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Fishery characterisation and Catch-Per-Unit-Effort indices for John dory in JDO 1

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John dory (*Zeus faber*) in JDO 1 is predominantly caught as a bycatch of the inshore trawl fisheries operating around the northern North Island. There is also a significant catch of John dory taken by the Danish seine fisheries in the Hauraki Gulf and, to a lesser extent, the Bay of Plenty.

Previous studies have partitioned JDO 1 into three sub-areas based on spatial differences in CPUE trends from the main fisheries: Bay of Plenty (BPLE), Hauraki Gulf and east Northland (HG-ENLD), and west coast North Island (WCNI). During the mid-1990s, annual catches from JDO 1 were at a historically high level and a substantial proportion (about 60%) of the total catch was taken from the HG-ENLD area. Annual catches from HG-ENLD fluctuated during the late 1990s–mid 2000s and then declined considerably during 2006/07–2011/12 and remained low through until 2016/17. Annual catches of John dory from WCNI and BPLE were generally lower than HG-ENLD and fluctuated about the average level over the last 22 years. Recent (2013/14–2016/17) annual JDO 1 catches were about 350 t, approximately half of the TACC level.

This study updates area-specific CPUE indices derived from the event based catch and effort records from the main northern inshore trawl fisheries, including data to the end of the 2016/17 fishing year. The CPUE indices were derived using a delta-lognormal approach that incorporated Generalised Linear Models of the occurrence of John dory in the trawl catch (binomial model) and the magnitude of positive John dory catches (lognormal model).

The area-specific CPUE indices are the accepted indices of abundance used for monitoring John dory abundance in JDO 1. The CPUE series for John dory in the HG-ENLD area steadily declined from the mid-2000s to reach a nadir in 2012/13. The CPUE indices gradually increased over the following four years and reached 65% of the target CPUE level in 2016/17. For the Bay of Plenty, the CPUE series also declined from 2008/09 to the lowest level in 2012/13 and then recovered over subsequent years; the 2016/17 index was at 85% of the target relative abundance level. For the west coast North Island, the CPUE indices declined from a high level over the last four years (from 2012/13) and the most recent index (2016/17) is at 79% of the Interim Target reference level.

For each of the three areas, the CPUE indices indicate that stock abundance has varied considerably over the study period. The trends in stock abundance are likely to have been strongly influenced by the variability in recruitment in each area.

1 INTRODUCTION

John dory (*Zeus faber*) in JDO 1 is predominantly caught by the inshore trawl and Danish seine fleets operating around the northern North Island. The Total Allowable Commercial Catch (TACC) for JDO 1 has been maintained at 704 t since 1989/90. During the early 1990s, annual catches from JDO 1 increased to about the level of the TACC and remained at that level during 1994/95–1998/99 (Fisheries New Zealand 2018). During the following years, annual catches have fluctuated with a general declining trend. Recent (2013/14–2016/17) annual catches were about 350 t, approximately half of the TACC level.

Bentley & Kendrick (2011) summarised trends in the JDO 1 fishery from 1989/90–2008/09. The analysis partitioned the JDO 1 fishstock into three areas: Bay of Plenty, Hauraki Gulf and east Northland (East), and west coast North Island (West). For each area, the trends in the main method fisheries were summarised and standardised CPUE analyses were conducted for the main fishing methods in each area (i.e. bottom trawl in all areas and Danish seine in the East and Bay of Plenty). The CPUE analyses were conducted using aggregated catch and effort data ("trip strata") and, for the trawl fisheries, separate analyses were conducted using the event based ("tow-by-tow") data which were available from a substantial proportion of the fleet from 1994/95 (Bentley & Kendrick 2011).

The analyses yielded different CPUE trends amongst the three areas, while trends for alternate CPUE series within each area tended to be similar. Bentley & Kendrick (2011) recommended a preferred CPUE series for the monitoring of John dory abundance in each area. In each of the three areas the preferred CPUE indices were based on data from inshore single trawl fisheries targeting a similar suite of species (snapper, John dory, trevally, tarakihi, red gurnard, and barracouta), and were based on "trip strata" analyses, thereby including all available data.

Dunn & Jones (2013) adopted similar fishery definitions to conduct an updated CPUE analysis for the three JDO 1 areas, extended to the 2010/11 fishing year. The standardised CPUE analyses derived combined delta-lognormal CPUE indices from the event based trawl catch and effort records. The resulting indices have been adopted by the Inshore Stock Assessment Working Group as the main indices for monitoring the abundance of the three components of the JDO 1 fishstock (Fisheries New Zealand 2018).

Langley (2015) updated the characterisation of the JDO 1 fishery and the three area specific trawl CPUE indices, extending the time-series to the 2013–14 fishing year. The study also derived CPUE indices from the Hauraki Gulf and Bay of Plenty Danish seine fisheries. The CPUE indices from the Danish seine fishery were comparable to the corresponding area specific trawl CPUE indices.

The current study provides a further update of the previous characterisations of the JDO 1 fishery to include catch and effort data from the 1989/90–2016/17 fishing years. For each of the three fishery areas, the time-series of area specific trawl CPUE indices was extended to include the 2016/17 fishing year. The study was funded by the Ministry for Primary Industries under Research Contract JDO2017-01.

2 DATA SETS

Commercial catch and effort data from the JDO 1 fishery were sourced from the Fisheries New Zealand database *warehou*. The analysis maintained the spatial stratification of JDO 1 adopted by Dunn & Jones (2013), including the extended definition of the WCNI fishery to encompass the north-western area of the JDO 2 Fishstock (specifically Statistical Areas 040 and 041). On that basis, the data extract was primarily based on fishing trips that landed either JDO 1 or JDO 2. The initial data set also included any additional fishing trips that targeted a range of inshore species (SNA, JDO, TRE, TAR, GUR, BAR, and FLA) within a statistical area valid for the three subareas of JDO 1 or the north-western area of JDO 2 (Statistical Areas 001–010 and 040–048) (Figure 1). For the qualifying trips, all effort data records were obtained regardless of whether or not John dory was landed. The estimated catch and landed catch records of all finfish species were sourced for the qualifying fishing trips. Data were complete to the end of the 2013/14 fishing year.

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. For the trawl and Danish seine fisheries, 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 landed greenweight that is obtained at the end of the trip was recorded on the Landings section of the CELR form.

From 1994/95, many of the inshore trawlers operating in JDO 1 reported fishing effort and catch data for individual trawls via the Trawl, Catch, Effort and Processing Return (TCEPR). In 2007/08, the Trawl, Catch and Effort Return (TCER) was introduced specifically for the inshore trawl fisheries and has been subsequently adopted by many of the vessels in the JDO 1 inshore trawl fishery. 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 TCEPR and TCER forms are reported at the end of a trip on the Catch Landing Return (CLR).

The Danish seine fleet continued to report catch and effort data via the CELR for the entire study period.

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.

2.1 Data processing

2.1.1 Fishery characterisation data set

The overall characterisation data set included all fishing trips that landed John dory (either JDO 1 or JDO 2) associated with fishing effort from within the statistical areas that approximate the area of JDO 1 or the north-western area of the JDO 2 (Statistical Areas 001–010 and 040–048) (Figure 1). The initial set of JDO landed catch records was screened to retain the records that represented the final destination of the JDO catch (destination codes L, A, C, E, and O). This resulted in a trivial reduction in the total JDO 1 landed catch included in the landings data set (Table 1). The landed catch from JDO 2 represented 9.9% of the total John dory catch within the characterisation data set.

Table 1: Total John dory (JDO 1 only) landed catch included in the fishery characterisation data set at each step of the catch grooming process.

Criterion	Landed catch (t)	Percent of total landed catch
All landing records	14 043.3	100.0%
Destination codes (L, A, C, E, O)	13 986.3	99.6%
Exclude landed catch outliers	13 644.7	97.2%
Associated effort records	13 482.5	96.0%

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 indicating a good correspondence between the landed catch and estimated catch (Figure 2).

Potentially erroneous landed catch records were identified based on the ratio of the trip landed catch to the aggregated estimated catch; i.e. where the ratio exceeded a factor of 4.0 and landed catches exceeded 250 kg. For these trips, the landed catches were corrected using the green weight equivalent of the processed catches. This resulted in a small reduction in the total JDO 1 catch included in the data set (Table 1).

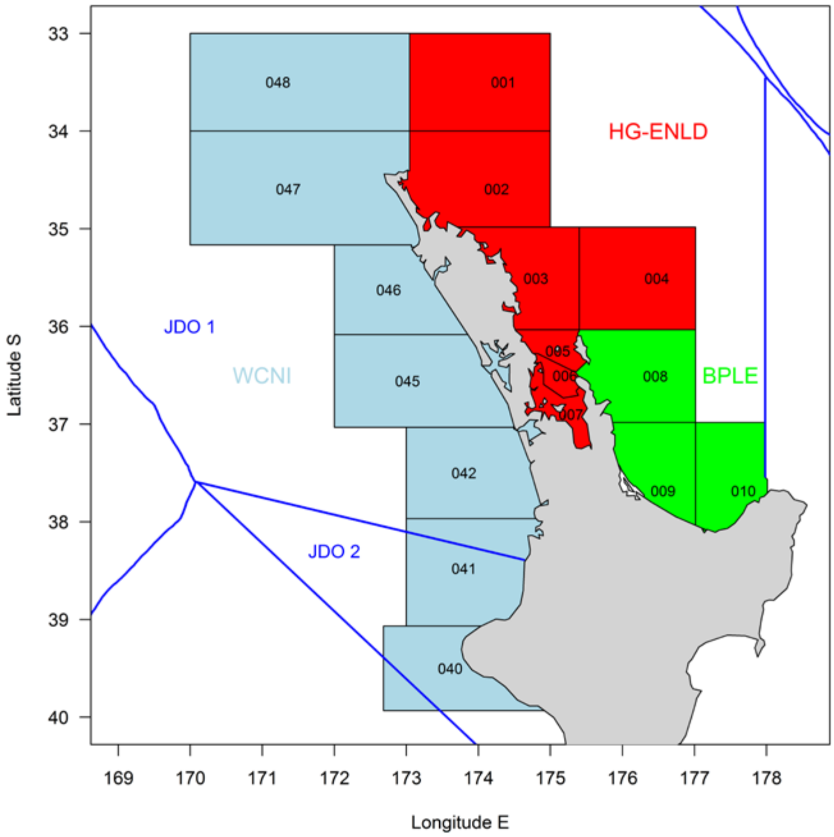

Figure 1: Map of JDO 1 fishery areas defined based on Statistical Areas.

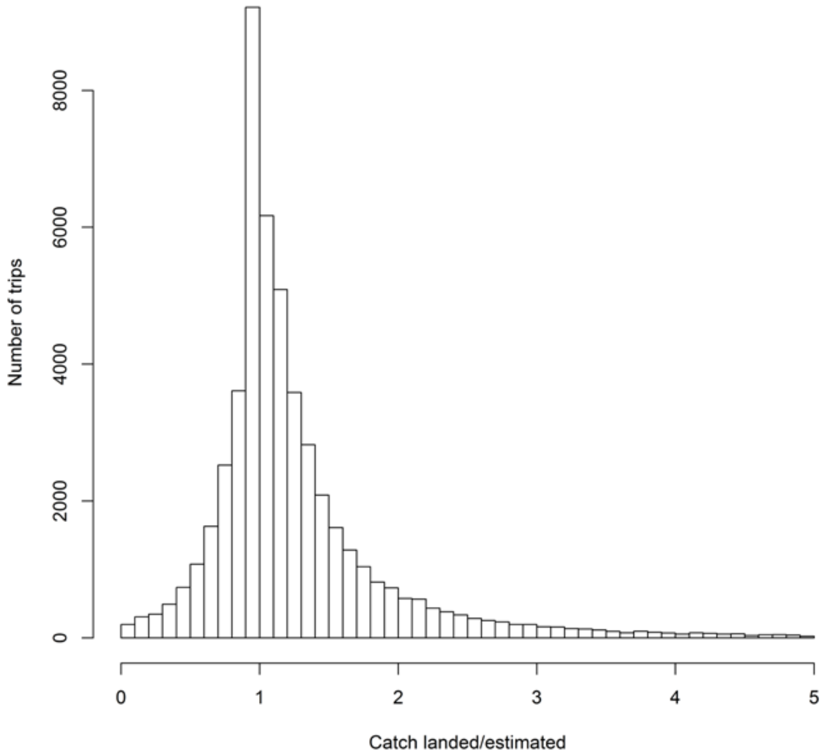

Figure 2: Ratio of the JDO 1 landed catch and the sum of John dory estimated catches from individual fishing trips.

During 1989/90–1993/94, most (93–99%) of the JDO 1 landed catch was associated with fishing effort recorded in the Catch Effort Landing Return (CELR) format (Figure 3). From 1994/95, many of the larger inshore trawl vessels operating in the snapper (SNA 1) fishery were required to complete the more detailed Trawl Catch Effort Processing Return (TCEPR) and, consequently, approximately 40–65% of the JDO 1 landed catch was reported from the associated Catch Landing Return (CLR) during 1994/95–2006/07 (Figure 3). In 2007/08, the Trawl Catch Effort Return (TCER) was introduced to facilitate the collection of the fishing event based catch and effort data from the inshore trawl fleet. Since 2007/08, the JDO 1 landed catch reported from trawl vessels has been relatively equally divided between vessels completing either the TCEPR or TCER form (about 35–40% of the catch from each). The remainder of the JDO 1 catch, primarily from the Danish seine fishery, has continued to be reported in the CELR format (25% of landed catch).

Trivial catches of John dory were reported from the Netting Catch Effort Return (NCER) and Lining Trip Catch Effort Return (LTCER) forms since the introduction of these reporting forms in 2006/07 and 2007/08, respectively (Figure 3).

For the main characterisation data set, catch and effort data from the qualifying 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 method specific fishing effort (number of trawls and hours fished) 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 for the vessel 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 data set to be influenced by the changes in reporting formats (from CELR to TCEPR and then TCER). Given the high proportion of the landed catch reported in the CELR format prior to 1994/95 it was considered important to maintain a consistent reporting format in the subsequent years.

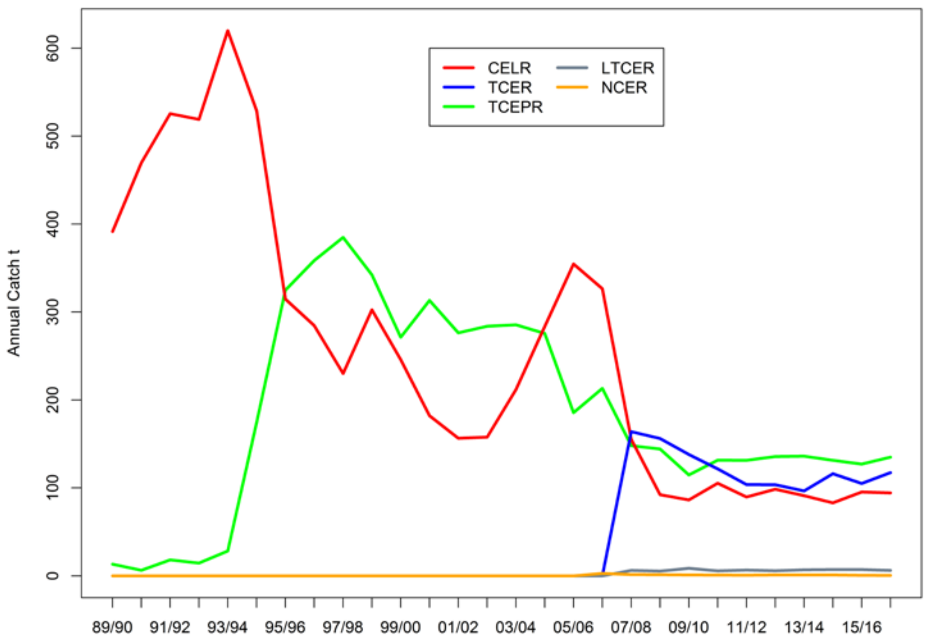

Figure 3: Total annual JDO 1 landed catch associated with the statutory catch and effort reporting forms.

Most (97.6%) of the trips with a landed catch of JDO 1 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 John dory (e.g. surface longline and troll) and/or target species that are unlikely to be associated with John dory (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 data set resulted in a small reduction in the overall quantity of JDO 1 landed catch (Table 1).

For 1989/90–2016/17, the JDO 1 landed catches included in the characterisation data set approximate the total annual JDO 1 catch reported in Fisheries New Zealand (2018) (Figure 4).

The estimated catches of John dory represented about 80–85% of the annual landed catches from 1989/90–2016/17 (Figure 4). Following the introduction of the TCEPR form in 1994/95, estimated catches were recorded from each trawl. Aggregating the trawl catches in a daily format, including the top five species only, reduced the annual John dory estimated catches by approximately 10–15% (Figure 4).

The landed catches of JDO 1 from each fishing trip were apportioned to the aggregate fishing effort records following the approach developed by Starr (2007). For fishing trips that recorded at least one top five estimated catch of John dory, the JDO landed catch was allocated to the individual fishing effort records in proportion to the individual estimated catches (represented 94.4% 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 trawls per day (represented 5.6% of total landed catch and 19.9% of positive catch records).

The characterisation data set was subdivided following the spatial stratification of JDO 1 adopted by Dunn & Jones (2013): West coast North Island (WCNI), Statistical Areas 040–048; Hauraki Gulf and east Northland (HG-ENLD), Statistical Areas 001–007; Bay of Plenty (BPLE) Statistical Areas 008–010 (Figure 1).

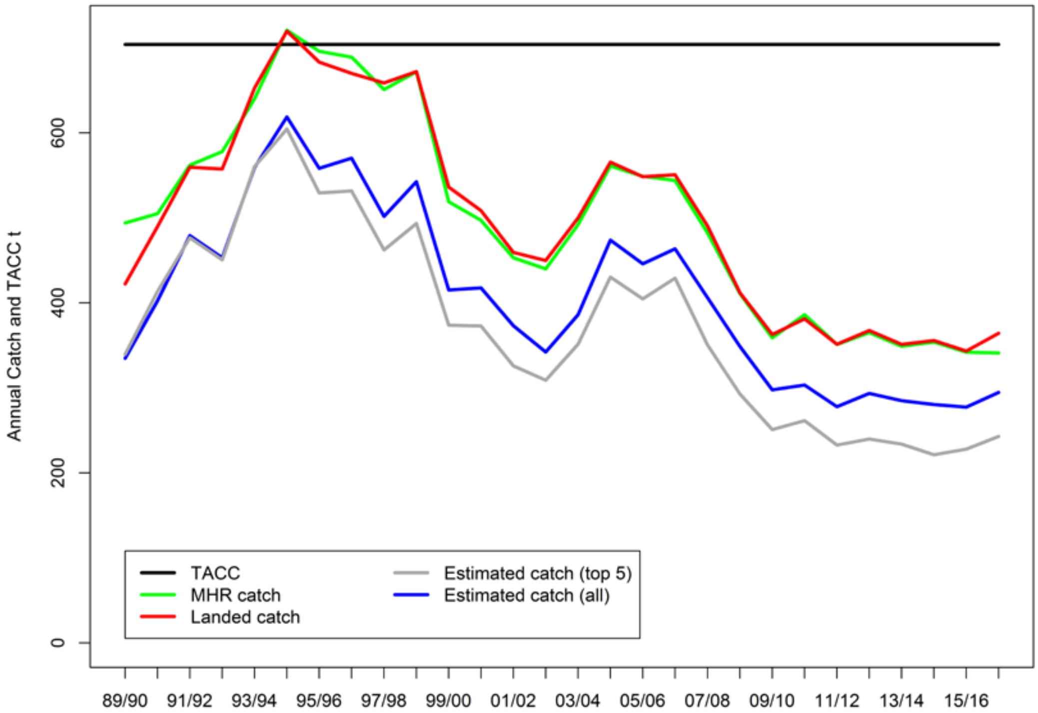

Figure 4: Comparison of total annual JDO 1 estimated and landed catches (t) by fishing year from vessel trip landing returns and the total reported landings (t) to the QMS (MHR).

2.1.2 Individual trawl data set

From 1994/95, fishing event based catch and effort data are available from the northern inshore trawl fleet, accounting for a substantial proportion of the total JDO 1 catch. Detailed fishing-event based catch and effort data were collected in TCEPR format from 1994/95 and in both TCEPR and TCER formats from 2007/08 (Figure 3). The three sets of area specific CPUE indices are based exclusively on the event based data from the single trawl fishery.

For this study, the fishery definitions of Dunn & Jones (2013) and Langley (2015) were applied to derive a composite TCEPR and TCER trawl catch and effort data set. The initial data set included all TCEPR and TCER effort data from fishing trips that included at least one single trawl that targeted one of the suite of inshore species (SNA, JDO, TRE, TAR, GUR, BAR) within the specified Statistical Areas (001–010 and/or 040–048).

In recent years, the northern inshore trawl fleet has been trialling modified trawl gear developed by Precision Seafood Harvesting (PSH). From 2015/16, single trawls deploying the PSH gear have been designated the PRB gear code for catch and effort reporting. These trawl records were included in the initial trawl data set. However, due to differences in the performance of the PSH trawl gear the records were not included in the CPUE analyses (i.e. BT only).

The TCER records the details of individual trawls including start and end time, target species, trawl speed, and the location and bottom depth at the start of a trawl. This represents a comparable subset of the fishing event data recorded using the TCEPR format. A notable difference between the two formats is that the TCER form has the facility to record the estimated catch of the eight main species caught from the trawl, while only the trawl catch of the five main species can be recorded in the TCEPR format. This difference has the potential to result in a change in the reporting of the catch of the minor species, potentially increasing the number of small catches reported in the TCER format and, thereby, reducing the proportion of zero catch records. In turn, this has the potential to influence the allocation of the landed catches amongst fishing events from a fishing trip as this is usually based on the corresponding estimated catches from individual trawls.

For the composite TCEPR/TCER data set, estimated catches of John dory were associated with the individual trawl records and the ranking of John dory amongst the estimated species catches from the individual trawl was determined based on the reported estimated catch weight. Overall, 90% of the John dory estimated catch from the TCER data was included amongst the five main ("top 5") species reported, representing 76% of the TCER trawls that reported an estimated catch of John dory. Correspondingly, John dory was reported as the 6–8th ranked species for 24% of the TCER trawls that reported an estimated catch of John dory (Figure 5). The median catch of John dory reported amongst the 6–8th ranked species was 6 kg compared to a median catch of 25 kg in the "top 5" species.

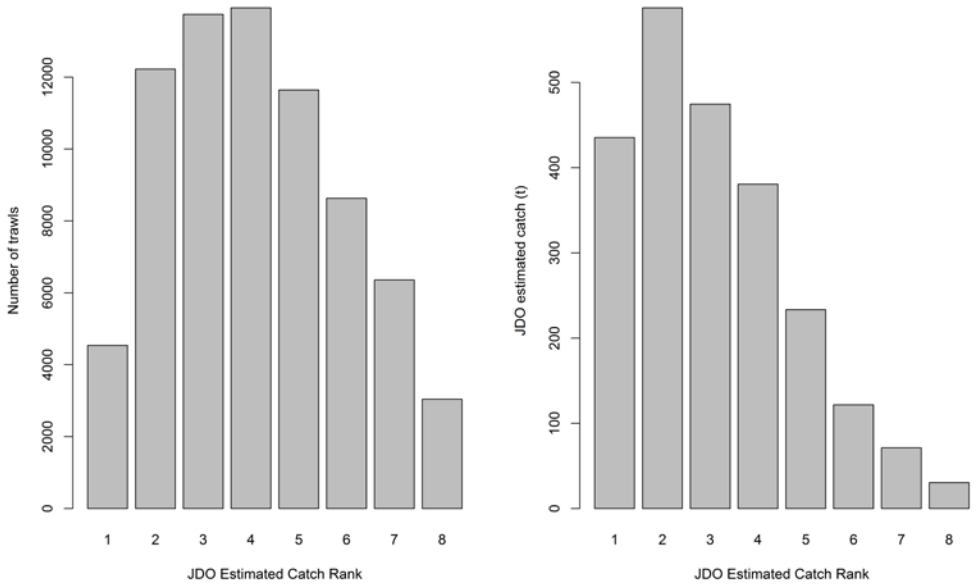

Figure 5: Distribution of John dory effort records (left) and estimated catch (right) from individual TCER trawl records, ranked by the catch weight of all species recorded from each trawl. The data set includes all trawl records where an estimated catch of JDO was reported.

For comparability with the TCEPR trawl records, John dory estimated catches from TCER records that were ranked lower than the 5th largest catch (i.e. the 6–8th ranked species) were reassigned an estimated catch of zero (0 kg). For each fishing trip, the aggregated top 5 estimated catch of John dory was determined. The landed catch of John dory from each fishing trip (from Section 2.1.1) was then allocated amongst the trawl records from the respective fishing trips in proportion to the estimated catches of John dory (top 5 species only). Most of the qualifying fishing trips included at least one trawl with an estimated catch of John dory, enabling 97% of the landed catches to be allocated in this manner. For the remainder of the trips (with no estimated catches of John dory), the landed catches were distributed equally amongst the individual trawl records (typically catches of less than 4 kg).

The trawl based catch and effort data set was utilised to augment the fishery characterisations by providing information about the spatial distribution of the trawl catch of John dory for each of the main fisheries. The data set was also used to configure the area specific trawl CPUE data sets for each fishery area.

3 FISHERY CHARACTERISATION

From the early 1990s, annual catches of JDO 1 increased to about the level of the TACC and remained at about that level during 1994/95–1998/99 (Figure 4). Annual catches fluctuated over the subsequent years; catches were relatively low in 2001/02–2012/13, recovered in 2004/05–2006/07 and then declined considerably during 2006/07–2009/10. Recent (2011/12–2016/17) annual catches were about 350 t, approximately half of the TACC level (of 704 t) (Figure 4).

The overall trends in JDO 1 annual catches are largely driven by the annual catch from the HG-ENLD area. During the 1990s, this area accounted for about 60% of the total JDO 1 catch; however, during 2010/11–2016/17 the HG-ENLD area only accounted for 35–40% of the total catch (Figure 6). The secondary peak in the total catch during 2005/06–2007/08 was also attributable to catches from the HG-ENLD area.

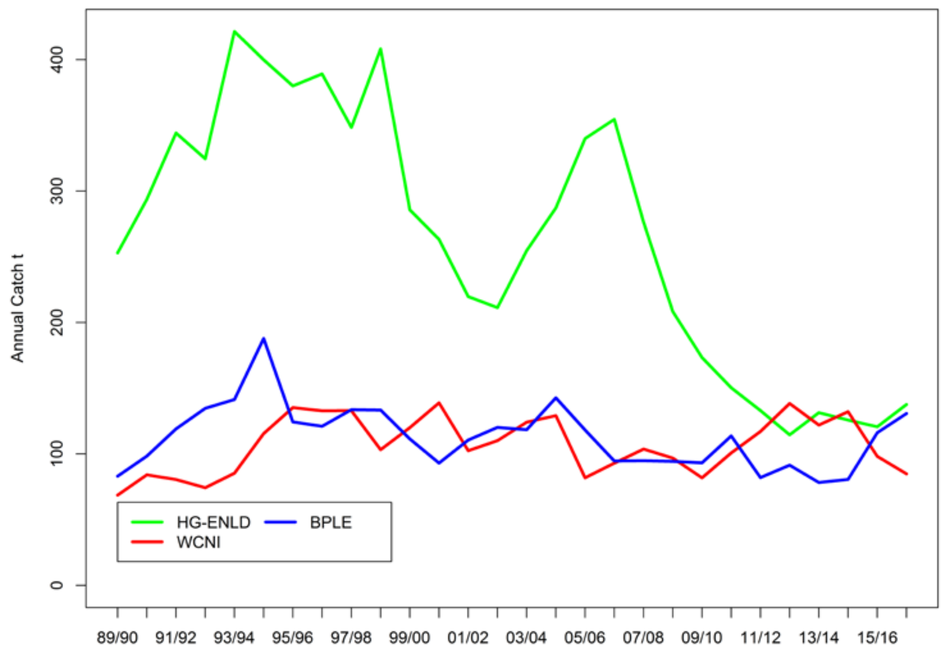

Figure 6: Annual catches of John dory by fishery area.

The WCNI and BPLE areas each accounted for about 20% of the annual JDO 1 catches during the late 1990s. Annual catches from the BPLE area tended to follow the trend in catches from the HG-ENLD area, increasing during the early 1990s to reach a peak in 1994/95 and generally declining over the subsequent years to 2014/15 (Figure 6). More recently, annual catches from the BPLE area increased to account for 37% of the total catch in 2016/17 (approx. 130 t) (Figure 6).

Annual catches from the WCNI area increased from 1993/94 to 1995/96 and fluctuated about the higher level until 2004/05 (Figure 6). Annual catches were lower during 2005/06–2009/10 and then returned to the higher level in 2012/13–2014/15 and then declined in the two subsequent years. The WCNI area accounted for 24% of the annual JDO 1 catch in 2016/17 (Figure 6).

The following sub-sections present separate fishery characterisations for each of the three fishery areas.

3.1 Bay of Plenty (BPLE)

Within the BPLE area, John dory was predominantly caught by single bottom trawl throughout the 1990s and 2000s with the method accounting for 70–80% of the annual catches (Figure 7). The annual catch from the single trawl fishery fluctuated about 80–100 t during this period but declined steadily from the mid 2000s to about 40 t in 2012/13–2015/16. Single trawl catches, including catches from PSH trawl gear, increased over the following two years to approach 80 t in 2016/17 (Appendix 1 Table A1). The PSH gear accounted for approximately 15% of the total catch in 2016/17 (equating to 24% of the trawl catch).

The remainder of the catch was mainly taken by pair trawl and Danish seine. Annual catches from the Danish seine method increased over the last decade from about 20 t during 2002/03–2007/08 to approximately 50 t in 2015/16 and 2016/17 (Figure 7). Limited pair trawling has occurred since the early 1990s.

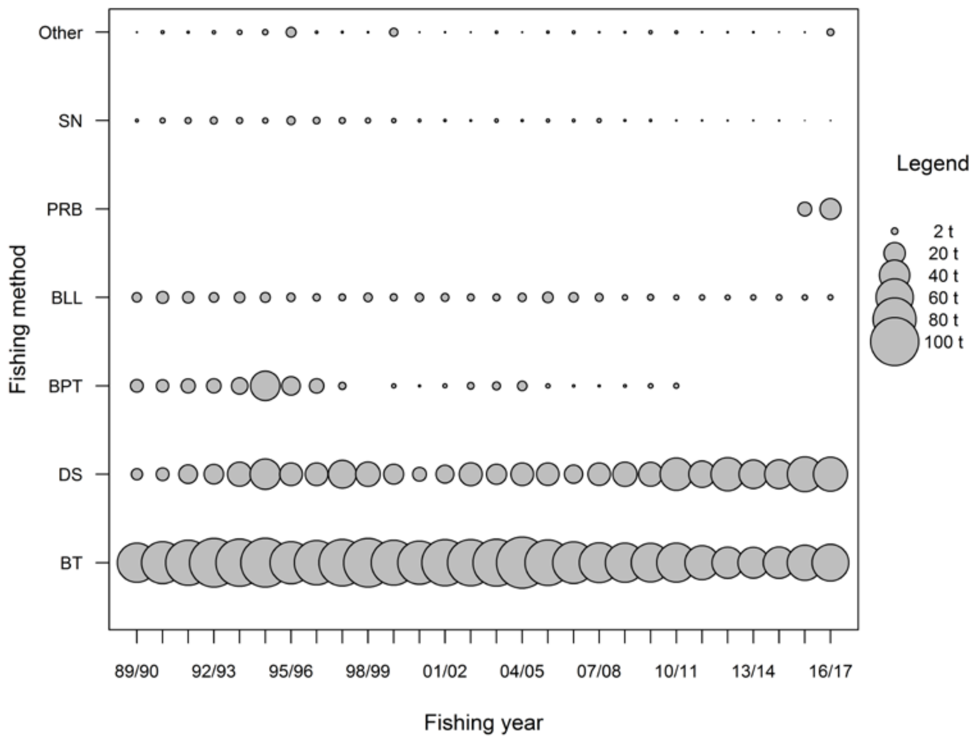

Figure 7: Landed catch of John dory from the Bay of Plenty fishery, by fishing method and fishing year.

The John dory catch from the single trawl fishery was taken by trawls targeting a range of species, principally snapper, John dory, trevally and tarahiki (Figure 8). The relative proportion of the John dory catch taken by the snapper target trawls declined during the 1990s with a corresponding increase in the proportion taken by the trevally and John dory target fishery species (Figure 8). In 2005/06, a considerable proportion of the John dory catch was taken by trawls targeting red gurnard; however, limited catch was taken from this fishery in subsequent years.

Catches of John dory from the Danish seine fishery were predominantly taken as a bycatch of snapper and red gurnard (Figure 8). A small John dory catch is taken by the snapper longline fishery and minor catches are also taken by the set net method.

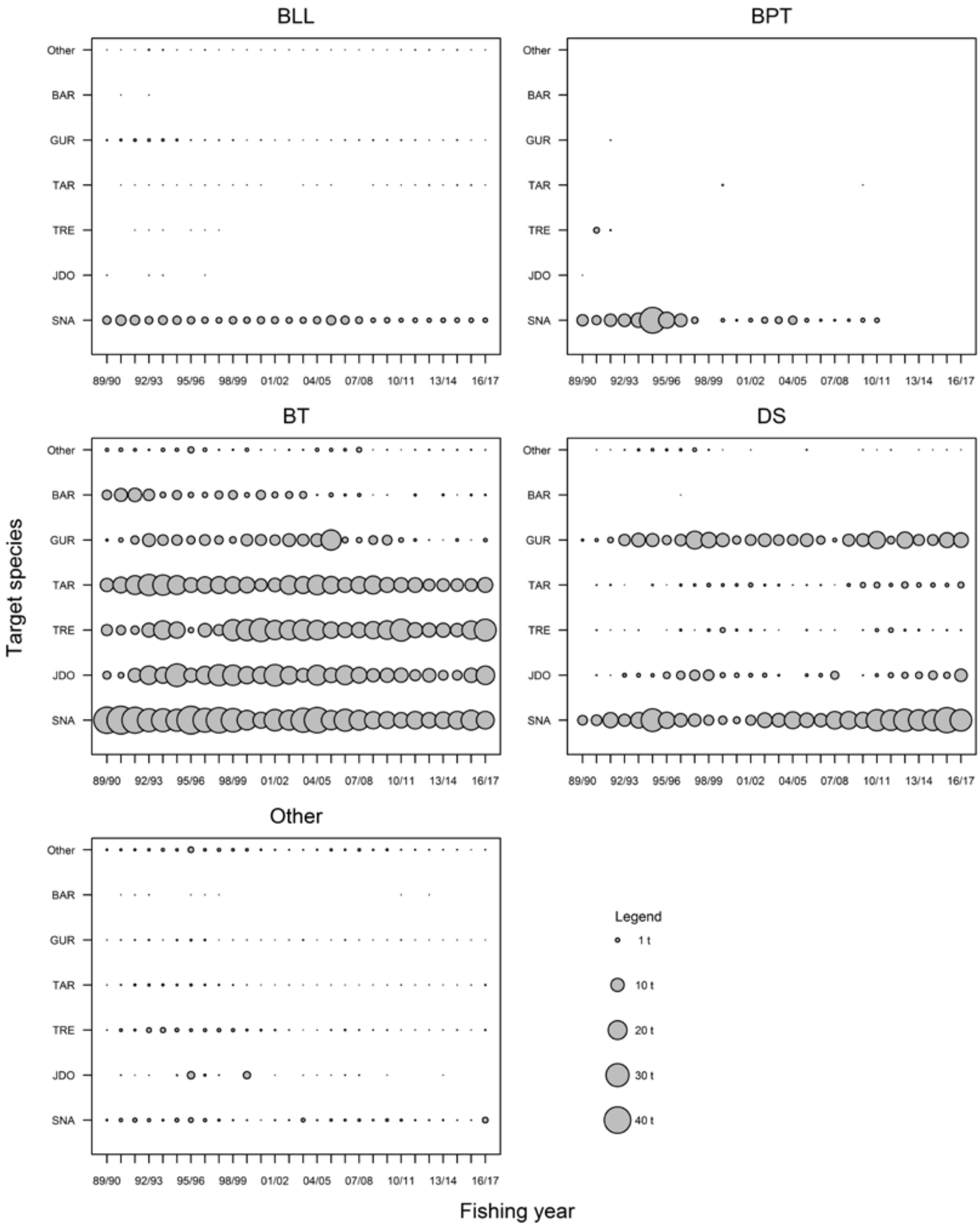

Figure 8: Landed catch of John dory from the Bay of Plenty fishery, by fishing method, target species and fishing year. The BT method includes catches from the PRB method (i.e. PSH gear).

