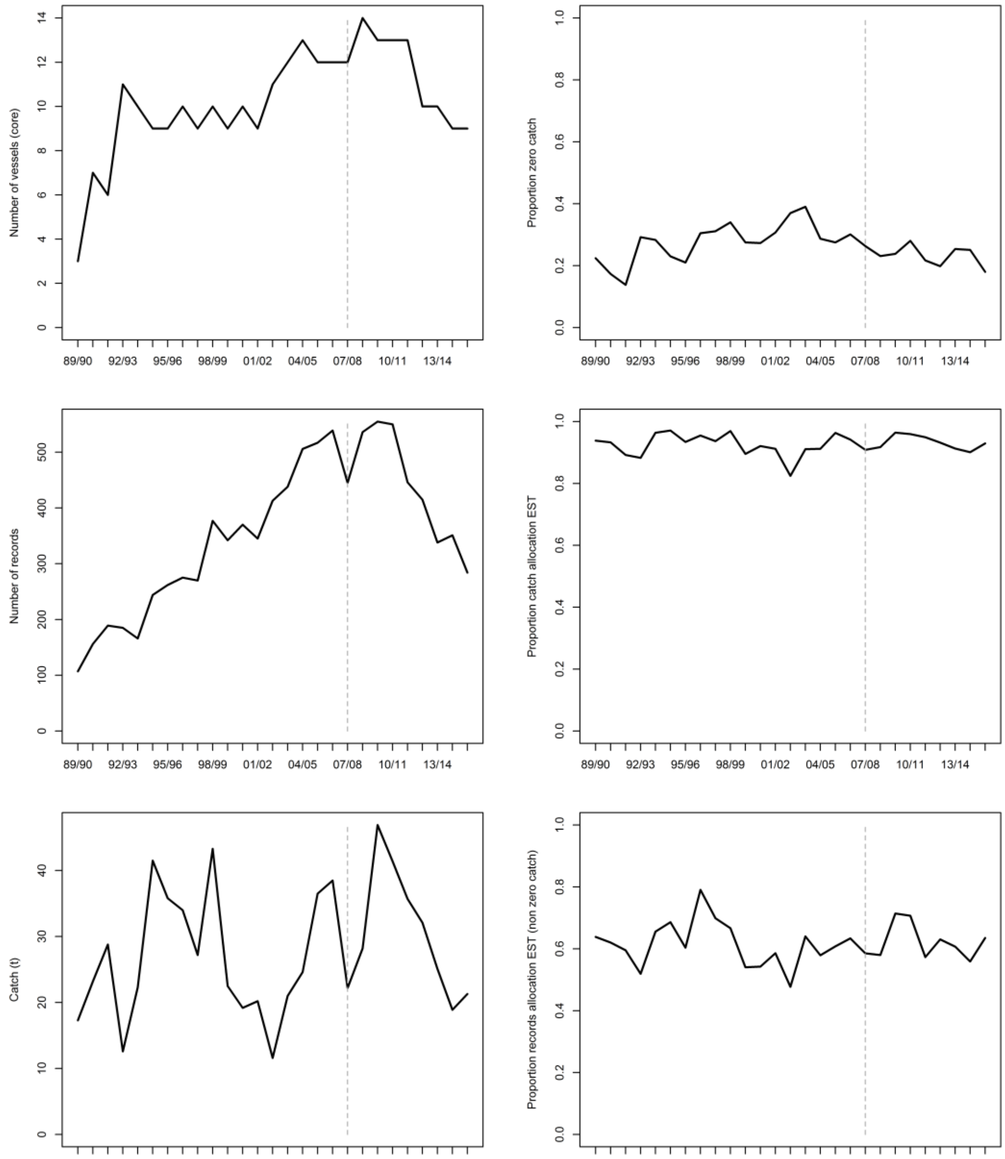

Figure 19: A summary of the data included in the BT-TAR2-North core vessel dataset by fishing year, including the proportion of the catch and effort records with blue moki catches allocated based on the distribution of estimated blue moki catch (rather than fishing effort). The dashed vertical line represents the year the TCER reporting form was introduced.

The average number of trawls conducted per fishing day increased during the early to mid-2000s, with a corresponding increase in the duration of fishing (Figure 20). The total fishing duration remained relatively stable during the subsequent years. There was no appreciable change in the main fishing effort metrics associated with the introduction of the TCER reporting form in 2007–08 (Figure 20).

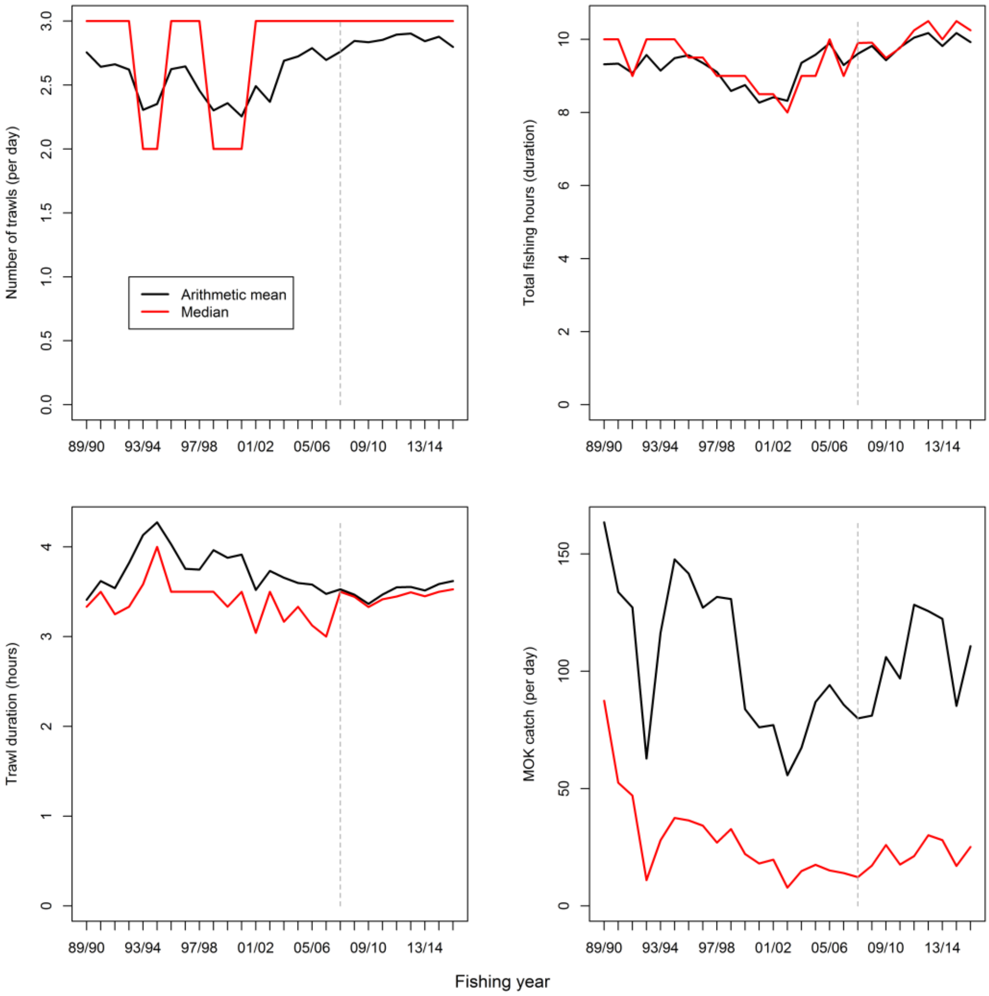

Figure 20: Annual trends in the main fishing effort metrics and blue moki catch rates (average and median) for the BT-TAR2-North core vessel dataset. The dashed vertical line represents the year the TCER reporting form was introduced.

Separate GLM analyses were conducted to model the occurrence of blue moki catches (presence/absence) and the magnitude of positive blue moki catches. The variables included in the BT-TAR2-North CPUE dataset are presented in Table 4. For the positive catch model, the dependent variable of the GLM was the natural logarithm of the daily catch of blue moki. The initial model included the explanatory variable *FishingYear* and assumed a lognormal error distribution. Additional predictor variables were included in the model using an AIC-based stepwise fitting procedure. The continuous variable *Duration* was incorporated as a third-order polynomial function of the natural logarithm of the value. Inclusion of variables in the final CPUE model was based on an acceptance criterion of an improvement of 0.5% in the Nagelkerke pseudo-R^2.

The positive catch CPUE model included all the available predictor variables: *FishingYear*, *Vessel*, *Month*, and *Duration* (Table 5). The distribution of the model residuals is consistent with the assumption of normality (Figure 21).

The annual indices derived from the positive catch CPUE model were relatively high during 1995–96 to 1998–99, with the exception of a lower index for 1992–93 (Figure 22). The indices declined considerably during 1999–2000 to 2002–03 and remained at a low level during 2002–03 to 2008–09. The indices increased somewhat in 2009–10 and fluctuated about that level for the remainder of the series (Figure 22).

The annual indices from the positive catch CPUE model are very similar to the overall trend in the unstandardised daily catch of blue moki (Figure 22), although the CPUE indices from the first three years were moderated by the inclusion of the *Vessel* variable in the CPUE model (Figure 23). The *Month* and *Duration* variables had little influence on the annual CPUE indices.

The occurrence of blue moki catch was predicted by the binomial model including the explanatory variables *FishingYear*, *Vessel*, *Month* and *Duration* (Table 6). None of these variables explained a significant proportion of the probability of catching blue moki and consequently the model is not considered to be very informative. The resulting annual indices derived from the binomial model are relatively constant throughout the time series and are very similar to the annual proportion of positive catch records (Figure 22).

The final (combined) BT-TAR2-North CPUE indices were determined from the product of the positive catch CPUE indices and the binomial indices following the approach of Stefansson (1996). The confidence intervals associated with the combined indices were determined using a bootstrapping approach. The trend in the combined CPUE indices is very similar to the positive catch CPUE indices (Figure 22).

