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Stock structure and fishery characterisation for New Zealand John dory

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EXECUTIVE SUMMARY

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The stock structure of John dory around New Zealand is uncertain. This report describes the development of a revised hypothesis of stock structure. The hypothesis was formulated using an holistic approach, where multiple observational data sets were analysed in order to increase the chances of correctly defining stocks, given that no single data set would provide complete and unequivocal information.

The observational data that were summarised and/or analysed included catch distribution, commercial fishery catch-per-unit-effort (CPUE) trends, research survey biomass trends, the location of spawning and nursery grounds, demographic characteristics including patterns in length and age composition, and anecdotal information from the commercial fishery.

The holistic analysis favoured the assumption of five stocks: (1) Hauraki Gulf and east Northland, (2) Bay of Plenty, (3) West coast North Island, (4) Southeast North Island, and (5) Northern South Island. John dory have been caught around most of the North Island and northern South Island of New Zealand, indicating that the boundaries between the assumed stocks were not distinct.

Commercial fishery catch distribution, CPUE analyses, length and age compositions, spawning and nursery grounds, and research trawl survey biomass trends all provide evidence to separate the northeast and northwest coasts of the North Island (JDO1). The distribution of John dory on the west coast North Island was continuous between JDO1 and the northern part of the west coast JDO2, and the combination of these areas was supported by CPUE analyses. The evidence to separate the northern South Island from stocks to the north included the occurrence of unusually large fish on the northwest South Island, commercial fishery catch distribution and CPUE analyses. A separate stock of John dory on the southeast coast of the North Island (east coast JDO2) was supported by the presence of spawning and nursery grounds, commercial fishery catch distribution, and CPUE analyses. Although geographically close, the separation of Hauraki Gulf and Bay of Plenty into two stocks was supported by the presence of spawning and nursery grounds, research trawl biomass trends, and CPUE analyses. John dory were very rarely reported from around the northeast, central, or southern South Island, and no stock was assumed to occur in these areas.

CPUE trends were estimated for use as indices of stock biomass. The John dory commercial fishery was characterised, and standardised commercial CPUE trends estimated for each stock using generalised linear models. The catch rate for Hauraki Gulf and east Northland between 1995–96 and 2010–11 showed an overall decline, but with a period of low catch rates around 1999–2000. The catch rate for the Bay of Plenty between 1995–96 and 2010–11 showed an initial decline to around 1999–2000, and then remained roughly flat. The catch rate for the West Coast North Island between 1994–95 and 2010–11 showed an initial decline to 1998–99, and then remained roughly flat. The catch rates for the Southeast North Island between 1989–90 and 2010–11 had peaks at the start of the time series, and then around 2000–01. The catch rate for the Northern South Island from 1991–92 to 2010–11 increased after 1998–99, and peaked in 2003–04. The standardised CPUE trends were in general accordance with reports from commercial fishers.

This work was carried out under Ministry for Primary Industries (MPI) contract INS2011/03, with specific objectives (1) to characterise the fisheries for John dory, (2) to determine rates of exchange/movement of John dory between FMAs throughout New Zealand and adjacent waters, and (3) to assess the appropriateness of managing these stocks as discrete management units.

1. INTRODUCTION

The John dory (*Zeus faber*) is an inshore demersal fish species commonly caught in commercial and recreational fisheries around the North Island of New Zealand (Ministry for Primary Industries 2012). Previous research on New Zealand John dory have included a review of the fishery (Hore 1988), three characterisations of the fishery and standardised catch-per-unit-effort (CPUE) analyses (Horn et al. 1999; Fu et al. 2008; Kendrick & Bentley 2011), determining fish age and growth (Hanchet et al. 2001), and catch sampling for length and age (Phillips & Horn 2004; Horn et al. 2007). New Zealand John dory have also been included in reviews of spawning and nursery areas (Hurst et al. 2000), and have been sampled in inshore trawl surveys (Stevenson 1998; Stevenson & Hanchet 2000; Morrison et al. 2001a; Morrison et al. 2001b). Studies focusing on John dory from outside of New Zealand have examined distribution and habitat selection (Dunn 2001; Vrgoč et al. 2006; Maravelias et al. 2007), production of sound (Onuki & Somiya 2004), feeding (Velasco & Olaso 1998; Silva 1999; Choi et al. 2011), demographic parameters (Smith & Stewart 1994; Dunn 2001; Yoneda et al. 2002), and fisheries (Dunn 2001). Although John dory from the northeast Atlantic are morphologically very similar to those in the southwest Pacific, DNA barcoding has suggested that they may be different species (Ward et al. 2008).

The overall objective of this study was to determine rates of exchange/movement of John dory (*Zeus faber*) between Fishery Management Areas (FMAs) throughout New Zealand, with specific objectives (1) to characterise the fisheries for John dory, (2) to determine rates of exchange/movement of John dory between FMAs throughout New Zealand and adjacent waters, and (3) to assess the appropriateness of managing these stocks as discrete management units. This work was carried out under Ministry for Primary Industries (MPI) contract INS2011/03.

1.1 Expected characteristics of a stock

In this report, the term 'stock' has a different meaning from 'population', and follows the Harden-Jones (1968) definition:

"Management stocks are considered to respond largely independently to the effects of exploitation, because recruitment, growth and mortality within the stock are of more significance than emigration or immigration to the stock".

We would expect a stock to have specific spawning and nursery grounds. We would also expect to see different biomass trends and length or age frequency distributions if there have been different recruitment or mortality patterns on each stock, independent stock movements (e.g., spawning, feeding, or ontogenetic migrations), and potentially different demographic characteristics such as patterns of growth and maturity. To allow effective fishery management and research, we would hope to see discrete fisheries for each stock.

1.2 Previous assumptions of stock structure

The assumption of John dory stock structure around New Zealand, at the time of writing (December 2012), is based upon the MPI administrative Fisheries Management Areas (FMAs) (MPI 2012). The stocks are labelled JDO1 (FMAs 1 & 9), JDO2 (FMAs 2 & 8), JDO3 (FMAs 3–6), JDO7 (FMA7), and JDO10 (FMA10) (Figure 1). Following Horn et al. (1999), JDO1 has been monitored as two separate stocks with a boundary at North Cape; JDO1 east (FMA1) and JDO1 west (FMA9), and JDO2 has been similarly split into east and west coast components (at the statistical area 016 boundary, on the Kapiti coast) for stock assessment purposes.

In fishery characterisation and CPUE analyses, Kendrick & Bentley (2011) split JDO1 east further, into East Northland and Bay of Plenty substocks, which were defined by statistical areas (Figure 1). The rationale for this split was simply that other stocks in the same northern trawl fishery were split in this way. The Bay of Plenty substock consisted of statistical areas 009, 010, and 107, and the East Northland substock as statistical areas 001–007 and 105–106. Kendrick & Bentley (2011) also considered a further split on the west coast of JDO1, as Ninety Mile beach (statistical areas 047–048), and Kaipara/Manukau (statistical areas 041–046), although the rationale for this split was not reported (Figure 1). Estimated CPUE trends for the proposed substocks supported the split within JDO1 east, but not within JDO1 west (Kendrick & Bentley 2011).