The data collected from TCER and TCEPR forms during 1994/95–2016/17 were used to characterise the depth distribution of the John dory catch from the BPLE single trawl fishery. Most of the catch was taken in the 20–120 m depth range corresponding to the depth range of the main target species (snapper and trevally) (Figure 9). The peak in catches at a depth of 100 m corresponds to a large number of trawls being conducted along the 100 m depth contour. Target John dory trawls tended to catch the species in a more restricted depth range (40–100 m). Overall, catches of John dory were minimal from trawls in depths greater than 150 m (Figure 9) despite a considerable proportion of fishing effort (primarily targeting tarakihi) occurring in depths exceeding 150 m.

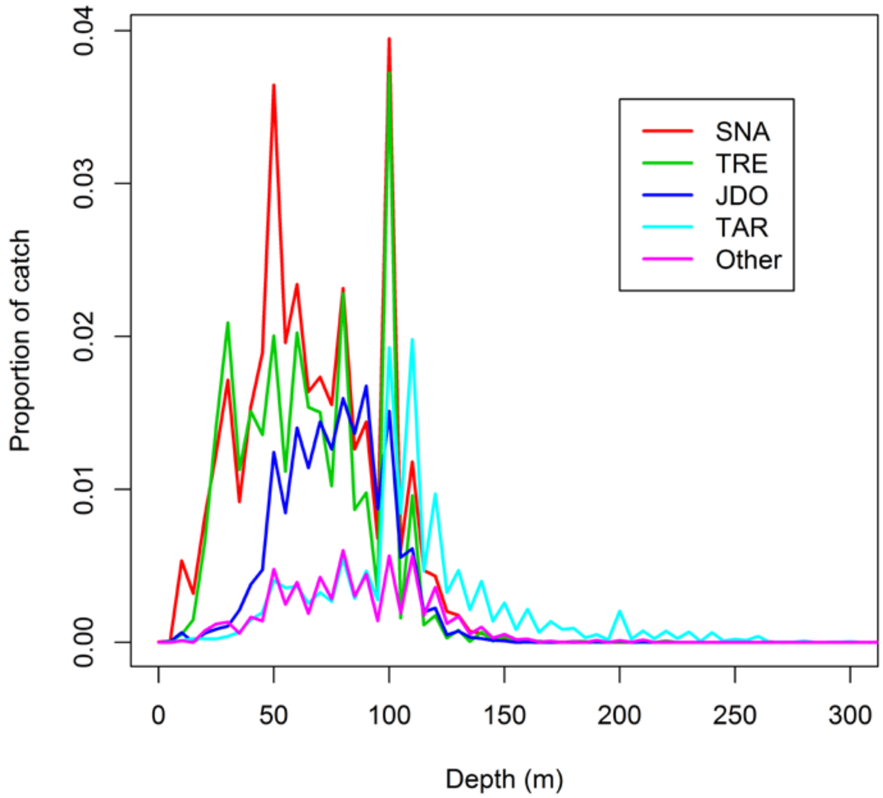

Figure 9: Proportional depth distribution of John dory single trawl (BT and PRB) catch from the BPLE fishery by bottom depth (5 metre depth intervals) and target species from 1994/95 to 2016/17 for the main bottom trawl target species (TCEPR or TCER records, all years combined).

The catch of John dory by the main fishing methods (BT and DS) is distributed throughout the Bay of Plenty (Figure 10). Overall, the John dory trawl catch is relatively evenly distributed throughout the Bay of Plenty within the 30–120 m depth range (Figure 11), although there are a number of localised areas which have supported higher catches, specifically to the east of Great Barrier Island, westward of Mayor Island, and in the eastern Bay of Plenty off the coast from Opotiki.

The recent increase in the Danish seine catch has primarily occurred in the central and eastern area of the Bay of Plenty (Statistical Areas 009 and 010), while annual catches have remained relatively stable in the western Bay of Plenty (008) (Figure 10).

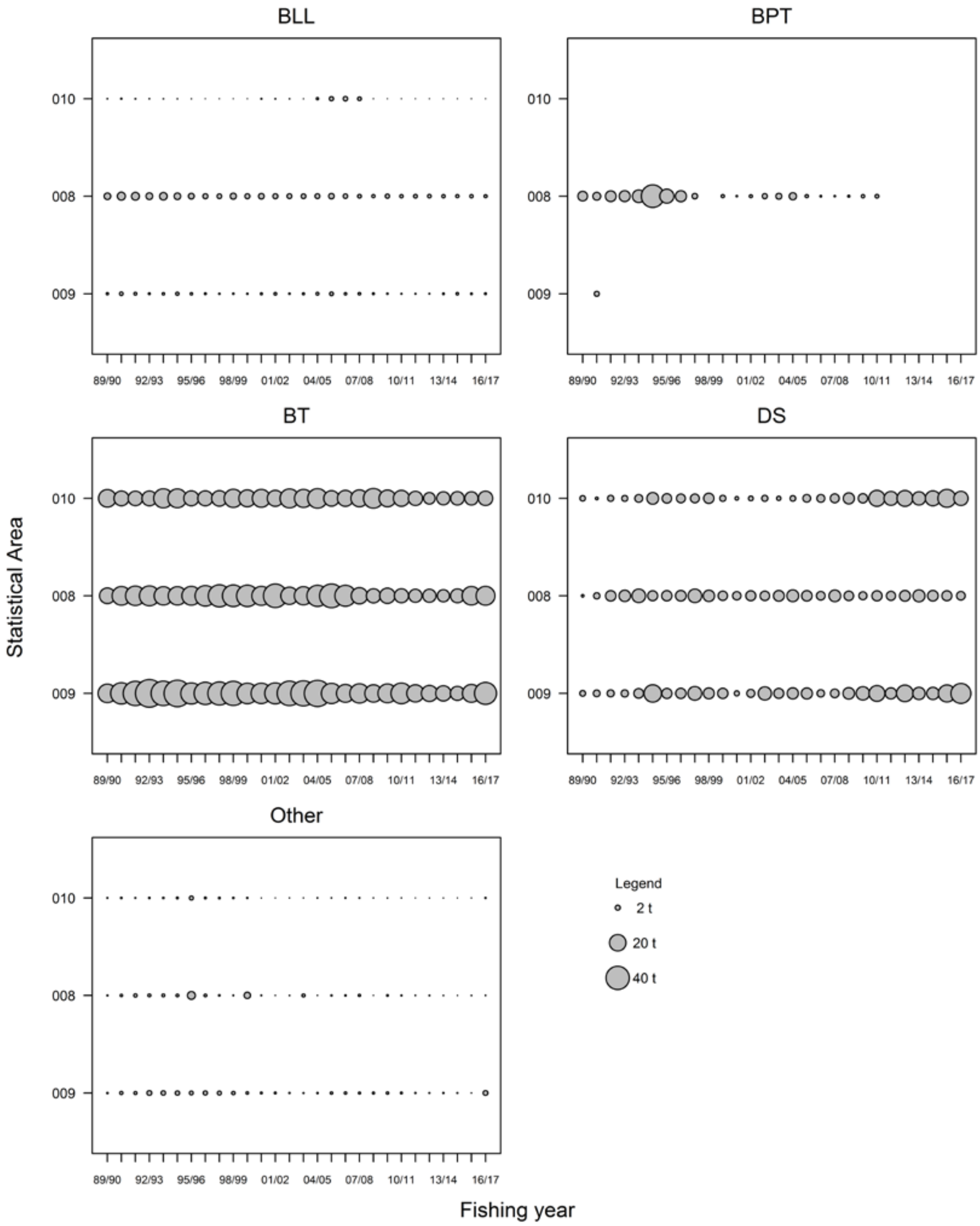

Figure 10: Annual distribution of John dory catch from BPLE by fishing method and statistical area. The area of the circle is proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

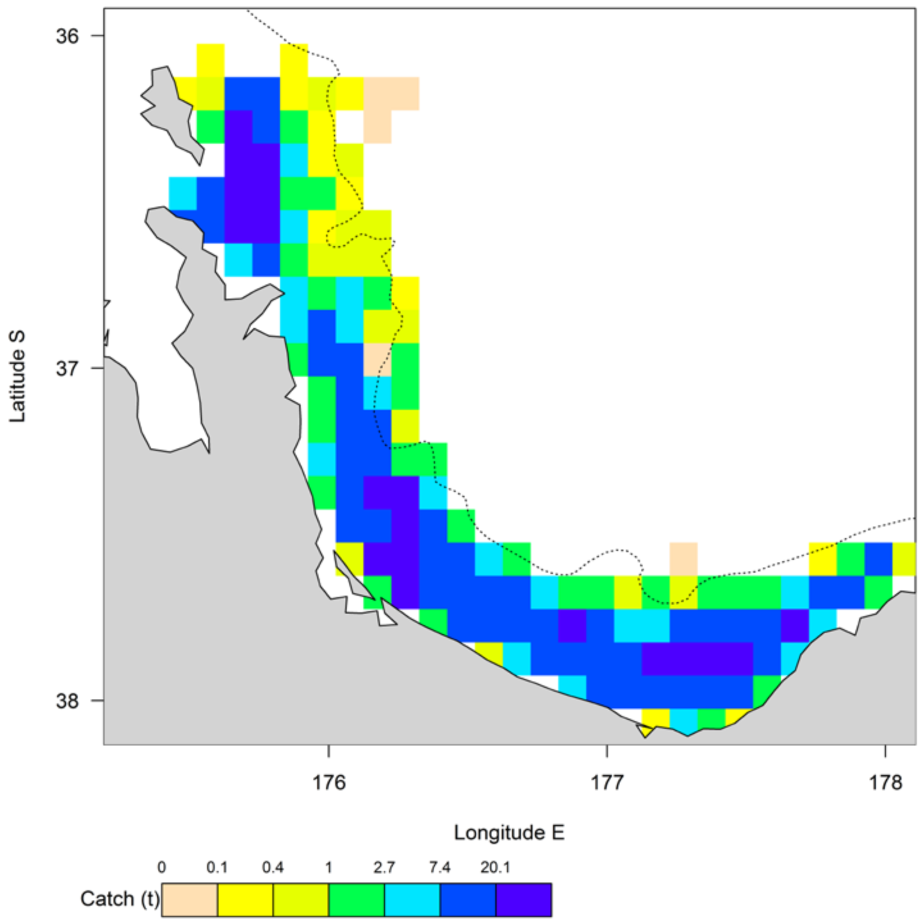

Figure 11: Spatial distribution of John dory single trawl catch (BT and PRB) from the Bay of Plenty for 1994/95–2016/17 fishing years (derived from TCER and TCEPR records). The catch data are aggregated by 0.1 lat/long spatial cells. The dashed line represents the 200 m depth contour.

The seasonal distribution of the catch of John dory from the trawl fishery has changed considerably over the study period (Figure 12), primarily in response to changes in the seasonal distribution of fishing effort. Trawl catch rates of John dory tend to be highest during December–March and low during April–June. During the early 1990s, trawl effort was concentrated during June–September and, consequently, most of the John dory catch was taken during that period (Figure 12). Since then, trawl effort was more evenly distributed throughout the year and a higher proportion of the annual catch was taken during December–March (Figure 12). From 2006/07–2016/17, this period accounted for 40–45% of the annual catch.

A similar pattern is evident for the Danish seine fishery. During the 1990s, fishing effort was concentrated during June–September resulting in moderate catches during that period (Figure 12). From 2007/08, fishing effort was more evenly distributed throughout the year and most of the Danish seine catch was taken during October–March (Figure 12) when catch rates are relatively high.

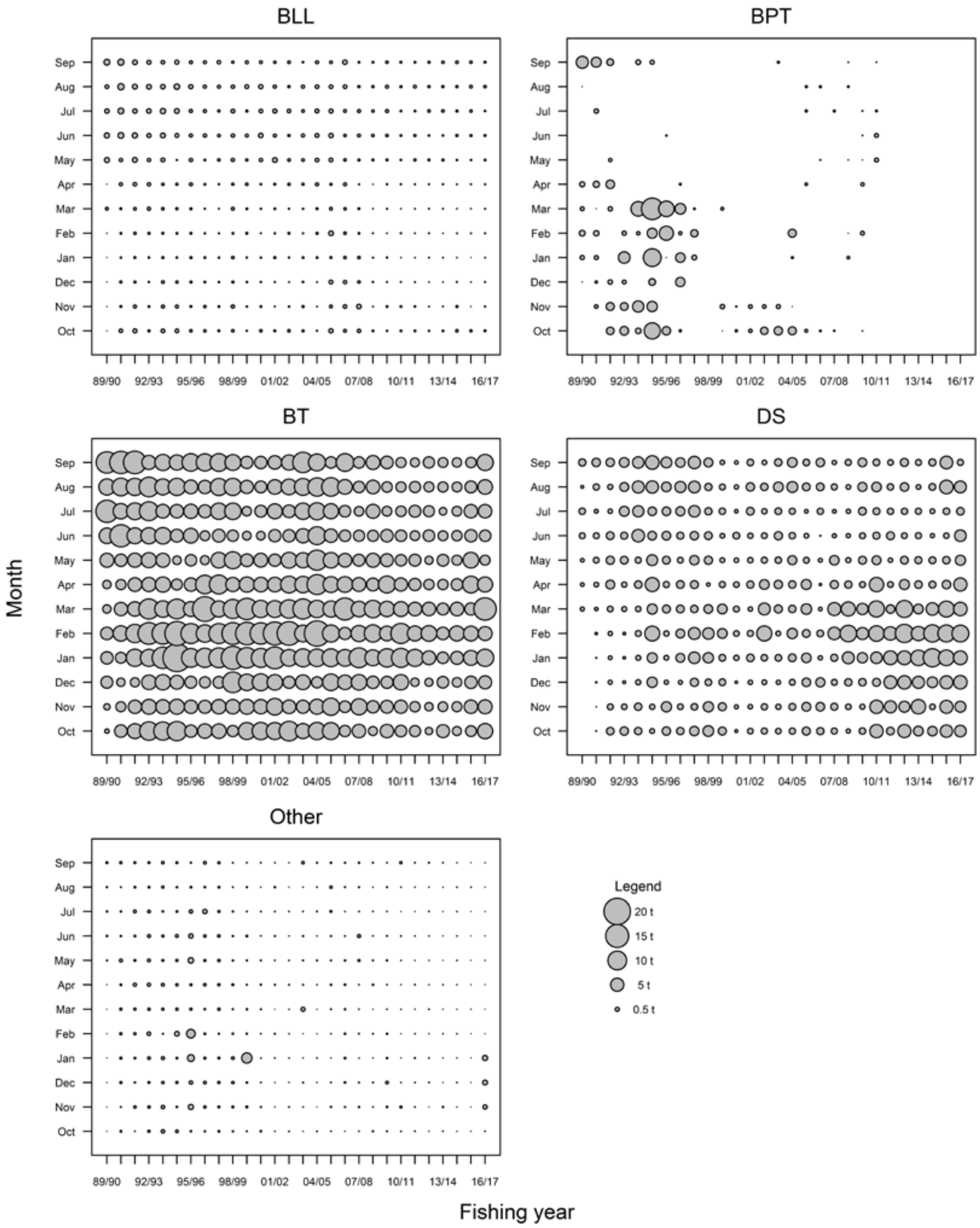

Figure 12: The monthly distribution of John dory catches from BPLE by method and fishing year. Circle areas are proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

3.2 Hauraki Gulf and east Northland (HG-ENLD)

The catch from the HG-ENLD fishery was predominantly taken by the single bottom trawl (61%) and Danish seine (31%) methods (Figure 13). The annual catch from both methods declined from the late 1990s, recovered during the mid-2000s and then continued to decline over the remainder of the period. In recent years (2012/13–2016/17), annual catches from both methods were 34% of the annual catch from the period of peak catch during the mid-1990s (1993/94–1998/99) (Appendix 1 Table A2).

For both the single trawl and Danish seine fisheries, John dory is predominantly caught either by target fishing or associated with targeting snapper (Figure 13). For the single trawl fishery, annual catches were dominated by snapper target fishing during the early 1990s. However, since the mid-

1990s 50–65% of the annual John dory catch from the single trawl fishery was taken from target trawls.

Conversely, for the Danish seine fishery, most of the catch taken during 1996/97–2006/07 was from target sets, while catches from the more recent period were attributed to sets targeting snapper.

Minor catches of John dory from HG-ENLD have also been taken by the snapper longline fishery and as a bycatch of the pair trawl fishery (Figure 13).

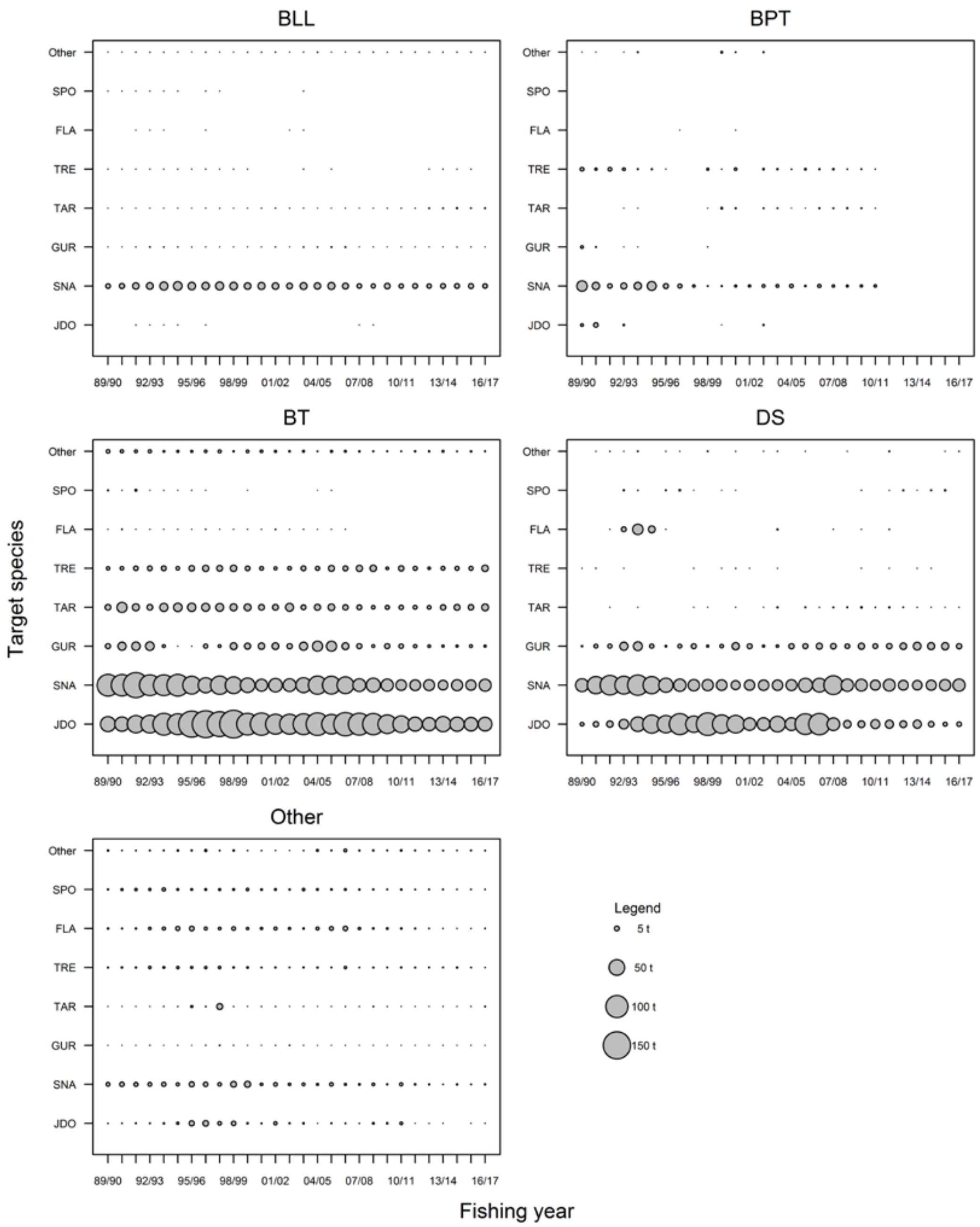

Figure 13: Landed catch of John dory from the HG-ENLD fishery by fishing method, target species and fishing year. The BT method includes catches from the PRB method (i.e. PSH gear).

Most of the John dory catch from the Danish seine fishery is taken from the central Hauraki Gulf (Statistical Area 006) (Figure 14), while the single trawl catch is predominantly taken from the outer Hauraki (005) and outer Bream Bay (003) (Figure 14 and Figure 15). Limited catch of John dory was taken by the single trawl fishery operating in the north of the HG-ENLD area (Great Exhibition Bay, Statistical Area 002).

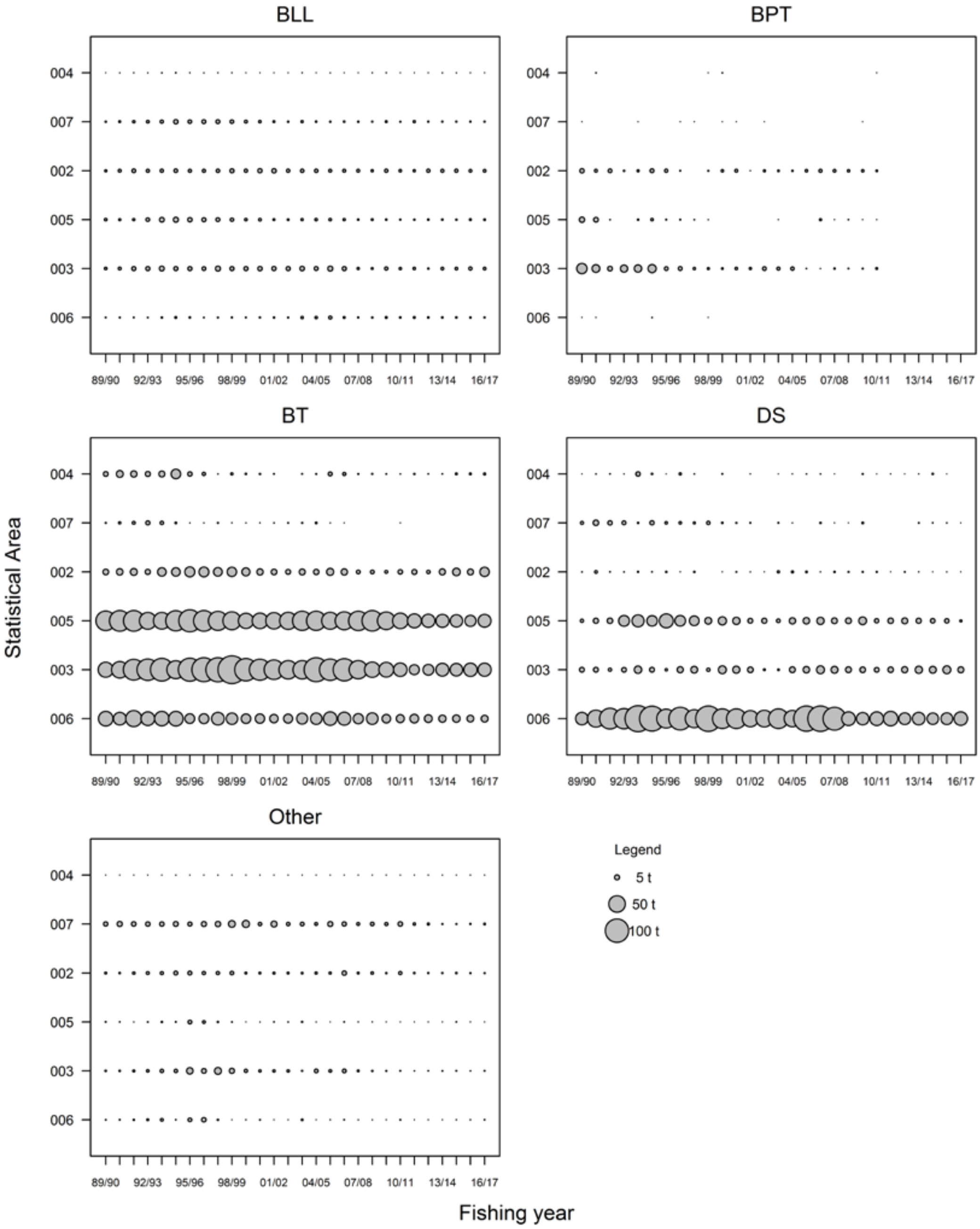

Figure 14: Annual distribution of John dory catch from HG-ENLD by fishing method and statistical area. The area of the circle is proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

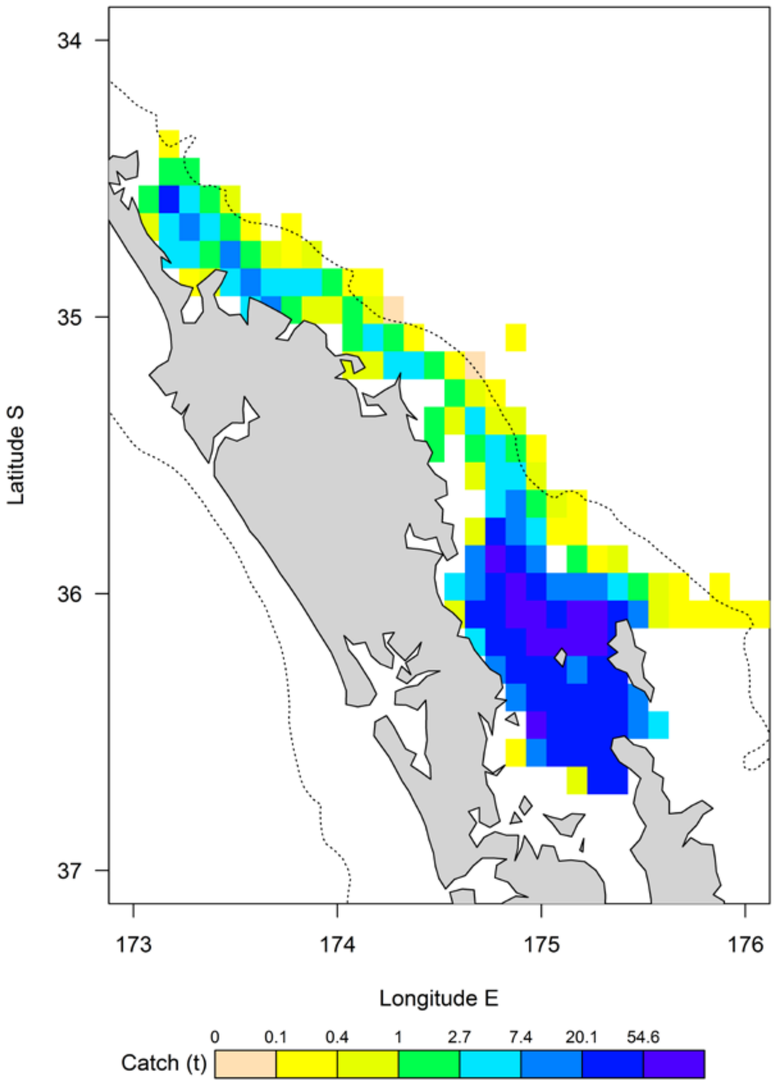

Figure 15: Spatial distribution of John dory single trawl (BT and PRB) catch from the HG-ENLD for 1994/95–2016/17 fishing years (derived from TCER and TCEPR records). The catch data are aggregated by 0.1 lat/long spatial cells. The dashed line represents the 200 m depth contour.

Most of the John dory trawl catch was taken in the 40–100 m depth range by the target fishery (Figure 16). The distribution of John dory catch from the snapper trawl fishery was concentrated about the 50 m depth contour. The depth distribution of catches is truncated at about 45–50 m which approximates the depth of the outer boundary of the Hauraki Gulf trawl exclusion zone.

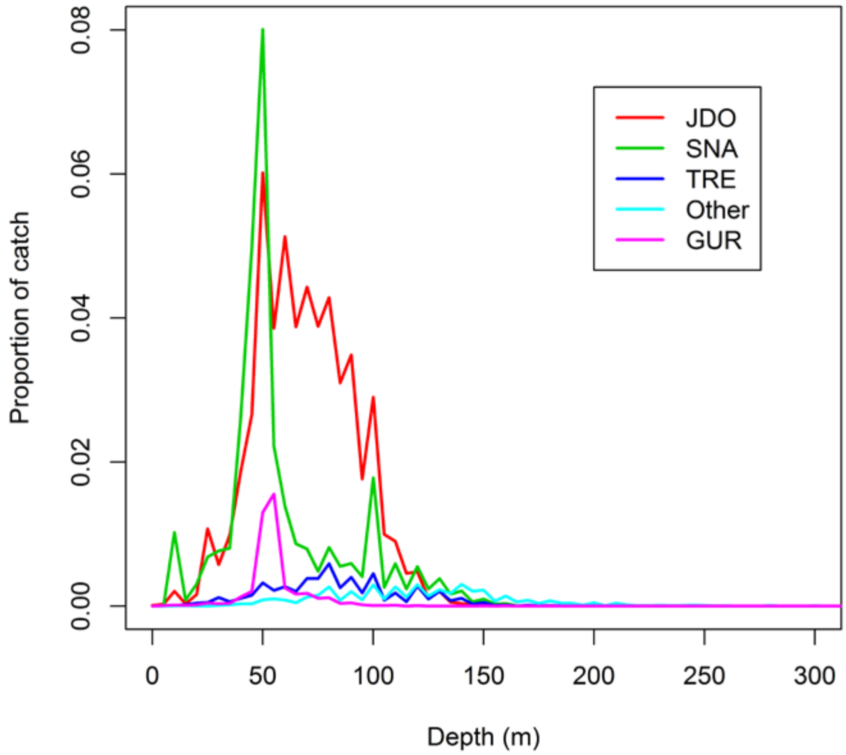

Figure 16: Proportional depth distribution of John dory single trawl catch (BT and PBR gear codes) from the HG-ENLD fishery by bottom depth (5 metre depth intervals) and target species from 1994/95 to 2016/17 for the main bottom trawl target species (TCEPR or TCER records, all years combined).

Monthly catches of John dory from the HG-ENLD single trawl fishery were generally highest during December–March and low during April–June. Since 2009/10, John dory catches from the single trawl fishery were increasingly concentrated during December–March (Figure 17).

The seasonal distribution of catch from the Danish seine fishery was variable amongst years (Figure 17). The variability in monthly catch from the Danish seine fishery is related to variability in the period of higher catch rates, rather than changes in the monthly distribution of fishing effort. This indicates that the effective targeting of John dory by the Danish seine method can be conducted throughout the year.

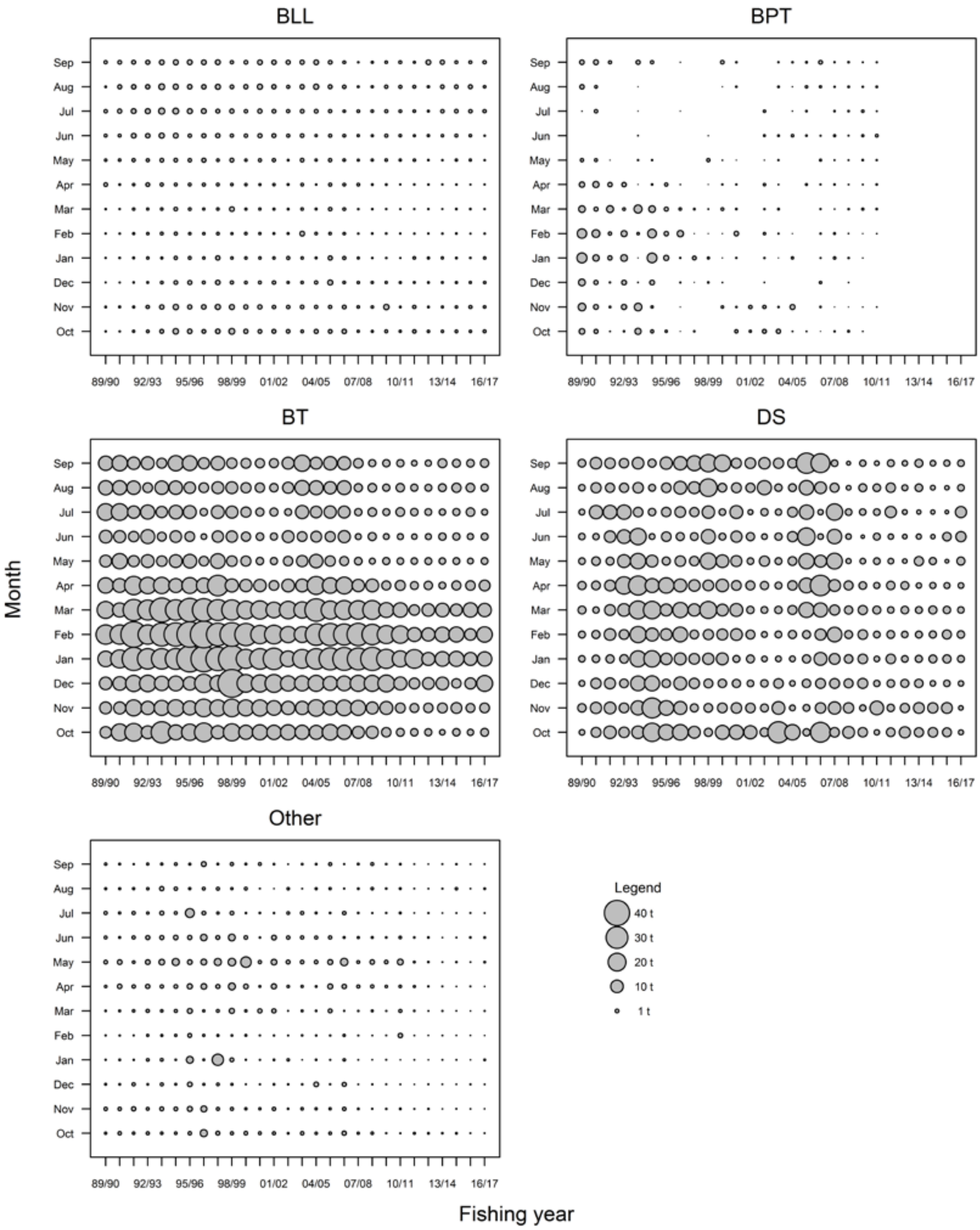

Figure 17: The monthly distribution of John dory catches from the HG-ENLD fishery by fishing method and fishing year. Circle areas are proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

3.3 West coast North Island (WCNI)

Most of the catch from the WCNI John dory fishery was taken by the single bottom trawl method (83%) with minor catches also taken by the pair trawl (7%) and Danish seine (3%) methods (Figure 18 and Appendix 1 Table A3). The trawl catch is predominately a bycatch from trawls targeting a range of inshore species: trevally, snapper, red gurnard and, to a lesser extent tarakihi. Since 2004/05, John dory catches from the snapper target trawl fishery have been relatively low, while catches from trawls targeting trevally and red gurnard have increased (Figure 18). This component of the fishery accounted for most of the increased level of the overall catch from the WCNI fishery during 2011/12–2013/14. Since then, there was an increase in the John dory catch from target trawls and from trawls targeting tarakihi.