Table 5: Summary of stepwise selection of variables in the BT-TAR2-North positive catch CPUE model. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	26	-13 220	26 496.3	0.056	*
Vessel	19	-12 827	25 747.7	0.159	*
Month	11	-11 987	24 089.4	0.342	*
Duration	3	-11 771	23 663.5	0.383	*

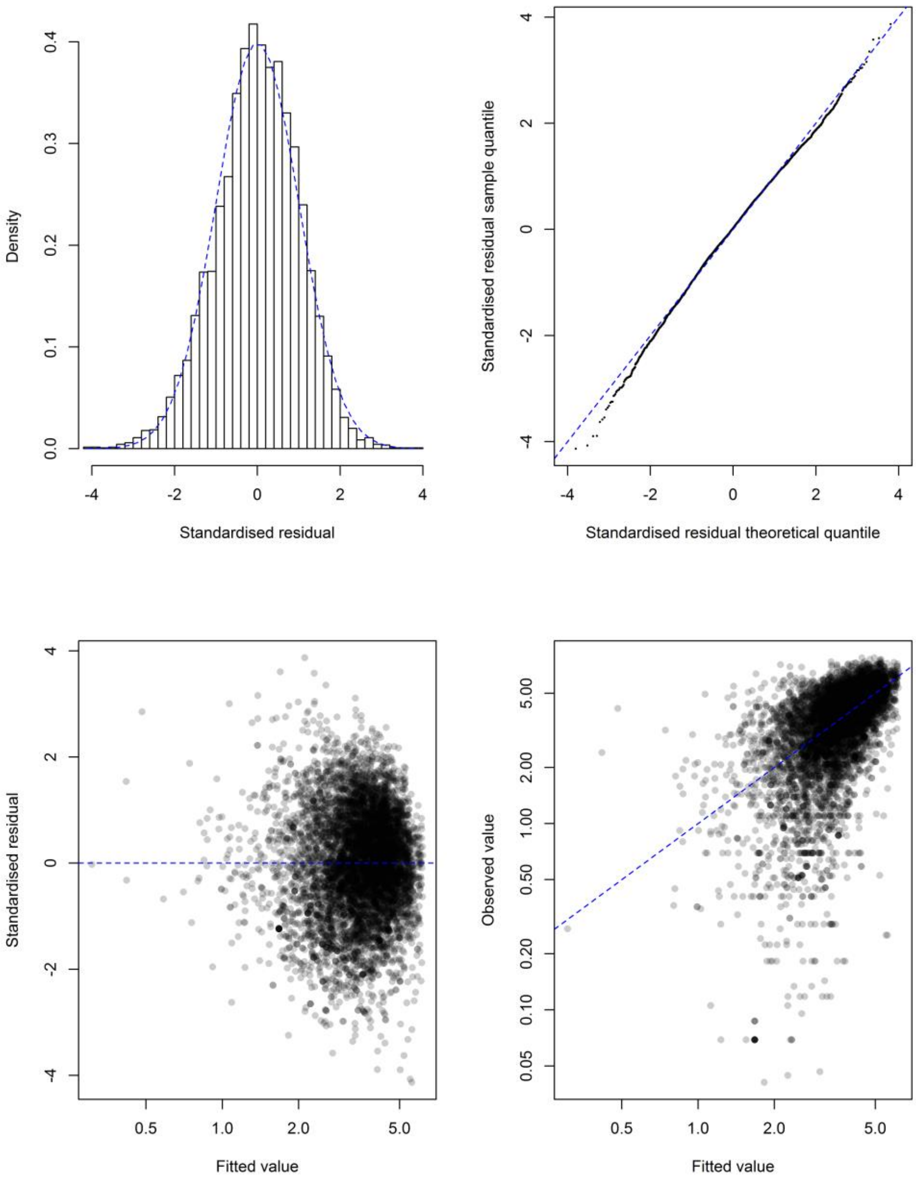

Figure 21: Residual diagnostics for the BT-TAR2-North positive catch CPUE model. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

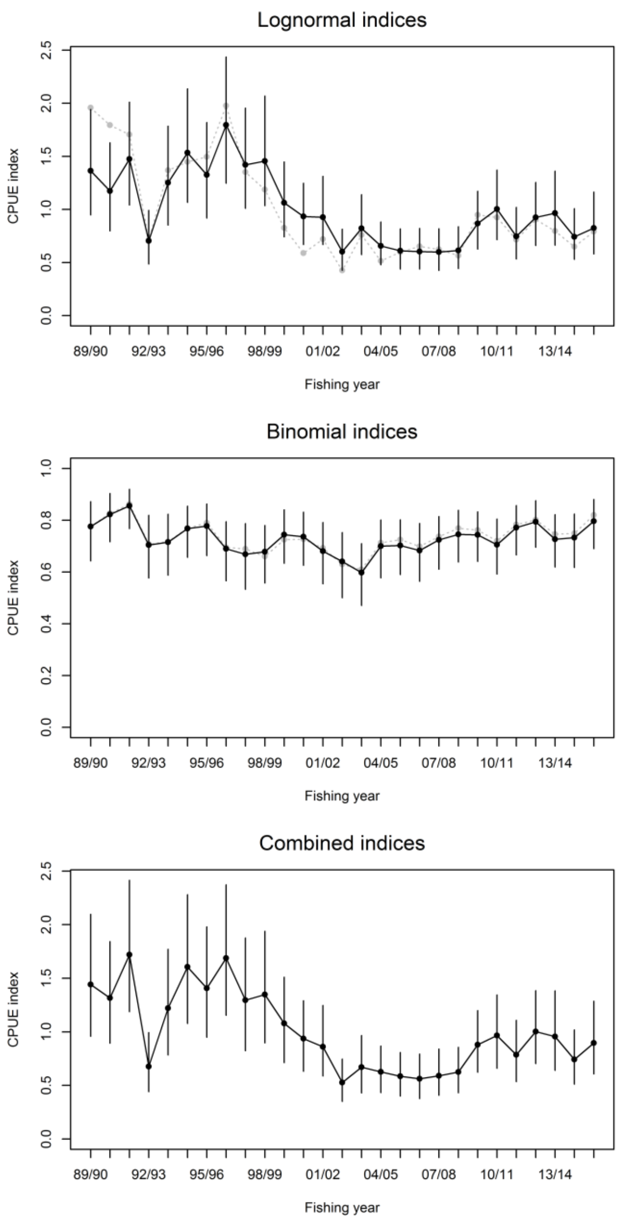

Figure 22: Top panel: A comparison of the BT-TAR2-North standardised CPUE indices and the geometric mean of the annual catch per day (grey line). Middle panel: A comparison of the binomial indices and the annual proportion of positive catch records (grey line) in the dataset. Bottom panel: The combined index. The error bars represent the 95% confidence intervals associated with each index.

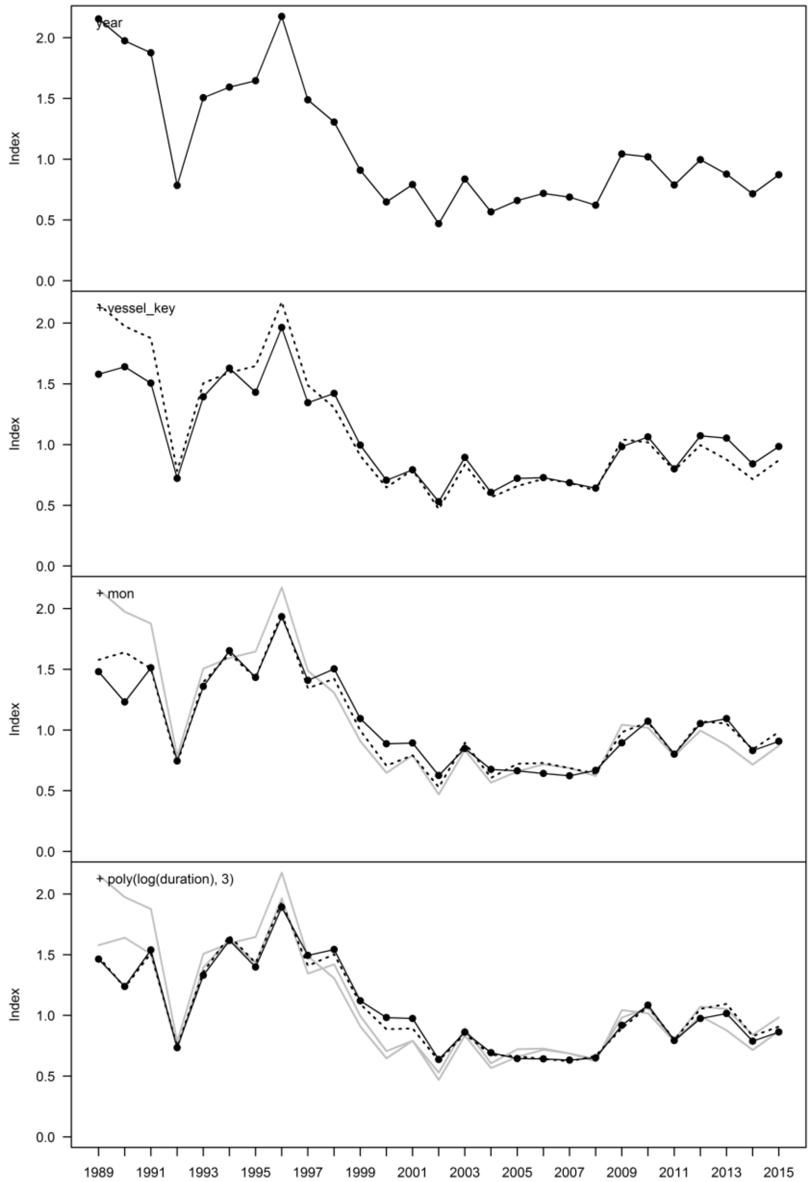

Figure 23: The change in the annual coefficients with the stepwise inclusion of each of the significant variables in the positive catch CPUE model for the BT-TAR2-North fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g., 1989 denotes the 1989–90 fishing year).

Table 6: Summary of stepwise selection of variables in the BT-TAR2-North catch occurrence CPUE model (binomial model). Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	26	-5 532	11 117.5	0.022	*
Vessel	19	-5 428	10 948.8	0.052	*
Month	11	-5 390	10 894.3	0.063	*
Duration	3	-5 385	10 891.0	0.065	*

4.2 SN-MOK1 CPUE

The SN-MOK1 CPUE dataset was comprised of daily aggregate catch and effort data from the set-net fishery targeting blue moki in Statistical Areas 014–016 (Table 7). Most of the data were from fishing during May–October. The dataset was limited to vessels that caught a minimum of 1000 kg of blue moki in at least five years. The core vessel dataset accounted for 82% of the blue moki catch included in the overall dataset. The core fleet included a total of 13 vessels of which four participated in the fishery for 14 or more years. In most years, the fleet comprised 4–7 vessels, although up to 10 vessels participated in the fishery in 2004–05 and 2005–06 (Figure 24).