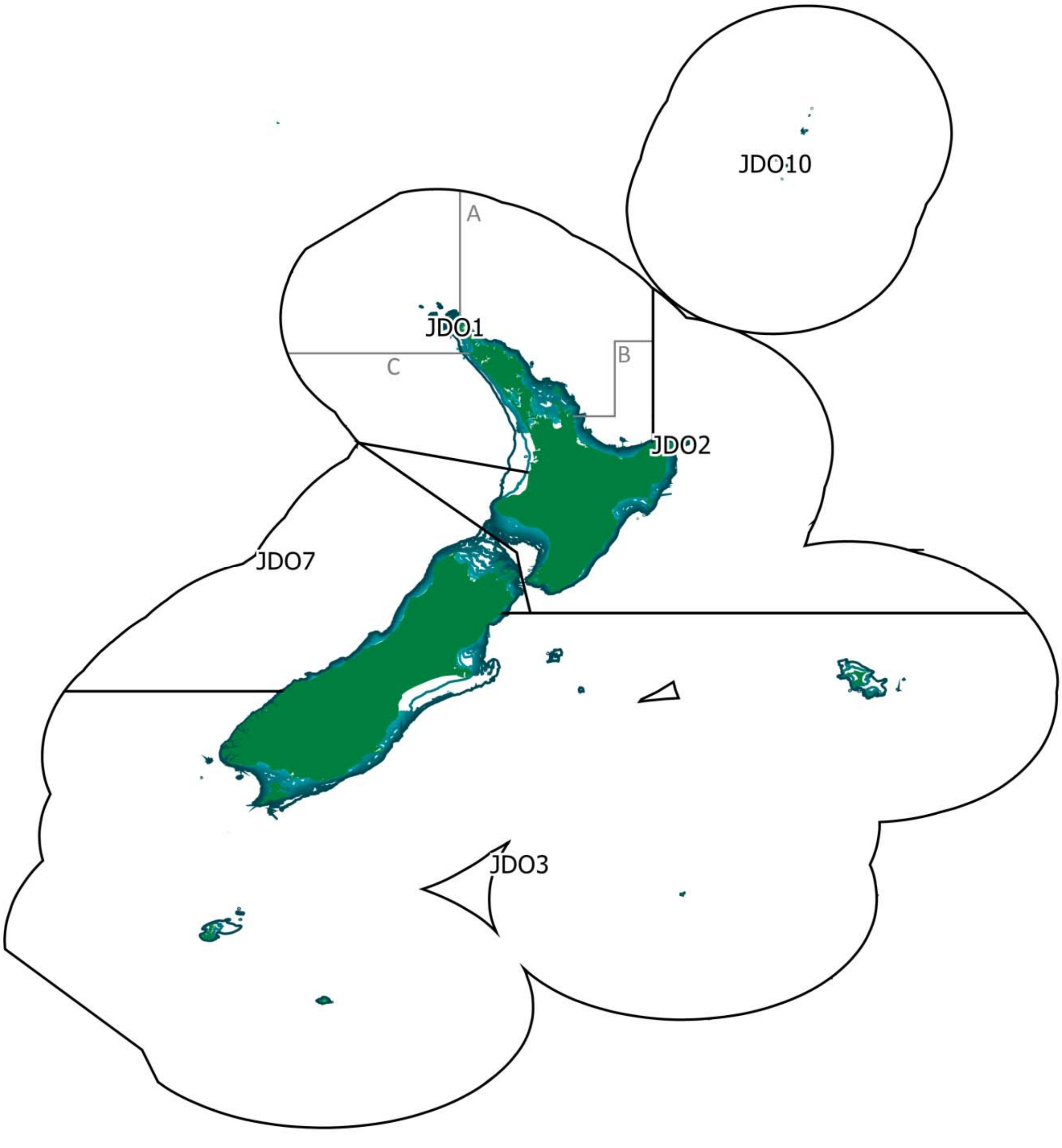


Figure 1: The Ministry for Primary Industries Quota Management Areas (QMAs) for John dory around New Zealand (thick black lines). The isobaths are shown for 10–100 m. The grey lines delineate: A, the assumed boundary between JDO1 east and JDO1 west; B, the assumed boundary between JDO1 East Northland (north and west of the line) and JDO1 Bay of Plenty; C, the assumed boundary between Ninety Mile Beach (north of the line) and Kaipara/Manukau. Base image and QMA boundaries from http://www.nabis.govt.nz.

2. METHODS

2.1 General approach to determining stock structure

The evaluation of stock structure hypotheses followed a holistic approach (Pawson & Jennings 1996, Begg & Waldman 1999). The observational data summarised and reviewed in this study included the location and timing of spawning and nursery grounds, regional differences in demographic characteristics, the location, timing, and trends in catches, trends in catch-per-unit-effort (CPUE), and anecdotal reports on these aspects. Because no single data set was treated as definitive, and the weights attached to each data set are qualitative, the overall conclusions about stock structure remain provisional.

Observational information that have been used for stock discrimination studies elsewhere, but were not considered here because no data were believed to exist, included morphometrics, natural tags (parasites), man-made tags, otolith microchemistry, and genetics.

2.2 Spawning and nursery grounds

A spawning ground was defined as an area where ripe and running John dory were observed, or where John dory eggs were observed. A prolonged spawning period has been observed in the East China Sea (Yoneda et al. 2002), which means that there could be a relatively long time period over which spawning fish can be observed.

A nursery ground was defined as an area where juvenile fish were observed. In this study, a juvenile John dory was defined as either age 0+ (age often being inferred from length), or where total length was less than 29 cm. The mean length at first maturity in the Hauraki Gulf was estimated to be 31.5 cm in females and 25 cm in males (Hore 1982). This is similar to the mean length at first maturity found in the northeast Atlantic (34.5 cm in females and 26 cm in males; Dunn 2001), and in the Adriatic Sea (31 cm in females; Vrgoč et al. 2006). In the Hauraki Gulf, the smallest mature female was 29 cm, and the largest immature female 37 cm, with the equivalent for males being 23 cm and 29 cm (Hore 1982); MPI (2012) report equivalent lengths of 29–35 cm for females and 23–29 cm for males. Whilst the lower lengths of maturity reported by MPI (2012) are consistent with Hore (1982), the origin of the upper lengths could not be determined. Hurst et al. (2000) defined juveniles as less than 36 cm TL, but this would seem to include a substantial proportion of mature fish. Although the lengths used to define 'juvenile' John dory have varied, a cut-off length of 29 cm was used because, in Hauraki Gulf samples (Hore 1982), it was the last length at which immature males were observed, and the first length at which mature females were observed, and it was consistent with the cut-off used in previous analyses by Morrison et al. 2001a, 2001b. A fish length of 29 cm is equivalent to a weight of about 370 g (Morrison et al. 2001a).

Egg (plankton) surveys were not included in the review, because data were sparse, and superficially at least, it seemed easier to detect spawning John dory than the resulting eggs or larvae. In the Hauraki Gulf, for example, where spawning John dory were observed, associated plankton surveys found no eggs or larvae at 31 sample stations (Hore 1982).

2.3 Demographic characteristics

John dory have been found to show rapid growth in the first year, seasonal patterns of growth, with females growing larger than males (Hore 1982; Dunn 2001; Hanchet et al. 2001). Smith & Stewart (1994) reported relatively slow growing fish off Australia, but Hanchet et al. (2001) attributed this to different interpretation of the otoliths, rather than to a real difference in growth rate. Because John dory otoliths are hard to interpret, vertebrae may be a better structure for determining age than otoliths (Yoneda et al. 2002). For this study, no analyses of size or age at maturity, size at age (growth), or growth model parameters, were completed because data were found to be deficient (see Results).

Length frequency distributions were available for several areas and years, from samples of both commercial fisheries and research trawl survey catches, and were simply compared by examining the overall length distribution, and position and number of length modes.

Age frequency distributions were available for the Hauraki Gulf and Bay of Plenty in JDO1 east (Hanchet et al. 2001), and JDO1 east and JDO1 west (Horn et al. 2007). These were compared by plotting the reported age frequency distributions and confidence intervals by sex and area, and evaluating the degree of overlap: no tests for statistically significant differences were completed, but a proportion at age in one sample outside of the confidence intervals of the proportion at age in another sample was considered to indicate a difference.

2.4 Research trawl survey biomass indices

If two areas are connected, we would expect biomass trends to be either similar (implying homogeneity), or perhaps opposing (implying movement from one to the other). Unrelated biomass trends can indicate separate stocks.

There were a number of sources of historical research trawl survey biomass trends, but where there was any conflict between estimates precedence was given to Horn et al. (1999). Horn et al. (1999) was preferred because it made, and documented, an attempt to standardise the surveys. Other reports consulted included the review of all RV Kaharoa trawl surveys around the North Island (Stevenson 1998; which was consistent with Horn et al. 1999), east coast South Island (Beentjes & Stevenson 2001), and all of New Zealand (Hurst et al. 2000).

There was substantial variability in the vessels, trawl gear, and timing of inshore fishing surveys. All used stratified random survey designs, but with some changes in strata in some survey series. All fished depths of about 10–200 m. Since the early 1990s most surveys have used RV Kaharoa.