Most of the Danish seine catch was taken as a bycatch of sets targeting red gurnard (Figure 18). A minor component of the John dory catch is taken as a bycatch of the mid-water trawl fishery targeting jack mackerel.

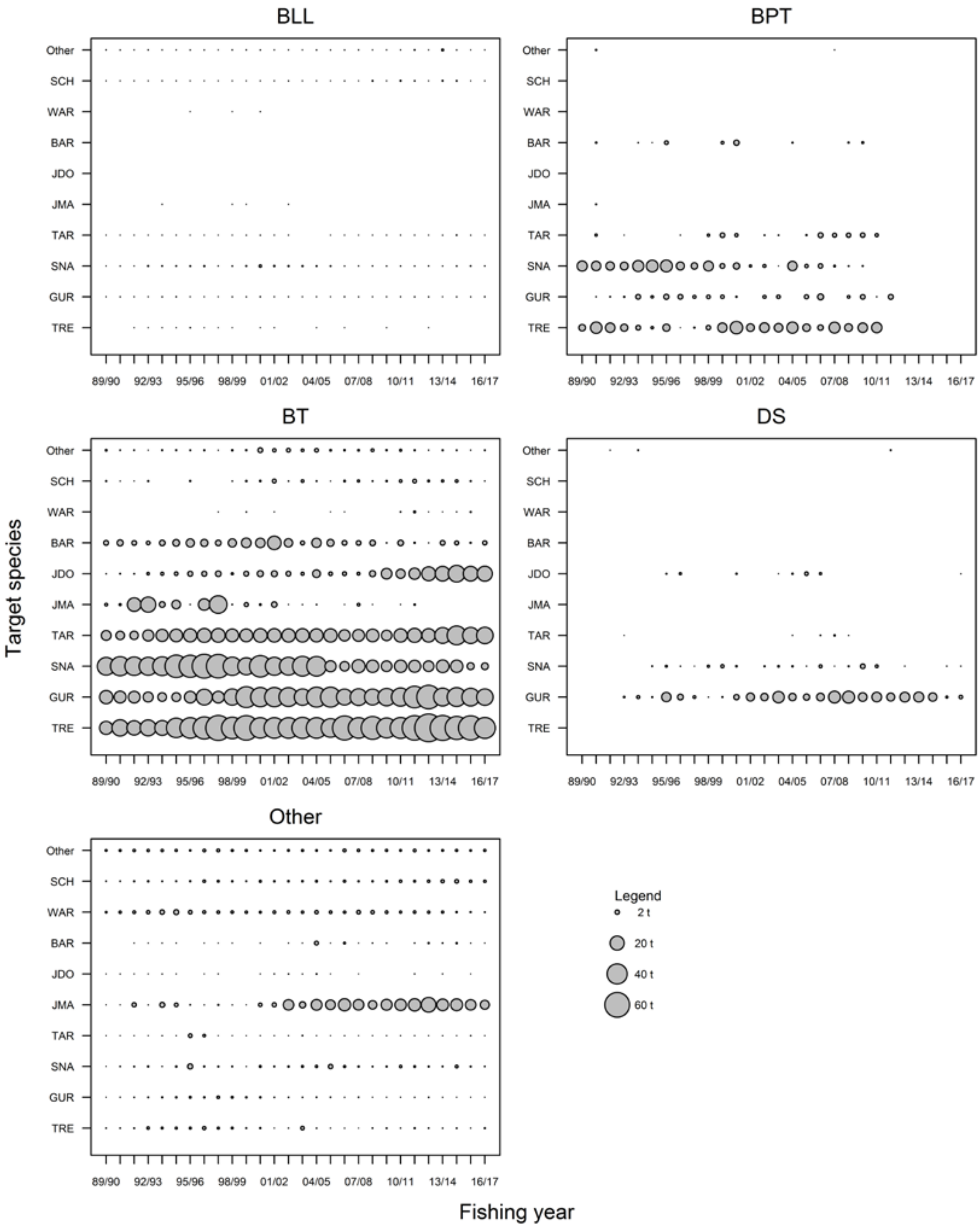

Figure 18: Landed catch of John dory from the WCNI fishery by fishing method, target species and fishing year. The BT method includes catches from the PRB method (i.e. PSH gear).

The John dory catch from the trawl fishery was taken throughout the WCSI fishery area between Cape Reinga and Cape Egmont, with the highest catches taken in North Taranaki Bight (Statistical Area 041), Ninety Mile Beach (047) and between the entrances of Kaipara and Manukau Harbours (042 and 045) (Figure 19 and Figure 20). The Danish seine fishery primarily operates in the northern WCNI fishery area (047) (Figure 19).

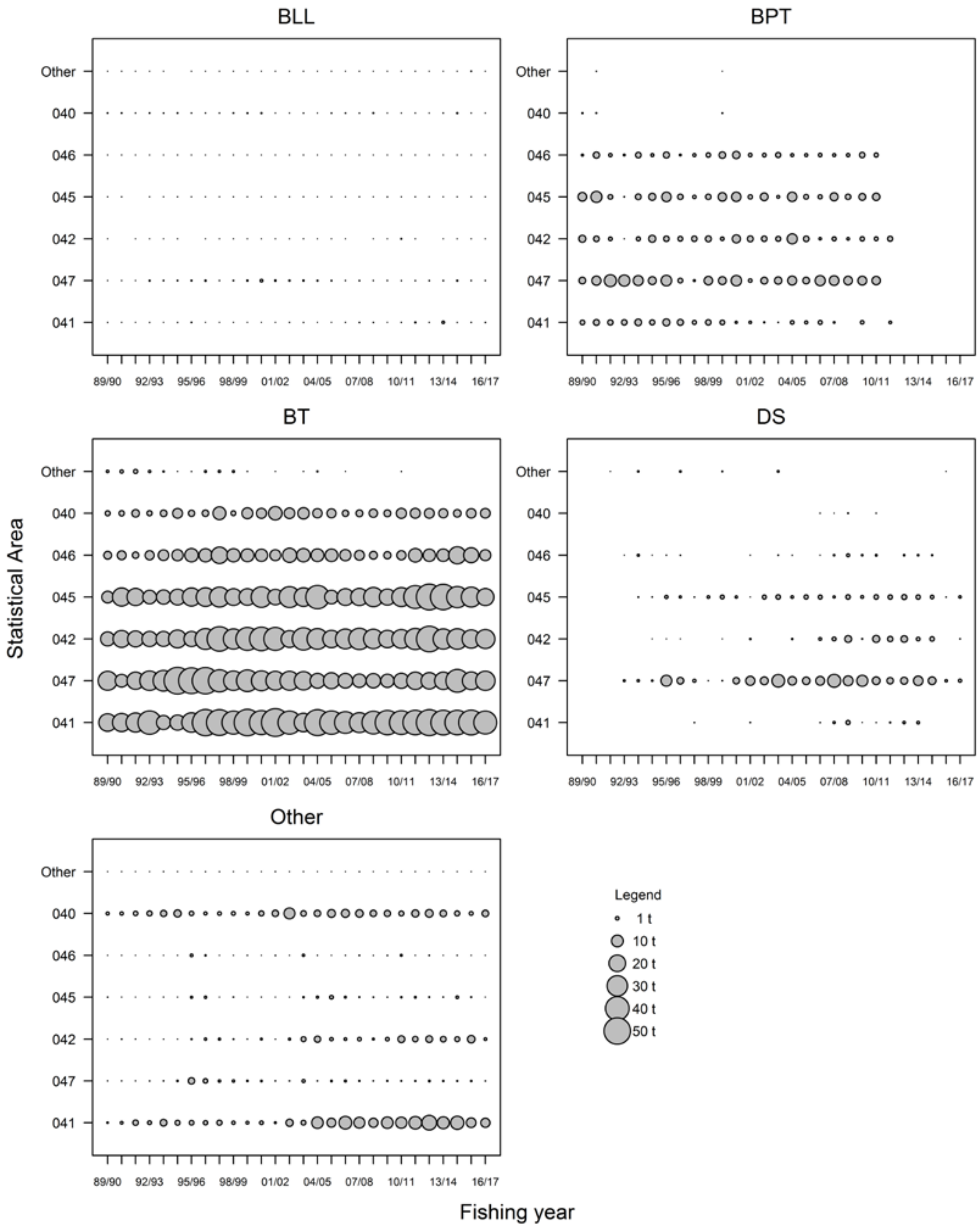

Figure 19: Annual distribution of John dory catch from the WCNI fishery by fishing method and statistical area. The area of the circle is proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

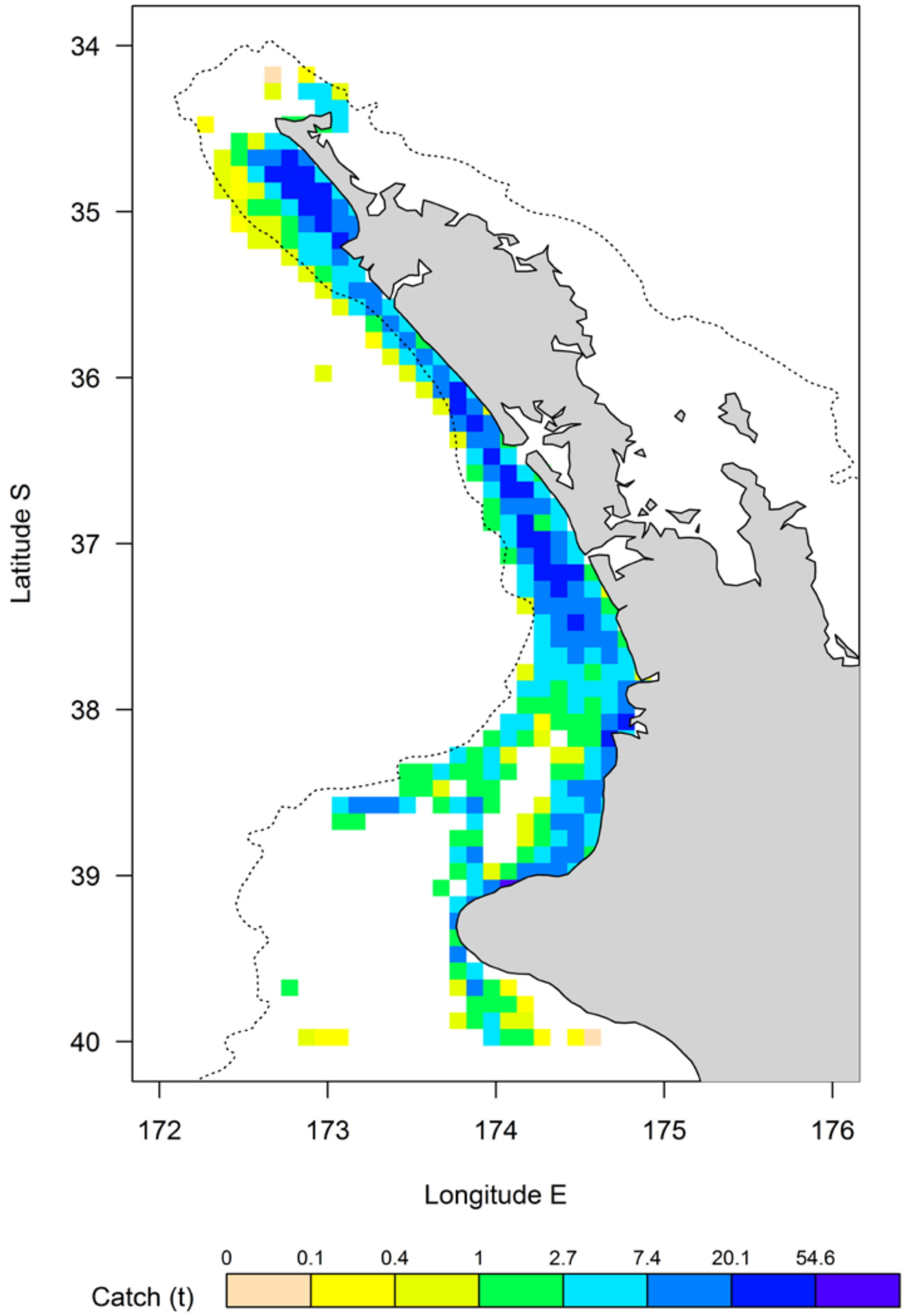

Figure 20: Spatial distribution of John dory single trawl catch from the WCNI fishery for 1994/95–2016/17 fishing years (derived from TCER and TCEPR records). The catch data are aggregated by 0.1 lat/long spatial cells. The dashed line represents the 200 m depth contour.

Most of the John dory trawl catch was taken in the 25–100 m depth range from trawls targeting trevally, snapper and red gurnard (Figure 21). The tarakihi trawl fishery occurs in deeper water and moderate catches of John dory are taken in 100–160 m depth range. Catches are small from the tarakihi trawls conducted in deeper water (Figure 21) (typically to depths of about 200 m).

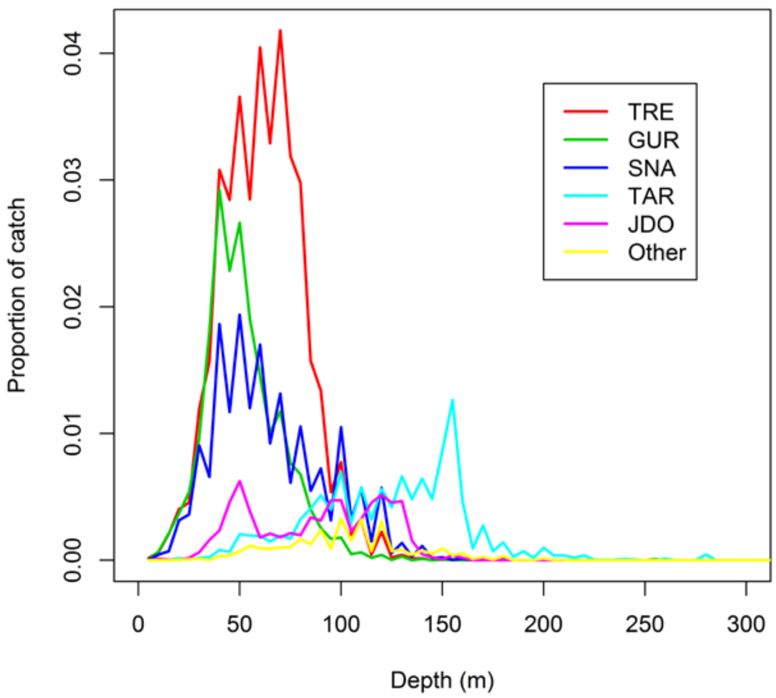

Figure 21: Proportional depth distribution of John dory single trawl catch from the WCNI fishery by bottom depth (5 metre depth intervals) and target species from 1994/95 to 2016/17 for the main bottom trawl target species (TCEPR or TCER records, all years combined).

Most of the John dory catch is taken during December–March and catches tend to be lowest during April–July (Figure 22). The seasonal distribution in catch tends to correspond with the seasonal pattern in both the distribution of the trawl effort in the WCNI fishery and the relative catch rate of John dory by the trawl fleet.

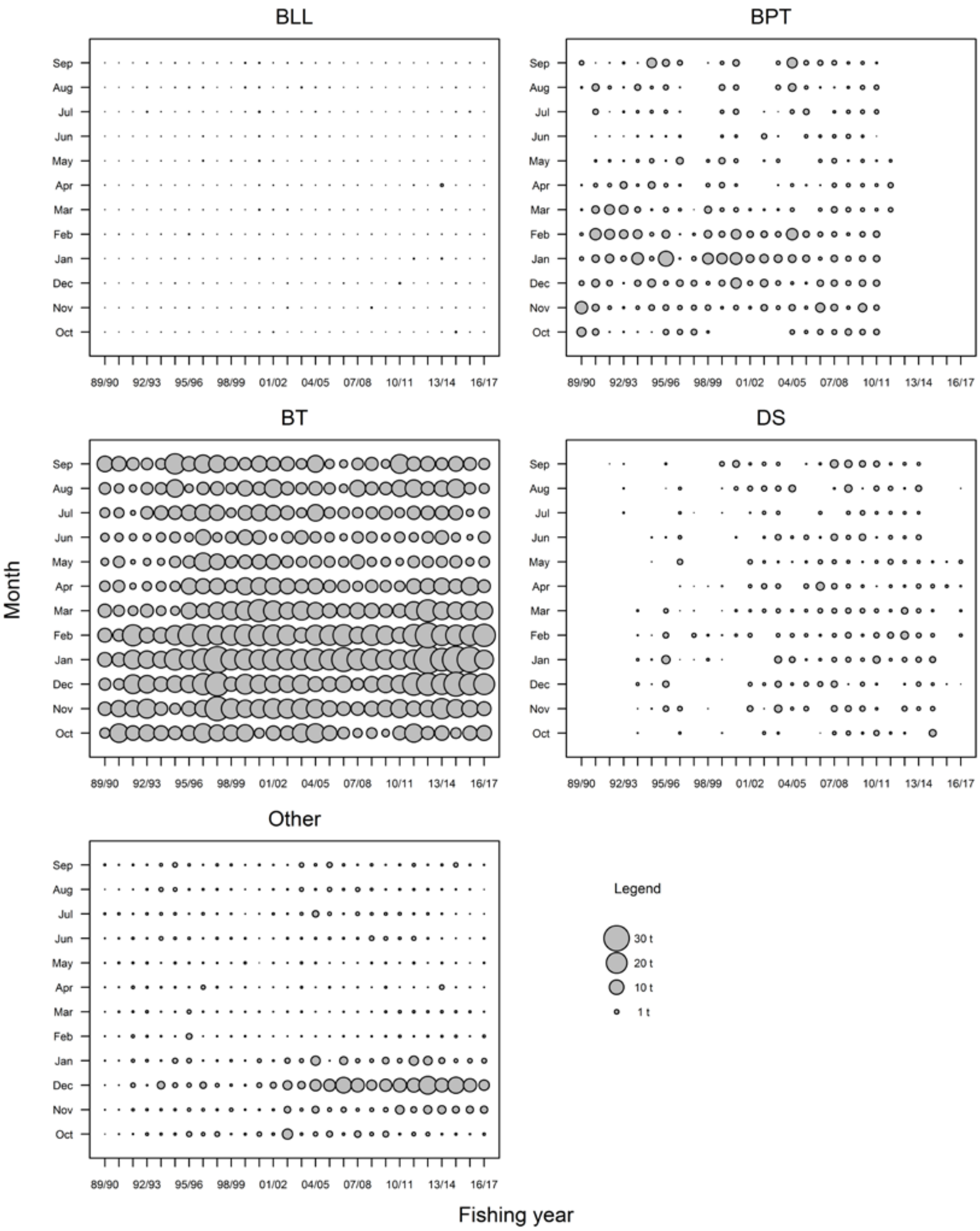

Figure 22: The monthly distribution of John dory catches from WCNI by fishing method and fishing year. Circle areas are proportional to the catch. The BT method includes catches from the PRB method (i.e. PSH gear).

4 CPUE Analyses

4.1 Methodology

For the three sub-areas of JDO 1, standardised CPUE analyses of the event based catch and effort data from the inshore trawl fisheries were conducted following the approach of Dunn & Jones (2013) and Langley (2015). The CPUE analyses were based on the trawl catch and effort data set configured in Section 2.1.2. Trawl records using PSH trawl gear (gear code PRB) were excluded from the data set.

The data set was partitioned by fishery area and restricted to 1994/95–2016/17 as very limited trawl based (i.e., tow by tow) catch and effort data are available from the preceding years. Each area-specific data-set was further limited to a set of (core) vessels that completed a minimum of 5 fishing trips in a minimum of five years (in the specific area). Fishing effort records were also restricted to the depth range of the John dory catches determined from the respective fishery area characterisations (Table 2).

A Generalised Linear Modelling (GLM) approach was used to separately model the occurrence of John dory catches (presence/absence) and the magnitude of positive John dory catches. The dependent variable of the catch magnitude CPUE models was the natural logarithm of catch and a lognormal error structure was assumed. The presence/absence of John dory catch was modelled based on a binomial distribution. The potential explanatory variables available for inclusion in each CPUE model are presented in Table 2.

Fishing location was categorised by assigning the trawl start location to a grid of 0.2 degree latitude/longitude cells (*Loc2* variable). The spatial resolution of the 0.2 degree grid approximates the average trawl distance (based on speed and trawl duration).

The dimensions of the trawl net (gear width and headline height) were also available for each fishing record. For most of the vessels included in the final CPUE analyses, the recorded trawl gear width and headline height were relatively constant throughout the study period.

Table 2: The variables available for inclusion in the single trawl CPUE analyses for the three areas.

Variable	Definition	Data type	Range
Vessel	Fishing vessel category	Categoric	
FishingYear	Fishing year	Categoric (23)	1994/95–2016/17
Month	Month	Categoric (12)	1–12
Latitude	Latitude at the start location of trawl	Continuous	
Longitude	Longitude at the start location of trawl	Continuous	
Loc2	Start location of trawl categorised by 0.2 degree latitude/longitude cell.	Categoric	
TargetSpecies	Declared target species for trawl.	Categoric	SNA,GUR,JDO,TRE,BAR,TAR
Duration	Natural logarithm of trawl duration (hours)	Continuous	Ln(0.5–6)
Depth	Fishing depth (m)	Continuous	< 150 (BPLE) < 200 (HG-ENLD) < 200 (WCNI)
StartTime	Hour at the start of trawl.	Continuous	0–23
Speed	Trawl speed (knots)	Continuous	2.0–5.0
Distance	Natural logarithm of trawl distance (*Speed* * *Duration*) (NM)	Continuous	Ln(1–22)
GearWidth	Wingspread of trawl gear (m)	Continuous	10–50
GearHeight	Headline height of trawl gear (m)	Continuous	0.5–10
JDOcatch	Scaled estimated JDO trawl catch (kg).	Continuous	0–1000 kg
JDObin	Presence (1) or absence (0) of JDO catch in trawl.	Categoric	

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). The continuous variables parameterised as a third order polynomial function, with the exception of the *Latitude* and *Longitude* variables which were parameterised using a fifth order polynomial to allow more complex spatial variation in catch rates. The categoric variable *FishingYear* was included in the initial model and subsequent variables were included in the model based on the improvement in the AIC. Additional variables were included in the model until the improvement in the Nagelkerke pseudo-R^2 was less than 0.5%.

The influence of each of the main variables in the CPUE models were examined following the approach of Bentley et al. (2011). Annual trends in the residuals of each model were examined with respect to target species and Statistical Area.

For each area, lognormal and binomial CPUE indices were calculated from the respective CPUE models. The delta-lognormal (combined) indices were determined from the product of the positive catch (lognormal) and binomial indices, following the approach of Stefansson (1996). The confidence intervals associated with the combined delta-lognormal indices were determined using a bootstrapping approach.

4.2 Bay of Plenty

The BPLE trawl CPUE analysis was based on the trawl event catch and effort data for the inshore bottom trawl fishery targeting the suite of inshore species within Statistical Areas 008–010 (Table 2). Catch and effort records were included regardless of whether or not there was an associated reported catch of John dory. The initial data set accounted for about 70–80% of the John dory catch from the BPLE trawl fishery from 1995/96–2006/07 (Figure 23). From 2007/08, almost all of the John dory trawl catch has been reported in event based format (i.e. TCEPR or TCER format).

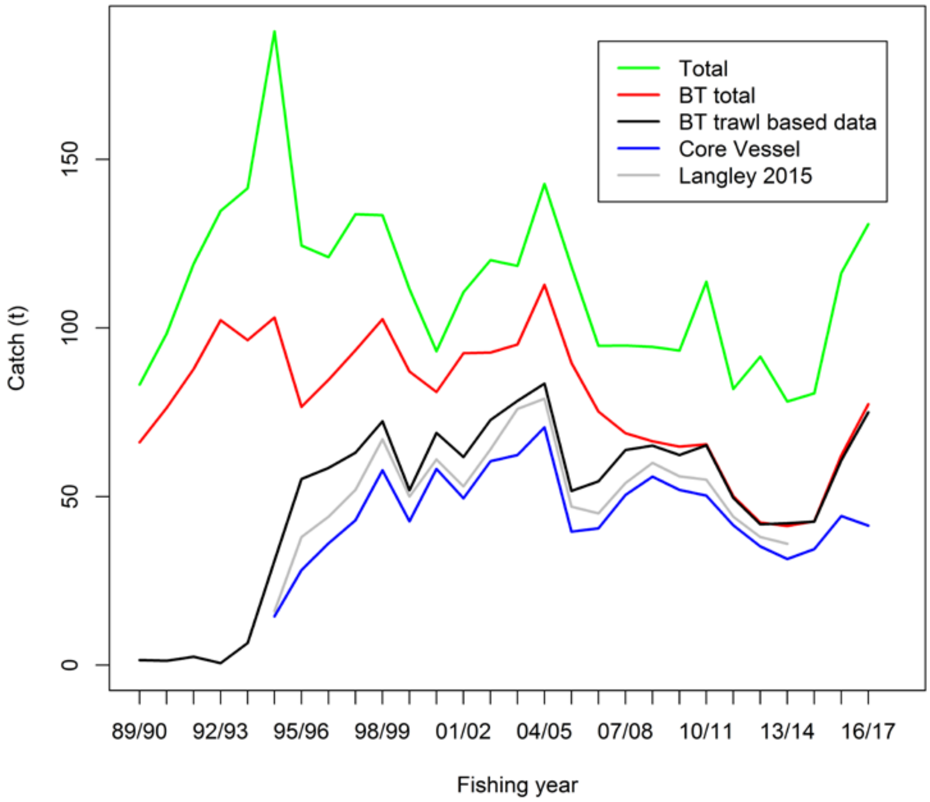

Figure 23: A comparison of the total Bay of Plenty (BPLE) annual JDO 1 catch and various subsets of the catch and effort data set, including the final trawl CPUE data set for the core fleet (Core Vessel). For comparison, the annual catch included in the CPUE analysis of Langley (2015) is also presented.

The core fleet, defined based on continuity criteria of a minimum of five trips in at least five years, accounted for 76% of the total John dory catch included in the trawl event based data set (from 1994/95 to 2016/17) (Figure 23). The criteria resulted in the selection of 32 unique vessels including nine vessels that had operated in the fishery for at least 15 years (Figure 24). Approximately half of the John dory catch included in the data set was taken by six vessels.

The annual catches included in the core vessel data set was slightly lower than the corresponding data from the previous CPUE analysis (Langley 2015). This was due to small refinements in the processing of the catch and effort data set and the implementation of the continuity criteria (Figure 23). The proportion of the trawl catch included in the core vessel data set declined in 2015/16 and 2016/17 due to the increased adoption of the PSH trawl gear (excluded from the core vessel data set) and the entrance of a new vessel into the fishery (Figure 23).

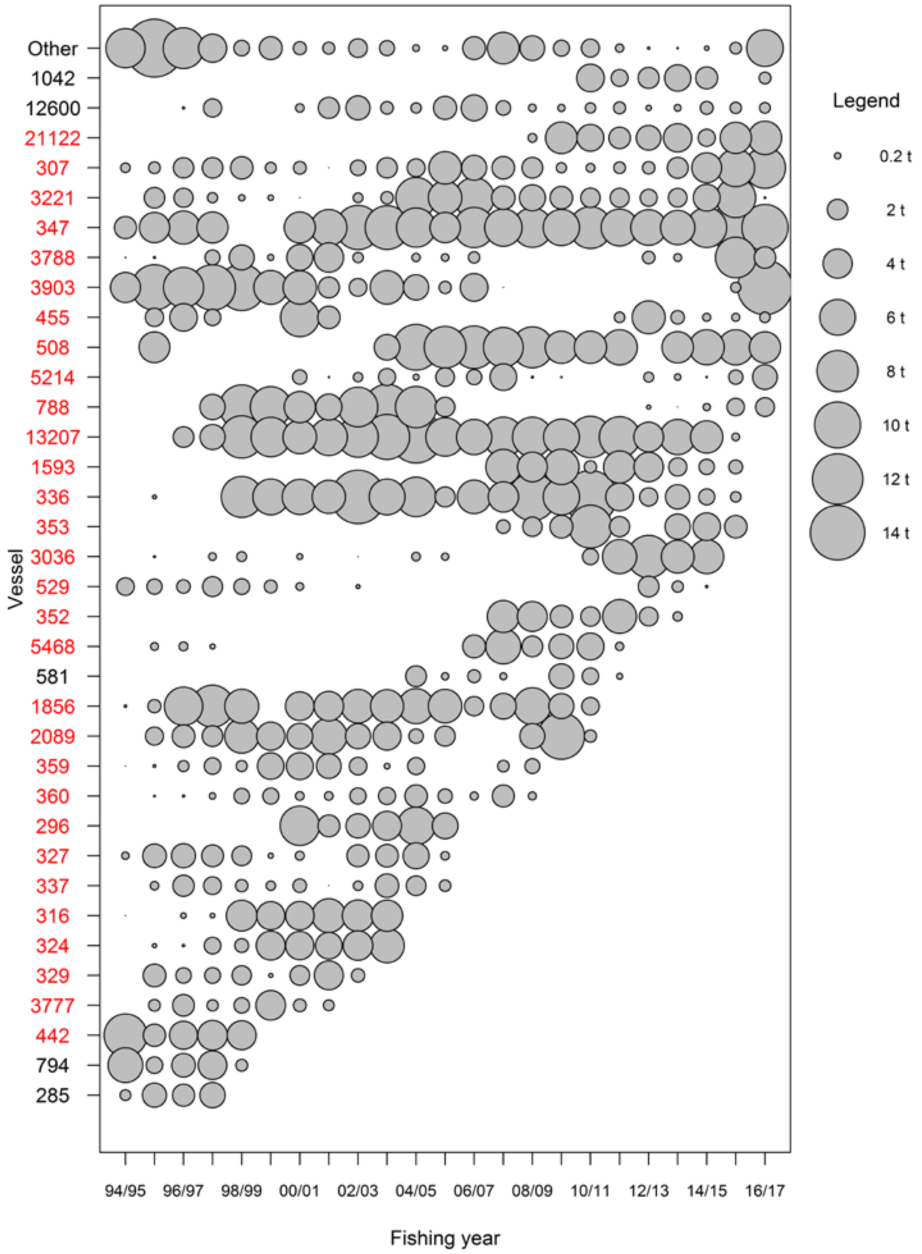

Figure 24: Distribution of John dory BPLE trawl catch by year and fishing vessel from the trawl based data set (BT gear only). The red labels denote the vessels comprising the core fleet included in the final trawl based CPUE data set.

The annual distribution of John dory catch and trawl effort by target species, month and statistical area are generally consistent with the trends described in the characterisation of the BPLE trawl fishery (Section 3.1). From the early 2000s, the distribution of fishing effort amongst the main target species (snapper, trevally and tarakihi) remained relatively stable (Figure 25). There was a decline in the proportion of tarakihi trawls from 2009/10 with a corresponding decline in the depth fished (Figure 26).

The total number of trawls included in the core vessel data set declined in 2014/15 and 2015/16, primarily due to a decline in the number of trawls targeting snapper (Figure 25).

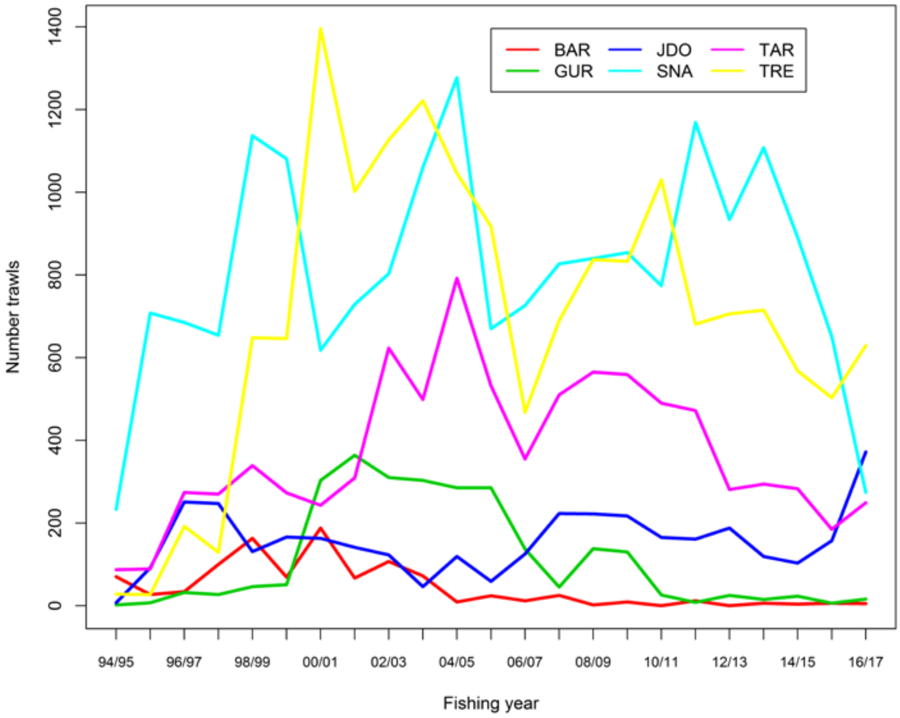

Figure 25: Annual distribution of trawl effort records by target species for the BPLE core vessel CPUE data set.

During 1994/95–1997/98, fishing effort was concentrated in the western Bay of Plenty along the eastern Coromandel coast. From 1996/97 to 2001/02, the distribution of fishing effort shifted eastwards with an increase in trawls in the eastern Bay of Plenty (Figure 26) between Whakatane and Te Kaha. This corresponded with a shift from targeting snapper to targeting trevally (Figure 25). From 2006/07, fishing effort was broadly distributed throughout the Bay of Plenty (Figure 26).

Trawl duration was generally shorter during the mid–late 1990s compared to 2000s (Figure 26) when there was a larger proportion of longer trawls (primarily targeting tarakihi). Trawl duration increased again during 2015/16 and 2016/17 corresponding to a decline in snapper target trawls. The diurnal distribution of fishing effort remained relatively constant throughout the study period (Figure 26).