Table 7: Variables included SN-MOK1 and SN-MOK3 CPUE datasets and the associated range for each variable.

Variable	Description	Variable type	Fishery	
			SN-MOK1	SN-MOK3
FishingYear	Fishing year	Categorical	1990–2016	1990–2016
Month	Month	Categorical	1–12	1–12
Vessel	Vessel identifier	Categorical		
StatArea	Statistical Area	Categorical	014–016	018
TargetSpecies	Target species	Categorical	MOK	MOK,SPO,TAR
Catch	Blue moki catch (kg)	Continuous	0–5 000	0–2 500
NetLength	Total length of net set (m)	Continuous	250–3 000	500–3 000
Duration	Total fishing duration (hr)	Continuous	>1	>1

The number of days fished per annum by the core fleet varied considerable over the study period. Fishing effort increased in the mid-1990s and was relatively high during 1996–97 to 2001–02 (Figure 24). The number of days fished dropped sharply in 2002–03 and continued to decline over the subsequent years.

Annual catches of blue moki were relatively low during the 1990s. Catches increased in 2000–01 and were maintained at a higher level until 2008–09 (Figure 24). Catches were generally lower in the subsequent years. There were a trivial number of records (days fished) with no blue moki catch (Figure 24).

There was considerable variation in the two main effort metrics (fishing duration and length of net set) during the study period (Figure 25). These differences were primarily attributable to changes in the composition of the fleet over time rather than fleet-wide changes in fishery operation.

The average daily catch of blue moki was very low during 1996–97 to 1999–2000 (Figure 25). There was a large increase in catch rates during the early 2000s and higher catch rates were maintained during 2004–05 to 2008–09. Annual catch rates were more variable in the subsequent years.

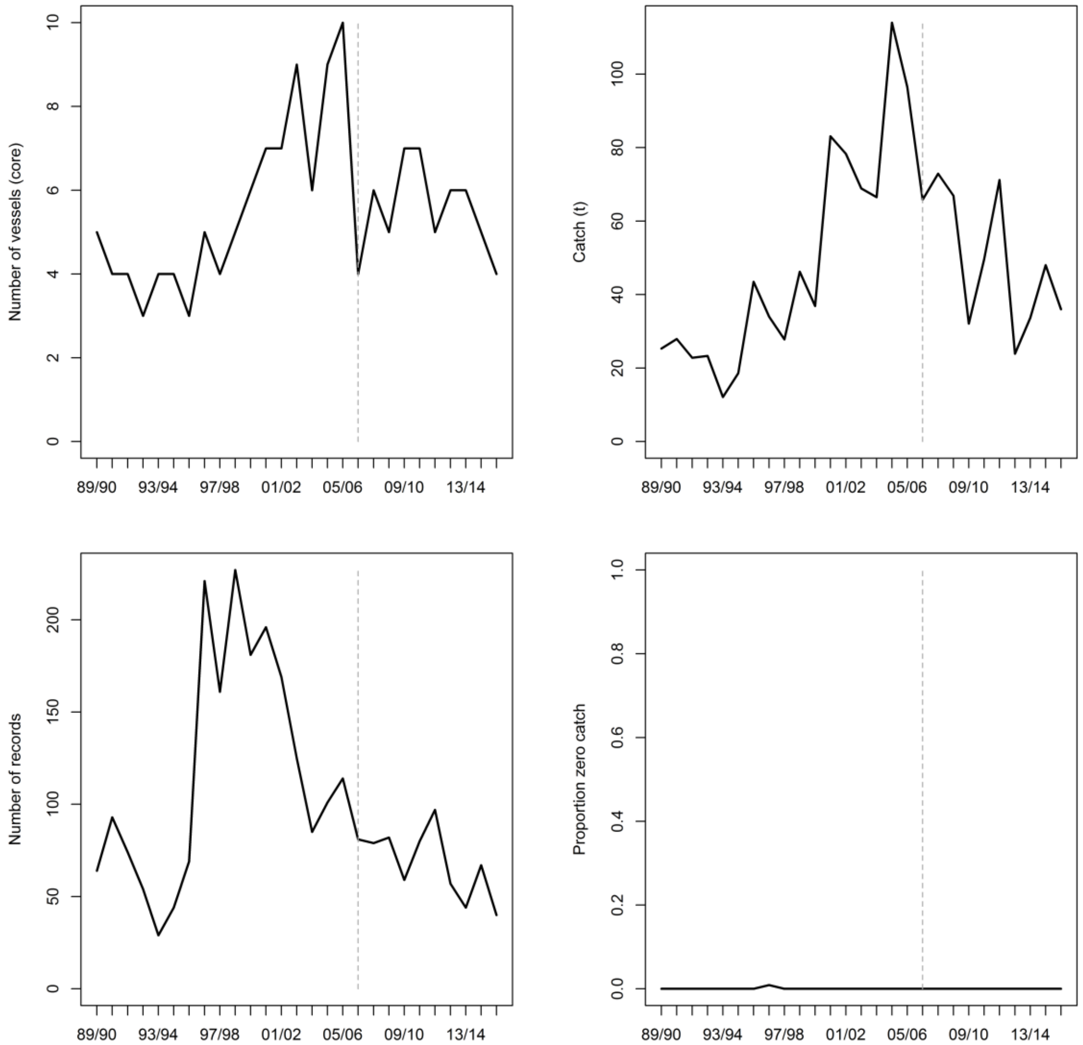

Figure 24: Summary of the SN-MOK1 CPUE dataset for the core fleet by fishing year. The vertical line represents the year the NCER reporting form was introduced.

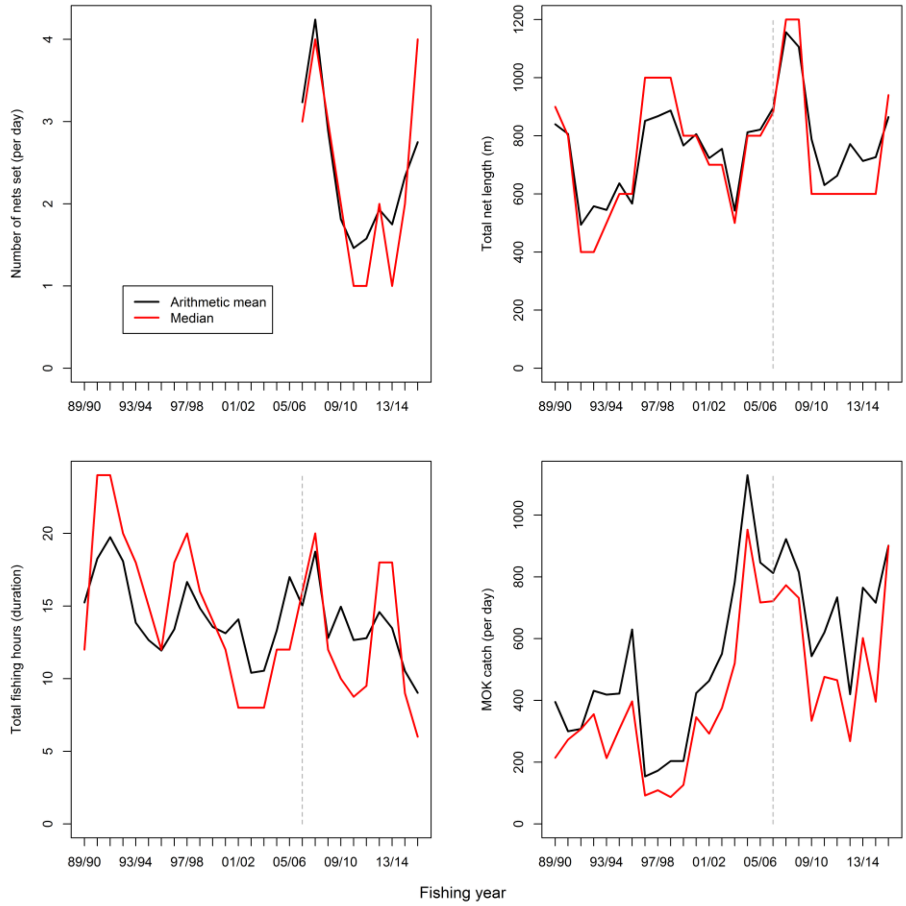

Figure 25: Annual trends in the fishing effort metrics and unstandardised catch rates (kg per day) for the SN-MOK1 CPUE core vessel dataset. The vertical line represents the year the NCER reporting form was introduced.

CPUE modelling was limited to the positive catch component only as negligible zero catch records were included in the dataset. The variables included in the SN-MOK1 CPUE dataset are presented in Table 7. The dependent variable of the GLM was the natural logarithm of the daily catch of blue moki. The initial model included the explanatory variable *FishingYear* and assumed a lognormal error distribution. Additional predictor variables (Table 8) were included in the model using an AIC-based stepwise fitting procedure. The interaction between the *Month* and *StatArea* variables was included to account for seasonal changes in the distribution of blue moki. The two continuous effort variables were incorporated as third-order polynomial functions of the natural logarithm of the variable. Inclusion of variables in the final CPUE model was based on an acceptance criterion of an improvement of 0.5% in the Nagelkerke pseudo-R^2.

The final CPUE model included the predictor variables *FishingYear*, *Vessel*, *Month*, *StatArea* and the *StatArea:Month* interaction (Table 8). Neither of the effort variables *NetLength* or *Duration* were included in the final model. The distribution of the model residuals is generally consistent with the assumption of normality (Figure 26), although the mode of the distribution is positively skewed indicating some violation of the distributional assumption.