For the inshore trawl survey of the west coast South Island and Tasman and Golden Bays (Stevenson & Hanchet 2000), the biomass index and length frequency distributions were updated to include the most recent survey years, using standard methods (M.Stevenson pers.comm.; Stevenson & Hanchet 2010).

2.5 Catch and effort data

Data were requested from the Ministry for Primary Industries catch-effort database warehou. The qualifying criteria for data analysis followed Kendrick & Bentley (2011): catch and effort records for trips that landed to JDO1, JDO2, JDO3, or JDO7, or had fishing events in a statistical area valid for these QMAs, and used bottom single or pair trawl, bottom longline or Danish seine method, and targeted any species excluding the following deepwater species (codes ORH, OEO, SOE, SOR, SSO, BOE, WOE, CDL, BYX, HOK, SCI, SQU, HAK, JMA). This included all effort data regardless of whether John dory was landed or not.

Catch Effort Landing Return (CEL) forms provide catch and effort totals summarised on a day-by-day basis. Trawl Catch Effort Processing Return (TCP; all trawlers over 28 m in length must complete these forms) and Trawl Catch Effort Return (TCE; a recently introduced version of the TCP for vessels 6–28 m in length) forms both provide more detail, and specify estimated catch and effort data for individual fishing events (e.g., tow-by-tow). Because no landing data are recorded on TCP or TCE forms, vessels completing these forms must also complete a Catch Landing Return (CLR) form, which records actual landings data for the vessel trip.

To combine the form types into a consistent data set, the TCP and TCE data were summarised to resemble CEL data. This loss of precision meant that fishing success rate was described in terms of successful days, rather than tows, in which JDO were caught, and the CPUE was based upon the daily total fishing events completed, rather than just the events that were actually successful in capturing JDO. In this case, proportion zero refers to the proportion of unsuccessful days.

Data grooming followed Fu et al. (2008). Missing values of start date, statistical area, target species, and fishing method, were replaced by the most common value from the same trip. Values of effort number (i.e., number of tows per day) that exceeded 10 were replaced with imputed median values from the same trip, as were fishing durations less than 0.25 hour or more than 12 hours (TCE) or 24 hours (CEL).

Data with destination code R (retained on board), Q (held in a receptacle on land for subsequent landing), and T (transferred to another vessel) were excluded. These fish were not identifiable in subsequent landings and so there would be a risk of double counting (Kendrick & Bentley 2011).

For the fishery characterisation, and selected CPUE analyses the data were compiled following Fu et al. (2008) and using the procedure proposed by Starr (2007) ("rolled-up" data). The aim of the procedure was to make the catch and effort data recorded on the different form types comparable, and to use the landed catch to correct the estimated catch on a proportional basis. The allocation of landings to effort was done first by summarising effort and estimated catch for a fishing trip, for every unique combination of fishing method, statistical area, and target species (referred to as a "trip-stratum"). The landed greenweight, recorded at the end of the trip, was then allocated to the tripstrata in proportion to the amount of effort. The data for each trip therefore included estimated and landed catch of JDO, total hours fished, total numbers of tows/sets/hooks, fishing year, statistical area, target species, month of landing, and a unique vessel identifier. Trips landing to more than one fishstock from straddling areas (041) or that used multiple methods with incompatible measures of effort, were excluded.

2.6 CPUE analyses

Two standardised catch-per-unit-effort (CPUE) analyses were completed: one to inform stock structure, and the other to estimate biomass trends. Both were carried out by fitting generalised linear models (GLMs) to CPUE, using the stepwise multiple regression technique described by Francis (2001).

The analysis to inform stock structure used groomed and combined ("rolled-up") catch and effort data. Only catch and effort records where catches of John dory were non-zero were included. The catch dependent variable was the natural log of catch (t) per stock-stratum, fitted using a normal error distribution and identity link function. Continuity rules were applied to the data selection in order to adequately estimate the categorical predictor effects in the model: where each vessel or target species included must have completed at least 5 years with 50 or more trip-stratum records per year. Following Kendrick & Bentley (2011), the data used were for bottom trawl and target species snapper (SNA), John dory (JDO), trevally (TRE), tarakihi (TAR), gurnard (GUR) and barracouta (BAR) only (their data selection "BT_MIX"), and the predictors fishing year, vessel, target species, day of the year (season), and tow duration were forced into the model. Different stock configurations were then examined by testing an additional "fishstock" predictor in this model. A fishstock by fishing year interaction was included to allow year trends to vary by stock. Each fishstock tested had a different allocation of catch and effort into spatial areas. This was effectively a conditional test of alternative stock structures, in which it was assumed that the most appropriate allocation would be the one that gave the maximum decrease in the Aikake Information Criterion (AIC), and explained the most deviance in CPUE.

The analysis to estimate biomass trends used only the tow-by-tow estimated catch and effort data (TCP and TCE forms) for the east Northland, Bay of Plenty, and west coast North Island stocks, and combined catch and effort data for the Hawkes Bay and west coast South Island stocks (see Results for stock rationale). The units of CPUE used were either estimated tonnes per tow (t/tow), or tonnes per trip-stratum respectively. Since there was a non-trivial proportion of zero catch tows in the data set, the models for the CPUE were split into two parts (1) a normal model for the natural log of the non-zero tows, with a normal error distribution and identity link function, and (2) a binomial model which estimates the probability of a non-zero catch, with a binomial response and logit link function. The combined model estimated catch rates from all tows (including those with zero catch) by combining results from the normal and binomial models. The coefficient of variation (c.v.) of the estimates from the combined model were calculated using a bootstrap procedure (Francis 2001). The data were restricted to selected target species, which followed either Kendrick & Bentley (2011) (see above), or were determined from fishery characterization analyses. Continuity rules were applied as before, except that for tow-by-tow data the rule was relaxed to include vessels with at least 3 years with 20 or more tows per year. The predictor variable fishing year was forced into the model, and other variables tested for inclusion, including target species, form type, statistical area, vessel, day of the year, fishing duration, and depth. Continuous predictors were logged where their distribution was highly skewed. All continuous predictors were tested as third order polynomials. A stepwise forward procedure was used to select predictor variables, and they were entered into the model in the order which gave the maximum decrease in the AIC. Interactions between predictors were only included where fishery characterization analyses indicated that they might be reasonable. Predictor variables were accepted into the final model if they explained at least 1% of the deviance and their predicted effects were sensible.

2.7 Anecdotal information

Eight fishers were successfully contacted and interviewed about John dory fisheries, covering the Hauraki Gulf, eastern Bay of Plenty and northern west coast of JDO1 (as far as off Waikato), and the eastern coast of JDO2 and Golden and Tasman Bays. Fishers used Danish seine (Hauraki Gulf and Bay of Plenty) or bottom trawls, and all had extensive experience fishing in their region. One fisher was retired, but the remainder were active. Efforts to contact fishers for the wider west coast region of the North Island were unsuccessful. Some information was also available from previous interviews of retired fishers from another MPI project (ZBD200801) and a John dory fishery characterisation (Dunn 2003).

The purpose of the interviews was to gain general information about the fishery, and some specific information pertinent to stock structure. Regarding the latter, fishers were asked a series of questions in relation to the occurrence, movements and spawning activity of adults and also presence of juveniles in their catches. The questions included: *Do you catch John dory all year around? When are John dory catches and catch rates highest, and when are they lowest? If the John dory come and go, where do you think they come from, and where do they go? Do you see ripe and running John dory? If so, where and when? Do you see small John dory? (i.e. <29 cm / 370 g / 11 inches / 0.8 lb)? If so, where and when? Do you think there is a "resident" population of John dory in your area?*

3. RESULTS

3.1 Stock structure

3.1.1 Spawning and nursery grounds

The only reports providing information on the location of spawning John dory were Hore (1982), Hurst et al. (2000), and Morrison et al. (2001b). Hore (1982) sampled the Hauraki Gulf during 1980–81, Hurst et al. (2000) reviewed all scientific trawl data available up until January 1999, and Morrison et al. (2001b) reviewed six trawl surveys of the Bay of Plenty completed between 1983 and 1999. Where John dory were not a target species, for example during the West Coast South Island trawl surveys, data on maturity stage were not collected (M. Stevenson pers. comm.)