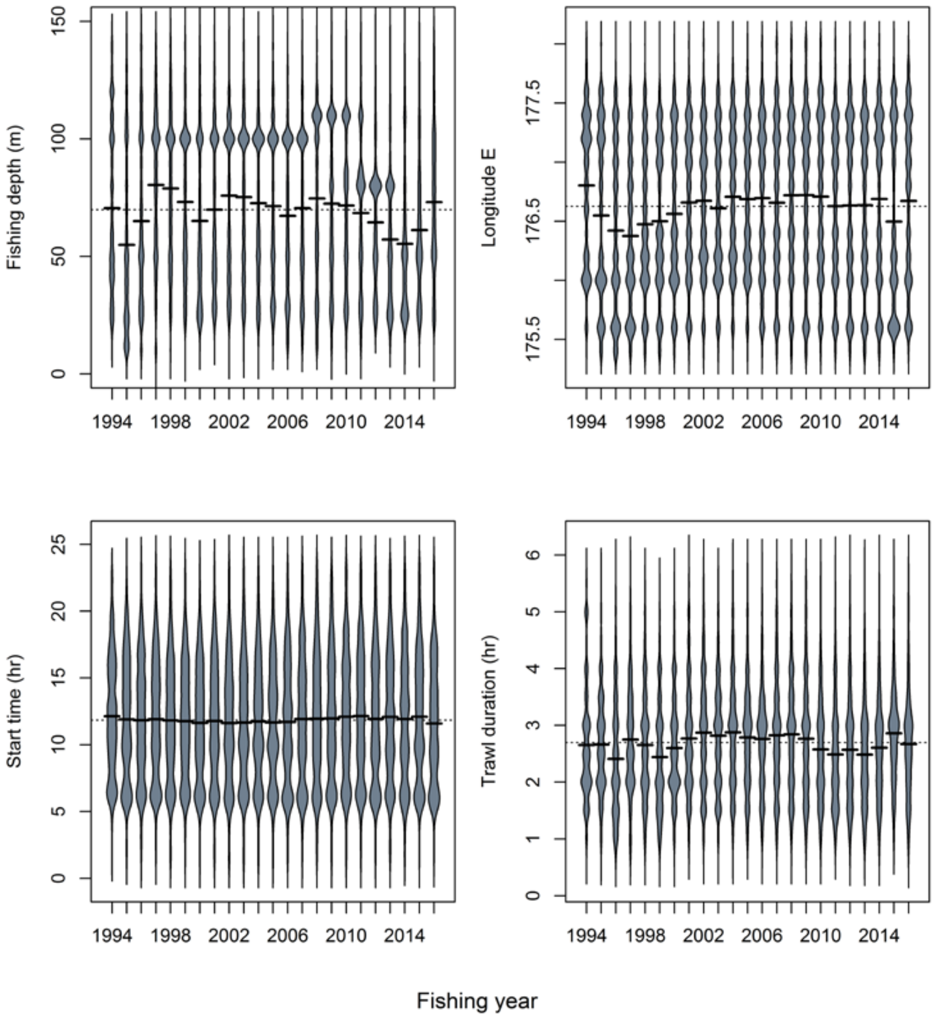

Figure 26: Beanplots of a range of descriptive variables characterising the fishing effort data included in the BPLE trawl CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the median value. The fishing year is denoted by the calendar year at the start of the fishing year (e.g. 1994 represents the 1994/95 fishing year).

The CPUE data set included a large proportion (45–55%) of trawl records with no John dory catch (Appendix 2 Table A4). The proportion of trawls that caught John dory fluctuated over the study period and the variation corresponds with the changes in the distribution of trawls amongst target species. For example, in 2006/07 there was a sharp decrease in the proportion of trawls with no associated John dory catch which corresponded to a decline in the proportion of trawls targeting tarakihi and trevally. Trawls targeting these species tended to have a lower overall probability of catching John dory (relative to trawls targeting snapper or John dory).

The lognormal (positive catch) CPUE model included the predictor variables *FishingYear*, *Loc2,* natural logarithm of *Distance*, *Vessel*, *TargetSpecies*, *Depth*, *Month* and *StartTime* (Table 3). Overall, the model explained 29.1% of the variation in the positive catch of John dory (Nagelkerke pseudo-R^2), while the *FishingYear* variable accounted for a small proportion of the variation (3.0%). The distribution of the CPUE model residuals is generally consistent with the assumption of normality, with the exception of a relatively small number of observations with a small JDO catch which are not well estimated by the model (Figure 27).

Table 3: Summary of stepwise selection of variables in the BPLE trawl 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	22	-37 806	75 659	0.030 *
Loc2	38	-36 260	72 643	0.142 *
Distance	3	-35 586	71 303	0.187 *
Vessel	31	-35 015	70 222	0.223 *
TargetSpecies	5	-34 529	69 259	0.253 *
Depth	3	-34 140	68 488	0.275 *
Month	11	-33 975	68 180	0.285 *
StartTime	3	-33 869	67 975	0.291 *
GearHeight	3	-33 825	67 893	0.294
GearWidth	3	-33 777	67 802	0.296
Duration	3	-33 742	67 737	0.298

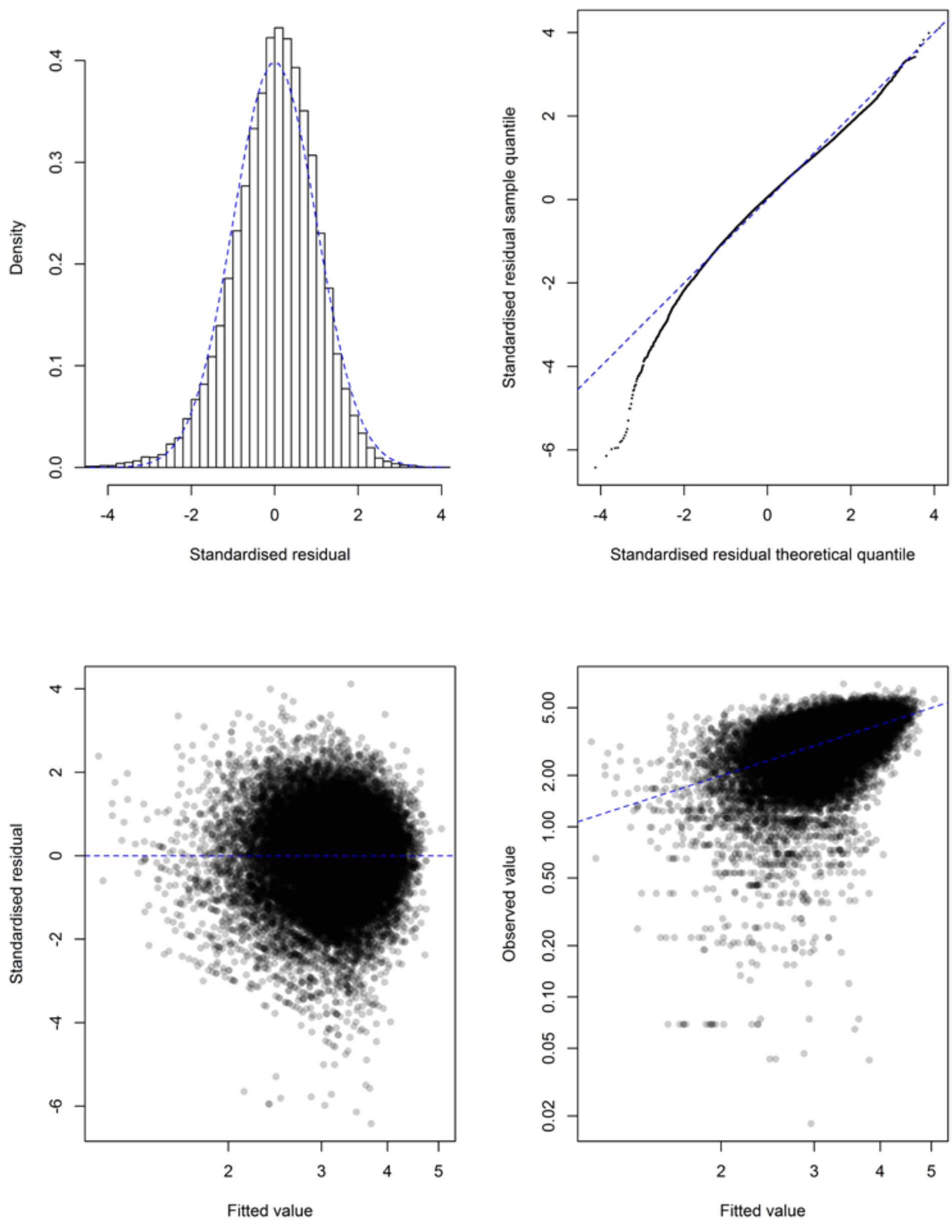

Figure 27: Residual diagnostics for the lognormal CPUE model for the BPLE trawl fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the lognormal CPUE model decline considerably during 1994/95–2002/03 and declined further during 2010/11–2012/13 (Figure 28). The annual indices increase during 2013/14–2015/16 and decline again in 2016/17.

The trend in the CPUE indices is generally consistent with the unstandardized annual catch rate (Figure 28). The *Loc2, TargetSpecies, Distance* and *Vessel* variables are the most influential variables included in the CPUE model. These variables collectively influence the magnitude of the trends in the CPUE indices at the start (1994/95–1995/96) and end (2015/16–2016/17) of the time-series (Figure 29, Appendix 4 Figures A1–A7).

An examination of the model residuals reveal that the trends in the lognormal CPUE indices are consistent amongst the main target species included in the data set (Figure 30). There is some variation in the CPUE trend amongst the constituent Statistical Areas, with the decline in the CPUE more pronounced in the western area (Statistical Area 008) (Figure 31). However, the trends in the individual Statistical Areas do not differ markedly from the overall CPUE time-series.

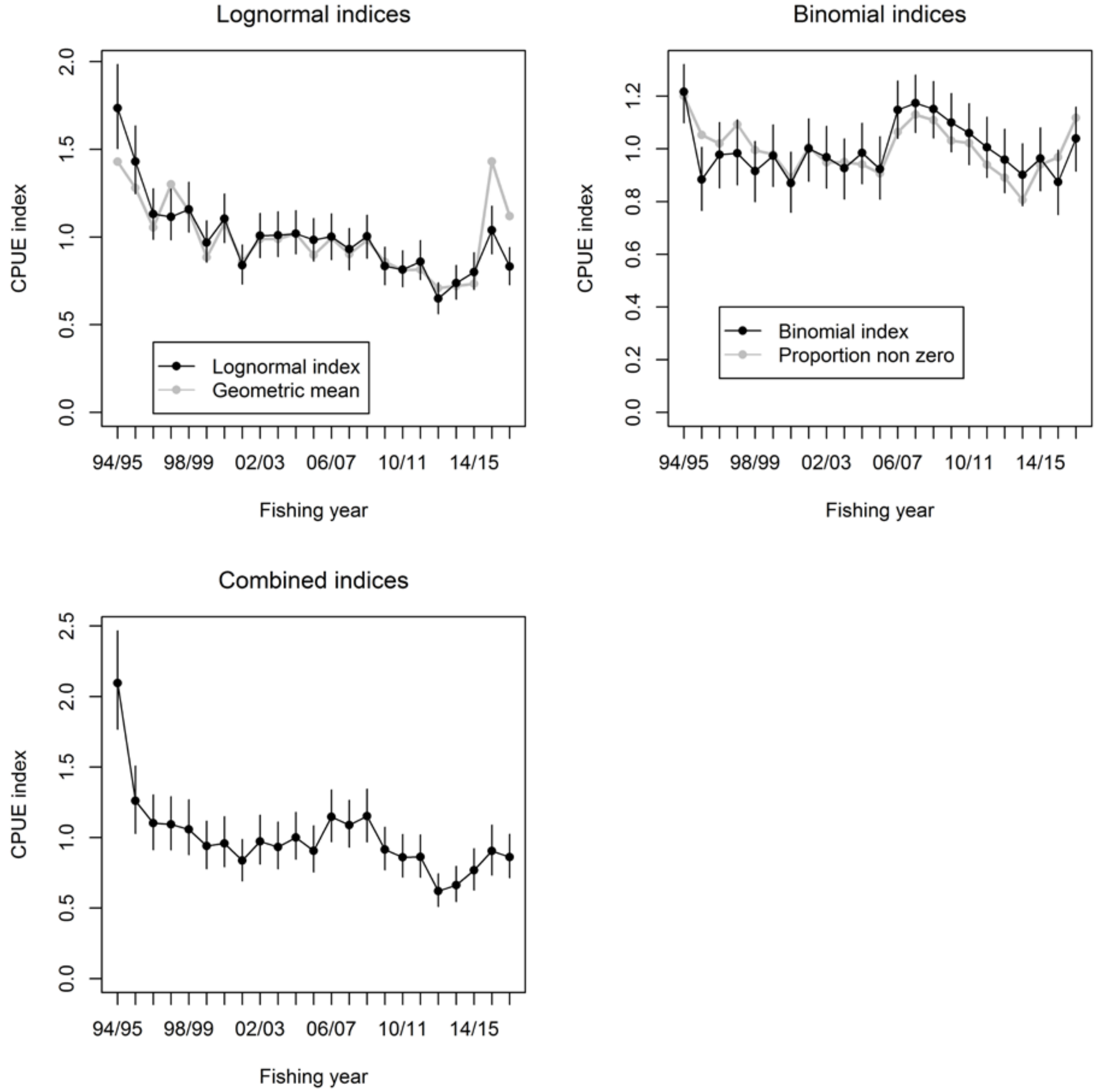

Figure 28: A comparison of the BPLE trawl standardised CPUE indices and the geometric mean of the annual catch per day (unstandardised) (top left panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (top right panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A7 (Appendix 3).

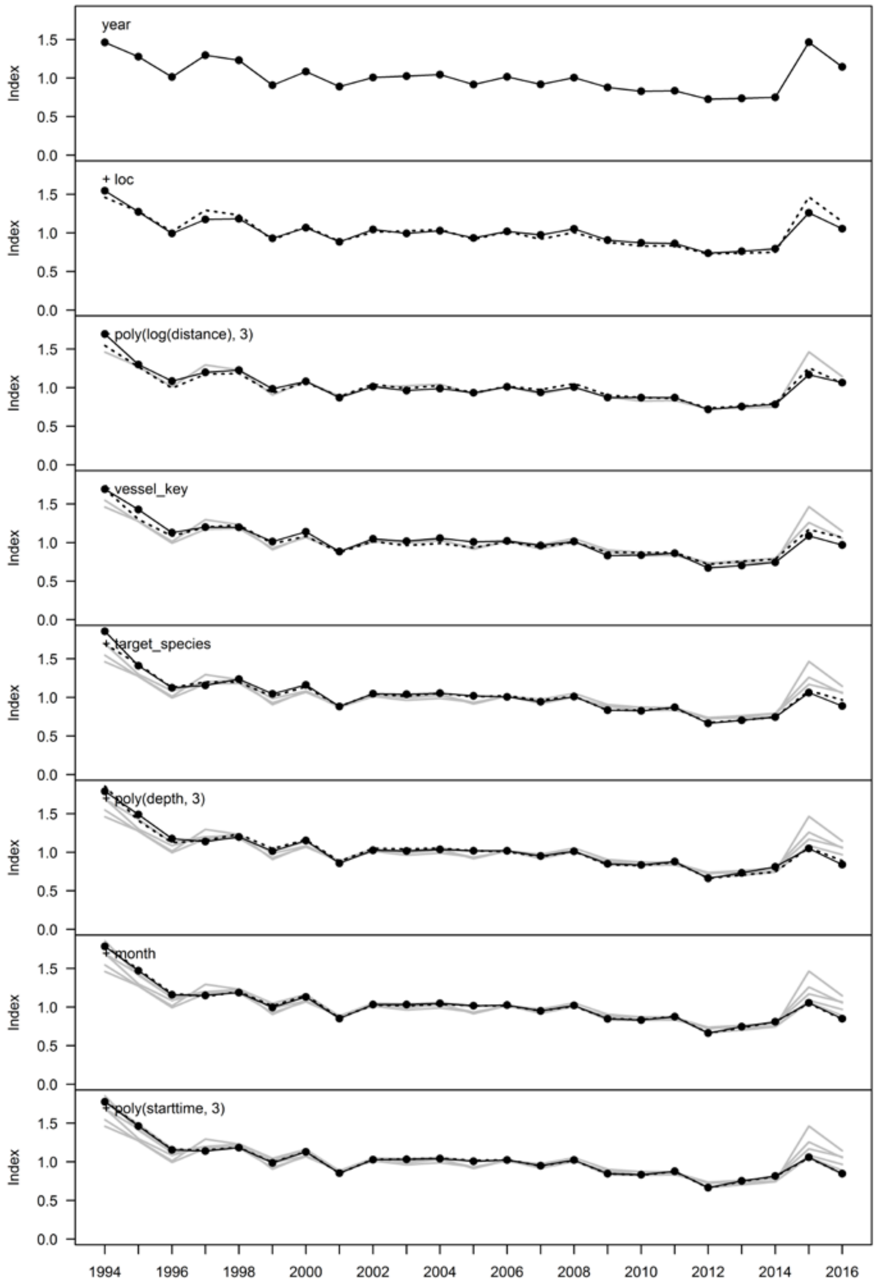

Figure 29: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the lognormal CPUE model for the BPLE trawl fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1994 denotes the 1994/95 fishing year).

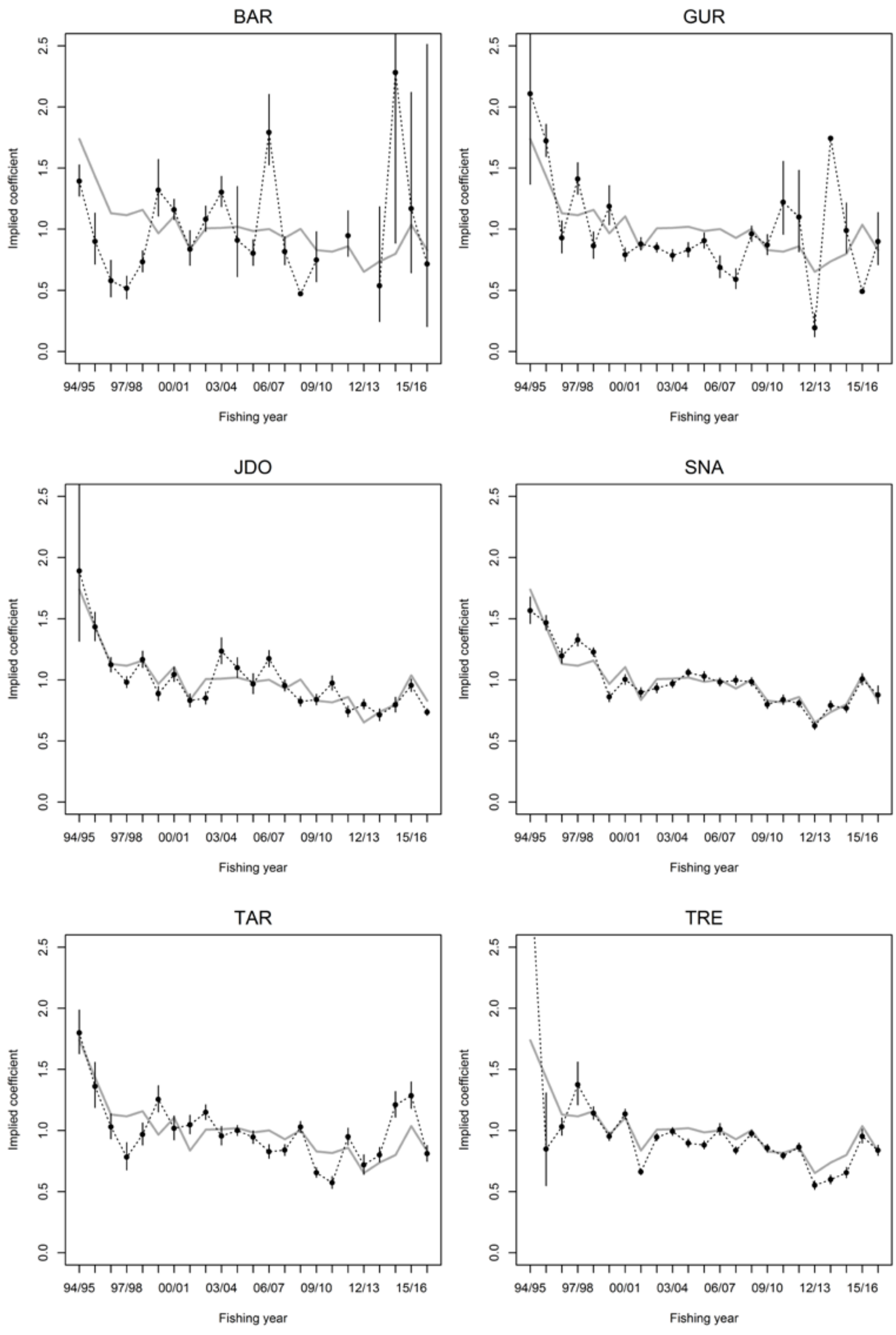

Figure 30: Annual implied coefficients (points) for the individual *TargetSpecies* included in the BPLE lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

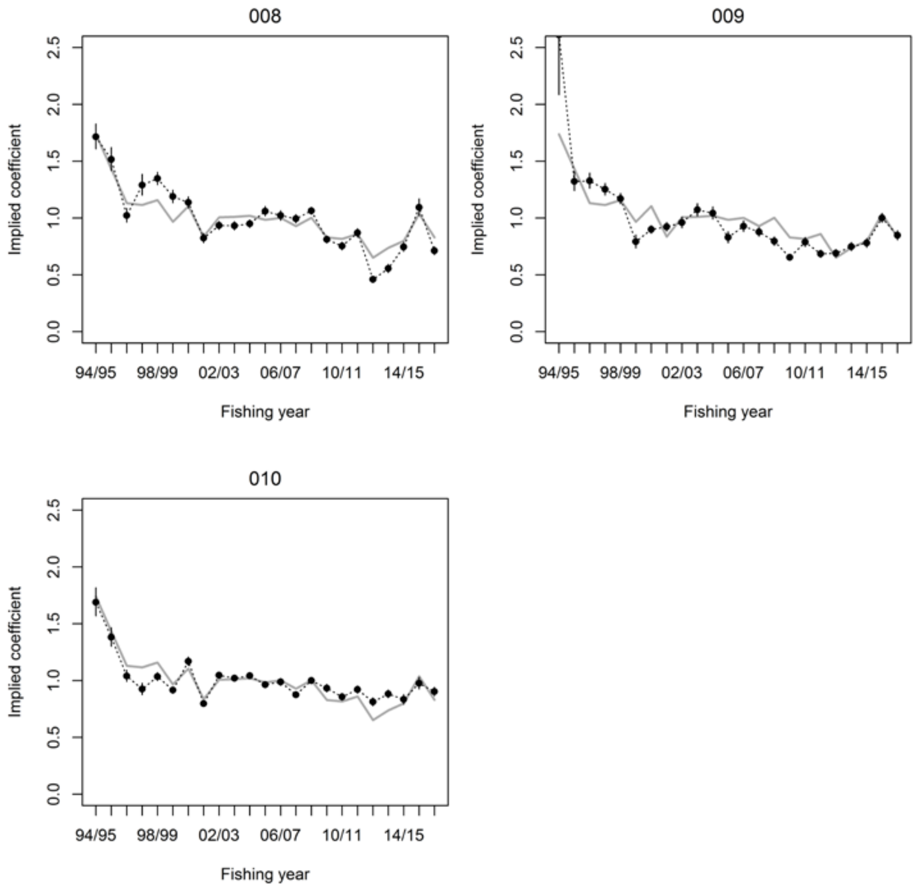

Figure 31: Annual implied coefficients (points) for the individual Statistical Areas included in the BPLE lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

The occurrence of John dory in the BPLE trawl catch was predicted by the binomial model including the explanatory variables *FishingYear, Vessel, Loc2, TargetSpecies, Depth* and *Duration* (Table 4).

The resulting annual indices derived from the binomial model were generally comparable to the annual proportion of positive catch records. The indices were relatively stable during 1995/96–2005/06 and increased sharply in 2006/07. The binomial CPUE indices decline from 2008/09 to 2013/14 (Figure 28), primarily driven by a decline in the occurrence of John dory catches from trawls targeting snapper and trevally. The indices from 2014/15–2016/17 have fluctuated at about the level of the 2013/14 index.

The combined BPLE trawl CPUE indices fluctuated over the time-series with a general declining trend; the indices dropped sharply from 1994/95 to 1995/96, declined by about one third during 1995/96–2001/02 and then recovered to the earlier level in 2006/07–2008/09. The indices subsequently declined to the lowest level in 2012/13 (49% of the 1995/96 index) and then increased in the following years. The 2016/17 index is at 68% of the 1995/96 level (Figure 28, Appendix 3 Table A7).

There is concern regarding the reliability of the 1994/95 index which is exceptionally high relative to the subsequent years. The index is comprised of data from a limited set of vessels and a limited number of trawl records. The 1994/95 index is also strongly influenced by the *TargetSpecies* variable, primarily the relatively high proportion of trawls targeting barracouta. This species was not consistently targeted over the time series and, consequently, the corresponding model coefficients (from the lognormal and binomial models) may not be well determined for the species.

Table 4: Summary of stepwise selection of variables in the BPLE John dory 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	22	-33 846	67 738.7	0.011	*
Vessel	31	-32 403	64 914.9	0.086	*
Loc2	38	-31 260	62 703.0	0.143	*
TargetSpecies	5	-30 586	61 365.7	0.175	*
Depth	3	-30 427	61 054.9	0.182	*
Duration	3	-30 293	60 791.2	0.189	*
Month	11	-30 213	60 654.4	0.192	
StartTime	3	-30 139	60 512.3	0.196	
GearWidth	3	-30 085	60 410.6	0.198	
Distance	3	-30 065	60 375.6	0.199	
GearHeight	3	-30 048	60 347.2	0.200	

4.3 Hauraki Gulf – east Northland

The HG-ENLD trawl CPUE analysis was based on the trawl event catch and effort data for the inshore bottom trawl fishery targeting the suite of inshore species within Statistical Areas 001–006 (Table 2). Catch and effort records were included regardless of whether or not there was an associated reported catch of John dory. The initial data set accounted for about 70–90% of the John dory catch from the HG-ENLD trawl fishery JDO 1 from 1996/97 to 2002/03 (Figure 32). During 2004/05–2006/07, a high proportion of the John dory trawl catch was associated with CELR data and, consequently, a lower proportion of the data was available for inclusion within the trawl event based data set. From 2007/08, almost all of the John dory trawl catch has been reported in event based format (i.e. TCEPR or TCER format) (Figure 32).

The core fleet generally accounted for about 80–90% of the annual John dory catch included in the trawl event based data set (from 1999/2000 to 2015/16), although the level of catch was lower in 2016/17 due to a higher proportion of the catch being taken using PSH trawl gear (Figure 32).

The core vessel selection criteria resulted in the selection of 33 unique vessels including seven vessels that operated in the fishery for at least 15 of the 23 years (Figure 33). Approximately half of the John dory catch included in the core vessel data set was taken by six vessels.

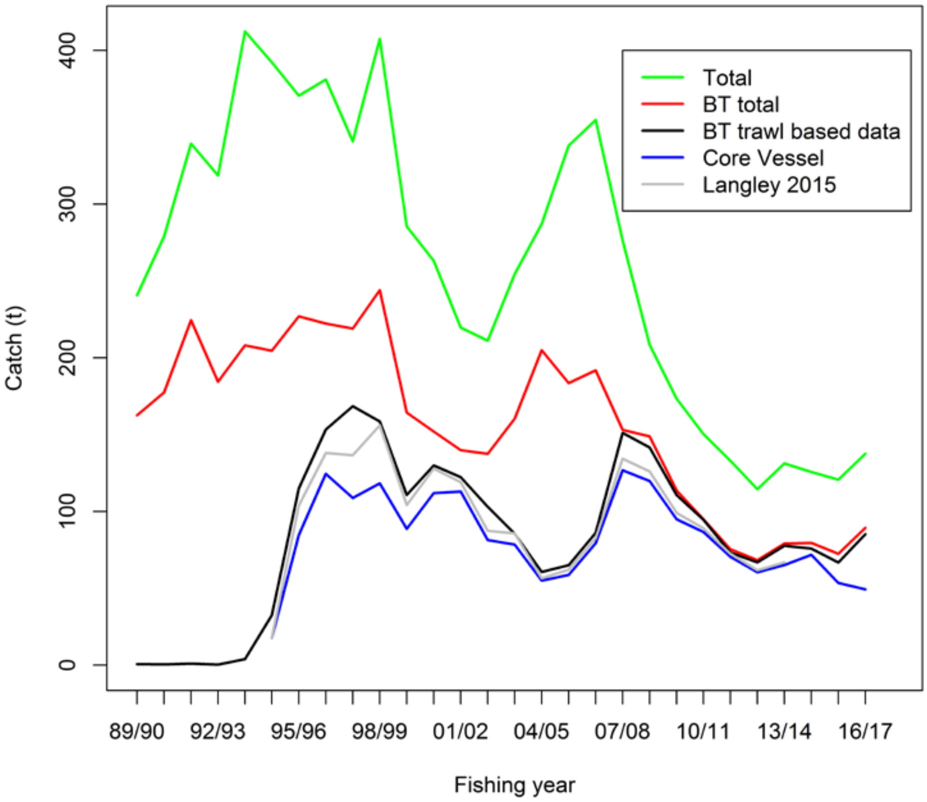

Figure 32: A comparison of the total Hauraki Gulf and east Northland (HG-ENLD) annual JDO 1 catch and various subsets of the catch and effort data set, including the final trawl CPUE data set for the core fleet (Core Vessel). For comparison, the annual catch included in the CPUE analysis of Langley (2015) is also presented.

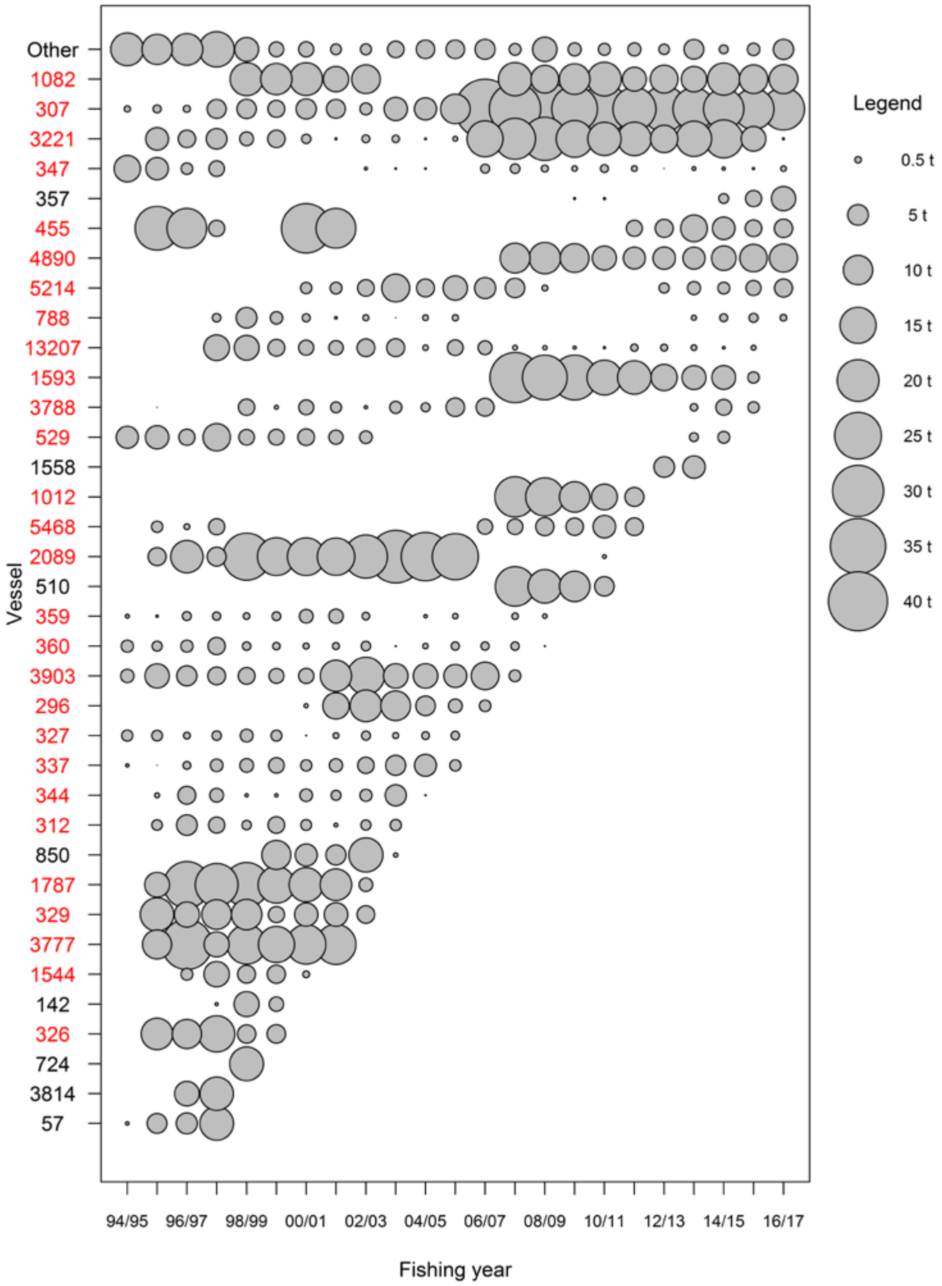

Figure 33: Distribution of John dory HG-ENLD trawl catch by year and fishing vessel from the trawl based data set (BT gear only). The red labels denote the vessels comprising the core fleet included in the final trawl based CPUE data set.

The annual distribution of John dory catch and trawl effort by target species, month and statistical area is generally consistent with the trends described in the characterisation of the HG-ENLD trawl fishery (Section 3.2). Most of the trawl records were associated with targeting snapper or John dory, although there was considerable variability in the annual distribution of fishing effort amongst the two target species (Figure 34). Snapper target trawls dominated the data set during the late 1990s, while John dory trawls accounted for a higher proportion of fishing effort during 2000/01–2002/03 and 2007/08–2009/10. The number of trawls targeting snapper declined during 2013/14–2016/17, while the number of trawls targeting John dory remained relatively stable. Accordingly, there was a comparable number of trawls targeting each species during 2015/16–2016/17.

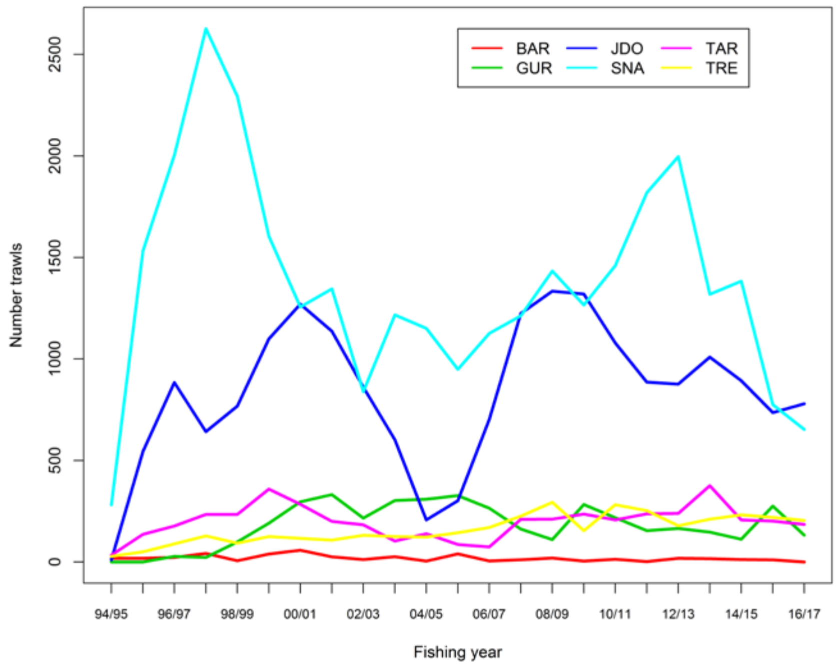

Figure 34: Annual distribution of trawl effort records by target species for the HG-ENLD core vessel CPUE data set.