Table 8: Summary of stepwise selection of variables in the SN-MOK1 positive catch CPUE model. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	26	-4 386	8 827.1	0.233	*
Vessel	12	-4 173	8 426.9	0.351	*
Month	11	-3 805	7 711.2	0.515	*
StatArea	2	-3 791	7 688.1	0.521	*
NetLength	3	-3 773	7 653.9	0.528	
Duration	3	-3 768	7 650.1	0.529	
StatArea:Month	22	-3 692	7 543.0	0.557	*

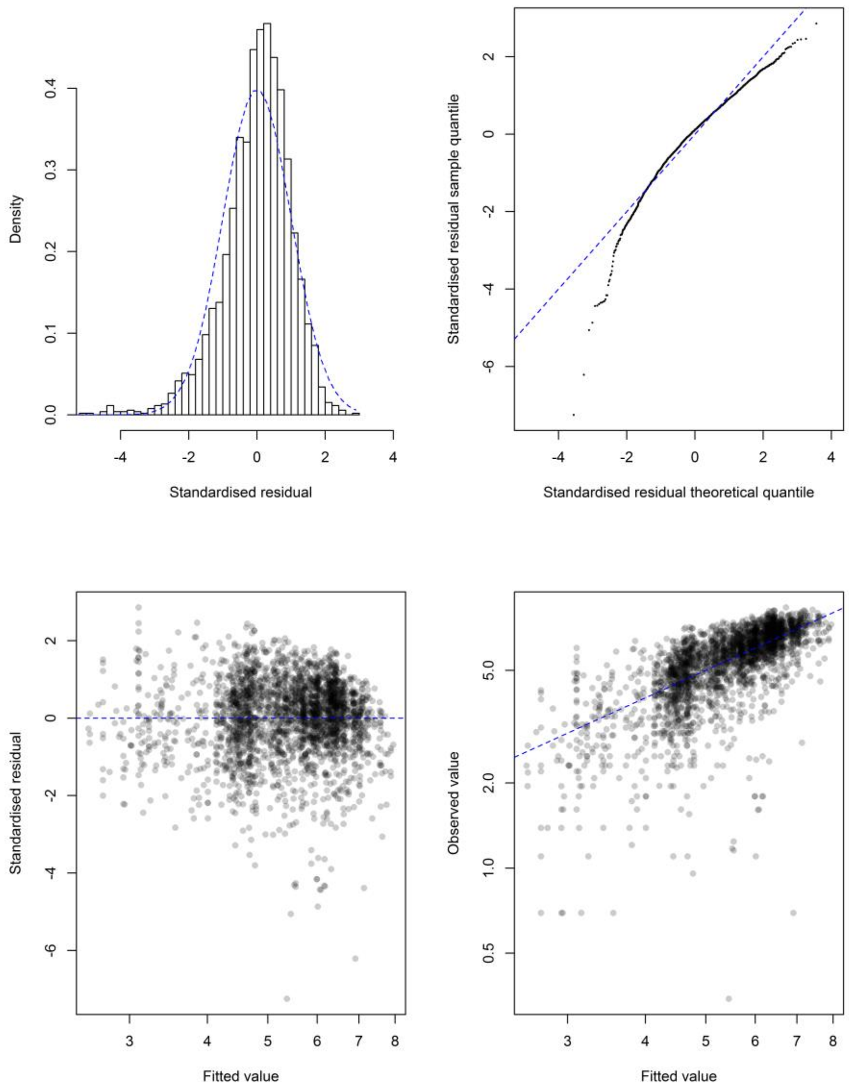

Figure 26: Residual diagnostics for the CPUE model for the SN-MOK1 fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The trend in the CPUE indices is moderated by the inclusion of the *Vessel* variable in the final CPUE model (Figure 27 and Figure 28). The effect was primarily due to the strong influence of three less efficient vessels in the years prior to 2000–01 and the dominance of a more efficient vessel during 2004–05 to 2008–09.

The CPUE indices decline during the early to mid-1990s and were relatively low from 1994–95 to 2003–04 (Figure 27). The indices increased in 2004–05 and remained at the higher level during 2005–06 to 2008–09. The CPUE indices were more variable for the subsequent years, although there was a general increase in the CPUE indices and the last three indices (2013–14 to 2015–16) were relatively high compared to the entire series (Figure 27).

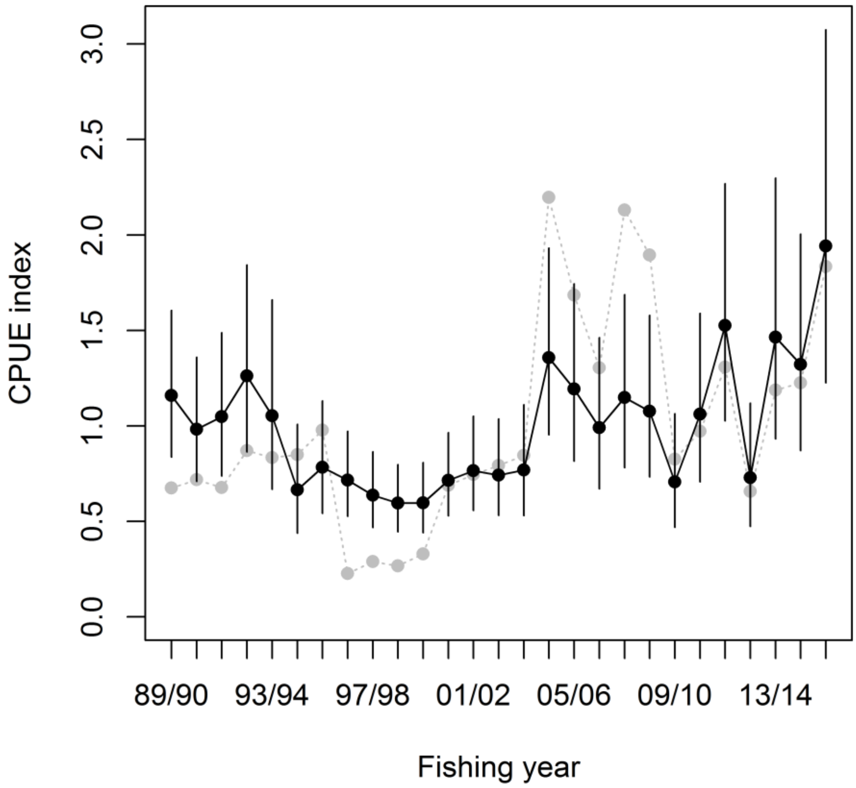

Figure 27: A comparison between the unstandardised and standardised CPUE indices for the SN-MOK1 fishery. The unstandardised indices represent the geometric mean of the blue moki catch per fishing day.

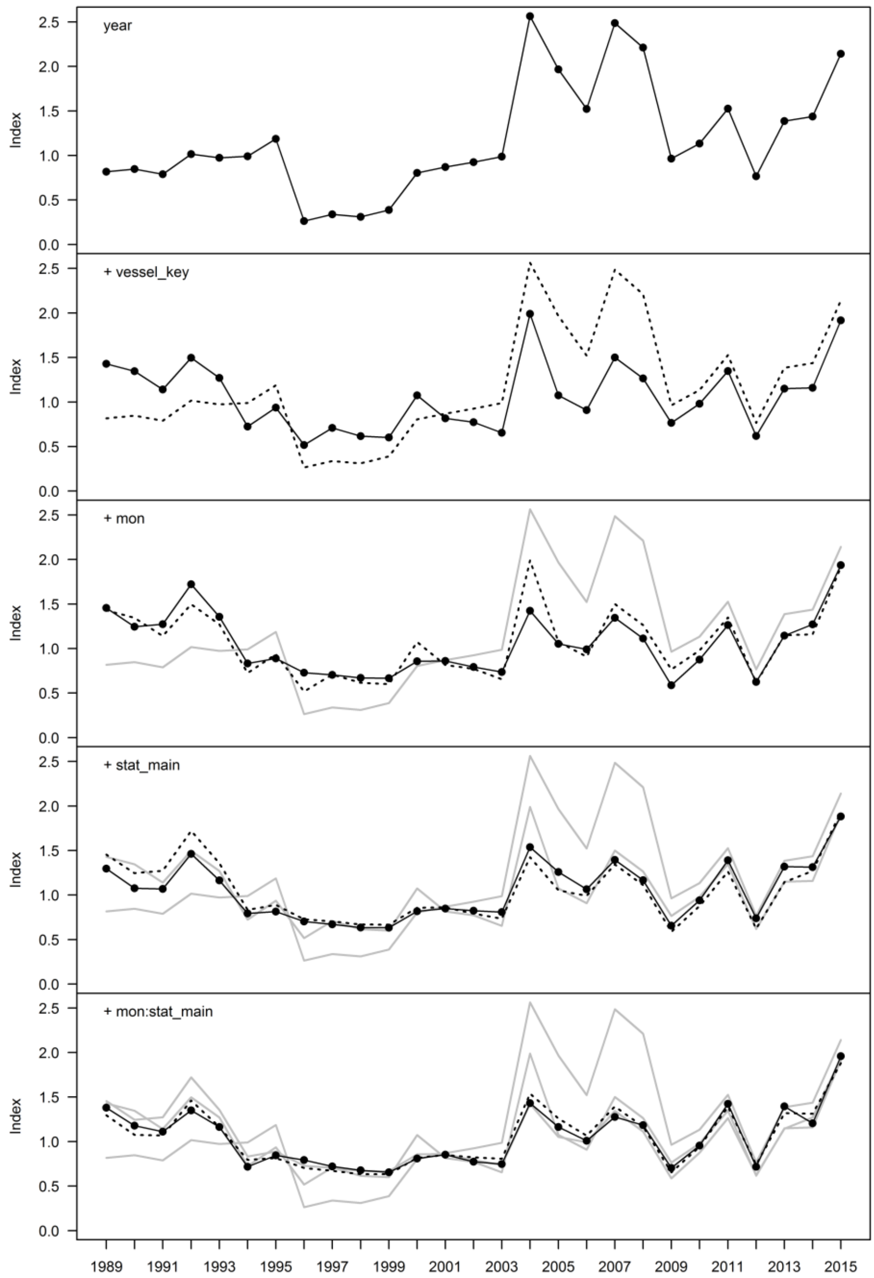

Figure 28: The change in the annual coefficients with the stepwise inclusion of each of the significant variables in the CPUE model for the SN-MOK1 fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g., 1989 denotes the 1989–90 fishing year).

4.3 SN-MOK3 CPUE

The SN-MOK3 CPUE dataset was comprised of daily aggregate catch and effort data from the set-net fishery targeting blue moki, tarakihi or rig in Statistical Area 018 (Table 7). Most of the data were from fishing during April–June and October–December. The dataset was limited to vessels that caught a minimum of 1000 kg of blue moki in at least six years. The core vessel dataset accounted for 86% of the blue moki catch included in the overall dataset.

The core fleet included a total of 12 vessels of which six participated in the fishery for 16 or more years. Prior to 2005–06, there were usually seven core vessels operating in the fishery each year. Since then, there was a gradual retirement of vessels, with only four core vessels participating in the fishery in

2014–15 to 2015–16 (Figure 29). Correspondingly, there was also a lower number of days fished in recent years.