Hore (1982) found John dory spawning in the Hauraki Gulf between December and April, with a peak in February and March. Hore (1982) concluded that large spawning aggregations probably did not occur, because adult size fish were observed to have asynchronous maturation. Morrison et al. (2001b) found John dory spawning in the Bay of Plenty, and also found asynchronous maturation. Although Hore

(1982) and Morrison et al. (2001b) sampled throughout the Hauraki Gulf and Bay of Plenty, neither actually mapped the location of spawning John dory within these areas.

The review by Hurst et al. (2000) included the Bay of Plenty trawl series data that were reviewed by Morrison et al. (2001b). Observations of ripe and running fish were sparse (Figure 2). Hurst et al. (2000) reported no spawning in the Hauraki Gulf, despite surveys taking place in that area. Ripe John dory were reported from October to January. Ripe and running fish were identified off the west coast of Northland, and northwest of Taranaki Bight, Bay of Plenty, with single occurrences north of Farewell Spit, and in Hawke's Bay (Figure 2). The surveys did not cover East Cape, the east coast North Island north of the Hauraki Gulf, or the west coast North Island south of Taranaki Bight. The scarcity of observations suggests that John dory do not form large spawning aggregations.

Detailed information on the location of nursery grounds was summarised by Stevenson (1998), and Hurst et al. (2000). Hurst et al. (2000) found that there were no MPI observer samples of John dory length distribution, only research samples. The analysis of research samples by Stevenson (1998) was more detailed than that by Hurst et al. (2000), but both show the same general patterns of John dory juvenile distribution.

Hurst et al. (2000) found juvenile (0+ group) John dory between Hawke's Bay on the east coast North Island anticlockwise around to Tasman and Golden Bay on the northern South Island, and the fish were ubiquitous around much of the North Island north of about 40°S (Figure 3). Juveniles were found on the open coast and sometimes many kilometres offshore, and did not seem to be associated with bays or estuaries. The distribution of juveniles around the northern North Island, for example between Bay of Plenty and Hauraki Gulf, and down the west coast from Northland to Taranaki, seems essentially continuous. No juvenile John dory were found in trawl surveys south of the southern edge of Hawke's Bay. Stevenson (1998) confirmed this overall distribution, but also showed juvenile John dory in the western Bay of Plenty, in the southern Hauraki Gulf, on the west coast North Island around Raglan, and in Hawke's Bay. Although no John dory have been formally reported on the east coast of the South Island (Beentjes & Stevenson 2001), adult John dory have been reported as far south as Stewart Island (Hurst et al. 2000).

Biomass surveys of the west coast South Island found juvenile John dory most frequently in Golden Bay (stratum 17), then the inner (stratum 18) and outer (stratum 19) Tasman Bay, and since 2007 also on the north west coast of the South Island, inshore between Cape Farewell and Karamea (stratum 1), and Karamea and Cape Foulwind (stratum 5) (Table 1).

In general accordance with the above observations, a distribution of spawning adult and juvenile John dory is summarised by NABIS (Figure 4). The lack of discrete spawning and nursery grounds prevents clear spatial distinctions being made, but areas where spawning and nursery grounds seem to be in close proximity include the Hauraki Gulf, Bay of Plenty, Hawke's Bay, west coast North Island north of Taranaki Bight (to Raglan), and the northern edge of the South Island (Tasman and Golden Bays).

Because of the likely spatially and temporally widespread spawning behaviour of John dory (Hore 1982), it seems likely that there is at least occasional spawning around much of the North Island. It is unclear whether spawning is really absent north of Hauraki Gulf because of the sparse sampling of this area.

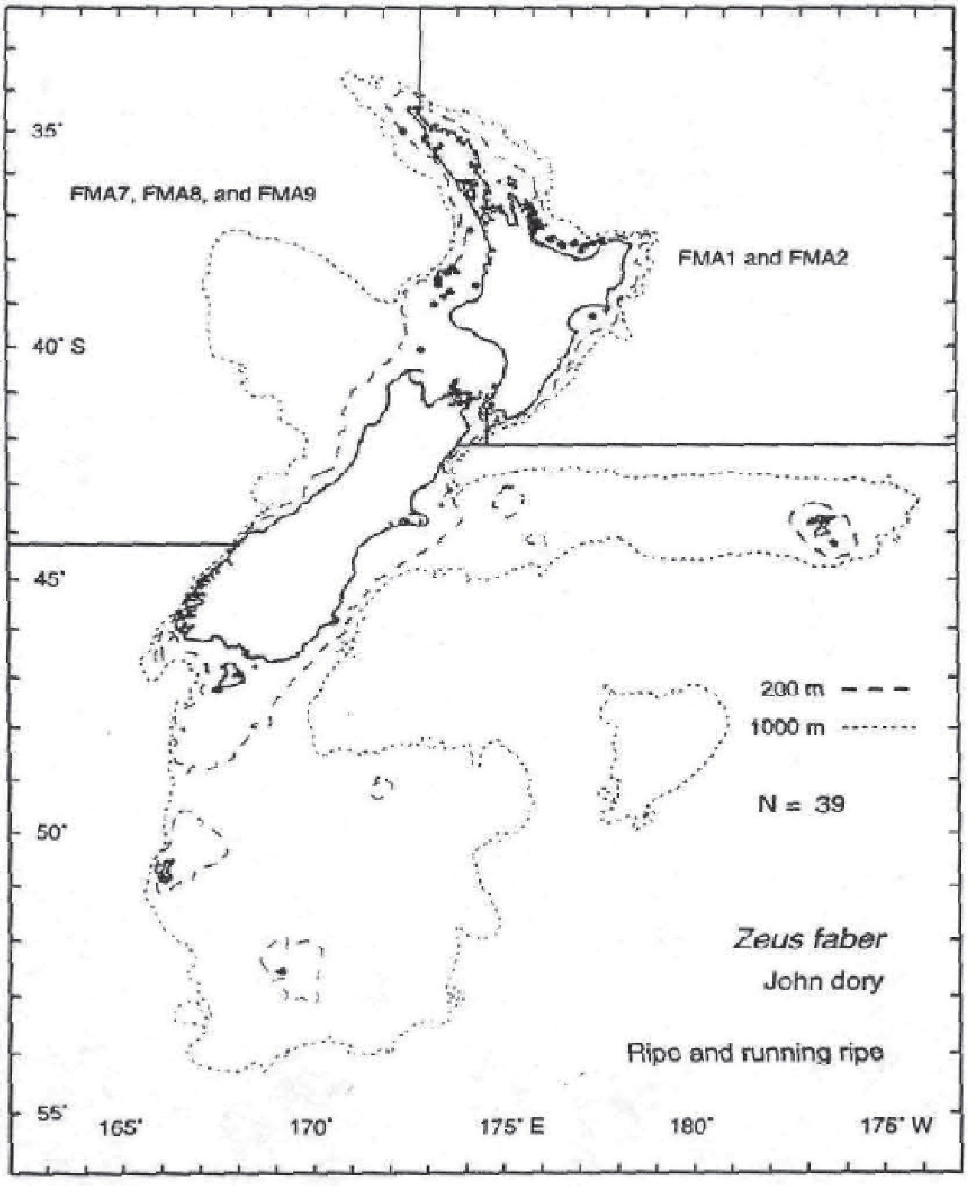


Figure 2: Observations of ripe and running ripe female John dory (black dots). Reproduced from Hurst et al. (2000).