There was considerable variability in trawl duration amongst years (Figure 35), primarily due to the proportion of tarakihi trawls in the data set. These trawls were considerably longer in duration than the trawls targeting the range of other species.

Fishing effort was concentrated in the outer Hauraki Gulf, extending north to Bream Head, around the 50 m depth contour (Figure 35). Limited fishing effort also occurred in the northern area of HG-ENLD (i.e. Great Exhibition Bay).

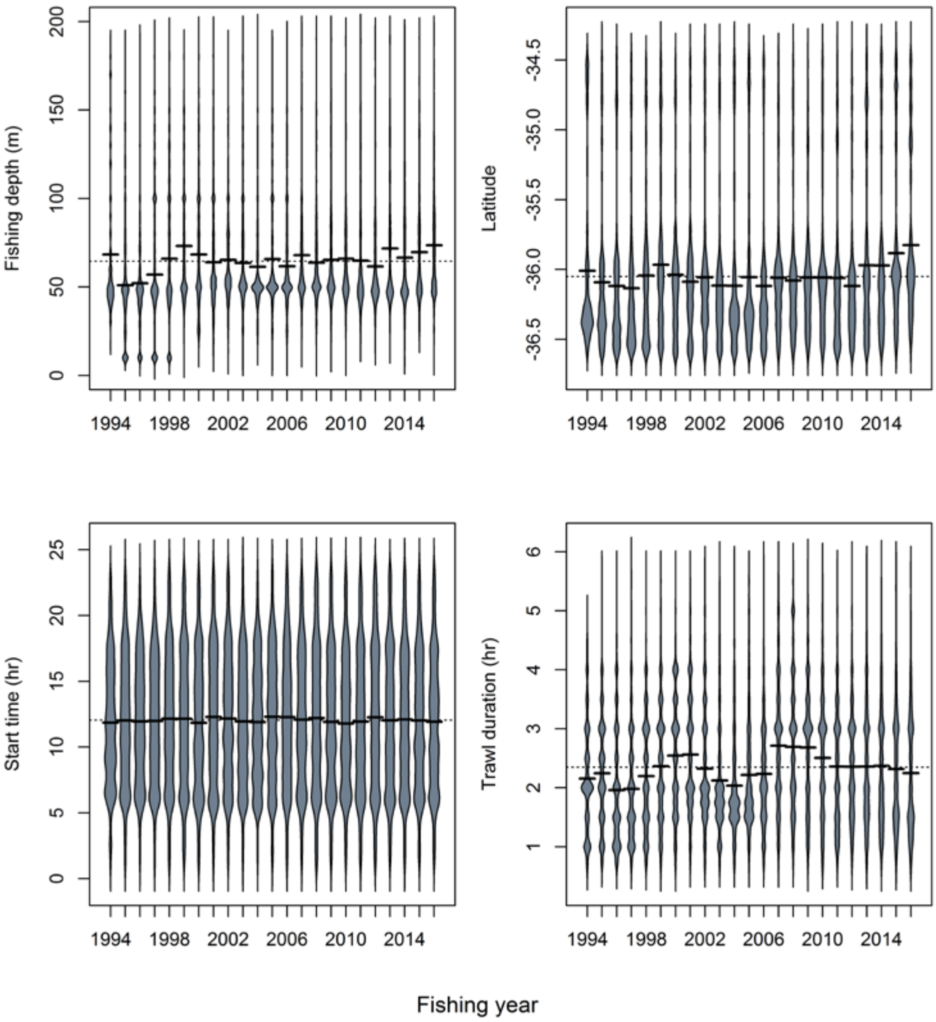

Figure 35: Beanplots of a range of descriptive variables characterising the fishing effort data included in the HG-ENLD trawl CPUE data set (core vessels). The "beans" represent the distribution of the annual data and the solid horizontal line represents the median value. The fishing year is denoted by the calendar year at the start of the fishing year (e.g. 1994 represents the 1994/95 fishing year).

The lognormal (positive catch) CPUE model included the predictor variables *FishingYear*, *Latitude, Month*, *Vessel*, natural logarithm of *Duration, TargetSpecies* and *StartTime* (Table 5). Overall, the model explained 44.1% of the variation in the positive catch of John dory (Nagelkerke pseudo-R^2), while the *FishingYear* variable accounted for a small proportion of the variation (3.3%). The distribution of the CPUE model residuals is generally consistent with the assumption of normality, with the exception of a relatively small number of observations with a small John dory catch which are not well estimated by the model (Figure 36).

Table 5: Summary of stepwise selection of variables in the HG-ENLD trawl 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	22	-60 620	121 288	0.033 *
Latitude	5	-56 756	113 570	0.196 *
Month	11	-54 700	109 480	0.272 *
Vessel	32	-52 963	106 070	0.331 *
Duration	3	-51 341	102 832	0.382 *
TargetSpecies	5	-49 927	100 015	0.423 *
StartTime	3	-49 572	99 310	0.433 *
Depth	3	-49 291	98 753	0.441 *
GearHeight	3	-49 247	98 672	0.442
GearWidth	3	-49 233	98 651	0.443
Speed	3	-49 226	98 641	0.443
Distance	3	-49 219	98 634	0.443

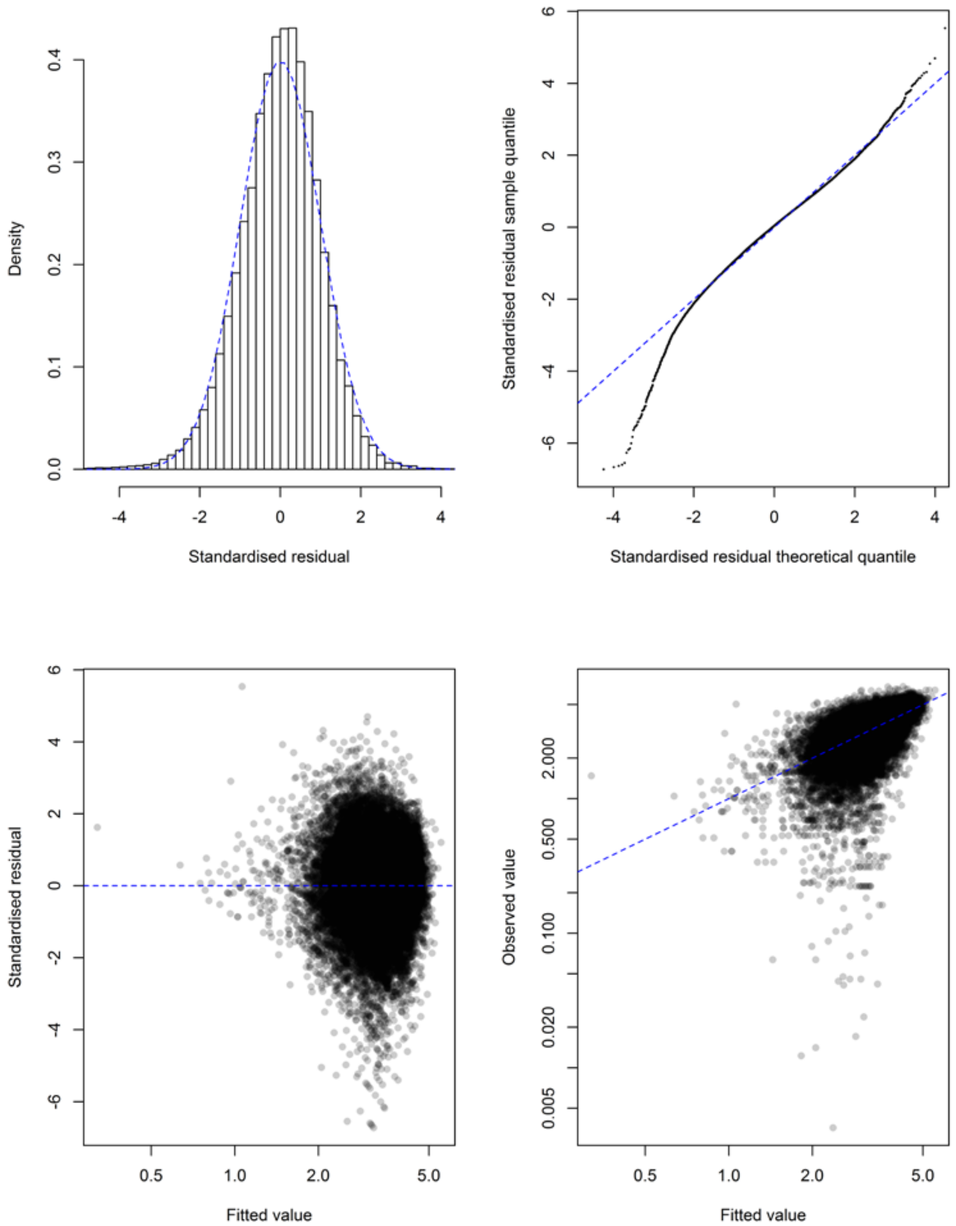

Figure 36: Residual diagnostics for the lognormal CPUE model for the HG-ENLD trawl fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom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

The annual indices derived from the lognormal CPUE model generally declined over the study period, from a relatively high level in 1995/96–1998/99 (Figure 37). There was a brief recovery in the CPUE indices during 2002/03–2004/05 and then the CPUE indices declined steadily from 2004/05 to 2012/13 and then increased slowly over the remainder of the time series (Figure 37). The index from 1994/95 is exceptionally high relative to the following years (1995/96–1998/99).

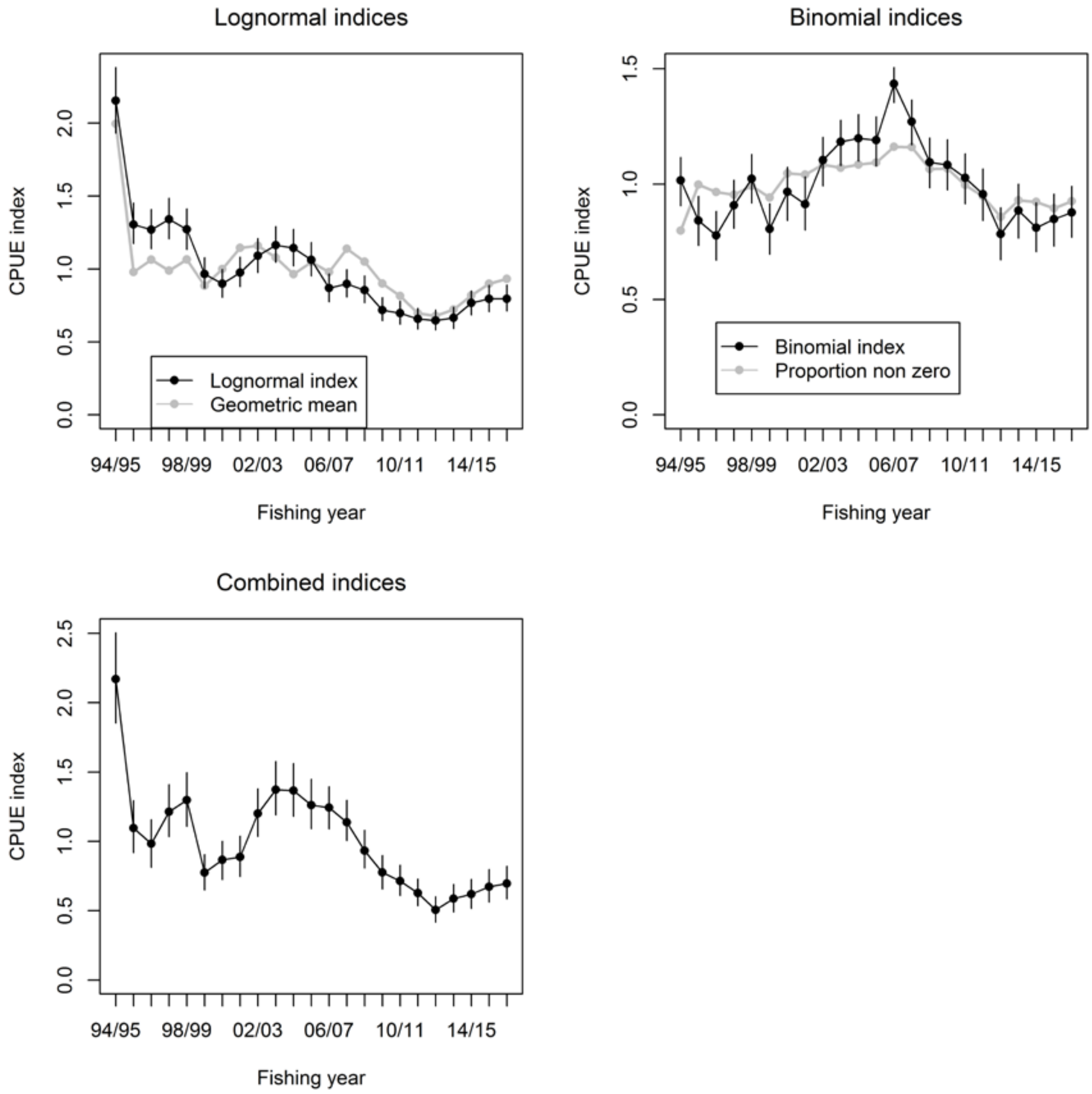

Figure 37: A comparison of the HG-ENLD trawl standardised CPUE indices and the geometric mean of the annual catch per day (unstandardised) (top left panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (top right panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A8 (Appendix 3).

The trends in the standardised CPUE indices are comparable to the trend in the unstandardized catch rates of John dory (Figure 37). The main deviation between the two sets of indices is attributable to a change in the composition of the fleet during 1995/96–1998/99 (Figure 38). A number of the main vessels operating in the fishery at that time tended to have lower overall catch rates of John dory (Appendix 4 Figure A10).

Standardised and unstandardised CPUE indices for 1994/95 were exceptionally high (Figure 37). The constituent data set included a small number of vessels and a relatively low proportion of the John dory catch and fishing effort compared to the following years. There were also a higher proportion of zero John dory catch records reported from 1994/95 (Appendix 2 Table A5). Consequently, the indices from 1994/95 are considered to be less reliable than for the other years.

The annual trends in the standardised CPUE indices are consistent amongst the constituent Statistical Areas (Figure 39) and amongst the individual target species (Figure 40).

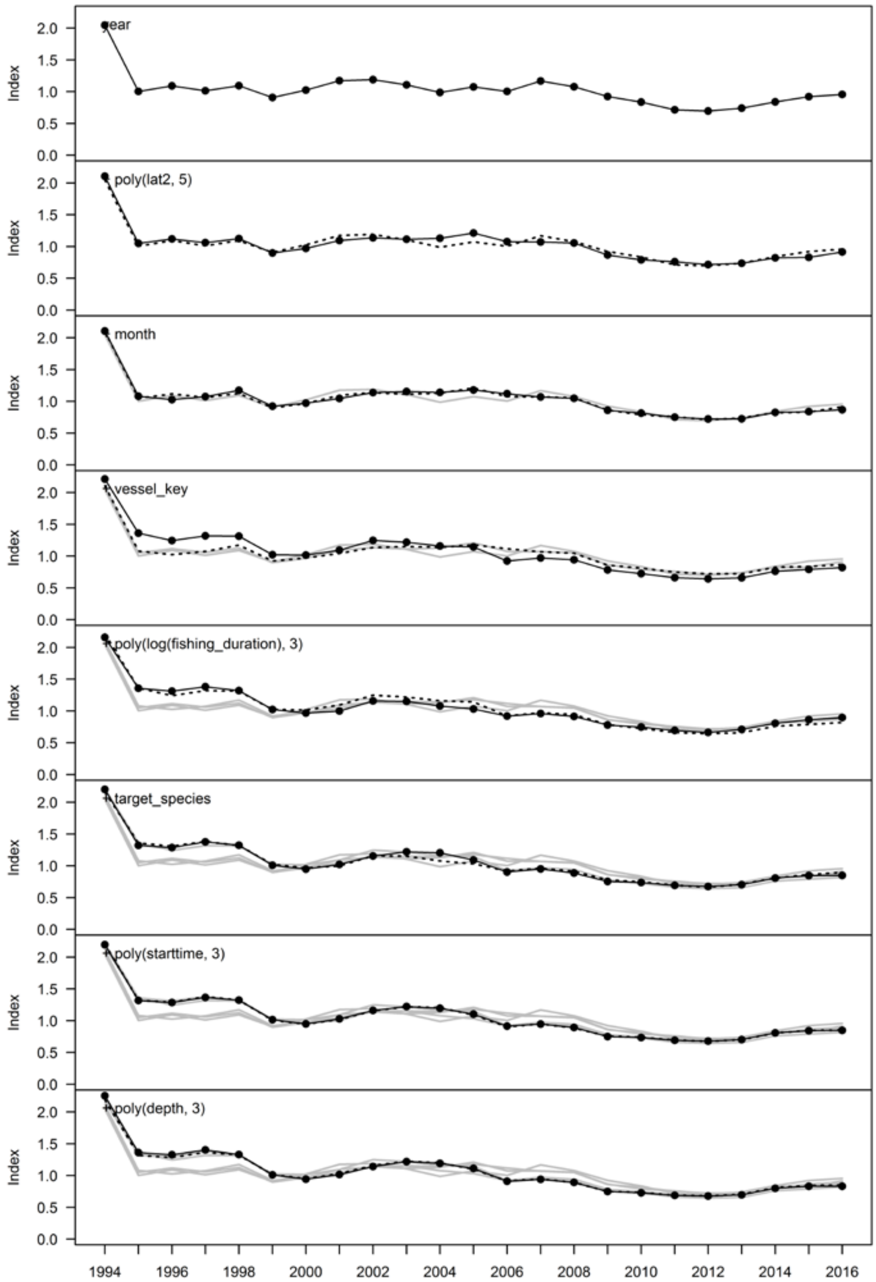

Figure 38: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the lognormal CPUE model for the HG-ENLD trawl fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1994 denotes the 1994/95 fishing year).

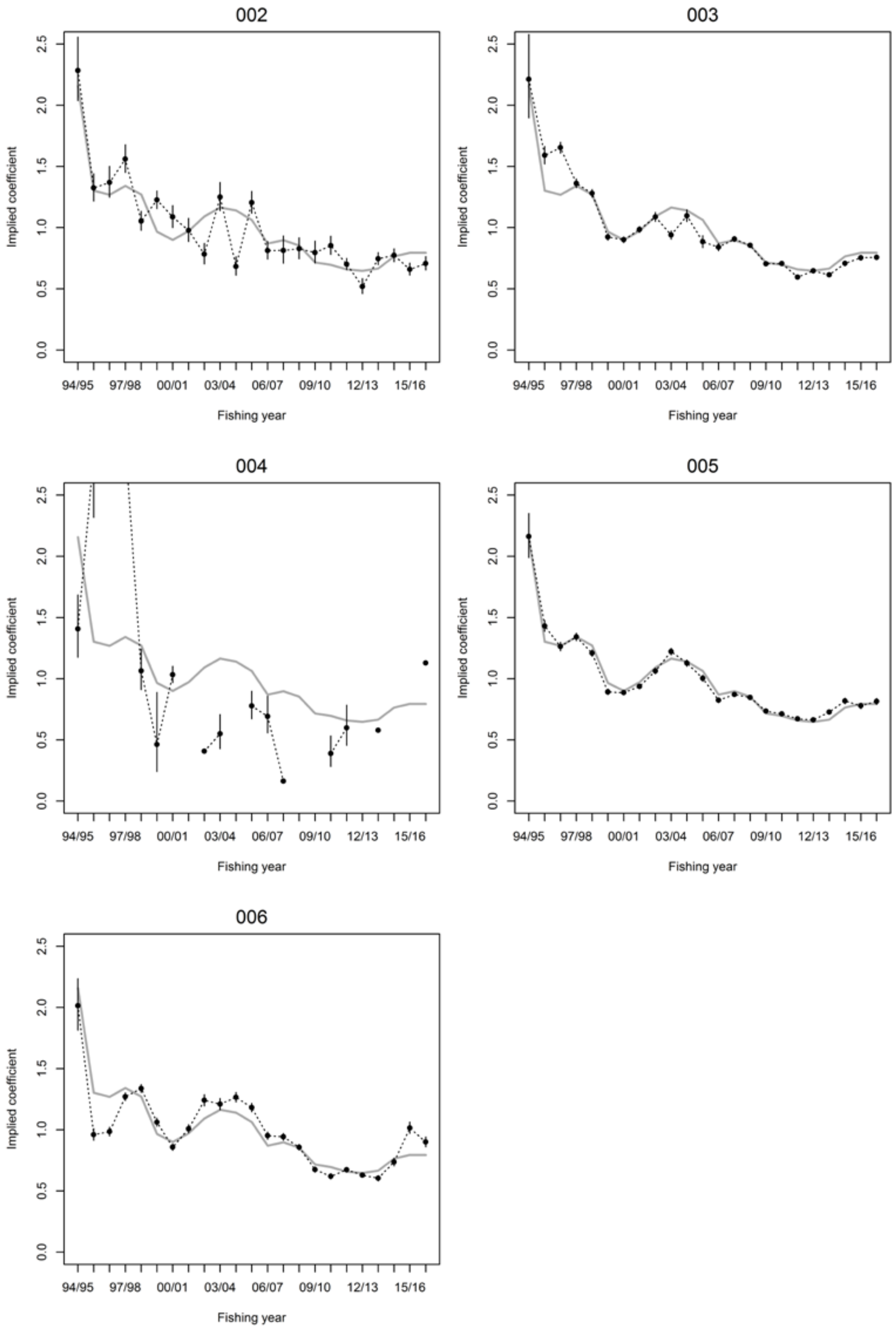

Figure 39: Annual implied coefficients (points) for the individual Statistical Areas included in the HG-ENLD lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

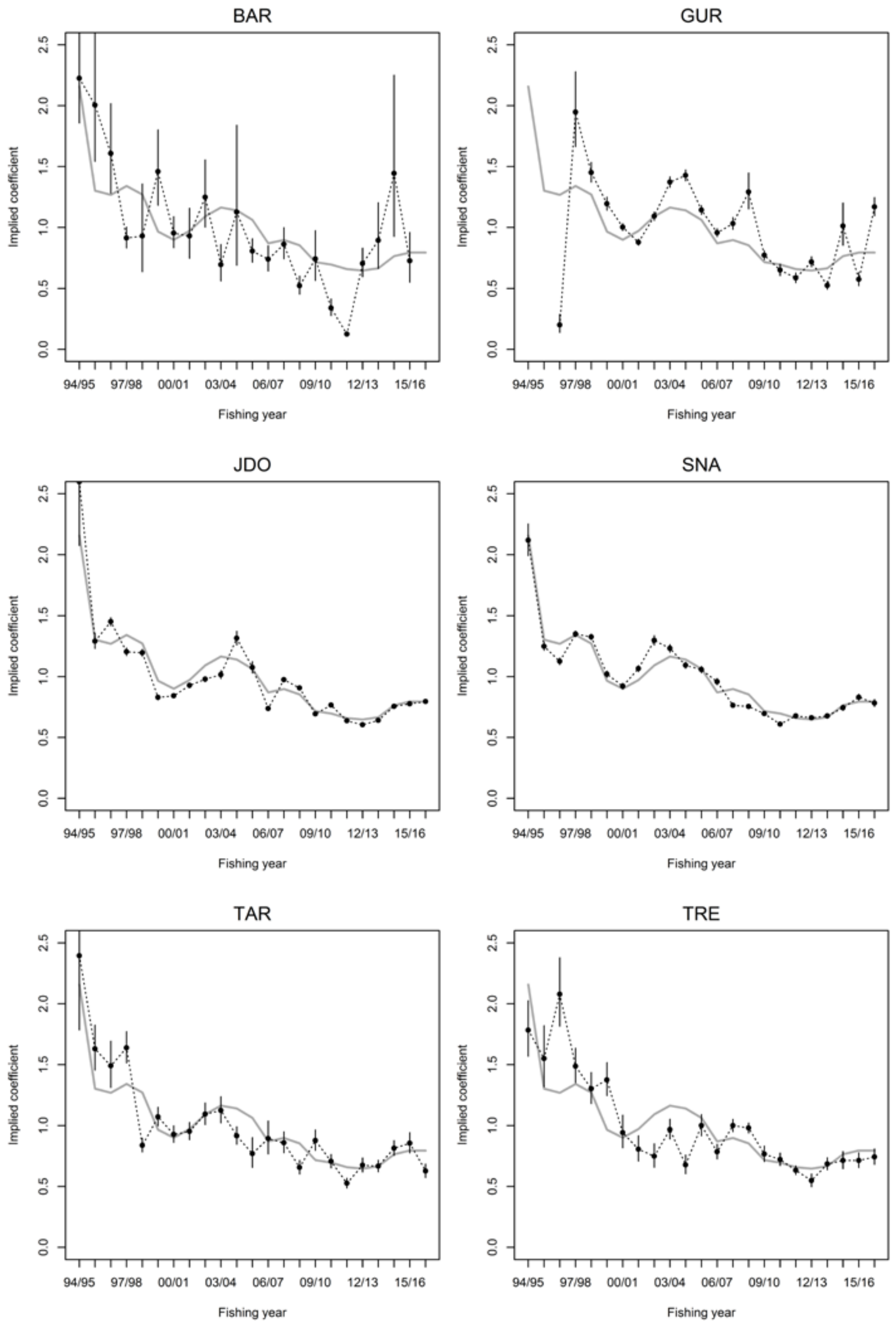

Figure 40: Annual implied coefficients (points) for the individual *TargetSpecies* included in the HG-ENLD lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

The HG-ENLD CPUE data set included a considerable proportion (30–40%) of trawl records with no John dory catch, particularly in 2011/2012–2016/17 (Appendix 2 Table A5). The occurrence of John dory in the trawl catch was predicted by the binomial model including the explanatory variables *FishingYear, TargetSpecies, Vessel, Month, Distance* and *Depth* (Table 6).

The annual indices derived from the binomial model increased from 2001/02 to 2006/07 to account for a shift towards target species and fishing vessels with a lower expectation of catching John dory

(Figure 37). The probability of catching John dory is predicted to have declined during 2007/08–2013/14 and remained at the lower level during the more recent years.

The lower indices in 1995/96–1998/99 and higher binomial indices in 2006/07–2007/08 tend to contradict the lognormal indices from the corresponding periods (Figure 37) although the trends in the two sets of indices are more comparable over the remainder of the time series.

The combined HG-ENLD trawl CPUE indices fluctuated during 1995/96–2007/08 and then steadily declined to a relatively low level in 2012/13 and recovered slightly during 2013/14–2016/17 (Figure 37, Appendix 3 Table A8).

Table 6: Summary of stepwise selection of variables in the HG-ENLD John dory 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	22	-37 425	74 896.0	0.024 *
TargetSpecies	5	-33 049	66 153.2	0.206 *
Vessel	32	-30 838	61 795.2	0.288 *
Month	11	-30 339	60 819.4	0.306 *
Distance	3	-29 934	60 016.5	0.320 *
Depth	3	-29 781	59 716.4	0.326 *
Latitude	5	-29 666	59 495.8	0.330
StartTime	3	-29 563	59 295.6	0.333
GearHeight	3	-29 512	59 201.0	0.335
GearWidth	3	-29 496	59 174.7	0.336
Duration	3	-29 481	59 150.7	0.336
Speed	3	-29 475	59 144.5	0.336

4.4 West coast North Island

The WCNI trawl CPUE analysis was based on the trawl event catch and effort data for the inshore bottom trawl fishery targeting the suite of inshore species within Statistical Areas 040–048 (Table 2). Catch and effort records were included regardless of whether or not there was an associated reported catch of John dory. The proportion of the total John dory trawl catch included within the trawl event based data set increased from about 60% in 1995/96–1997/98 to 80–90% in 2002/03–2006/07 (Figure 41). From 2007/08, almost all of the John dory trawl catch has been reported in event based format (i.e. TCEPR or TCER format).

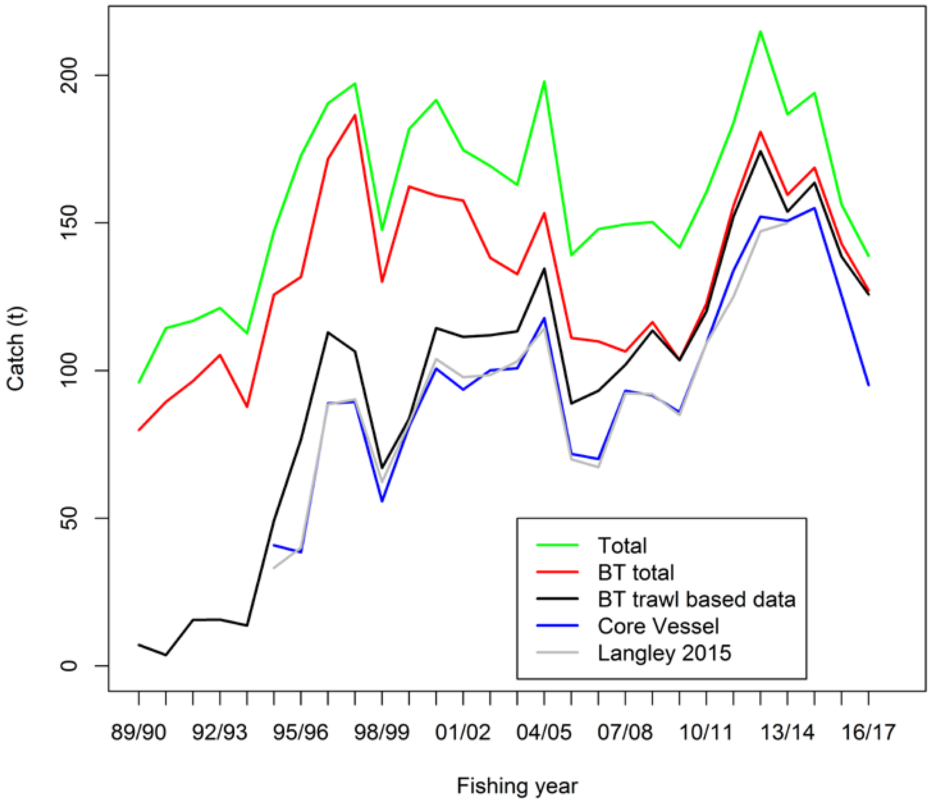

Figure 41: A comparison of the total West coast North Island (WCNI) annual John dory catch and various subsets of the catch and effort data set, including the final trawl CPUE data set for the core fleet (Core Vessel). For comparison, the annual catch included in the CPUE analysis of Langley (2015) is also presented.

The core fleet accounted for 86% of the total John dory catch included in the trawl event based data set from 1994/95 to 2015/16 (Figure 41). However, the fact that the proportion of the trawl catch included in the core vessel data set declined to 76% in 2016/17 is partly due to the adoption of PSH gear by a number of vessels. This component of the catch is not included within the core vessel data set.

The core vessel selection criteria resulted in the selection of 31 unique vessels including four vessels that operated in the fishery for at least 15 of the 23 years (Figure 42). Approximately half of the John dory catch included in the data set was taken by six vessels.

In recent years, an increasing proportion of the total John dory catch was caught by a single vessel (12600); the vessel accounted for 25–30% of the catch during 2007/08–2016/17 (Figure 42).

For 1995/96–2003/04, a high proportion of the records included within the data set were from trawls targeting snapper and trevally (Figure 43). The number of trawls targeting snapper dropped markedly in 2004/05 and continued to decline over subsequent years, while the number (and proportion) of trawls targeting red gurnard increased. The number of trawls targeting trevally and tarakihi remained relatively stable from the early 2000s (Figure 43).

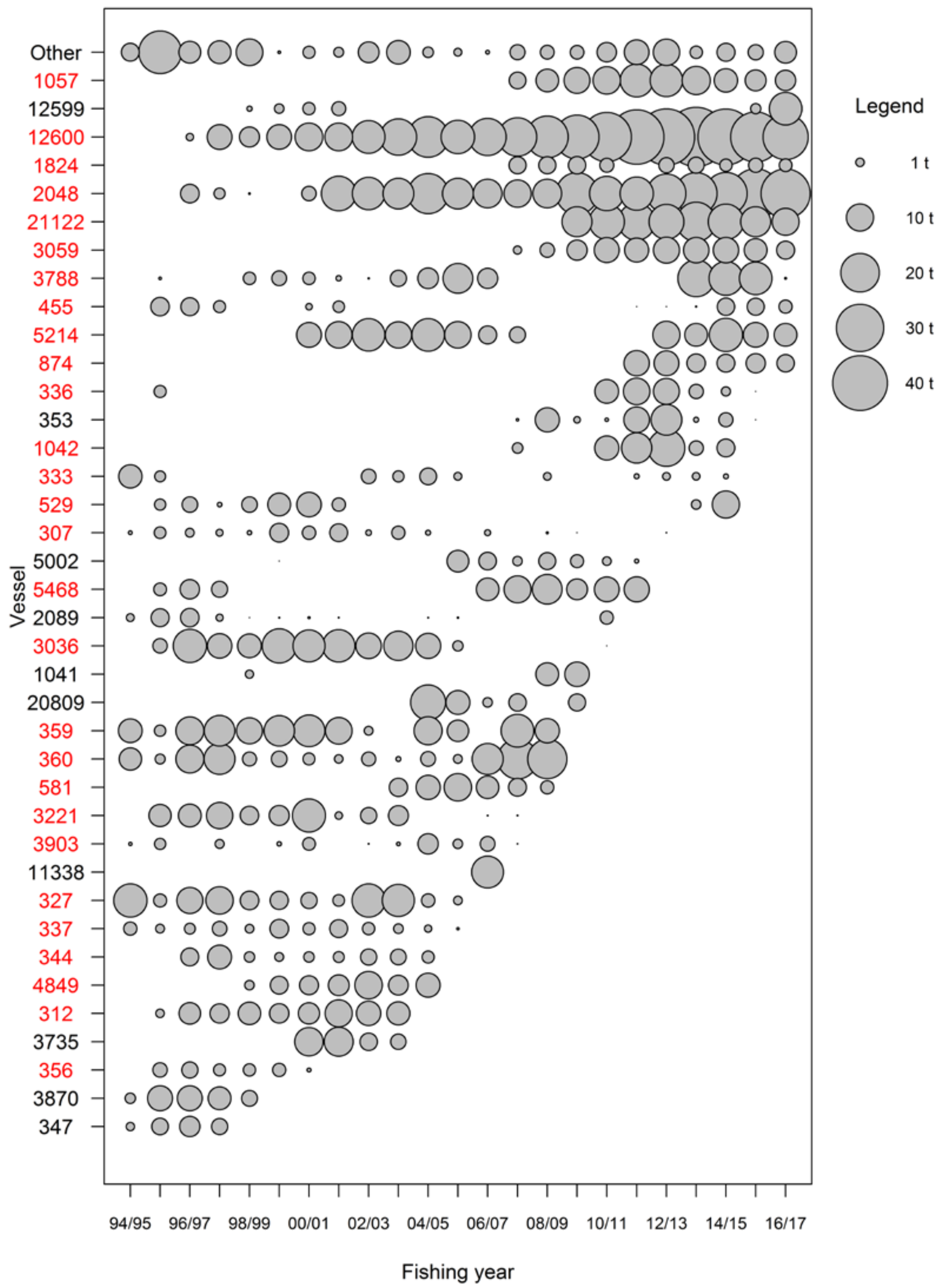

Figure 42: Distribution of John dory WCNI trawl catch by year and fishing vessel from the trawl based data set (BT gear only). The red labels denote the vessels comprising the core fleet included in the final trawl based CPUE data set.