The annual catch of blue moki by the core fleet increased from the mid-2000s and reached a peak in 2010–11 to 2012–13 (Figure 29). The annual catch was lower in the three subsequent years. In most years, there was a small proportion (less than 5%) of fishing days with no catch of blue moki.

The average length of net set and fishing duration were relatively stable over the study period (Figure 30), reflecting the stability of the core fleet operating in the fishery. The average catch rate (kg per day) of blue moki increased considerably from the early 2000s (Figure 30). The increase in catch rate corresponds to an increase in the level of targeting of blue moki by the fleet from 2007–08.

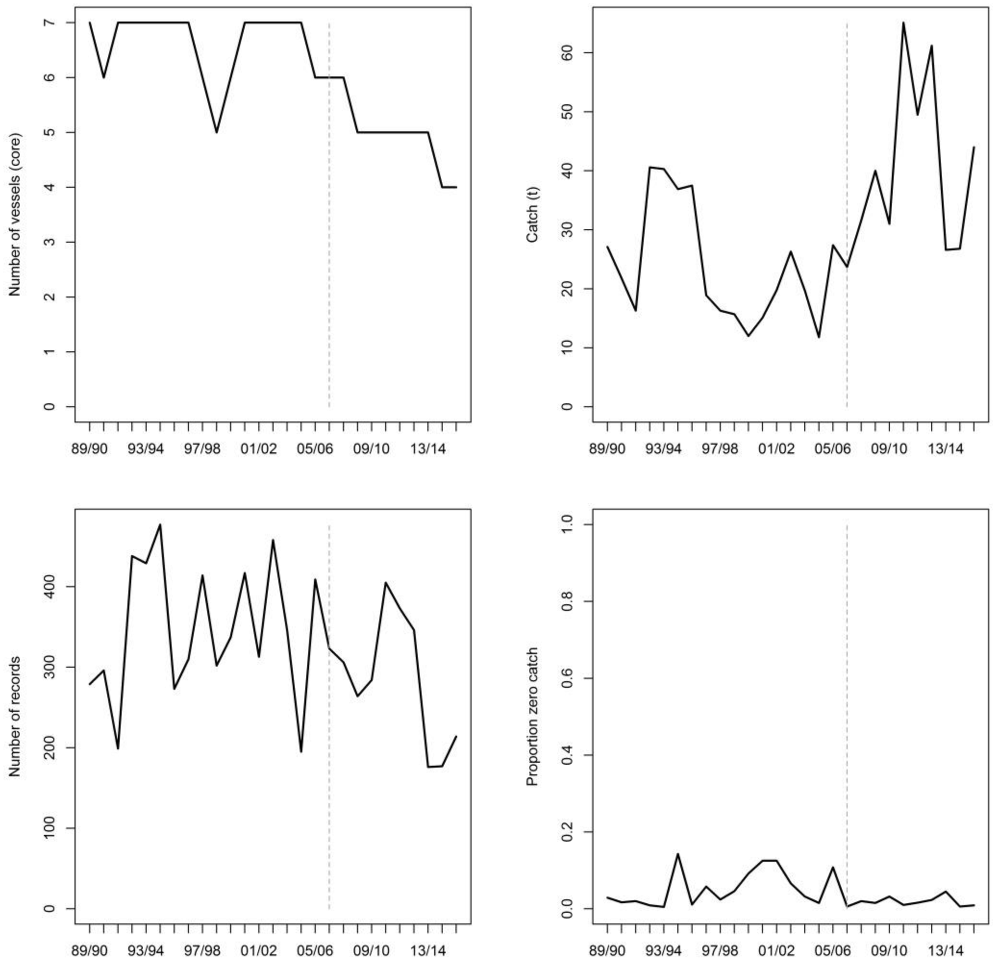

Figure 29: Summary of the SN-MOK3 CPUE dataset for the core fleet by fishing year. The vertical line represents the year the NCER reporting form was introduced.

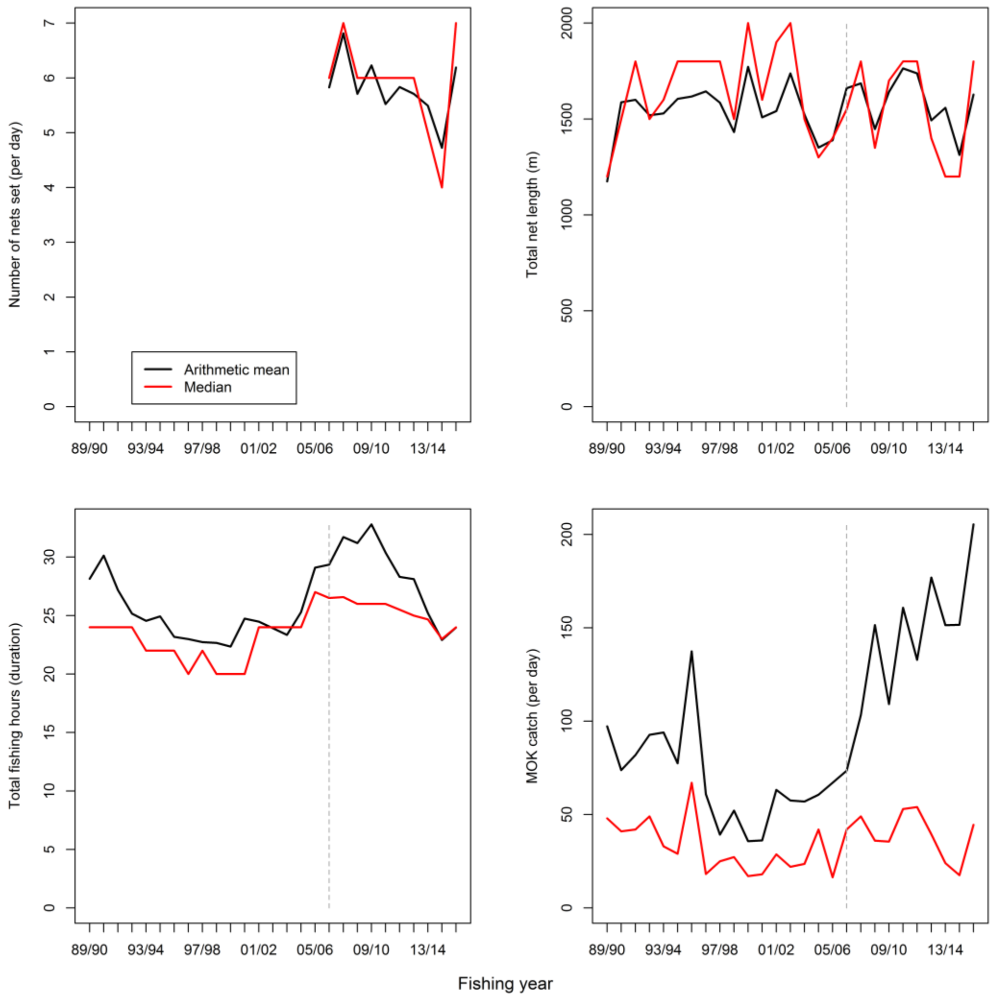

Figure 30: Annual trends in the fishing effort metrics and unstandardised catch rates (kg per day) for the SN-MOK3 CPUE core vessel dataset. The vertical line represents the year the NCER reporting form was introduced.

Given the low proportion of zero-catch records, CPUE modelling was limited to the positive catch component only. The variables included in the SN-MOK3 CPUE dataset are presented in Table 7. The dependent variable of the GLM was the natural logarithm of the daily catch of blue moki. The initial model included the explanatory variable *FishingYear* and assumed a lognormal error distribution. Additional predictor variables (Table 9) were included in the model using an AIC-based stepwise fitting procedure. The two continuous effort variables were incorporated as third-order polynomial functions of the natural logarithm of the variable. Inclusion of variables in the final CPUE model was based on an acceptance criterion of an improvement of 0.5% in the Nagelkerke pseudo-R^2.

The final CPUE model included the predictor variables *FishingYear*, *Vessel*, *Month* and *NetLength* (Table 9). The effort variable *Duration* was not included in the final model. The distribution of the model residuals is consistent with the assumption of normality (Figure 31).

Table 9: Summary of stepwise selection of variables in the SN-MOK3 positive catch CPUE model. Model terms are listed in the order of acceptance to the model. AIC: Akaike Information Criterion; *: Term included in final model.

Term	DF	Log likelihood	AIC	Nagelkerke pseudo-R^2 (% Improvement)	
FishingYear	26	-15 773	31 601.9	0.034	*
Vessel	11	-15 531	31 139.1	0.090	*
Month	11	-12 994	26 087.7	0.517	*
Target	2	-12 933	25 970.0	0.524	*
NetLength	3	-12 837	25 780.9	0.535	*
Duration	3	-12 837	25 785.5	0.535	