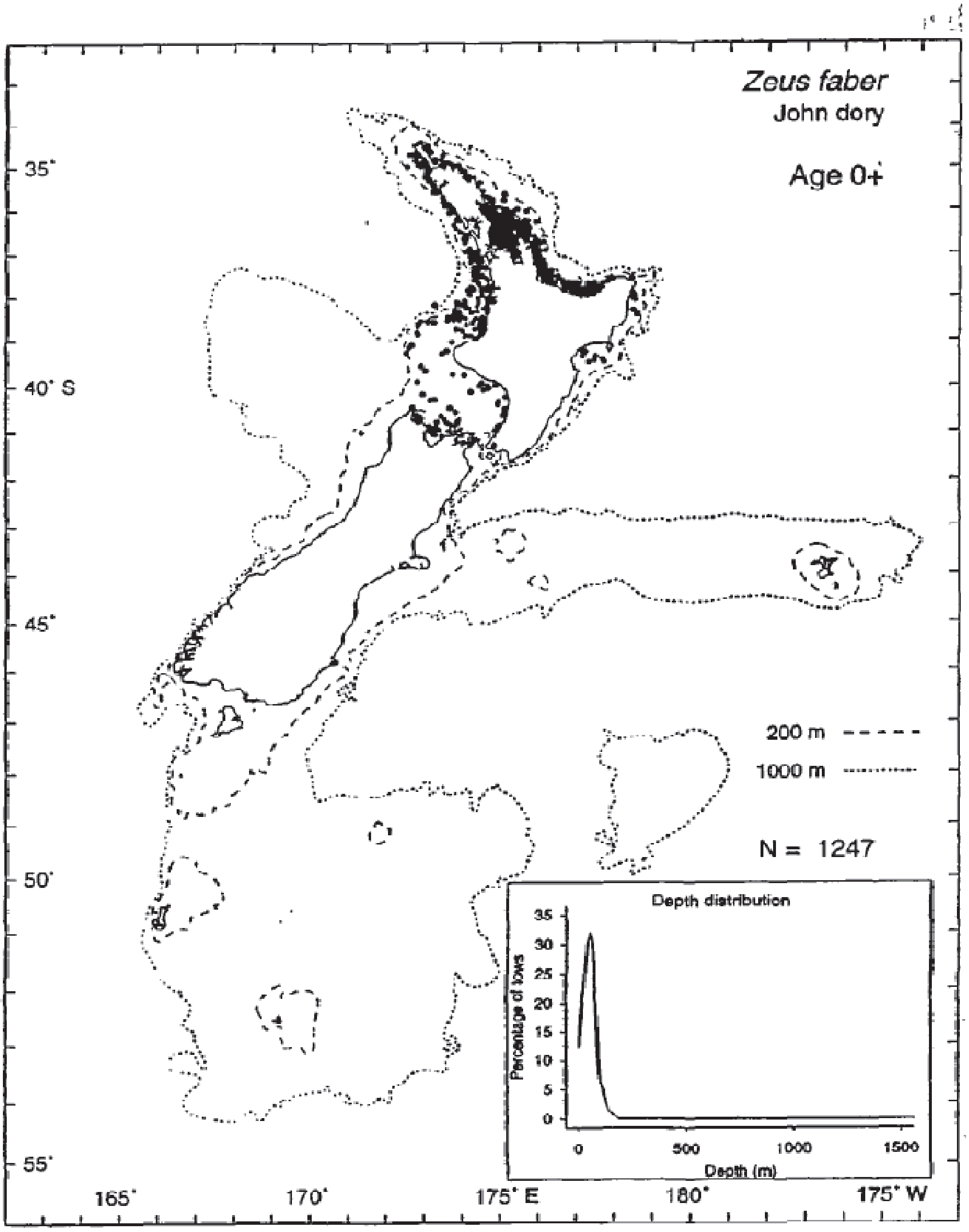


Figure 3: Observations of age 0 (0+ group) John dory (black dots). Reproduced from Hurst et al. (2000).

Table 1: Biomass estimate (c.v. in parentheses) for juvenile (less than 29 cm total length) John dory from the west coast South Island trawl surveys, by stratum and year. Biomass estimates were zero for 1992 and 2005.

Stratum	1994	1995	1997	2000	2003	2007	2009	2011
1	0	0	0	0	0	0	0	0.3 (100)
2	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0.2 (100)	0.2 (100)	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0
17	0.2 (100)	0.1 (100)	0	0.1 (100)	0	0	0.1 (100)	0.1 (100)
18	0	0.3 (57)	0	0	0.1 (100)	0	0.2 (100)	0
19	0	0	0.1 (100)	1 (78)	0	0.1 (100)	0.4 (51)	0

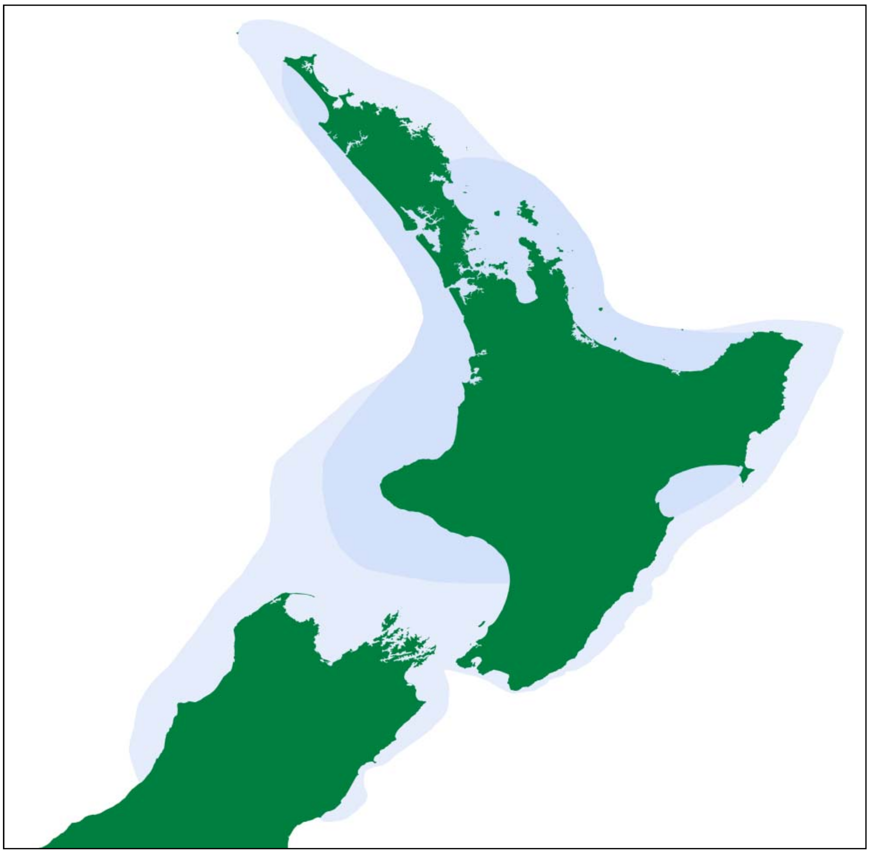


Figure 4: Summarised distribution of John dory juveniles (light shading) and spawning adults (dark shading), compiled by experts for the MPI NABIS database (http://www.nabis.govt.nz**).**

3.1.2 Demographic characteristics

The only available maturity at length data found for John dory were from the Hauraki Gulf (Hore 1982). Because no other areas were studied, no comparisons were possible, and maturity at length data were not considered further. No maturity at age data were found.

Hanchet et al. (2001) provide the only growth parameter estimates for New Zealand. Parameters estimated from otolith-based age data were only presented for JDO1 as a whole, so no comparisons were possible; parameters from length modal analyses were reported for east and west JDO1 but without confidence intervals, and size at age for the different areas were very similar. As a result, size at age and growth model parameters were not considered further.

Length and age compositions for John dory in the commercial catch were provided by Hanchet et al. (2001), Phillips & Horn (2004), and Horn et al. (2007). Phillips & Horn (2004) estimated length and age compositions for the east and west stocks of JDO1 in 2002–03, and found that the length frequency distribution (LF) of the east stock had an almost normal distribution with a mode at 35 cm, whereas the LF for the west stock was more bimodal in distribution with modes at 25 cm and 37 cm. When translated into an age frequency distribution (AF), the modal age was the same in both stocks, but the west stock had relatively few 2 year olds, and a greater proportion of old (more than 4 years) male fish (Figure 5). Based on the overlap of the estimated AFs, there is a difference between east and west JDO1 in males, but not females (Figure 5). Horn et al. (2007) estimated length and age compositions for the east and west stocks of JDO1 in 2004–05, and found that the distributions of the LFs were effectively reversed, with the east stock more bimodal than the west stock. Based on the overlap of the estimated AFs, there may be a difference between east and west JDO1 in females, but not males (Figure 6).