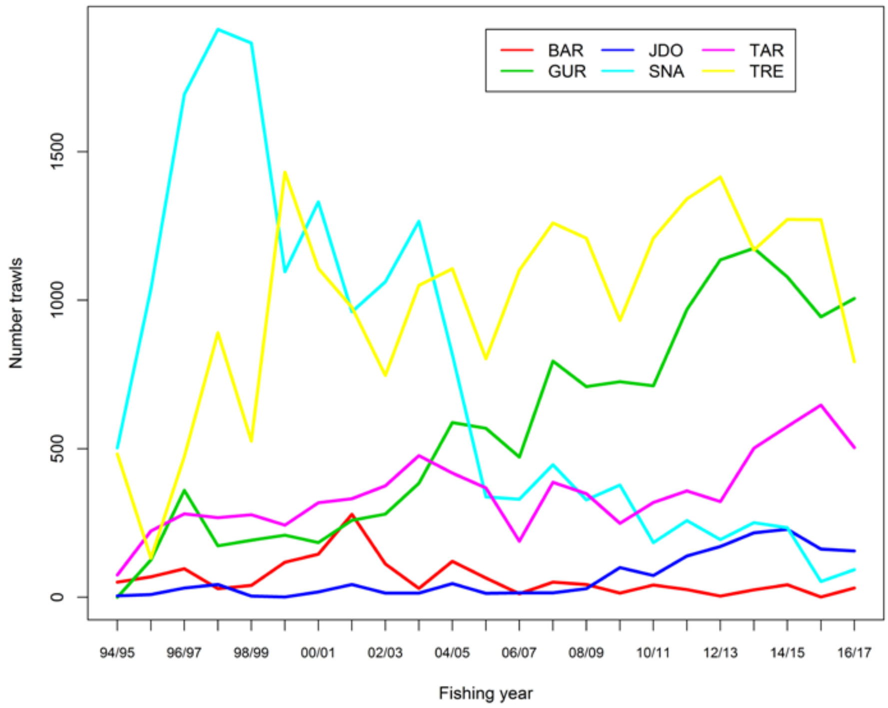

Figure 43: Annual distribution of trawl effort records by target species for the WCNI core vessel CPUE data set.

Within the WCSI area, fishing effort and John dory catch was concentrated in three main sub-areas: Ninety Mile Beach, North Taranaki Bight and the area adjacent to Kaipara and Manukau Harbours (Figure 20 and Figure 44a). Since 1998/99, there was considerably less effort off Ninety Mile Beach, while from 2007/08 there was an increase in the proportion of effort within the Northern Taranaki Bight and a corresponding reduction in effort in the Kaipara–Manukau area (Figure 44a). Trawl duration was generally longer during the early–mid 2000s, primarily due to a higher proportion of trawls targeting red gurnard and tarakihi during that period (Figure 44a).

From 2003/04, trawling speed became considerably more variable (Figure 44b), reflecting the more diverse nature of the fishery following the reduction in the number of trawls targeting snapper (Figure 43). Since 2009/10, there has been a marked decline in the headline height of the trawl gear used in the fishery (Figure 44b). This is primarily related to a change in the trawl gear used by the dominant vessel in the fishery (vessel 12600) in 2012/13.

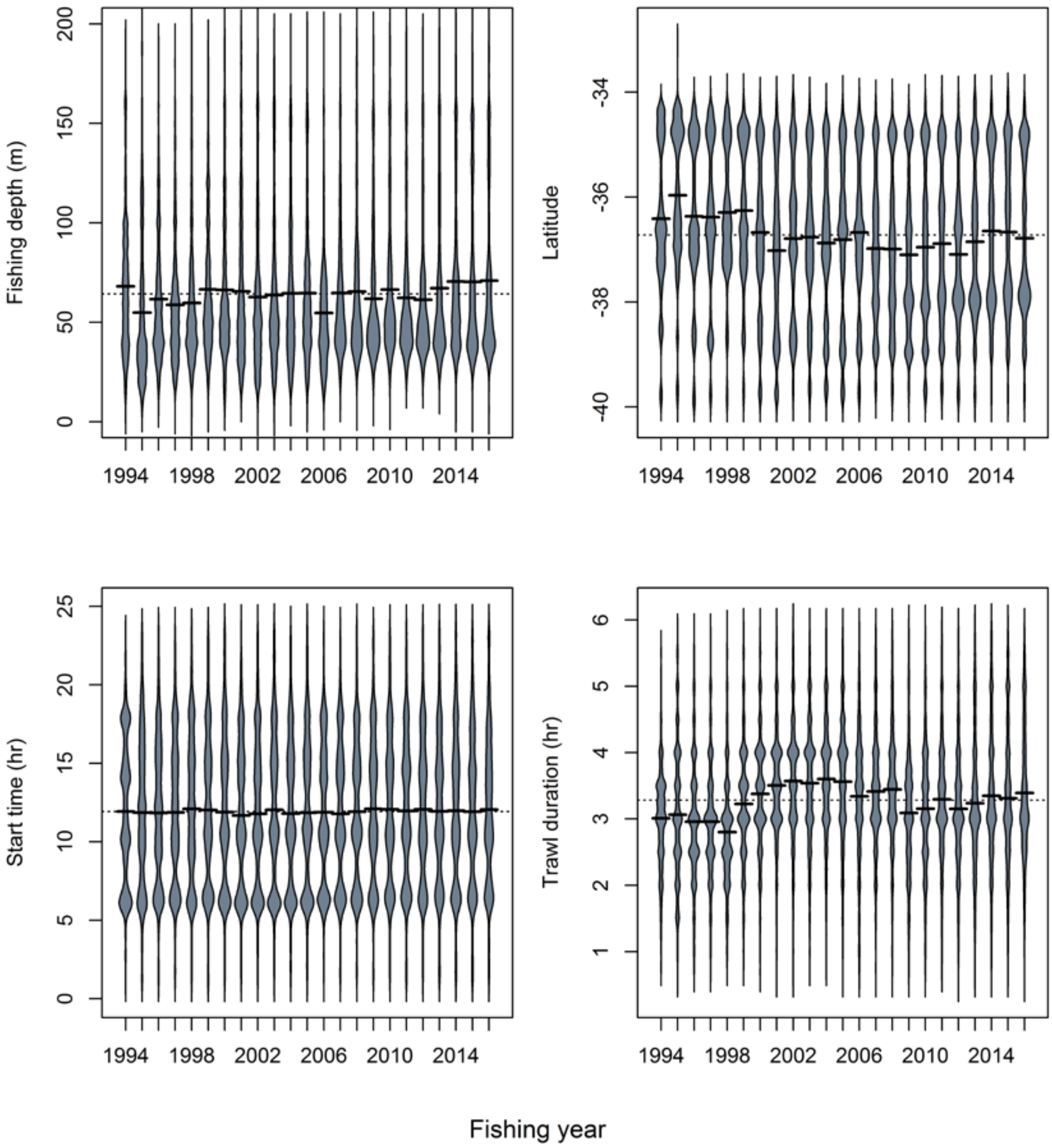

Figure 44a: Beanplots of a range of descriptive variables characterising the fishing effort data included in the WCNI trawl CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the median value. The fishing year is denoted by the calendar year at the start of the fishing year (e.g. 1994 represents the 1994/95 fishing year).

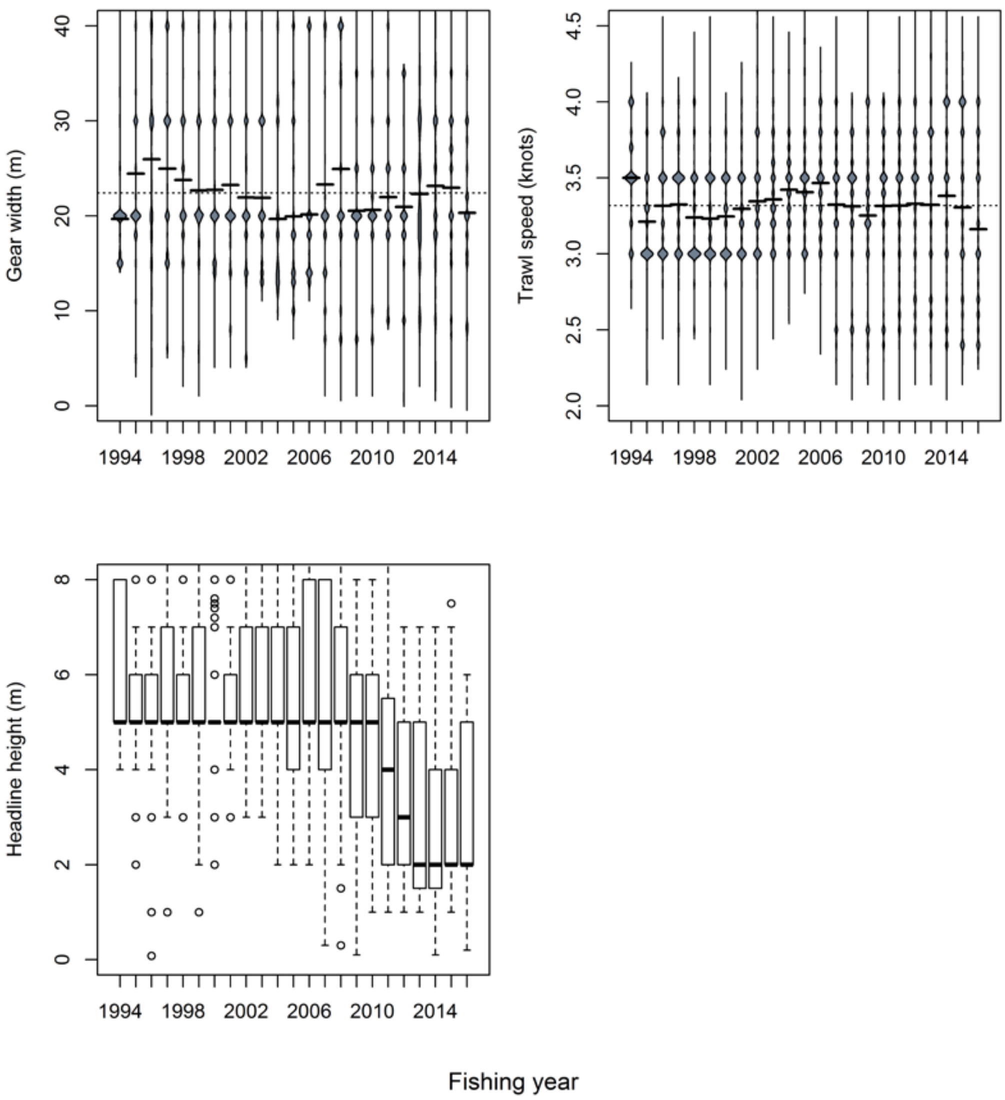

Figure 44b: Beanplots of a range of descriptive variables characterising the fishing effort data included in the WCNI trawl CPUE data set (core vessels). The "beans" represent the distribution of the yearly data and the solid horizontal line represents the median value. The fishing year is denoted by the calendar year at the start of the fishing year (e.g. 1994 represents the 1994/95 fishing year).

The CPUE data set included a relatively high proportion of trawl records with no associated John dory catch (Appendix 2 Table A6), although the overall proportion of nil catch records declined steadily from about 60% in 1994/95–1999/2000 to about 40% in 2010/11–2016/17.

The lognormal (positive catch) CPUE model included the predictor variables *FishingYear*, *Vessel*, *Depth*, natural logarithm of *Distance*, *TargetSpecies* and *Latitude* (Table 7). Overall, the model explained 37.2% of the variation in the positive catch of John dory (Nagelkerke pseudo-R^2), while the *FishingYear* variable accounted for a small proportion of the variation (2.1%). The distribution of the CPUE model residuals is generally consistent with the assumption of normality, with the exception of a relatively small number of observations with a small John dory catch which are not well estimated by the model (Figure 45).

Table 7: Summary of stepwise selection of variables in the WCNI trawl 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	22	-48 236	96 520	0.021	*
Vessel	30	-43 860	87 828	0.263	*
Depth	3	-42 924	85 963	0.307	*
Distance	3	-42 312	84 743	0.334	*
TargetSpecies	5	-41 830	83 790	0.355	*
Latitude	5	-41 425	82 990	0.372	*
Month	11	-41 346	82 854	0.375	
StartTime	3	-41 275	82 718	0.378	
GearHeight	3	-41 230	82 634	0.380	
GearWidth	3	-41 211	82 601	0.381	
Duration	3	-41 200	82 586	0.381	
Speed	3	-41 192	82 575	0.382	

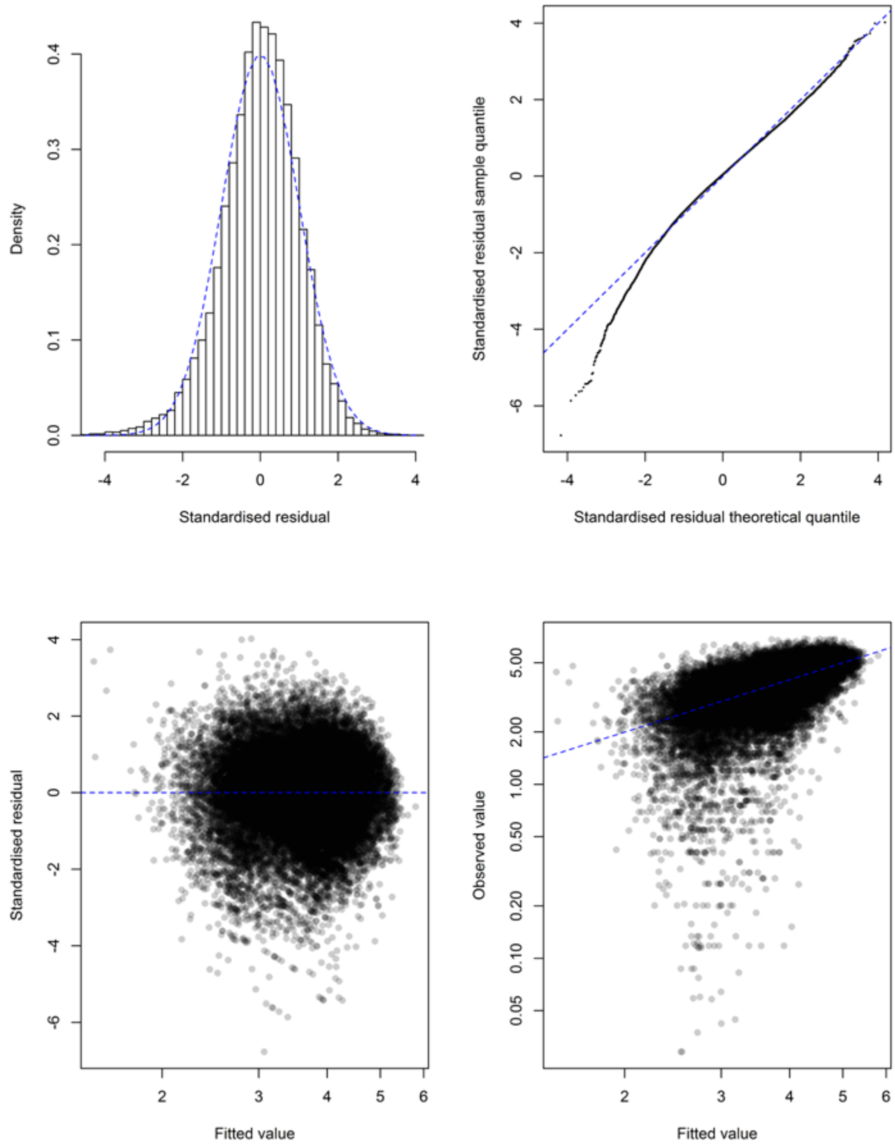

Figure 45: Residual diagnostics for the lognormal CPUE model for the WCNI trawl fishery. Top left: histogram of standardised residuals compared to standard normal distribution. Bottom left: quantile-quantile plot of standardised residuals. Top right: fitted values versus standardised residuals. Bottom right: observed values versus fitted values.

The annual indices derived from the lognormal CPUE model fluctuated (by about ± 20%) over the study period with no appreciable trend. The CPUE indices were higher during 1995/96–1996/97, 2000/01–2002/03 and 2010/11–2012/13 and have declined in the more recent years (Figure 46). The annual trends in the unstandardized average annual catch rates were similar to the standardised CPUE indices. Deviations between the two sets of indices were primarily attributable to changes in the composition of the fishing fleet accounted for by the inclusion of the *Vessel* variable in the CPUE model (Figure 47, Appendix 4 Figure A15).

An analysis of the model residuals revealed that trends in the annual CPUE indices were generally consistent amongst the constituent Statistical Areas (Figure 48) and amongst the main declared target species (Figure 49). However, there were appreciable differences in the CPUE trends amongst some of the main vessels in the fleet (Figure 50); for example, one vessel (Vessel 12600) achieved considerably higher catch rates during 2010/11–2014/15 than the remainder of the fleet.

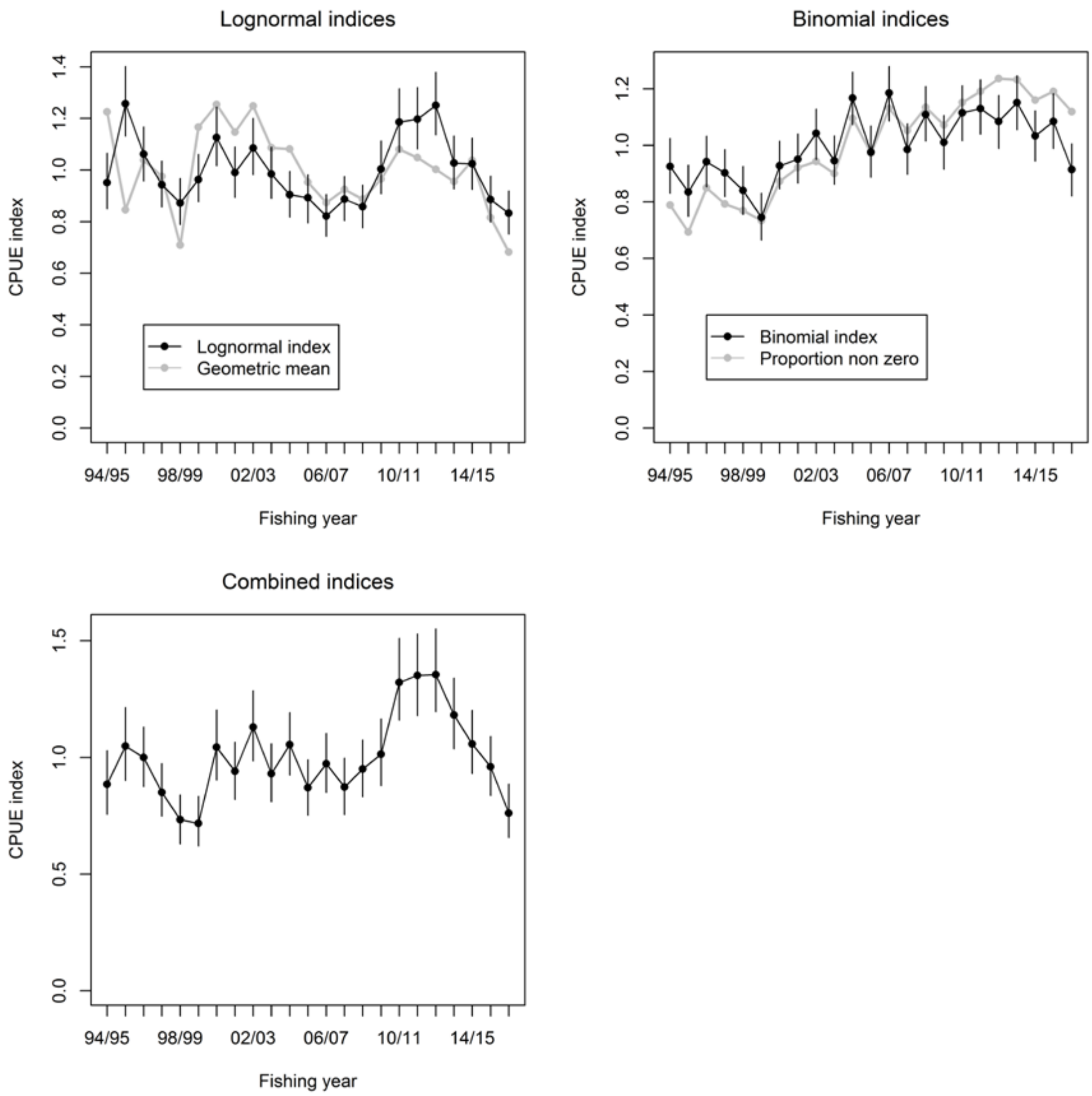

Figure 46: A comparison of the WCNI trawl standardised CPUE indices and the geometric mean of the annual catch per day (unstandardised) (top left panel), a comparison of the binomial indices and the annual proportion of positive catch records in the data set (top right panel) and the combined index (bottom panel) . The error bars represent the 95% confidence intervals associated with each index. The annual indices are provided in Table A9 (Appendix 3).

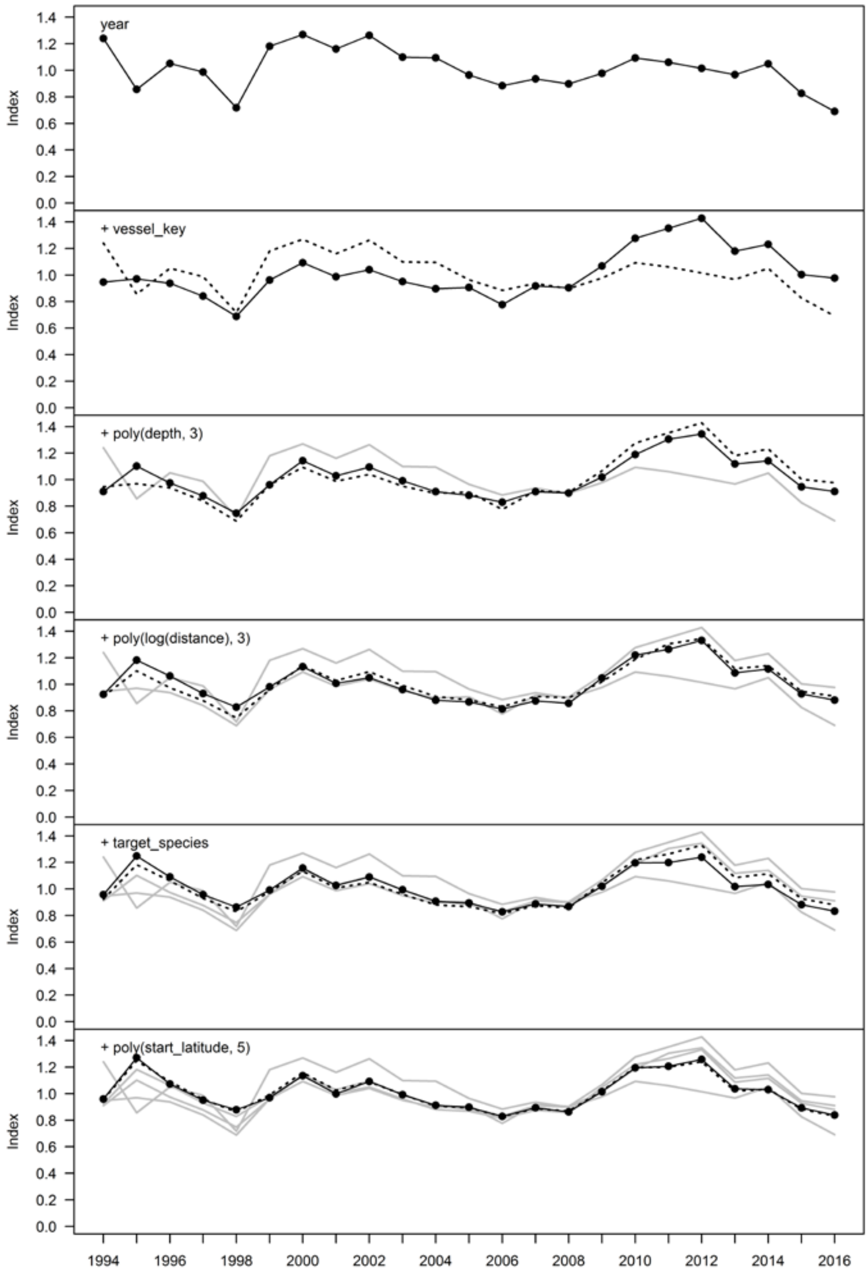

Figure 47: The change in the annual coefficients with the step-wise inclusion of each of the significant variables in the lognormal CPUE model for the WCNI trawl fishery (from top to bottom panel). The solid line and points represent the annual coefficients at each stage. The fishing year is denoted by the calendar year at the beginning of the fishing year (e.g. 1994 denotes the 1994/95 fishing year).

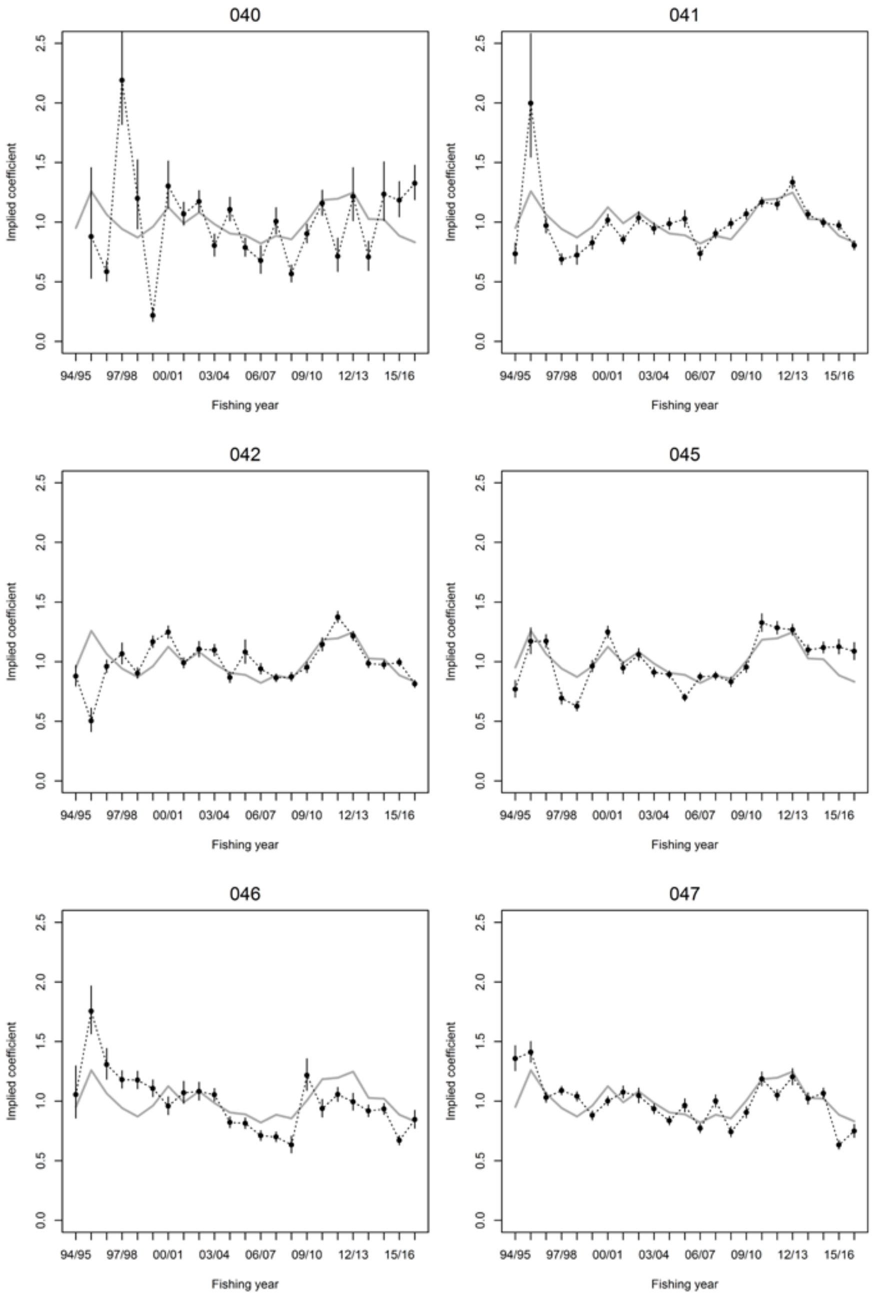

Figure 48: Annual implied coefficients (points) for the individual Statistical Areas included in the WCNI lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

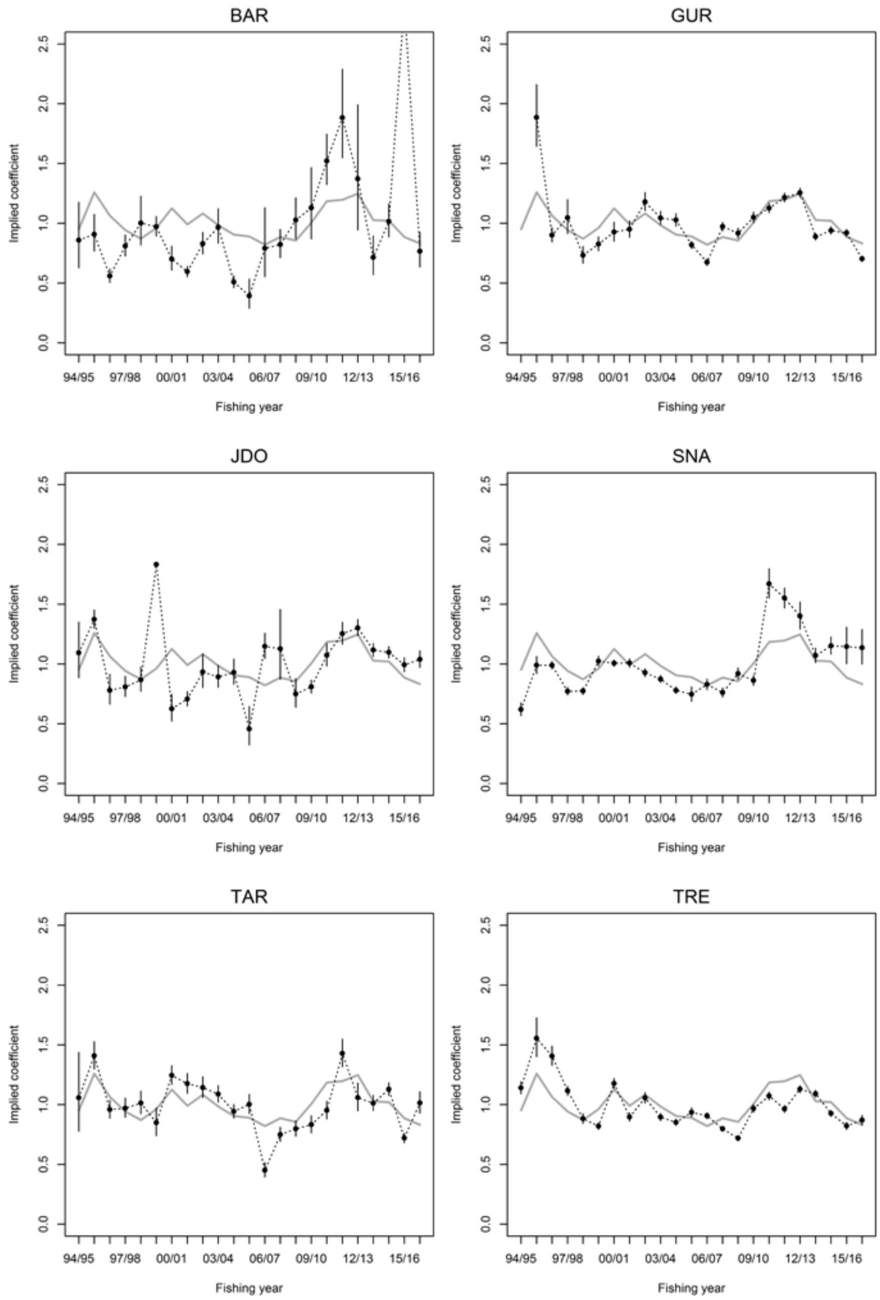

Figure 49: Annual implied coefficients (points) for the individual *TargetSpecies* included in the WCNI lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

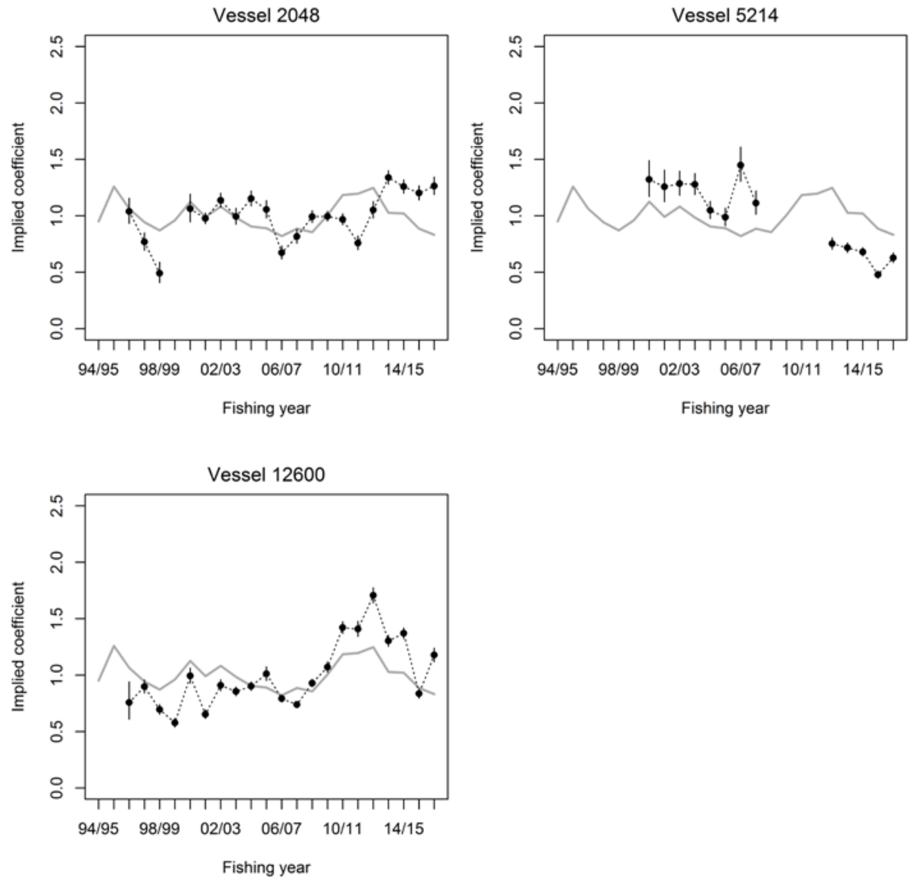

Figure 50: Annual implied coefficients (points) for a subset of the core vessels included in the WCNI lognormal CPUE model. The grey line represents the annual CPUE indices derived from the positive catch CPUE model. The confidence intervals represent the standard error of the annual residuals.