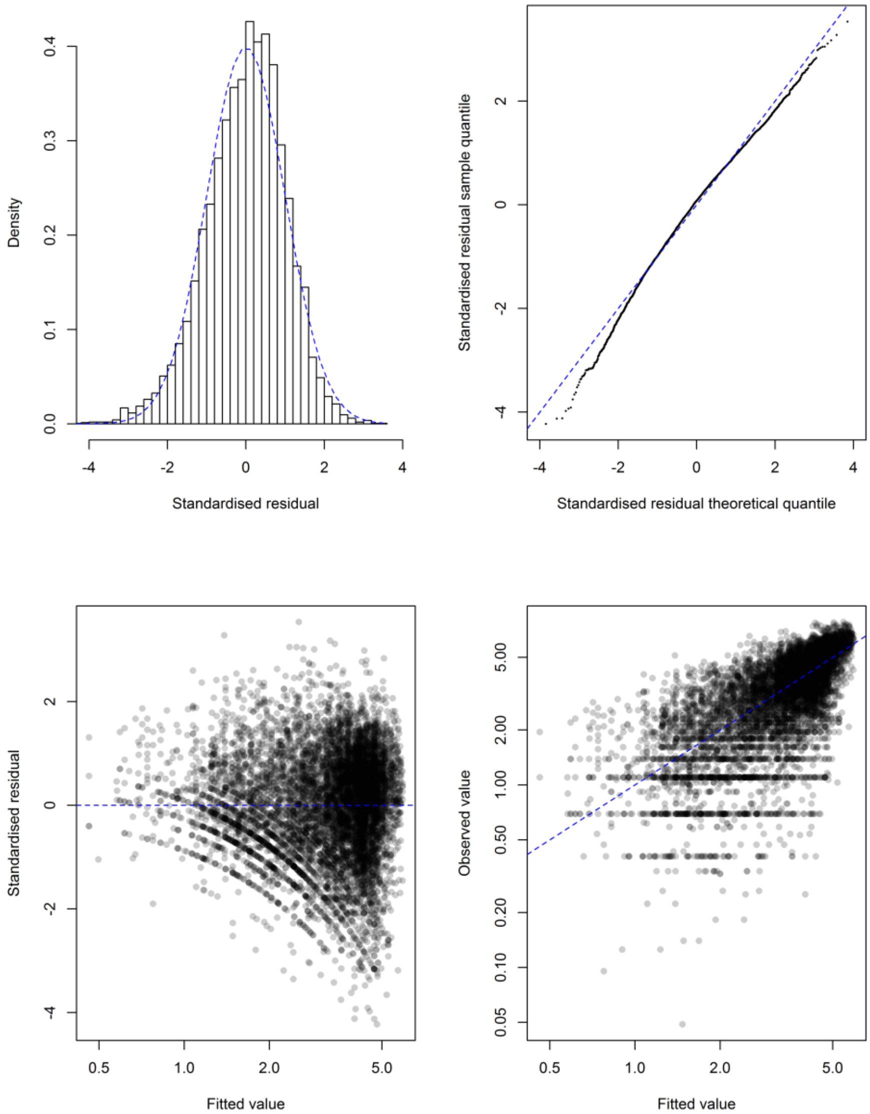

Figure 31: Residual diagnostics for the CPUE model for the SN-MOK3 fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The resulting SN-MOK3 CPUE indices are comparable to the annual trend in the unstandardised catch rates (Figure 32). The CPUE indices fluctuated during the 1990s and early 2000s with periods of lower CPUE in 1996–97 to 1999–2000 and 2002–03 to 2005–06. There was a steady increase in CPUE from the mid-2000s and CPUE indices for the most recent years are the highest of the time series (Figure 32).

There is potential for the recent increase in the CPUE indices to be strongly influenced by the increase in the targeting of MOK since 2007–08. However, excluding the MOK target records from the dataset did not appreciably change the resulting CPUE indices. Thus, the trend in blue moki CPUE is consistent for the target and non-target fisheries (TAR and SPO). This is also evident from the small influence on the CPUE indices associated with the inclusion of the *TargetSpecies* variable in the model (Figure 33).

Month was the most influential variable included in the model. The inclusion of this variable slightly accentuated the increasing trend in the CPUE indices (Figure 33). This is attributable to an increase in the amount of set-net fishing effort in the peripheral months (outside the main blue moki seasons) in more recent years.

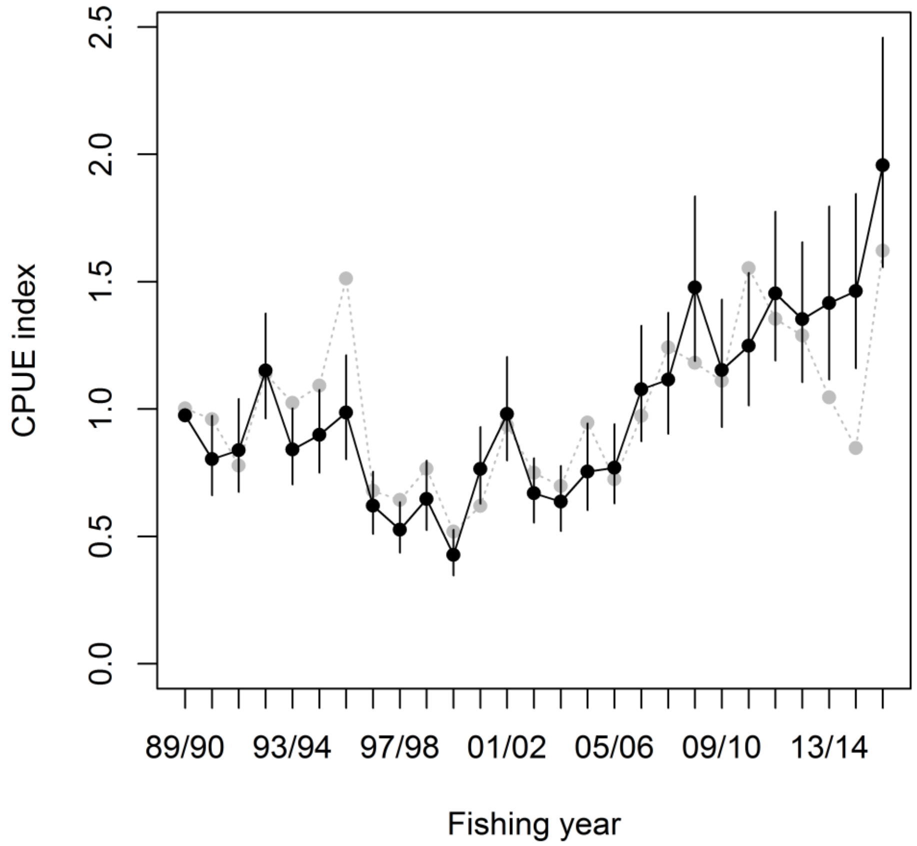

Figure 32: A comparison between the unstandardised and standardised CPUE indices for the SN-MOK3 fishery. The unstandardised indices represent the geometric mean of the blue moki catch per fishing day.

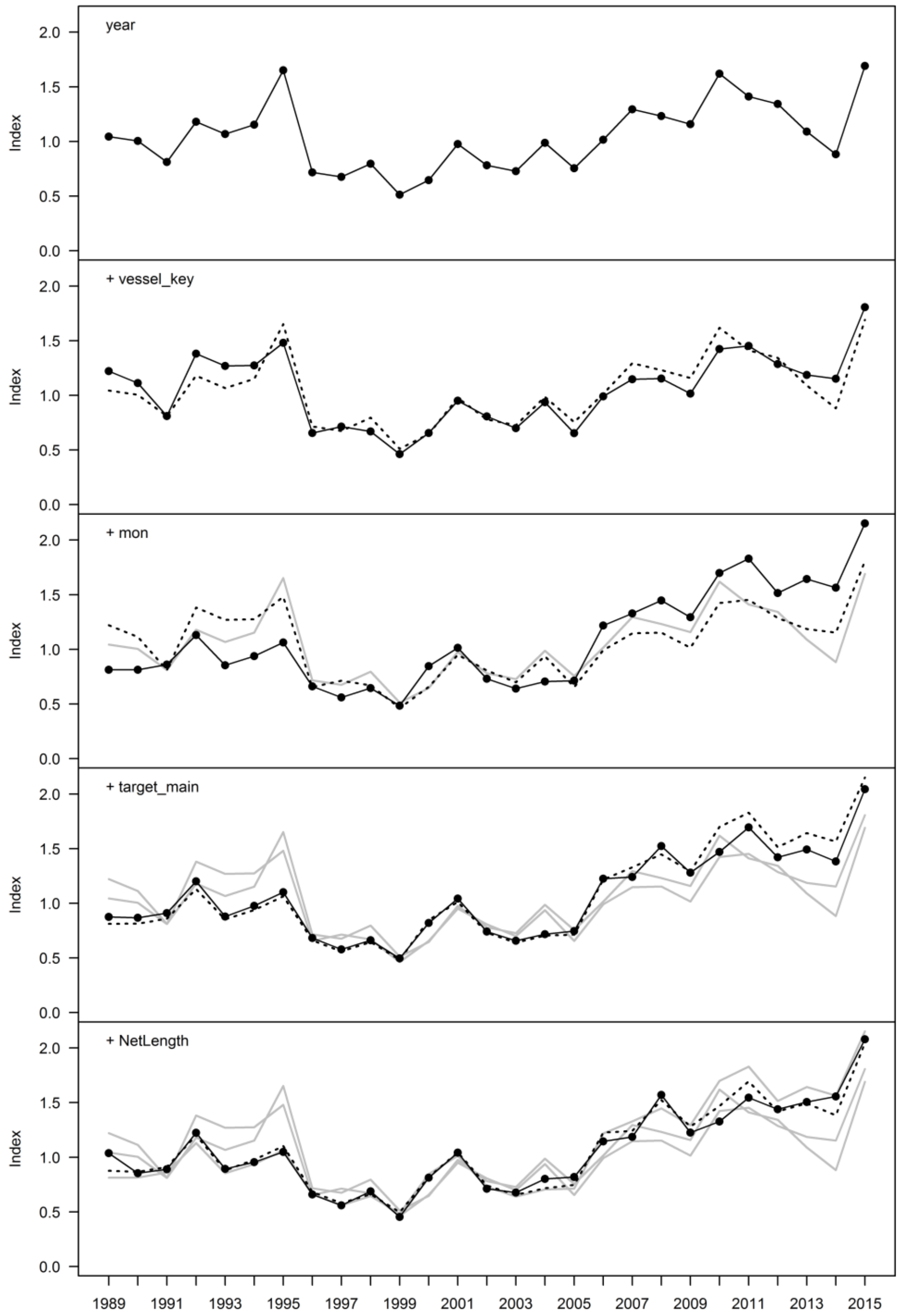

Figure 33: The change in the annual coefficients with the stepwise inclusion of each of the significant variables in the CPUE model for the SN-MOK3 fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g., 1989 denotes the 1989–90 fishing year).

5 DISCUSSION

To support the current analyses, additional CPUE analyses were conducted using detailed event-based catch and effort data from the trawl and set-net fisheries (TCER and NCER). These analyses encompassed a restricted time period (from 2007–08 and 2006–07, respectively). Nonetheless, the annual indices were very similar to the corresponding CPUE indices derived from the daily aggregate datasets. Further, the CPUE indices derived from the SN-MOK1 and BT-TAR2-North were comparable to the results of corresponding analyses by Bentley & Kendrick (in prep).

The fishery characterisation summarised the spatio-temporal trends in blue moki catch and catch rate and postulated that the eastern stock could be composed of three components based on the summer distribution of blue moki, either from the magnitude of catch during the summer period or inferred from apparent movements. These three areas are East Cape (013), Cook Strait (016) and an area south of Kaikoura. The BT-TAR2-North CPUE indices correspond to the East Cape area, while the SN-MOK3 CPUE indices correspond to the component of the stock migrating from the southern area. The SN-MOK1 CPUE indices are considered to encompass the amalgamation of fish migrating from both the southern area and Cook Strait area.