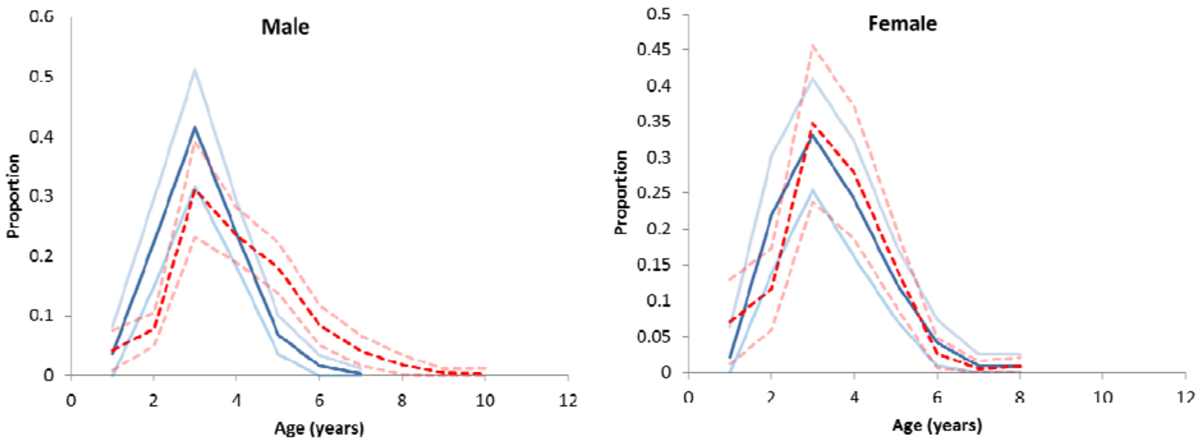


Figure 5: Estimated proportion at age (dark shaded lines) with 95% credible intervals (light shaded lines) for male and female John dory from the east coast of JDO1 (solid lines) and west coast JDO1 (broken lines). Estimates from Phillips & Horn (2004).

Hanchet et al. (2001) estimated AFs for the Hauraki Gulf in October–November 1997, and Bay of Plenty in February 1999. Although patterns in estimated year class strength were not the same between the two areas, and fish of ages 8 and 9 years were only reported from the Bay of Plenty, the AFs were highly uncertain and overall there is probably no difference (Figure 7).

There was little difference in composition between the Hauraki Gulf and Bay of Plenty, estimated LFs from both areas in May 1987 appeared very similar (Hanchet et al. 2001) (Figure 8).

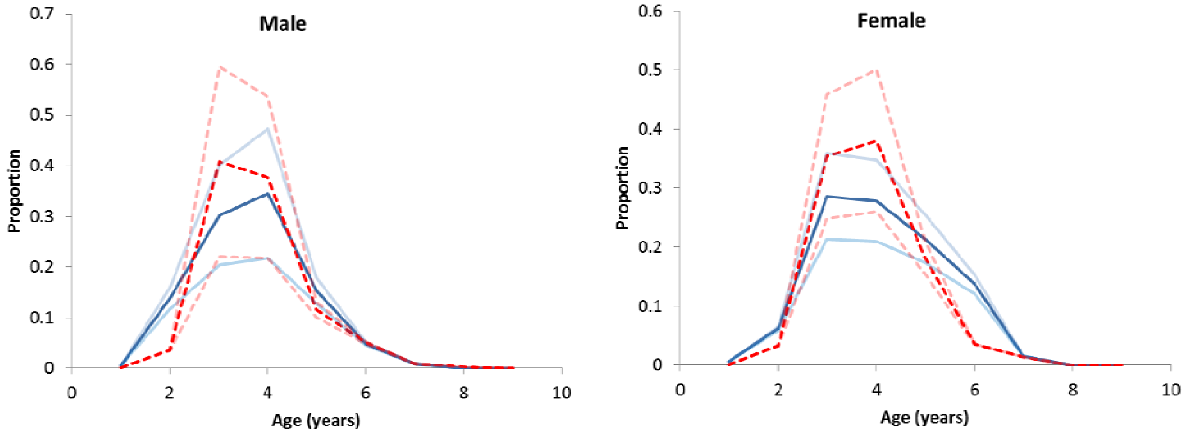


Figure 6: Estimated proportion at age (dark shaded lines) with 95% credible intervals (light shaded lines) for male and female John dory from the east coast of JDO1 (solid lines) and west coast JDO1 (broken lines). Estimates from Horn et al. (2006).

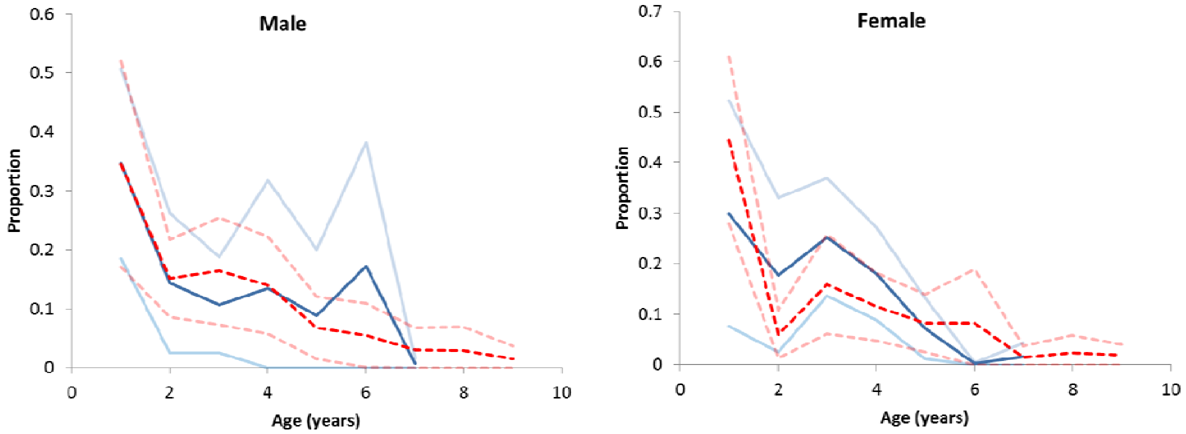


Figure 7: Estimated proportion at age (dark shaded lines) with 95% credible intervals (light shaded lines) for male and female John dory from the Hauraki Gulf (solid lines) and Bay of Plenty (broken lines). Estimates from Hanchet et al. (2001).

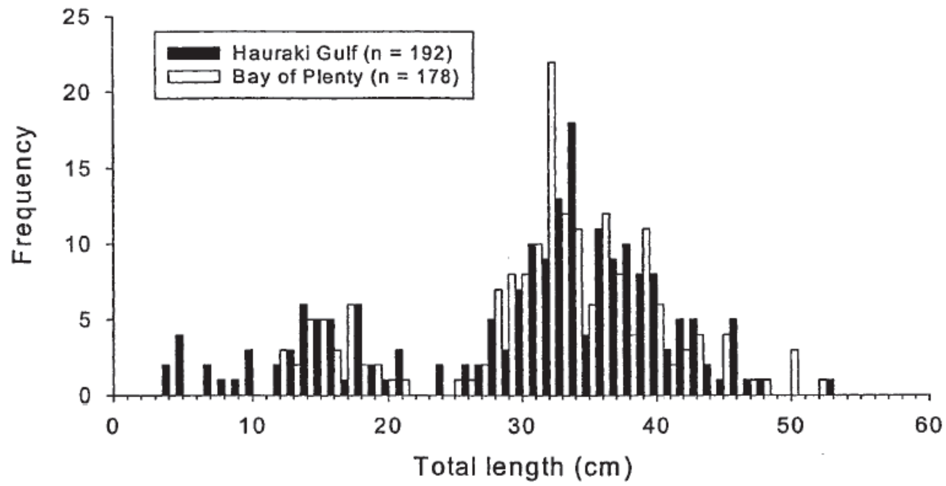


Figure 8: Length frequency distribution of John dory from research surveys of the Hauraki Gulf and Bay of Plenty in May 1987. Reproduced from Hanchet et al. (2001).

The size of fish in the first length mode (usually 1+ fish), was not a reliable measure of dissimilarity between regions because the mode moved substantially during the year due to rapid juvenile growth. The growth of the first length mode is clearly described in the month-by-month LFs presented by Horn et al. (1999).

Samples of John dory from the Bay of Plenty included very few fish greater than 50 cm TL (Morrison et al. 2001a). Similarly, John dory greater than 50 cm TL were rare in samples of John dory from the commercial fisheries in both JDO1 east, and JDO1 west (Phillips & Horn 2004, Horn et al. 2007).