The occurrence of John dory in the WCNI trawl catch was predicted by the binomial model including the explanatory variables *FishingYear, Vessel, Depth, Latitude, TargetSpecies* and *Month* (Table 8). The annual indices derived from the binomial model generally increased from during the early 2000s and then stabilised at the higher level before declining in the most recent year (2016/17) (Figure 46). The trend in the CPUE indices was comparable to the increase in the (unstandardized) proportion of positive catch records in the data set, although the extent of the increase was moderated by the standardisation procedure.

Table 8: Summary of stepwise selection of variables in the WCNI John dory 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	22	-42 976	85 998.7	0.039	*
Vessel	30	-40 697	81 499.2	0.129	*
Depth	3	-39 644	79 399.4	0.168	*
Latitude	5	-39 148	78 418.1	0.186	*
TargetSpecies	5	-38 813	77 758.2	0.198	*
Month	11	-38 678	77 510.3	0.203	*
StartTime	3	-38 553	77 265.4	0.208	
Duration	3	-38 519	77 204.6	0.209	
GearHeight	3	-38 483	77 138.9	0.210	
Duration	3	-38 478	77 133.5	0.210	

The incorporation of the binomial indices in the combined index accentuates the trend in the lognormal indices over the last decade, increasing the magnitude of the peak in 2010/11–2012/13 and the extent of the decline over the subsequent years (Figure 46). The combined index for 2016/17 is below (76%) the average of the entire time series.

The differences in the annual trends in John dory catch rates evident amongst the key vessels included in lognormal CPUE analysis highlighted concerns that differences in the behaviour of individual vessels may be unduly influencing the CPUE indices (Figure 50). This is particularly the case for one vessel (Vessel 12600) which accounted for 25–30% of the annual John dory catch and 15–25% of the trawl record during 2009/10–2016/17. The sensitivity of the model results to these data was investigated by repeating the standardisation procedure without the data from Vessel 12600. The resulting lognormal indices were lower during 2009/10–2016/17, while the binomial indices were slightly higher. These differences were countered in the derivation of the combined indices which were very similar regardless of whether or not data from Vessel 12600 were included (Figure 51).

The compensatory effect of combining the lognormal and binomial CPUE indices is consistent with the influence of differences in the reporting of small John dory catches by individual vessels identified in the previous analysis (Langley 2015).

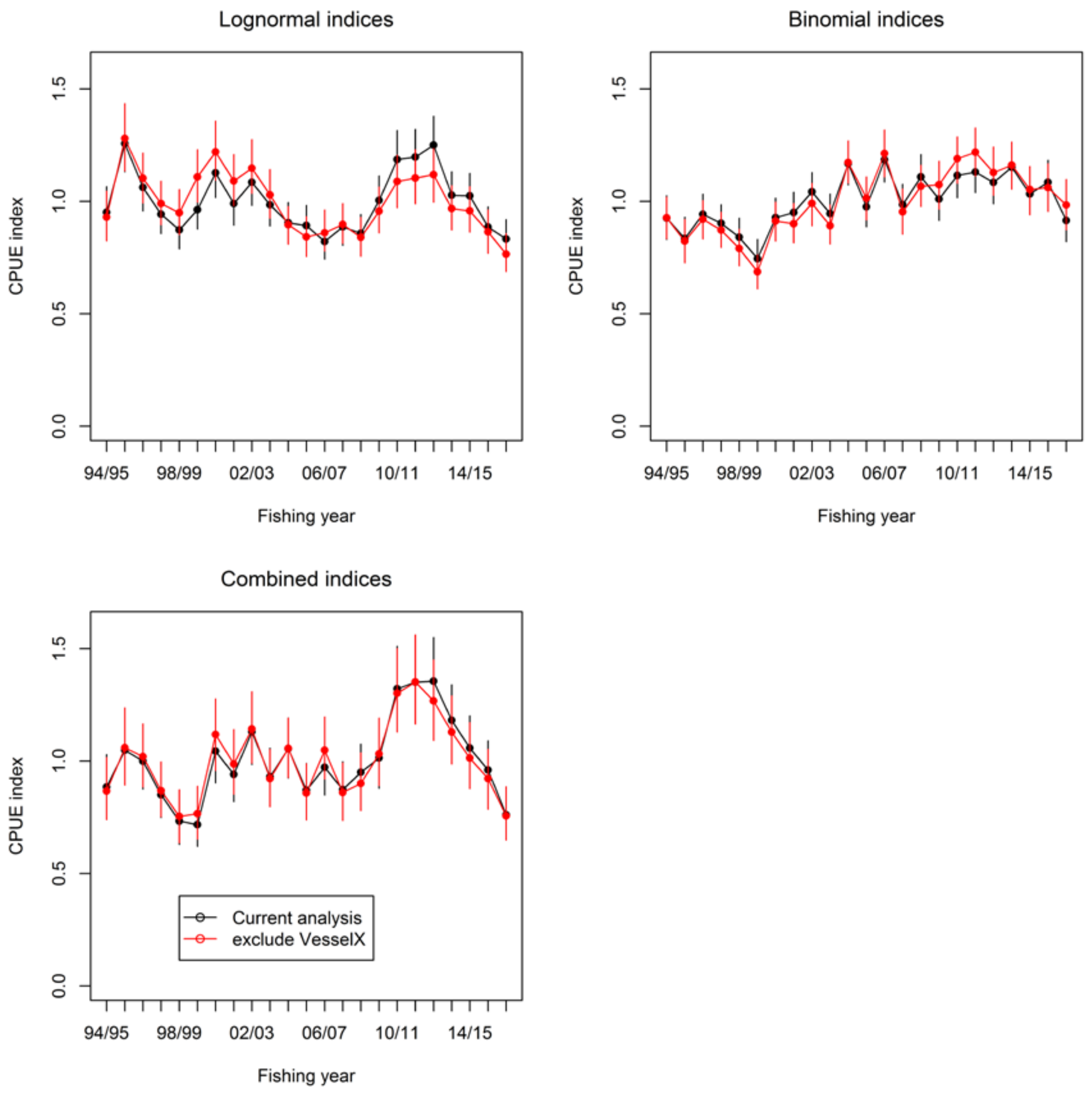

Figure 51: A comparison of the WCNI trawl standardised CPUE indices and the standardised indices derived from the data set excluding one of the main vessels (VesselX i.e. Vessel 12600). The error bars represent the 95% confidence intervals associated with each index.

5 DISCUSSION

The area specific event scale (tow-by-tow) bottom trawl CPUE indices have been accepted for monitoring of the relative abundance of John dory within the sub-areas of JDO 1. Limited data are available to validate this assumption, although the trends in CPUE indices are generally corroborated by the trends in John dory abundance from the time series of northern inshore trawl surveys (which ceased in 2000) (Langley 2015). There were also comparable trends in the area specific CPUE indices from the trawl and Danish seine fisheries in the Hauraki Gulf and Bay of Plenty to 2013/14 (Langley 2015).

The commercial sector nevertheless expressed concerns that changes in the operation of the trawl fishery, particularly in the Hauraki Gulf, may not be adequately accounted for in the CPUE analysis (Northern Inshore Finfish Working Group, 18 April 2018). These changes in fishing behaviour have been adopted to minimise the catches of snapper in the trawl fishery. The trawl based data set includes location and fishing depth, with the result that significant changes in the distribution of fishing effort are likely to be adequately accounted for in the analysis. Although declaration of the target species of the trawl may not be reported consistently over the time-series of the analysis, model trials that excluded the declared target species did not result in appreciably different CPUE indices for the Hauraki Gulf trawl fishery. There are, however, other changes in the operation of the trawl fleet, such as changes in configuration of trawl gear, that have the potential to influence the CPUE indices for John dory.

Langley (2015) highlighted the potential for changes in the frequency of reporting of small catches to introduce a bias in the CPUE indices for John dory and other species that may represent a minor component of the total catch. That study indicated that the combined CPUE indices, incorporating indices from a binomial (presence/absence) model and a positive catch (e.g. lognormal) model, effectively removed the potential for biases introduced by variable reporting of small catches. This conclusion was, however, based on a relatively simple simulation study and further work has been scheduled to investigate these issues.

One recent development in the northern inshore trawl fishery has been the adoption of the PSH gear by a significant proportion of the fleet. For example, trawls using the PSH gear accounted for about 25% of the fishing effort in the Hauraki Gulf fishery in 2016/17. A preliminary analysis of the Hauraki Gulf trawl catch and effort data indicated that PSH gear may be less efficient at catching John dory than standard trawl gear. The possible difference in relative performance between the two gears meant that PSH trawls were excluded from the derivation of the CPUE indices. An increase in the adoption of the PSH gear by the trawl fleet may limit the catch and effort data set available in future years. This may necessitate the inclusion of PSH trawls in the CPUE analyses once sufficient data are available to reliably estimate the relative efficiency of the two types of trawl gear.

6 MANAGEMENT IMPLICATIONS

The area specific CPUE indices represent the primary monitoring tool for JDO 1. During the 2018 assessment process, the Northern Inshore Fishery Assessment Working Group accepted the updated time-series of CPUE indices for the three areas of JDO 1. There are marked differences in the trends in the CPUE indices from the three areas of JDO 1 (Figure 52). This result is consistent with the previous CPUE studies and supports the conclusion that JDO 1 should be monitored at the regional scale rather than as a single JDO 1 entity (Bentley & Kendrick 2011, Dunn & Jones 2013).

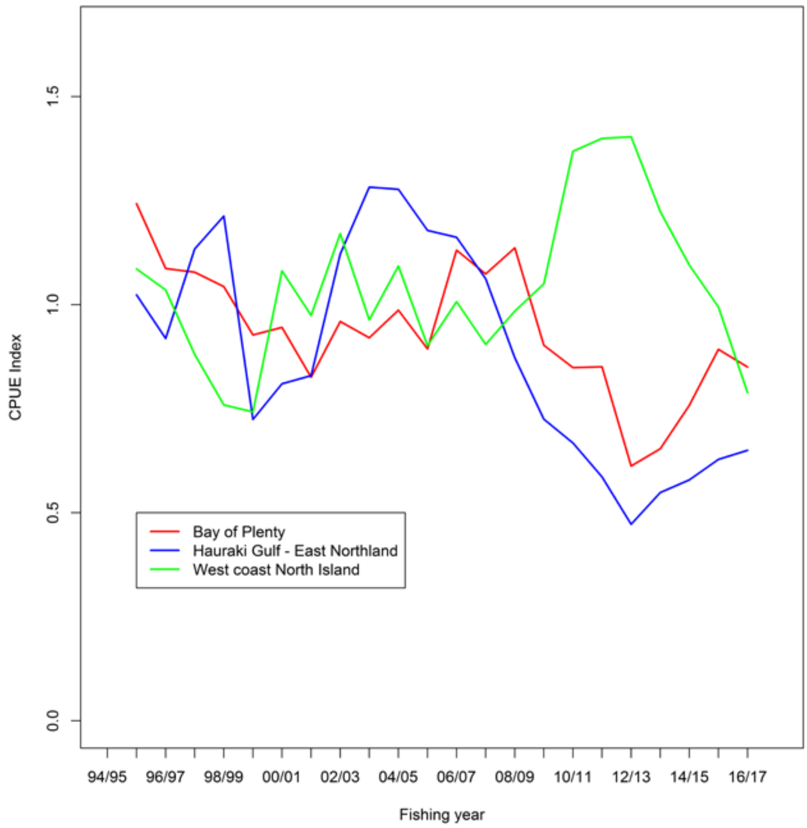

Figure 52: A comparison of the combined trawl based CPUE indices derived for each of the three fishery areas of JDO 1. Each series is normalised relative to the average from of the indices 1995/96-2010/11. CPUE indices from 1994/95 are considered unreliable and have been excluded.

For each area, the recent CPUE indices are compared to an Interim Target reference point established at the average of the CPUE indices for the period 1995/96–2010/11, and accepted by the WG as a proxy for Bmsy. Soft and Hard Limit reference points were defined as 50% and 25% of the Interim Target level, respectively.

The CPUE indices indicate that John dory abundance in the Hauraki Gulf-east Northland area has increased gradually over recent years from a relatively low level and is currently above the Soft Limit but well below the Interim Target reference level. Annual catches from the fishery have remained at a low level over the last six years (from 2011/12).

For the Bay of Plenty, the CPUE indices increased over the last four years (from 2012/13) and the most recent index (2016/17) is at 85% of the Interim Target reference level. Catches have increased in recent years and continued catches at the current level may cause the stock to decline (Fisheries New Zealand 2018).

For the west coast North Island, the CPUE indices declined from a high level over the last four years (from 2012/13) and the most recent index (2016/17) is at 79% of the Interim Target reference level.

The CPUE indices from each of the three areas have varied over the time series and it is considered that trends in stock abundance are likely to be strongly influenced by variation in recruitment (Fisheries New Zealand 2018).

It is anticipated that the JDO 1 CPUE indices will be updated again in 2021 (to include data to the end of the 2019/20 fishing year).

7 ACKNOWLEDGMENTS

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APPENDIX 1. SUMMARY OF ANNUAL CATCHES BY AREA AND METHOD

Table A1: Annual catches (tonnes) of John dory from the Bay of Plenty (BPLE) fishery by fishing method.

Fishing year	Fishing method				Total
	BT	DS	BPT	Other	
1989/90	66.1	5.6	7.1	4.4	83.2
1990/91	76.3	7.3	6.8	7.9	98.3
1991/92	87.8	15.0	8.8	7.4	119.0
1992/93	102.3	16.7	8.9	6.8	134.7
1993/94	96.4	25.6	11.9	7.5	141.4
1994/95	103.1	40.1	37.8	6.9	187.9
1995/96	76.6	22.5	14.7	10.6	124.4
1996/97	84.6	22.4	9.2	4.8	121.0
1997/98	93.4	34.0	2.4	3.9	133.7
1998/99	102.6	26.2	0.0	4.6	133.4
1999/2000	87.1	17.4	0.9	6.1	111.5
2000/01	81.0	8.3	0.3	3.5	93.1
2001/02	92.5	14.1	0.8	3.2	110.6
2002/03	92.7	23.0	2.1	2.3	120.1
2003/04	95.1	17.4	2.8	3.1	118.4
2004/05	112.8	22.6	4.0	3.3	142.7
2005/06	89.6	22.0	0.9	5.7	118.2
2006/07	75.2	14.6	0.3	4.6	94.7
2007/08	68.8	22.0	0.3	3.7	94.8
2008/09	66.4	26.0	0.4	1.6	94.4
2009/10	64.8	25.0	0.9	2.6	93.3
2010/11	65.5	45.4	1.2	1.6	113.7
2011/12	50.1	30.3	0.0	1.5	81.9
2012/13	42.3	47.9	0.0	1.3	91.5
2013/14	41.3	35.5	0.0	1.4	78.2
2014/15	42.7	36.4	0.0	1.5	80.6
2015/16	62.2	52.7	0.0	1.4	116.3
2016/17	77.4	50.0	0.0	3.4	130.8

Table A2: Annual catches (tonnes) of John dory from the Hauraki Gulf and east Northland (HG-ENLD) fishery by fishing method.

Fishing year	Fishing method				Total
	BT	DS	BPT	Other	
1989/90	162.6	38.2	29.2	10.7	240.7
1990/91	177.4	70.8	17.7	13.0	278.9
1991/92	224.5	91.3	7.6	15.9	339.3
1992/93	184.4	104.9	10.7	18.6	318.6
1993/94	208.1	166.9	12.3	25.0	412.3
1994/95	204.6	143.2	17.5	26.9	392.2
1995/96	227.0	105.4	5.3	32.8	370.5
1996/97	222.3	125.8	3.6	29.3	381.0
1997/98	219.0	88.2	1.5	32.2	340.9
1998/99	244.0	132.5	1.5	29.4	407.4
1999/2000	164.3	96.9	2.2	22.0	285.4
2000/01	152.0	92.1	3.3	15.7	263.1
2001/02	139.9	59.6	1.2	19.0	219.7
2002/03	137.5	57.5	4.0	12.1	211.1
2003/04	160.4	75.7	2.8	15.6	254.5
2004/05	204.9	64.4	2.9	14.9	287.1
2005/06	183.5	134.0	1.6	18.9	338.0
2006/07	191.8	141.0	3.2	18.7	354.7
2007/08	153.1	112.8	2.3	8.1	276.3
2008/09	148.9	48.6	1.8	9.1	208.4
2009/10	113.6	48.1	1.8	9.9	173.4
2010/11	95.0	42.5	1.7	11.2	150.4
2011/12	75.4	50.3	0.0	7.3	133.0
2012/13	68.3	40.0	0.0	6.2	114.5
2013/14	79.1	45.5	0.0	6.7	131.3
2014/15	79.6	38.9	0.0	7.2	125.7
2015/16	72.5	41.4	0.0	6.8	120.7
2016/17	89.4	41.6	0.0	6.6	137.6

Table A3: Annual catches (tonnes) of John dory from the West Coast North Island (WCNI) fishery by fishing method.

Fishing year	Fishing method				Total
	BT	DS	BPT	Other	
1989/90	79.9	0.0	14.9	1.2	96.0
1990/91	89.4	0.0	23.3	1.7	114.4
1991/92	96.5	0.0	16.4	4.0	116.9
1992/93	105.3	0.3	12.1	3.5	121.2
1993/94	87.8	1.2	17.1	6.6	112.7
1994/95	125.7	0.3	15.0	6.2	147.2
1995/96	131.7	9.5	23.8	7.8	172.8
1996/97	171.7	4.2	9.2	5.4	190.5
1997/98	186.5	0.9	5.6	4.2	197.2
1998/99	130.1	0.6	14.1	2.9	147.7
1999/2000	162.3	1.4	16.0	2.1	181.8
2000/01	159.3	3.7	24.0	4.6	191.6
2001/02	157.6	6.5	6.7	3.9	174.7
2002/03	138.2	5.9	11.7	13.5	169.3
2003/04	132.7	13.5	8.8	7.9	162.9
2004/05	153.3	6.2	21.7	16.7	197.9
2005/06	111.1	5.6	9.3	13.1	139.1
2006/07	109.9	7.8	11.9	18.3	147.9
2007/08	106.5	14.5	14.1	14.4	149.5
2008/09	116.4	14.6	9.4	9.9	150.3
2009/10	103.6	10.0	14.1	14.0	141.7
2010/11	122.6	10.2	11.8	15.8	160.4
2011/12	155.7	6.9	2.7	18.4	183.7
2012/13	180.8	9.8	0.0	24.2	214.8
2013/14	159.5	10.1	0.0	17.2	186.8
2014/15	168.7	7.3	0.0	18.0	194.0
2015/16	142.9	0.6	0.0	12.7	156.2
2016/17	127.1	1.5	0.0	10.2	138.8

APPENDIX 2. CPUE DATA SETS

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

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1994/95	8	72	14.5	427	1 133	33.3
1995/96	21	170	28.2	950	2 528	41.5
1996/97	19	230	36.1	1 468	3 536	43.3
1997/98	23	243	43.0	1 427	3 924	39.3
1998/99	20	345	57.8	2 464	6 540	44.7
1999/2000	18	284	42.7	2 286	5 581	45.6
2000/01	23	393	58.2	2 911	7 569	50.5
2001/02	19	398	49.5	2 612	7 232	44.1
2002/03	21	432	60.5	3 093	8 884	47.3
2003/04	19	434	62.3	3 201	9 017	47.2
2004/05	18	409	70.5	3 528	10 153	47.7
2005/06	17	362	39.6	2 487	6 927	49.6
2006/07	13	245	40.6	1 823	5 035	40.9
2007/08	15	341	50.5	2 320	6 550	37.2
2008/09	17	356	55.9	2 604	7 399	38.4
2009/10	15	392	52.0	2 602	7 192	42.7
2010/11	15	343	50.3	2 485	6 404	43.2
2011/12	13	349	41.5	2 503	6 230	47.8
2012/13	14	328	35.2	2 134	5 484	50.5
2013/14	16	318	31.5	2 257	5 606	55.2
2014/15	15	289	34.4	1 872	4 880	47.8
2015/16	15	232	44.2	1 508	4 314	46.2
2016/17	11	208	41.4	1 545	4 127	37.9

Table A5: Summary of the catch and effort data from the Hauraki Gulf-East Northland (HG-ENLD) single trawl CPUE data set (core vessels only).

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1994/95	9	57	17.8	371	799	43.1
1995/96	20	283	84.7	2 280	5 121	28.9
1996/97	23	383	124.5	3 204	6 284	31.2
1997/98	25	461	108.8	3 695	7 317	32.0
1998/99	23	401	118.3	3 494	7 674	29.3
1999/2000	23	382	88.7	3 417	8 086	32.9
2000/01	25	395	112.0	3 280	8 346	25.4
2001/02	23	379	113.0	3 147	8 068	25.8
2002/03	21	288	81.4	2 242	5 207	22.7
2003/04	18	284	78.5	2 376	5 049	23.7
2004/05	17	208	55.0	1 933	3 933	22.7
2005/06	15	221	58.7	1 848	4 100	22.1
2006/07	11	271	79.4	2 342	5 231	17.2
2007/08	14	349	126.8	3 046	8 262	17.3
2008/09	13	320	119.8	3 401	9 161	24.1
2009/10	11	320	95.0	3 263	8 750	23.9
2010/11	12	291	86.7	3 259	8 162	29.0
2011/12	12	304	70.5	3 351	7 909	32.5
2012/13	11	283	60.5	3 473	8 182	38.9
2013/14	15	317	65.2	3 078	7 264	33.7
2014/15	14	312	71.8	2 839	6 732	34.2
2015/16	12	247	53.5	2 217	5 139	36.2
2016/17	10	192	49.3	1 954	4 396	34.0

Table A6: Summary of the catch and effort data from the west coast North Island (WCNI) single trawl CPUE data set (core vessels only).

Fishing year	Number vessels	Number trips	JDO catch (t)	Number trawls	Duration (hrs)	Percent zero catch
1994/95	9	87	40.9	1 116	3 358	59.6
1995/96	19	195	38.5	1 597	4 893	64.5
1996/97	18	326	88.9	2 935	8 680	56.5
1997/98	19	334	89.4	3 315	9 806	59.4
1998/99	18	249	55.8	2 906	8 143	60.6
1999/2000	16	268	81.2	3 098	9 993	62.4
2000/01	19	278	100.7	3 103	10 481	55.3
2001/02	17	300	93.6	2 850	9 992	52.8
2002/03	17	264	100.1	2 590	9 245	51.7
2003/04	17	288	100.8	3 221	11 401	53.9
2004/05	16	280	117.8	3 096	11 148	43.9
2005/06	13	230	71.8	2 156	7 677	50.2
2006/07	11	206	70.1	2 119	7 078	42.1
2007/08	13	315	93.2	2 954	10 084	46.1
2008/09	11	263	91.6	2 667	9 185	41.9
2009/10	8	252	85.9	2 399	7 414	45.1
2010/11	10	276	109.2	2 538	8 003	41.0
2011/12	11	328	133.9	3 091	10 185	39.0
2012/13	12	354	152.1	3 242	10 223	36.7
2013/14	14	408	150.7	3 339	10 806	36.9
2014/15	14	385	155.0	3 430	11 485	40.6
2015/16	11	342	125.3	3 078	10 195	39.0
2016/17	10	321	95.1	2 583	8 758	42.7

APPENDIX 3. TABULATED CPUE INDICES

Table A7: Annual BPLE trawl CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	Combined			Binomial			Lognormal		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
94/95	0.664	0.561	0.782	0.667	0.603	0.724	1.000	0.868	1.143
95/96	0.399	0.326	0.478	0.484	0.421	0.551	0.824	0.719	0.941
96/97	0.349	0.290	0.413	0.536	0.467	0.603	0.652	0.569	0.735
97/98	0.347	0.290	0.409	0.539	0.474	0.609	0.643	0.567	0.734
98/99	0.335	0.279	0.402	0.502	0.439	0.564	0.668	0.593	0.756
99/00	0.298	0.247	0.354	0.534	0.470	0.598	0.558	0.494	0.629
00/01	0.304	0.252	0.364	0.477	0.417	0.541	0.637	0.559	0.718
01/02	0.265	0.220	0.313	0.549	0.481	0.611	0.483	0.422	0.550
02/03	0.308	0.258	0.367	0.531	0.467	0.595	0.581	0.509	0.654
03/04	0.296	0.247	0.352	0.508	0.444	0.569	0.582	0.513	0.660
04/05	0.317	0.268	0.374	0.540	0.476	0.602	0.588	0.521	0.663
05/06	0.287	0.240	0.343	0.506	0.444	0.574	0.567	0.498	0.637
06/07	0.364	0.308	0.424	0.630	0.571	0.690	0.577	0.502	0.652
07/08	0.345	0.296	0.401	0.643	0.583	0.702	0.536	0.469	0.605
08/09	0.365	0.307	0.426	0.631	0.571	0.689	0.578	0.507	0.648
09/10	0.290	0.245	0.340	0.603	0.543	0.664	0.481	0.420	0.543
10/11	0.273	0.229	0.324	0.581	0.516	0.642	0.469	0.413	0.532
11/12	0.273	0.228	0.323	0.552	0.489	0.615	0.496	0.437	0.565
12/13	0.197	0.162	0.235	0.526	0.457	0.589	0.374	0.324	0.426
13/14	0.210	0.173	0.252	0.494	0.430	0.559	0.425	0.372	0.483
14/15	0.244	0.199	0.292	0.529	0.462	0.592	0.461	0.404	0.525
15/16	0.287	0.233	0.345	0.479	0.412	0.546	0.599	0.521	0.678
16/17	0.273	0.227	0.325	0.570	0.502	0.635	0.479	0.419	0.542

Table A8: Annual HG-ENLD trawl CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	Combined			Binomial			Lognormal		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
94/95	0.566	0.483	0.653	0.569	0.508	0.625	1.000	0.897	1.106
95/96	0.286	0.240	0.337	0.471	0.411	0.530	0.606	0.546	0.674
96/97	0.256	0.212	0.302	0.435	0.375	0.494	0.589	0.529	0.654
97/98	0.316	0.270	0.367	0.509	0.453	0.570	0.622	0.561	0.689
98/99	0.338	0.289	0.390	0.573	0.514	0.632	0.590	0.527	0.655
99/00	0.202	0.170	0.236	0.451	0.390	0.512	0.448	0.404	0.500
00/01	0.226	0.189	0.261	0.541	0.472	0.601	0.417	0.374	0.463
01/02	0.231	0.195	0.270	0.511	0.449	0.578	0.453	0.409	0.502
02/03	0.313	0.270	0.359	0.618	0.556	0.674	0.506	0.453	0.561
03/04	0.358	0.311	0.411	0.663	0.605	0.715	0.540	0.486	0.600
04/05	0.356	0.308	0.407	0.671	0.616	0.729	0.531	0.475	0.591
05/06	0.329	0.285	0.377	0.667	0.604	0.723	0.493	0.442	0.549
06/07	0.324	0.284	0.363	0.803	0.758	0.843	0.404	0.360	0.449
07/08	0.296	0.262	0.338	0.712	0.656	0.764	0.416	0.375	0.463
08/09	0.243	0.211	0.282	0.613	0.551	0.672	0.397	0.357	0.442
09/10	0.202	0.171	0.234	0.606	0.546	0.668	0.333	0.300	0.373
10/11	0.186	0.159	0.216	0.575	0.512	0.634	0.324	0.289	0.362
11/12	0.164	0.140	0.190	0.535	0.472	0.597	0.305	0.273	0.339
12/13	0.132	0.109	0.157	0.439	0.377	0.503	0.300	0.270	0.334
13/14	0.153	0.128	0.180	0.496	0.429	0.560	0.309	0.275	0.342
14/15	0.161	0.135	0.189	0.454	0.396	0.514	0.356	0.318	0.395
15/16	0.175	0.147	0.208	0.475	0.409	0.536	0.369	0.329	0.412
16/17	0.181	0.153	0.214	0.491	0.431	0.555	0.369	0.331	0.413

Table A9: Annual WCNI trawl CPUE indices and the lower (LCI) and upper (UCI) bounds of the 95% confidence intervals.

Fishing	Combined			Binomial			Lognormal		
year	Index	LCI	UCI	Index	LCI	UCI	Index	LCI	UCI
94/95	0.407	0.348	0.473	0.404	0.363	0.448	1.000	0.894	1.120
95/96	0.482	0.414	0.558	0.365	0.327	0.406	1.322	1.190	1.474
96/97	0.459	0.402	0.519	0.411	0.373	0.451	1.116	1.007	1.227
97/98	0.391	0.344	0.447	0.394	0.358	0.430	0.991	0.902	1.088
98/99	0.337	0.289	0.385	0.367	0.330	0.404	0.918	0.830	1.017
99/00	0.329	0.285	0.383	0.325	0.290	0.363	1.013	0.923	1.115
00/01	0.480	0.415	0.553	0.405	0.369	0.443	1.184	1.070	1.309
01/02	0.432	0.377	0.490	0.415	0.378	0.454	1.041	0.940	1.146
02/03	0.519	0.453	0.591	0.455	0.415	0.493	1.141	1.033	1.262
03/04	0.427	0.372	0.486	0.413	0.376	0.451	1.035	0.937	1.145
04/05	0.485	0.425	0.548	0.510	0.469	0.550	0.951	0.860	1.047
05/06	0.400	0.346	0.455	0.426	0.388	0.467	0.938	0.837	1.033
06/07	0.447	0.390	0.507	0.517	0.474	0.559	0.863	0.782	0.952
07/08	0.401	0.347	0.458	0.430	0.392	0.470	0.933	0.846	1.026
08/09	0.437	0.382	0.494	0.484	0.443	0.528	0.902	0.816	0.990
09/10	0.466	0.404	0.535	0.441	0.400	0.483	1.056	0.955	1.170
10/11	0.607	0.533	0.694	0.487	0.444	0.529	1.247	1.125	1.383
11/12	0.621	0.542	0.703	0.493	0.454	0.538	1.259	1.138	1.388
12/13	0.623	0.549	0.712	0.473	0.432	0.514	1.315	1.196	1.450
13/14	0.543	0.477	0.615	0.503	0.461	0.544	1.080	0.975	1.190
14/15	0.486	0.428	0.552	0.451	0.412	0.490	1.077	0.973	1.182
15/16	0.441	0.385	0.501	0.474	0.432	0.516	0.931	0.840	1.026
16/17	0.350	0.302	0.407	0.399	0.359	0.439	0.876	0.791	0.966

APPENDIX 4. CPUE MODEL DIAGNOSTICS – INFLUENCE PLOTS

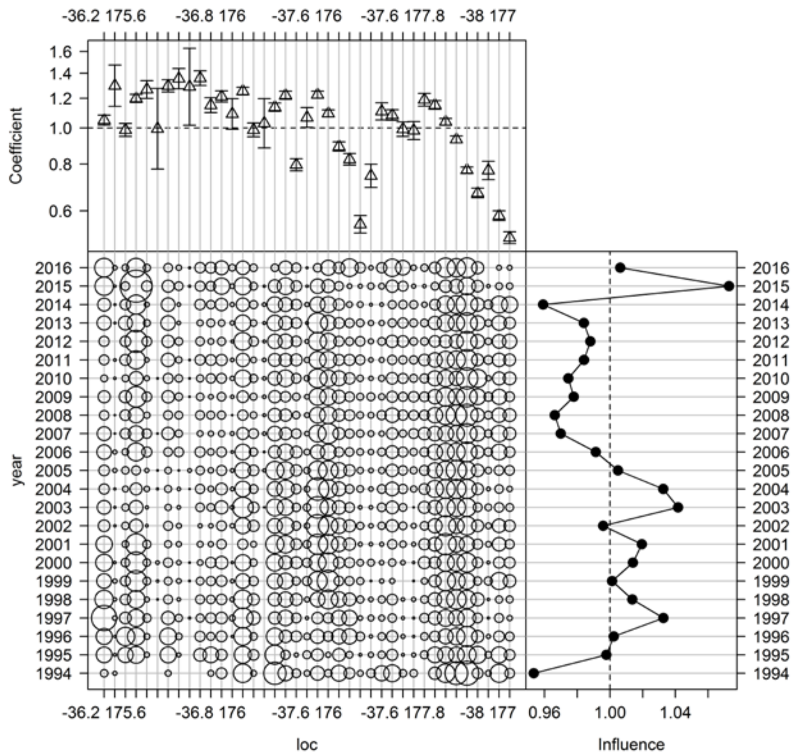

Figure A1: Influence plot for the *Loc* variable from the BPLE lognormal CPUE model.

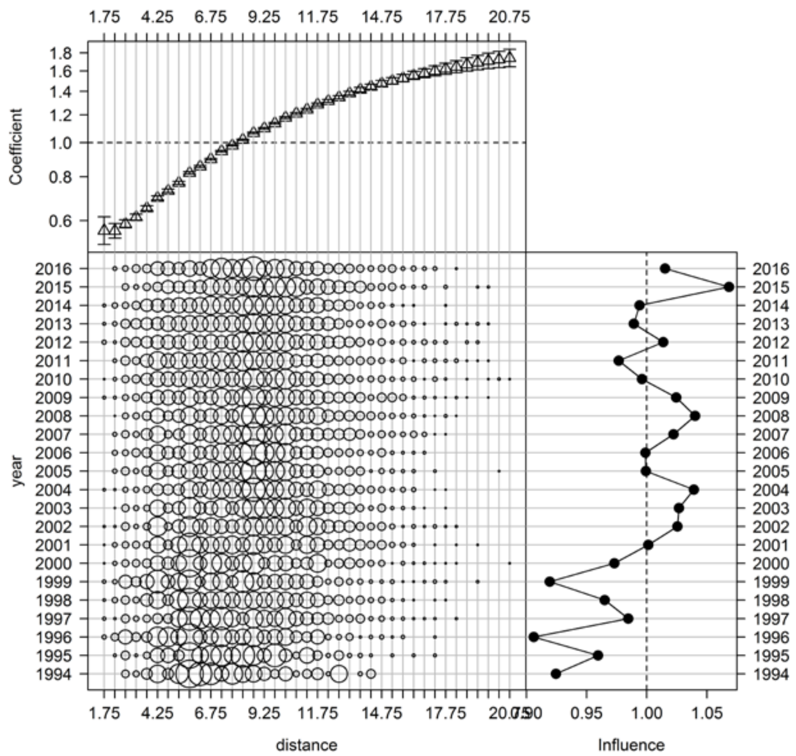

Figure A2: Influence plot for the *Distance* variable from the BPLE lognormal CPUE model.