There are broadly similar trends in the annual CPUE indices from the SN-MOK1 and SN-MOK3 fisheries. Both sets of indices declined during the mid-1990s and were relatively low during the late 1990s (Figure 34). There was a steady increase in the SN-MOK3 CPUE indices from the early 2000s. There was also a general increase in the SN-MOK1 CPUE indices over the same period, although the indices were considerably more variable between years. The indices were relatively poorly determined during the latter period, due (in part) to the lower number of records included in the analysis.

In contrast, the BT-TAR2-North CPUE indices were relatively high during 1995–96 to 1998–99, low during 2002–03 to 2008–09 and only increased slightly during the more recent years (Figure 34).

The two sets of CPUE indices from the set-net fisheries (SN-MOK1 and SN-MOK3) are dominated by the data from the peak fishing periods. The main fishing seasons are considered to target the migrations of blue moki to and from the East Cape spawning grounds. The passage of the spawning migrations includes the area of the BT-TAR2-North fishery (Statistical Area 013).

The BT-TAR2-North CPUE indices are dominated by fishing event records from outside of the main spawning period of July–September. Thus, the CPUE indices primarily represent the trends in catch rate of fish that remain resident in the East Cape area. There is a marked seasonal increase in the catch rate of blue moki in the BT-TAR2-North fishery. However, the annual trends in the unstandardised catch rate of blue moki from the BT-TAR2-North fishery were very similar between the spawning (July–September) and non-spawning (October–June) periods.

Thus, the trends in the CPUE indices from the BT-TAR2-North fishery differ markedly from both the SN-MOK1 and SN-MOK3 fisheries both within and outside of the spawning period. This suggests that the BT-TAR2-North CPUE indices are not strongly influenced by the trends in the relative abundance of the blue moki migrating to the spawning grounds during July–September (as indexed by the SN-MOK1 and SN-MOK3 CPUE indices). There are a range of potential explanations that could account for this observation:

a. The component of the population that migrates to the East Cape (013) area represents a relatively small proportion of the blue moki population in the area. Thus, changes in the abundance of the migrating component of the stock would have only minor influences on the BT-TAR2-North CPUE indices.
b. The migrating component of the stock is not vulnerable to the BT-TAR2-North fishery and, therefore, trends in the relative abundance of the migrating component of the stock are not incorporated in the BT-TAR2-North CPUE indices.
c. The trawl and set-net fisheries harvest a different proportion of the population age structure (i.e., differences in selectivity of the two fishing methods).
d. The BT-TAR2-North CPUE indices do not represent a reliable index of stock abundance.
e. The CPUE indices for the SN-MOK1 and SN-MOK3 fisheries do not represent a reliable index of stock abundance.

The CPUE modelling of the BT-TAR2-North fishery reveals that catch rates of blue moki are substantially higher (by a factor of 4–5) in June–July and September compared to the summer months (December–April). Catch rates also drop markedly during August coinciding with the main period of spawning (Francis 1981). These seasonal trends in CPUE indicate that there is a considerable increase in the abundance of blue moki, which is consistent with the influx of a large proportion of the population into the area around the spawning period.

An examination of the spatio-temporal trends in the trawl catch rates of blue moki in Statistical Area 013 and the adjacent Statistical Areas (012 and 014) did not fully elucidate the movements of blue moki into the area (Figure 35). Nonetheless, there is some indication of the northward movement of fish through Statistical Area 014 during June and early July and continuing northward through Statistical Area 013 and a reciprocal southward movement during September and early October (Figure 35).

Catches of blue moki from the Bay of Plenty (008–010) are relatively minor and most of the catch has been taken during the main spawning period (June–September). On that basis, the area does not appear to account for a significant proportion of the stock biomass that is influencing the relative abundance of blue moki available to the BT-TAR2-North fishery.

Manning et al. (2010) sampled the age composition of the MOK 1 trawl and set-net fisheries during the 2004–05 and 2005–06 fishing years. The sampling was partitioned by season: ‘in season’ incorporating October and June–September and ‘out season’ encompassing the other months. Sufficient samples were available from the trawl fishery to compare the age composition between seasons. The ‘in season’ age composition comprised a larger proportion of older fish (greater than 10 years) compared to the ‘out season’ age composition.

The ‘in season’ age compositions from the trawl and set-net fisheries were similar. However, most of the trawl samples were taken from catches from Statistical Areas 014 and 015 and there was limited sampling of the catch from Statistical Area 013. Therefore, the results of the sampling do not provide a direct comparison of the age compositions from the BT-TAR2-North fishery and the SN-MOK1 fishery. However, the comparison between the age compositions from ‘in season’ and ‘out season’ may indicate some difference in the availability of older fish to the trawl fishery between the two seasons.

These observed differences in the age compositions of the trawl catch between the seasons also indicates that the migrating component of the stock appears to be vulnerable to the trawl fishery, at least in Statistical Areas 014 and 015. On that basis, the second potential explanation (b) appears to be unlikely.

There is limited information available to evaluate the reliability of the individual sets of CPUE indices as direct indicators of stock abundance. Each of the sets of CPUE indices varied considerably over the study period. The age composition data from the MOK 1 fishery reveals considerable variability in year class strength (Manning et al. 2010). The age compositions reveal a strong mode of fish in age classes 7–12 years corresponding to relatively strong recruitment during the 1990s. These age classes would have entered the fishery from about the mid-1990s and may have contributed to the higher CPUE in the BT-TAR2-North fishery during the late 1990s. No additional data are available from the fishery to interpret the subsequent trends in the CPUE indices from the BT-TAR2-North fishery (Figure 34).

The decline in CPUE indices from the BT-TAR2-North fishery in the late 1990s and early 2000s is consistent with previous observations from participants in the FMA 2 trawl fishery during the early 2000s (Langley & Walker 2004). The comments from one of the main trawl operators were summarised as follow.

> ‘Moki used to migrate in large schools over the soft bottom and they got some big catches. Now they tend to catch a few mixed in with the rest of the catch, maybe only catching some lone fish. There appear to be less around than 3–4 years ago, unless they are in shallower waters around the rocks. Chris did notice a couple of years with higher moki abundance in the mid-1990s.’

There was no corresponding trend in the CPUE indices from the two set-net fisheries; i.e., there was no period of higher CPUE indices during the late 1990s. There are similar trends in the CPUE indices from these two fisheries, although the indices are not sufficiently similar to corroborate trends in abundance from the two set-net fisheries. The recent trends in the CPUE indices from both fisheries are consistent with the higher catches from Statistical Areas 016 and 018 in recent years.

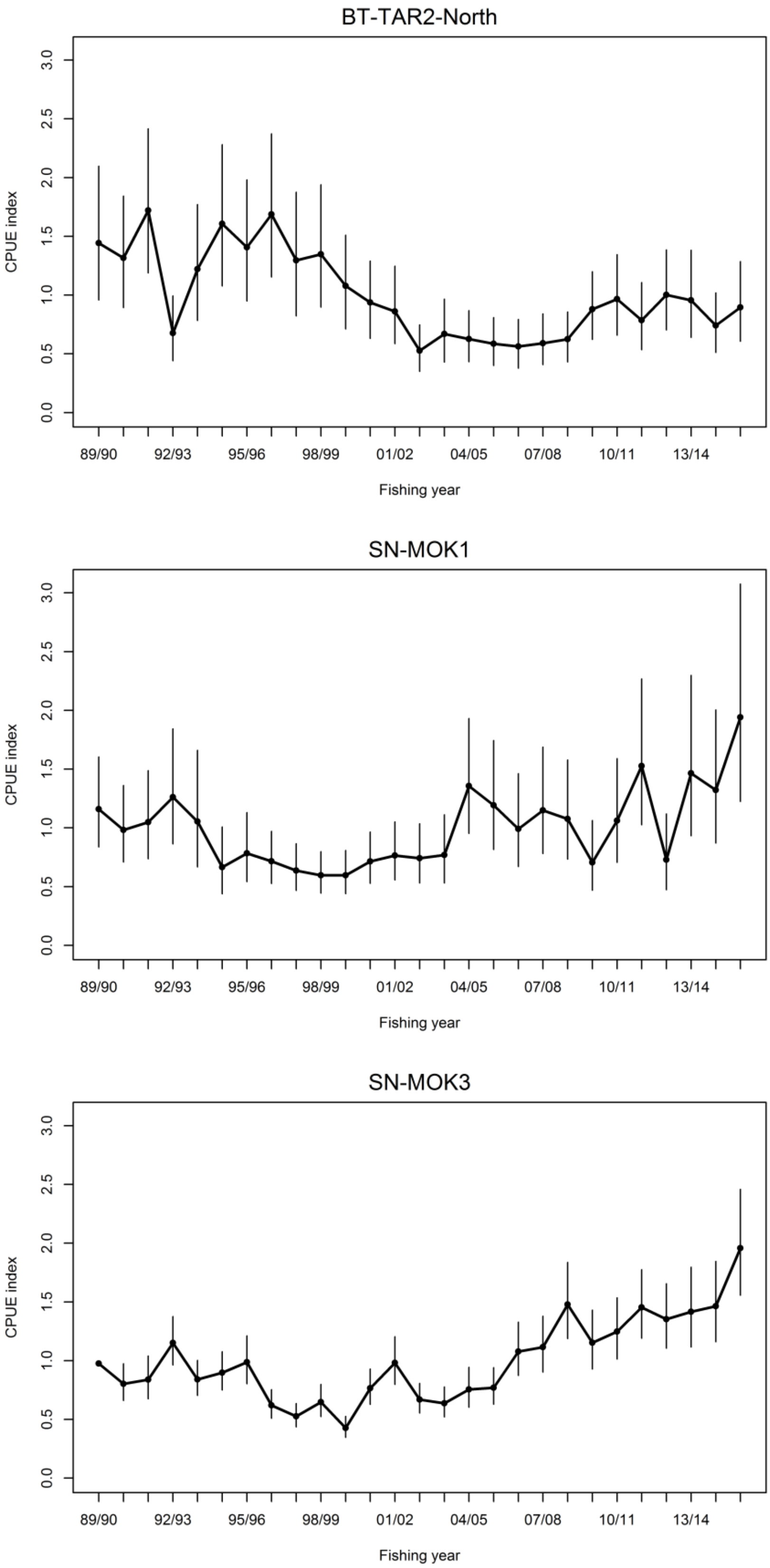

Figure 34: A comparison of the three sets of CPUE indices from the BT-TAR2-North, SN-MOK1 and SN-MOK3 analyses. The vertical lines represent the 95% confidence intervals.