John dory sampled during the west coast South Island trawl surveys were relatively large, with a mode in the LF at 45 cm TL or larger, and fish up to 60 cm TL (Figure 9) (Stevenson, pers.comm.). The west coast South Island fish appeared to grow, or survive, to be larger than those on the west coast North Island (Figure 10). However, the trawl gears used to sample the west coast North and South Islands were not the same, with the trawl used in the north being a high opening trawl, with cut-away lower wings, and 40 mm mesh codend, whereas the trawl used to the south was a modified 'alfredo' (full-wing) design with a 74 mm mesh codend. The degree to which the LFs may be biased by the different trawl designs is unknown, but the potential for bias makes LF comparisons tentative.

Samples from the west coast South Island were predominantly female; because females grow larger than males this is also consistent with a large mean size on the west coast South Island. This is in contrast to other areas, where males dominated, including the Bay of Plenty (Morrison et al. 2001a), and commercial catch samples around JDO1 (Phillips & Horn 2004, Horn et al. 2007).

3.1.3 Research trawl survey biomass indices

The c.v.s of the biomass estimates were often high, therefore biomass trends were uncertain, and comparison of biomass trends is tentative (Table 2). The survey biomass estimates did indicate some general patterns: (1) that juveniles and adults were present in all areas surveyed, but the proportion of biomass apportioned to juveniles was relatively low in JDO2 east, and in JDO7 (Table 2); (2) there were no obvious gaps in the distribution of juvenile John dory down the west coast of JDO1 (Figure 11), but there were patches of juvenile John dory occurrence on the east coast in JDO2, in particular around East Cape and in Hawkes Bay (Figure 12).

The point estimates for biomass suggest different trends in juveniles and adults within all survey areas except the Bay of Plenty. Because of sporadic coverage, very few comparisons of relative biomass trends across different areas were possible.

The different biomass trends for JDO1 west and JDO2 west suggest that these areas could be separate (across four surveys), although the difference only occurs in the last year. But the similarity in the biomass trend for the first three years of the four suggests caution.

There were also different biomass trends in JDO1 west and JDO1 east Hauraki Gulf (across four surveys); whilst both series were relatively flat, the biomass tended to go up in Hauraki Gulf, and down in JDO1 west.

A comparison of three years for Hauraki Gulf and Bay of Plenty suggested a difference between these areas, with biomass in the Bay of Plenty increasing, and biomass in the Hauraki Gulf being low–high–low.

Further comparisons were limited to only two years and cannot be used to make inferences (JDO2 east and JDO2 west, JDO2 east and west coast South Island, west coast South Island and Hauraki Gulf).

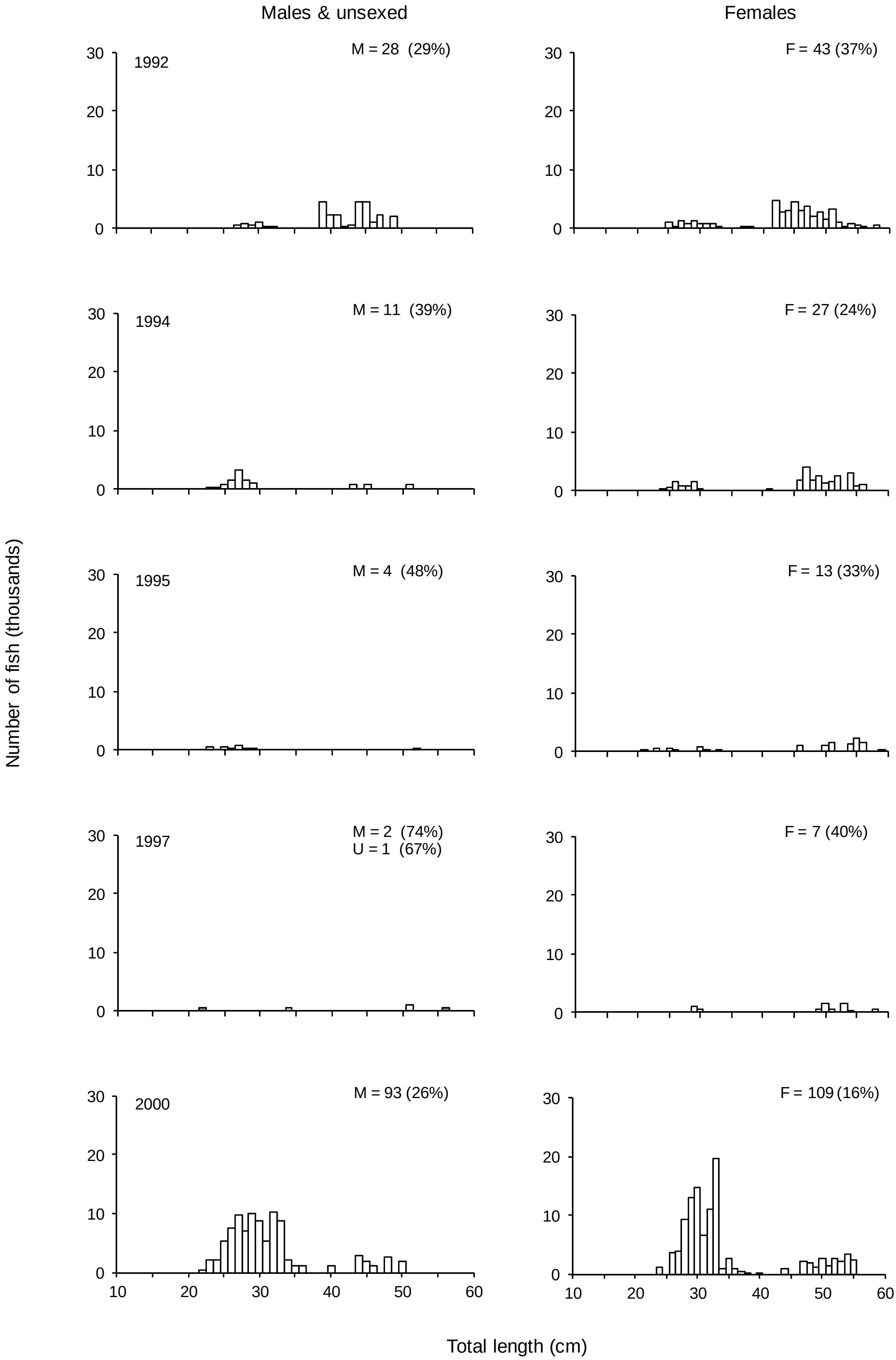


Figure 9: Scaled length frequency distributions for John dory sampled in the west coast South Island trawl survey (February–March), by year and sex (Stevenson, pers.comm.).