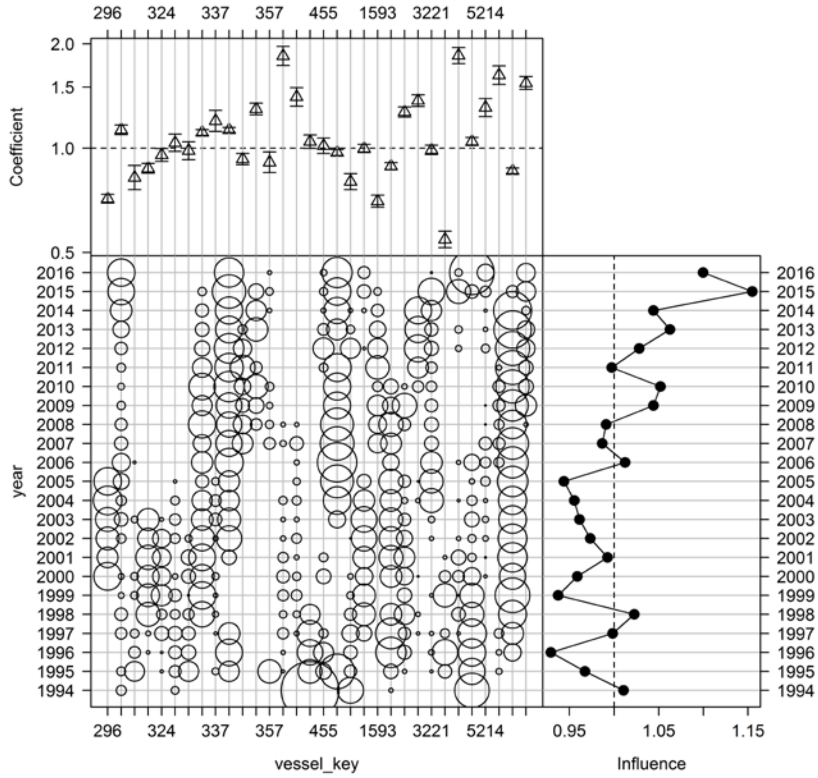

Figure A3: Influence plot for the *Vessel* variable from the BPLE lognormal CPUE model.

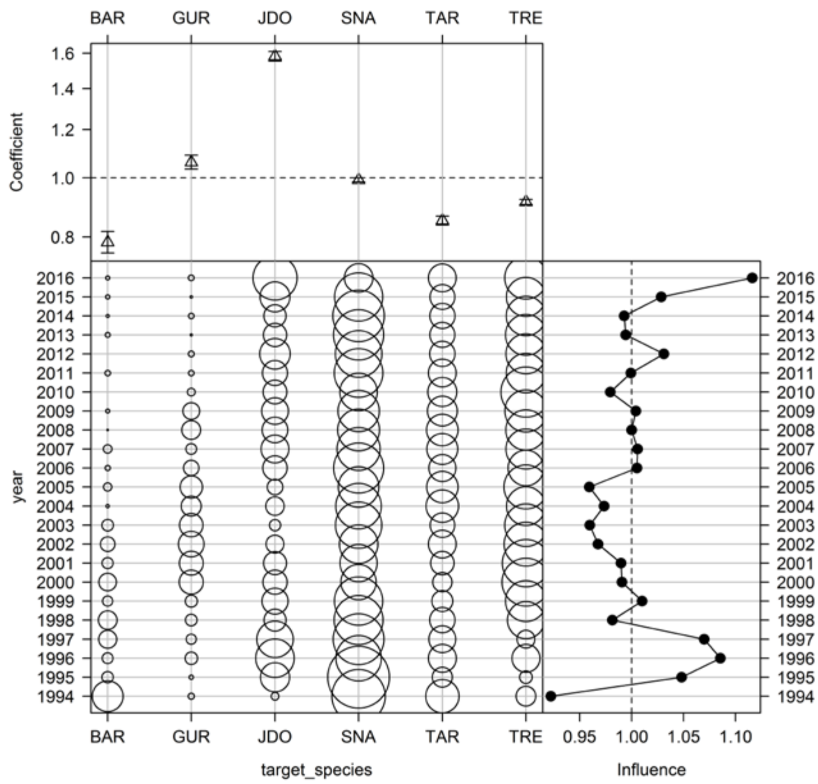

Figure A4: Influence plot for the *TargetSpecies* variable from the BPLE lognormal CPUE model.

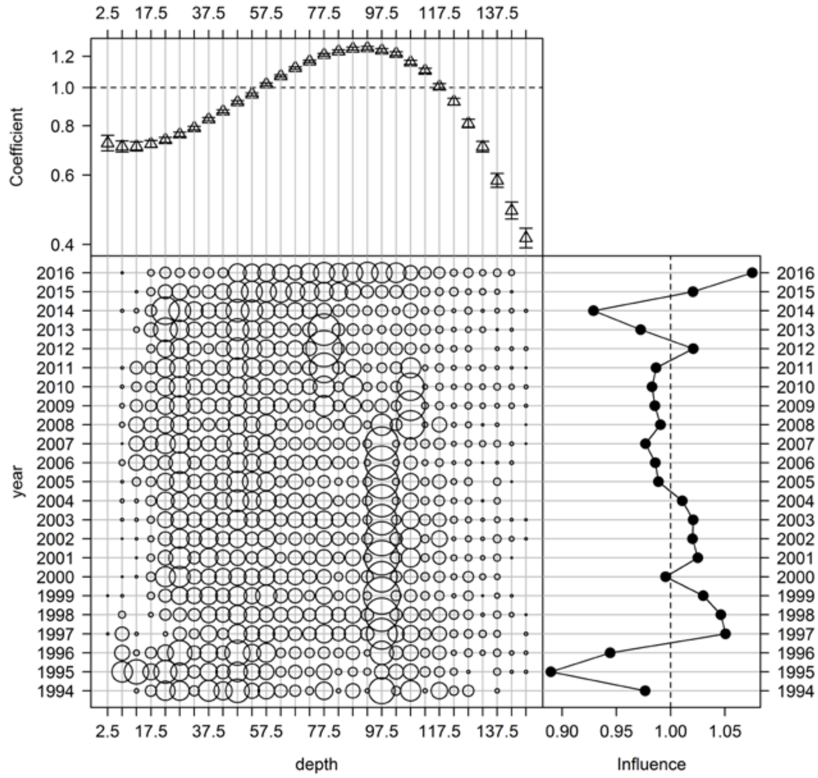

Figure A5: Influence plot for the *Depth* variable from the BPLE lognormal CPUE model.

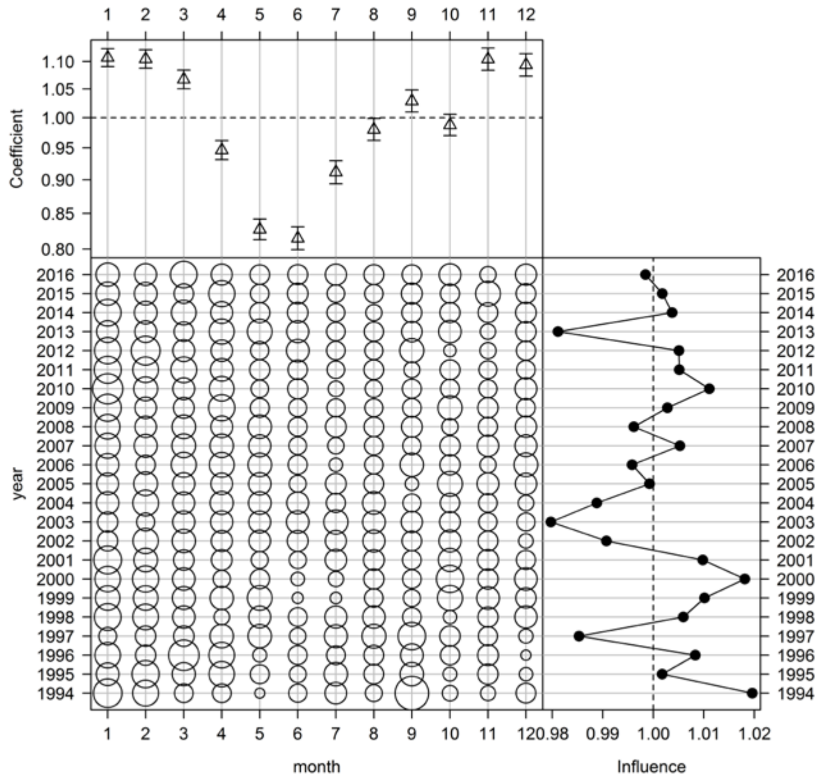

Figure A6: Influence plot for the *Month* variable from the BPLE lognormal CPUE model.

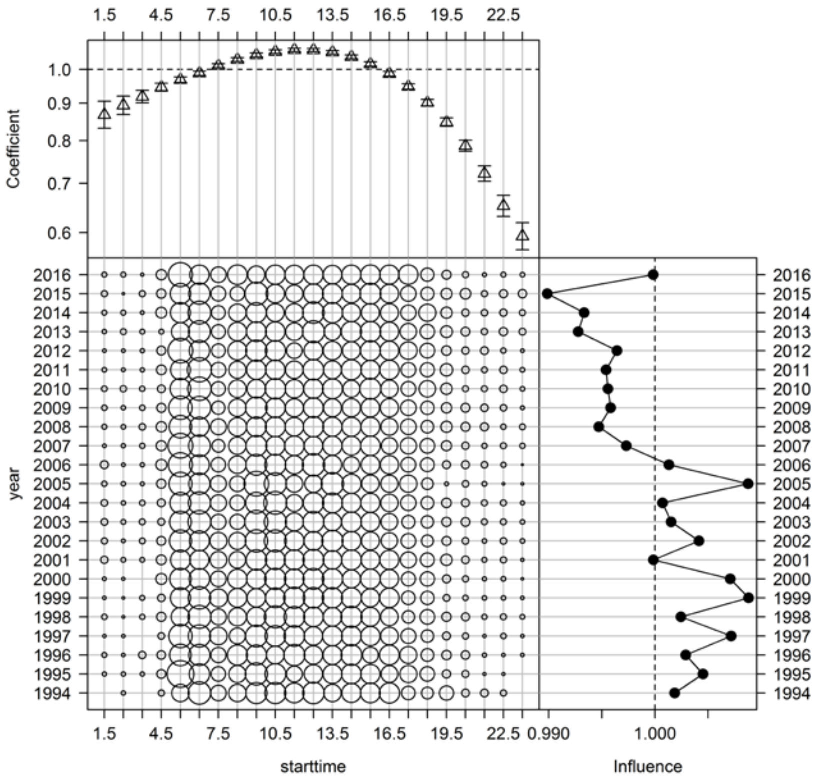

Figure A7: Influence plot for the *StartTime* variable from the BPLE lognormal CPUE model.

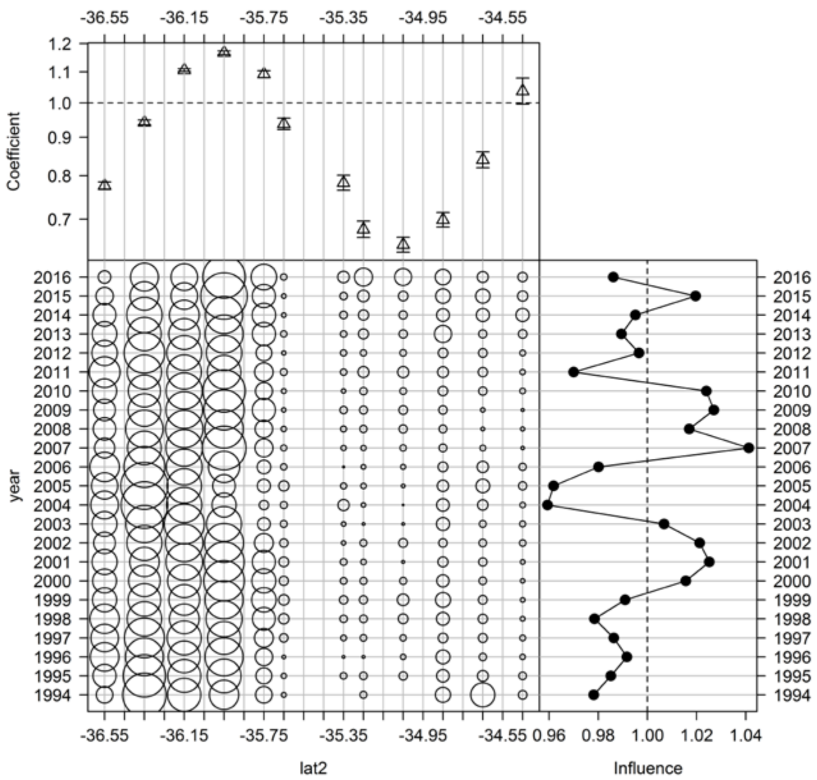

Figure A8: Influence plot for the *Latitude* variable from the HG-ENLD lognormal CPUE model.

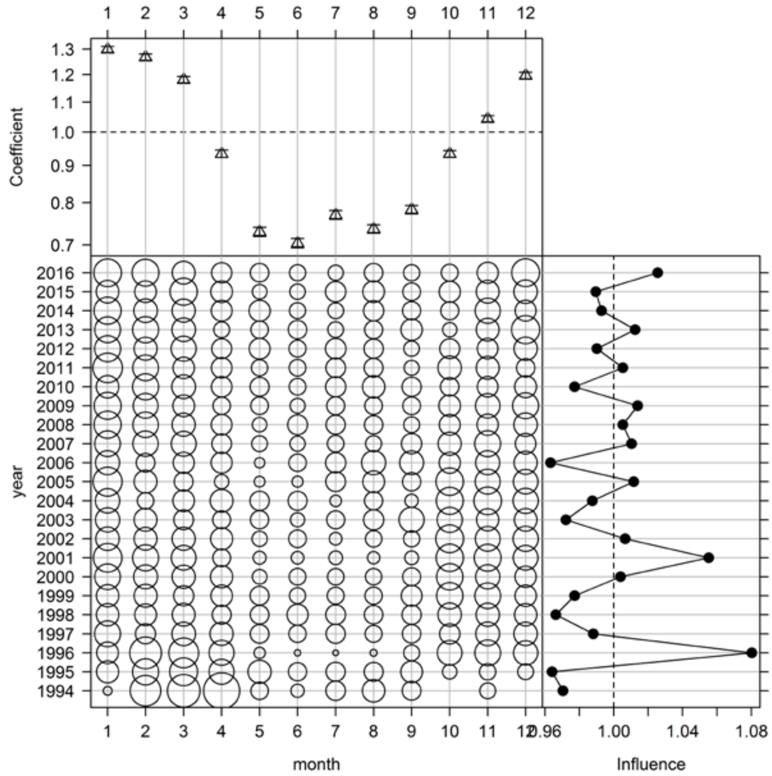

Figure A9: Influence plot for the *Month* variable from the HG-ENLD lognormal CPUE model.

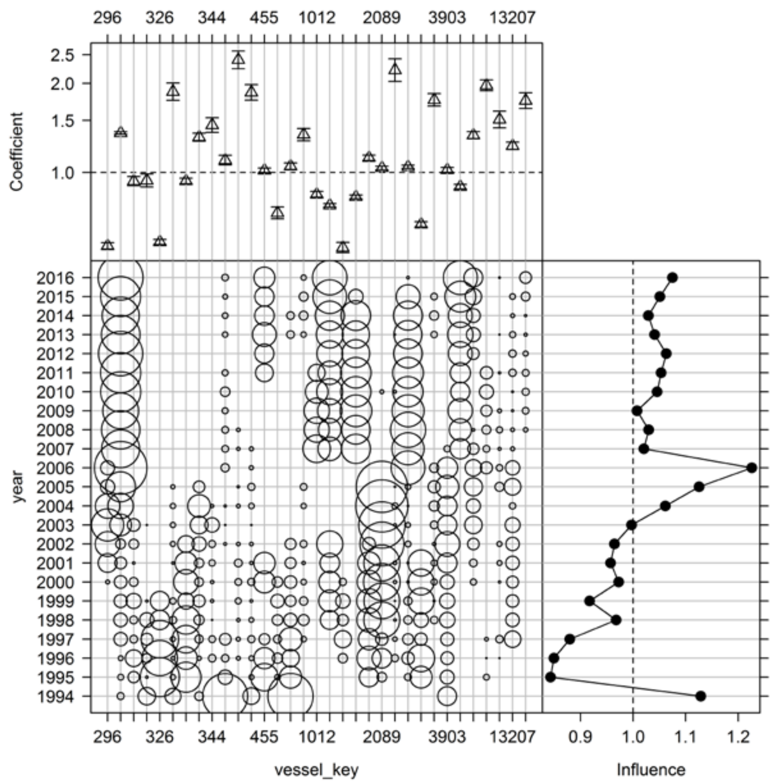

Figure A10: Influence plot for the *Vessel* variable from the HG-ENLD lognormal CPUE model.

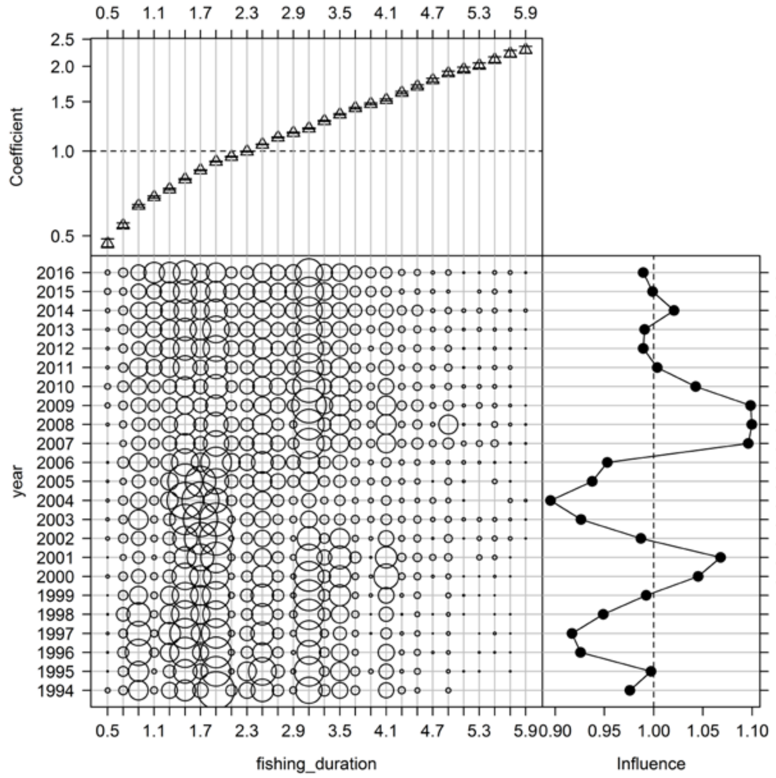

Figure A11: Influence plot for the *Duration* variable from the HG-ENLD lognormal CPUE model.

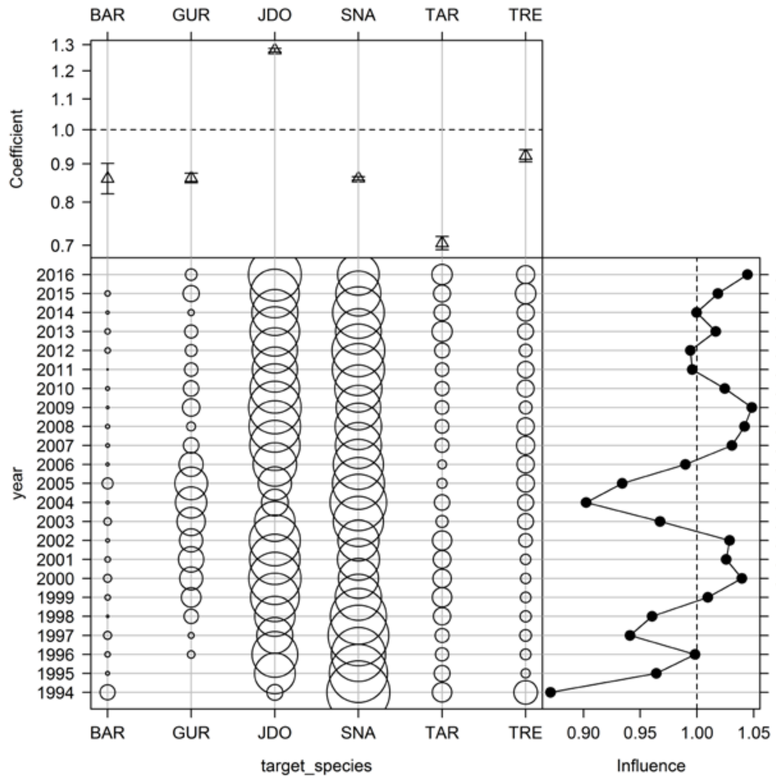

Figure A12: Influence plot for the *TargetSpecies* variable from the HG-ENLD lognormal CPUE model.

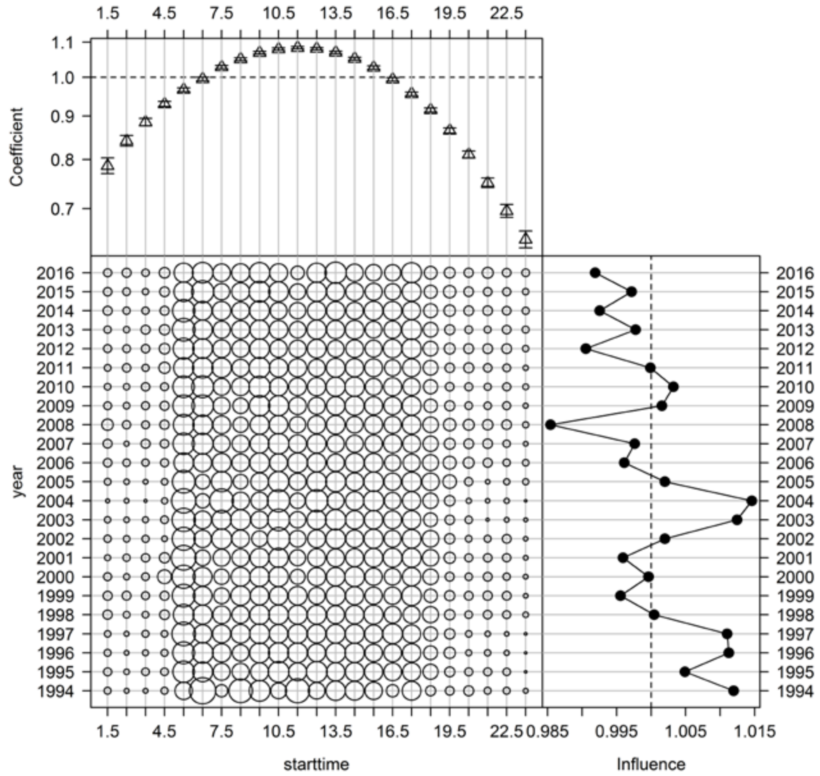

Figure A13: Influence plot for the *StartTime* variable from the HG-ENLD lognormal CPUE model.

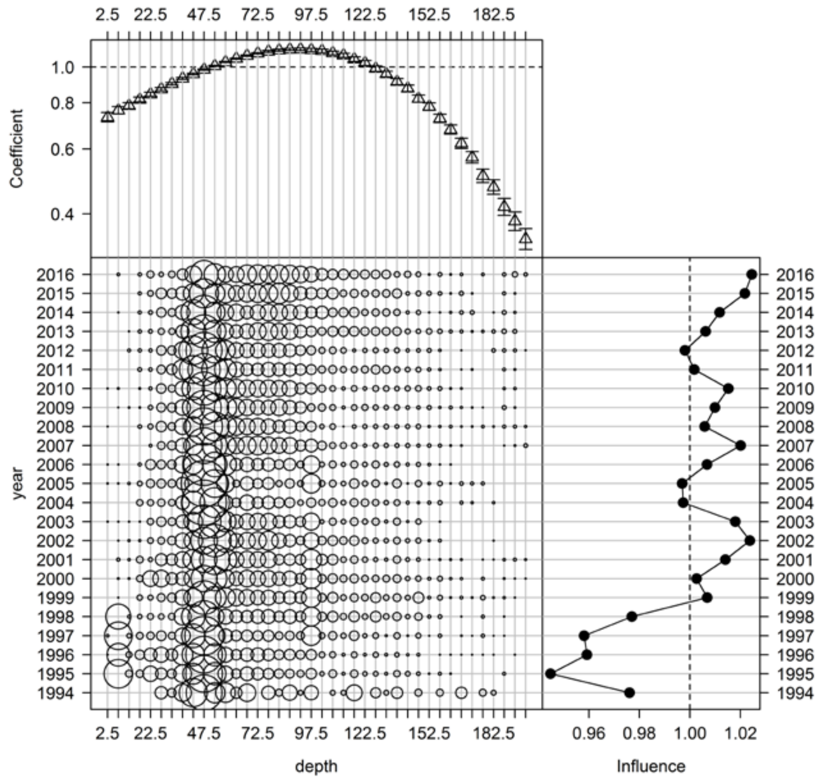

Figure A14: Influence plot for the *Depth* variable from the HG-ENLD lognormal CPUE model.

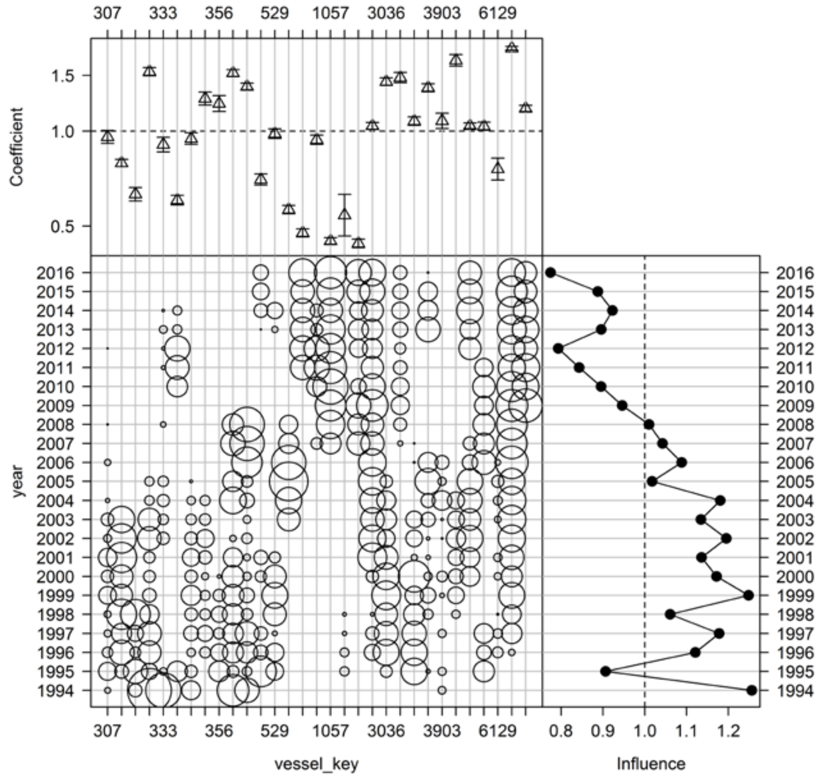

Figure A15: Influence plot for the *Vessel* variable from the WCNI lognormal CPUE model.

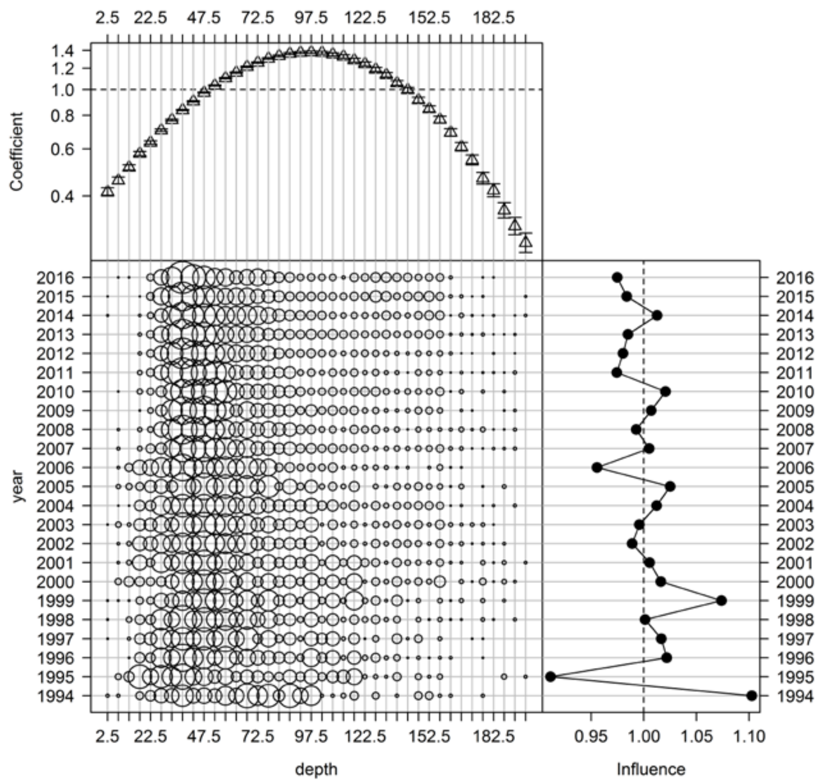

Figure A16: Influence plot for the *Depth* variable from the WCNI lognormal CPUE model.

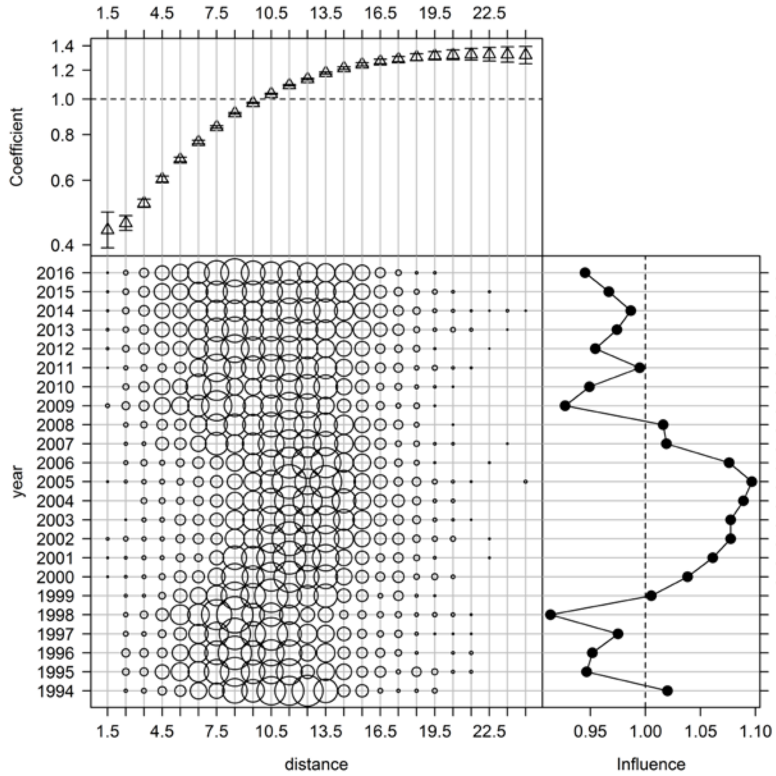

Figure A17: Influence plot for the *Distance* variable from the WCNI lognormal CPUE model.

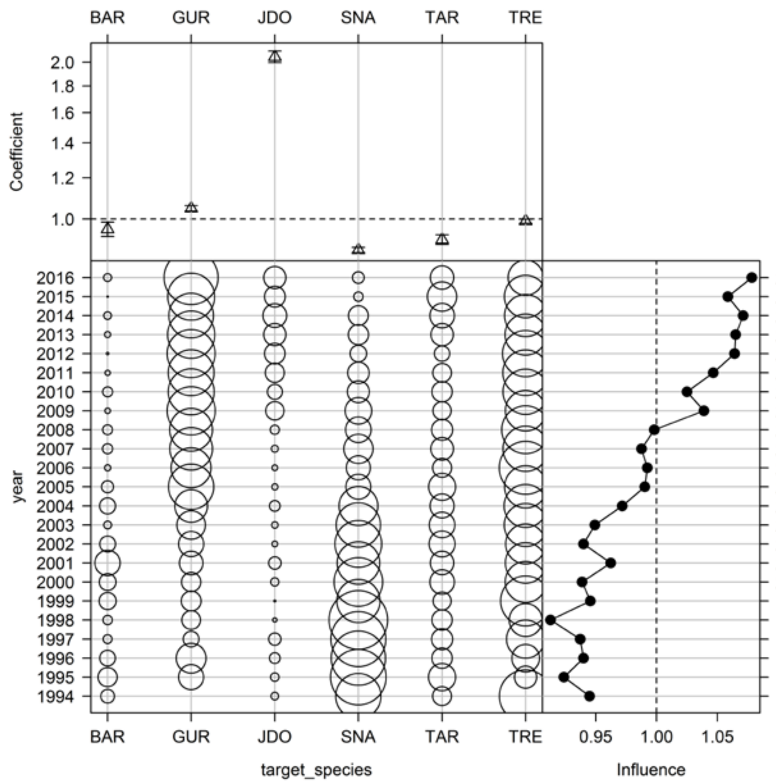

Figure A18: Influence plot for the *TargetSpecies* variable from the WCNI lognormal CPUE model.

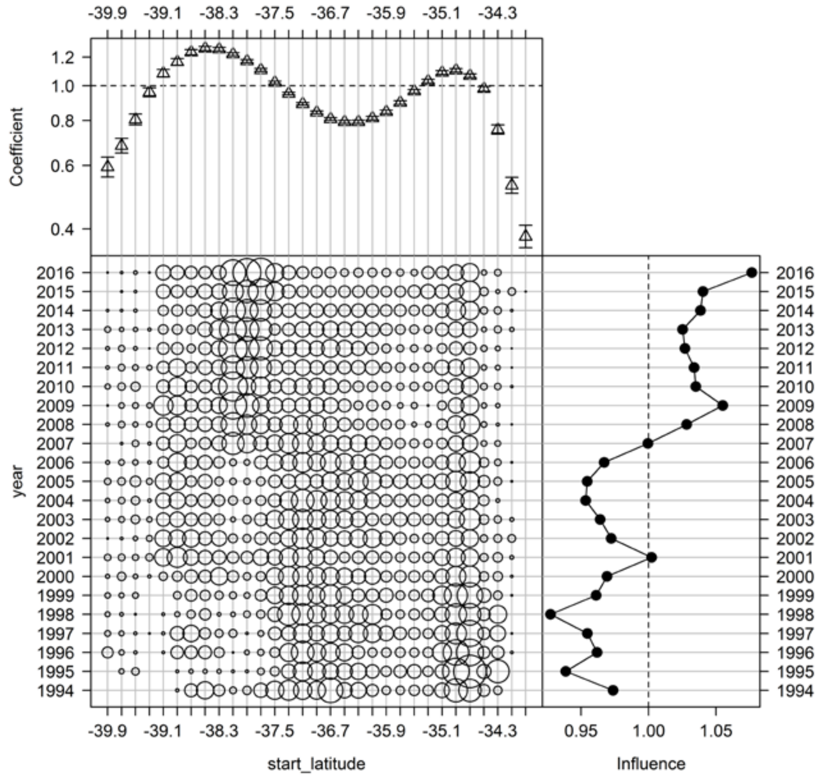

Figure A19: Influence plot for the *Latitude* variable from the WCNI lognormal CPUE model.