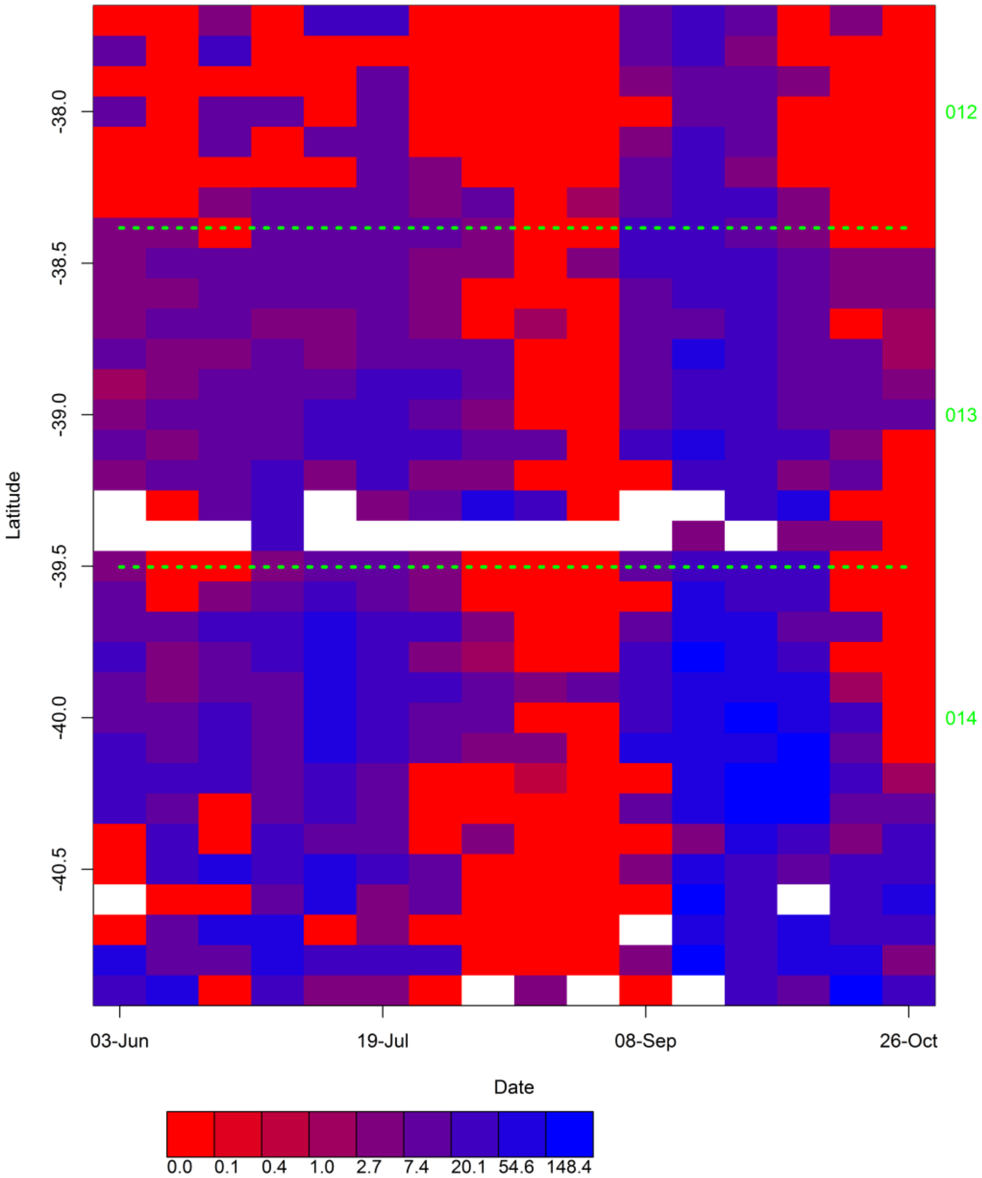

Figure 35: Spatio-temporal pattern of blue moki catch rates (median catch per trawl) from the tarakihi trawl fishery in Statistical Areas 012, 013 and 014 by 10-day period and 0.1 degree of latitude, 2007–08 to 2015–16 fishing years combined (Source: TCER format data). White blocks represent time-area cells with very limited data.

In the mid-1990s, there was a large increase in the MOK 1 TACC (from 200 t to 400 t) in response to increasing annual catches. Since then, there have been changes to the provisions associated with the management of bycatch species (bycatch trade-offs, deemed values, etc.). The catch balancing provisions changed in the early 2000s with the introduction of the Annual Catch Entitlement (ACE) provisions and increased deemed values associated with over-catch. It is unknown whether these changes resulted in an appreciable change in the operation of the BT-TAR2-North fishery that may have influenced the corresponding CPUE indices. However, there was no indication of a pronounced change in the CPUE indices corresponding to the introduction of these management provisions.

6 MANAGEMENT IMPLICATIONS

The results of the study were presented to the Southern Inshore Stock Assessment Working Group (SINSWG) on 14 March 2017. SINSWG rejected the SN-MOK1 and SN-MOK3 CPUE indices as robust monitoring tools that could be used to determine stock status against Harvest Standard reference points, for the following reasons:

1. High inter-annual variation in the CPUE indices due to the low precision of CPUE indices derived from limited catch/effort datasets from these small fisheries and/or inter-annual variation in the catchability (availability) of migrating fish.
2. Possible hyperstability as a result of fishing directed at dense schools of migrating fish.

Nevertheless, the WG did conclude that the SN-MOK1 and SN-MOK3 CPUE indices were likely to be broadly indicative of trends in abundance.

The two sets of set-net CPUE indices are considered to represent the component (or components) of the blue moki stock migrating northward prior to spawning and then returning southward following spawning. These CPUE indices indicate that there has been a general increase in the abundance of adult blue moki within MOK 3 and the southern area of MOK 1 from the late 1990s. This is consistent with the estimates of total mortality derived from the population age structure in 2005–06 that indicated fishing mortality on the adult population was less than natural mortality (M).

The BT-TAR2-North CPUE indices contrast the trend in the CPUE indices from the two set-net fisheries. The BT-TAR2-North CPUE indices declined from 1996–97 to 2002–03 and remained at a relatively low level during 2002–03 to 2008–09. The index increased in 2009–10 and remained at about that level during 2010–11 to 2015–16. These recent indices are at a level considerably lower than the indices from 1989–90 to 1996–97 (with the exception of the low 1992–93 index).

The BT-TAR2-North CPUE indices are considered to be predominantly comprised of a component of the blue moki stock that remains in the Gisborne–Mahia area throughout the year. The trawl catch is probably comprised of both immature and mature blue moki, although limited sampling of this component of the stock was conducted during the catch sampling programme. The SINSWG considered that the BT-TAR2-North CPUE indices potentially provide an index of abundance for the resident portion of the population.

The contrasting trends in the CPUE indices (SN-MOK1 and SN-MOK3 versus BT-TAR2-North) are indicative of differences in the stock dynamics (recruitment and/or exploitation) in the two components of the stock (resident and migrating). It was not considered feasible to amalgamate the three sets of CPUE indices to derive a composite set of abundance indices for the MOK 1&3 stock as the relative proportion of the stock biomass monitored by each CPUE series is unknown. Thus, the utility of the CPUE indices is limited to the monitoring of the two components of the stock separately.

7 ACKNOWLEDGMENTS

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APPENDIX 1: TABULATED CPUE INDICES

Table A1: Annual CPUE indices for the BT-TAR2-North (MOK 1), SN-MOK1 and SN-MOK3 fisheries and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals. The BT-TAR2-North indices are from the combined (delta-lognormal) CPUE model.

Fishing	BT-TAR2-North			SN-MOK1			SN-MOK3		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
89–90	1.442	0.958	2.097	1.159	0.837	1.605	0.975	0.780	1.121
90–91	1.315	0.893	1.843	0.982	0.710	1.360	0.803	0.662	0.974
91–92	1.720	1.189	2.415	1.048	0.738	1.487	0.838	0.675	1.040
92–93	0.676	0.441	0.993	1.262	0.864	1.843	1.151	0.963	1.376
93–94	1.220	0.784	1.771	1.053	0.668	1.660	0.840	0.705	1.003
94–95	1.606	1.079	2.281	0.665	0.439	1.008	0.898	0.750	1.076
95–96	1.406	0.949	1.980	0.783	0.543	1.131	0.987	0.803	1.211
96–97	1.687	1.155	2.372	0.715	0.527	0.971	0.620	0.510	0.754
97–98	1.295	0.824	1.876	0.636	0.468	0.865	0.526	0.436	0.635
98–99	1.347	0.898	1.939	0.596	0.445	0.798	0.647	0.525	0.798
99–00	1.079	0.712	1.510	0.597	0.441	0.807	0.427	0.347	0.526
00–01	0.937	0.632	1.290	0.714	0.529	0.964	0.764	0.628	0.930
01–02	0.860	0.588	1.247	0.765	0.557	1.050	0.981	0.798	1.205
02–03	0.526	0.352	0.746	0.742	0.532	1.036	0.669	0.554	0.807
03–04	0.669	0.430	0.965	0.768	0.531	1.111	0.636	0.521	0.777
04–05	0.627	0.433	0.868	1.357	0.954	1.931	0.754	0.603	0.944
05–06	0.585	0.401	0.808	1.193	0.816	1.744	0.770	0.630	0.941
06–07	0.562	0.378	0.793	0.990	0.671	1.462	1.077	0.874	1.328
07–08	0.590	0.408	0.840	1.149	0.782	1.688	1.115	0.903	1.378
08–09	0.624	0.432	0.856	1.076	0.734	1.578	1.477	1.189	1.836
09–10	0.879	0.623	1.199	0.706	0.469	1.063	1.153	0.929	1.430
10–11	0.966	0.659	1.345	1.061	0.708	1.590	1.248	1.014	1.535
11–12	0.786	0.536	1.107	1.526	1.027	2.268	1.454	1.191	1.775
12–13	1.002	0.704	1.384	0.728	0.474	1.119	1.353	1.106	1.655
13–14	0.956	0.641	1.382	1.464	0.933	2.298	1.416	1.116	1.796
14–15	0.741	0.512	1.018	1.321	0.871	2.005	1.463	1.160	1.845
15–16	0.895	0.607	1.286	1.941	1.226	3.075	1.957	1.557	2.459