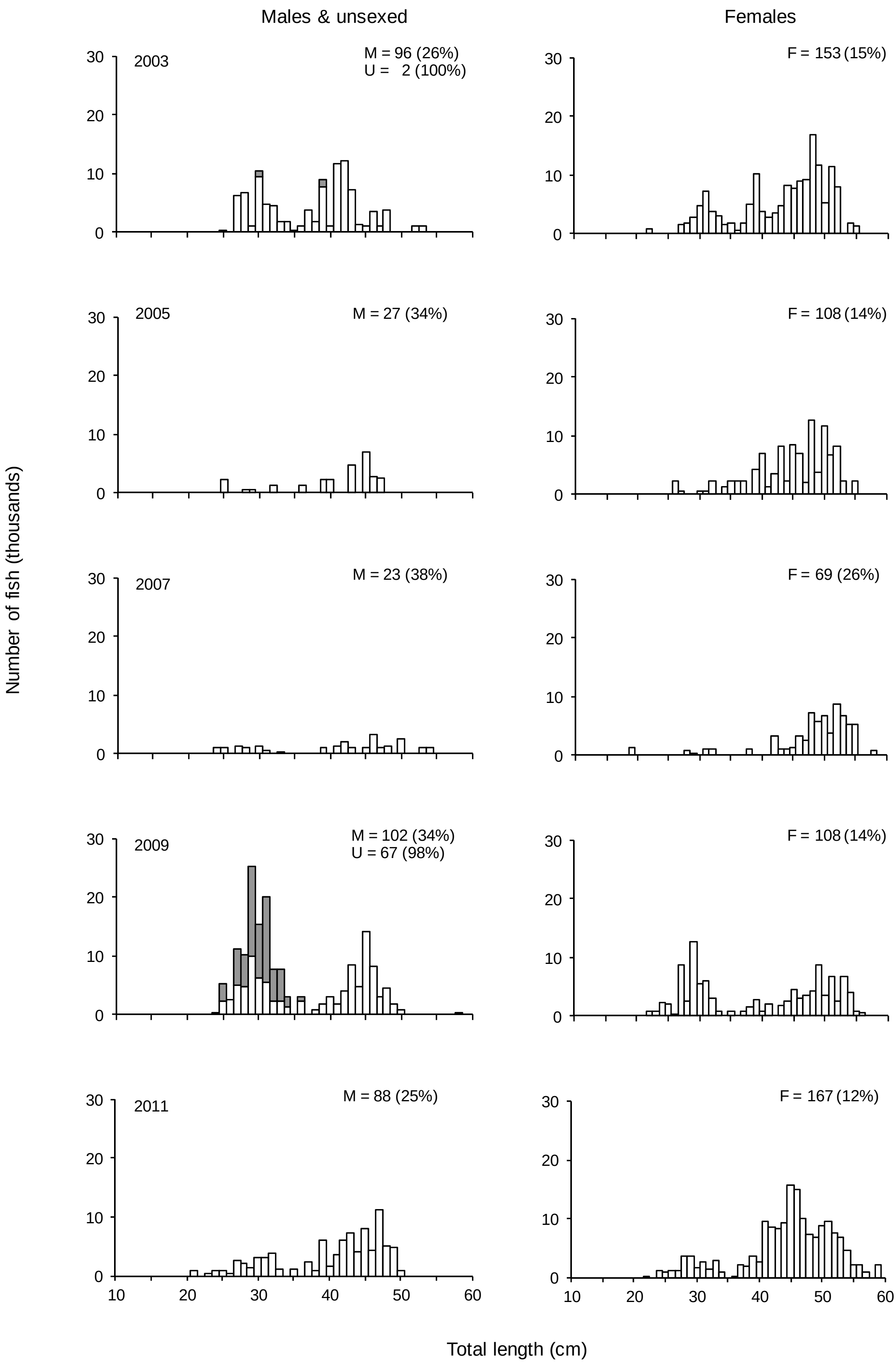


Figure 9(cont.): Scaled length frequency distributions for John dory sampled in the west coast South Island trawl survey (February–March), by year and sex (Stevenson, per.comm.).

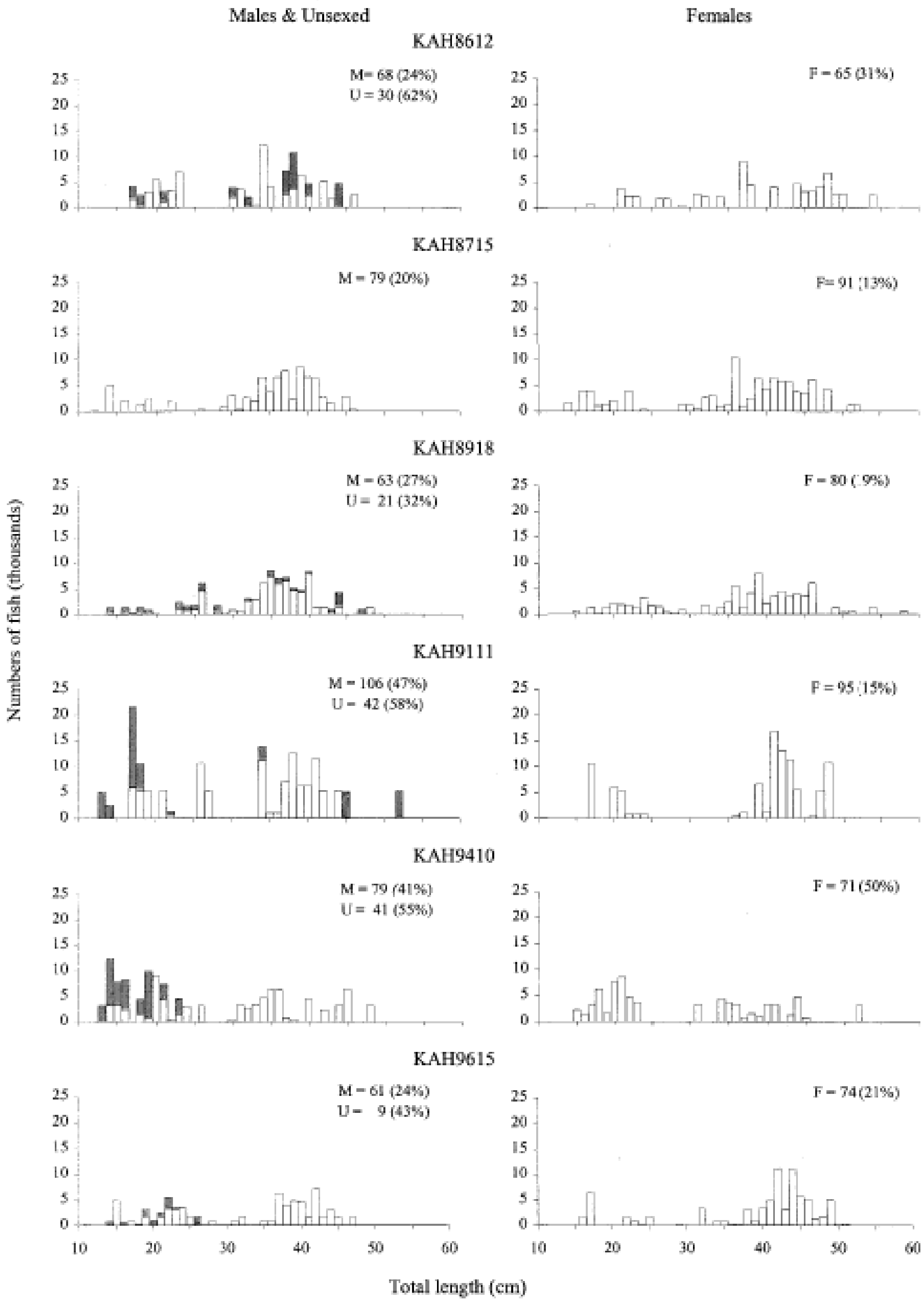


Figure 10: Scaled length frequency distributions for John dory sampled in the west coast North Island trawl survey (October–December), by year and sex. Reproduced from Morrison et al. (2001a).

Table 2: John dory biomass estimates from RV *Kaharoa* research trawl surveys. Coefficient of variation (c.v.) of biomass estimates are given in parentheses. All estimates taken from Horn et al. (1999), except WCSI (this study). WCNI, west coast North Island; ECNI, east coast North Island; WCSI, west coast South Island; Source: 1, Horn et al. 1999; 2, Morrison et al. 2001a; 3, Morrison et al. 2001b; 4, this study.

Region			Bay of Plenty		Hauraki Gulf					WCNI	ECNI			WCSI
Area			JDO1E		JDO1E	JDO1W + JDO2W	JDO1W	JDO2W	JDO1W	JDO2W	JDO2E			JDO7
Size group	Juv.	All	1+	Juv.		Juv.	All	All	Juv.	Juv.	Juv.	All	Juv.	Adult
	<33 cm	All	All	<30 cm	All	<29 cm	all	all	<29 cm	<29 cm	All	all	<29 cm	>28 cm
Season			Feb–Mar		Oct–Nov					Oct–Dec	Feb–Apr			Feb–Mar
Source	1	1	2	1	1	3	1	1	1	1	1	4	4	4
1983	18 (29)	113 (24)	113 (24)	–	–	–	–	–	–	–	–	–	–	–
1984	–	–	–	–	281 (22)	–	–	–	–	–	–	–	–	–
1985	35 (18)	128 (12)	111 (12)	–	236 (20)	–	–	–	–	–	–	–	–	–
1986	–	–	–	24 (28)	211 (25)	9 (37)	155 (35)	–	8 (40)	–	–	–	–	–
1987	–	–	–	18 (37)	181 (12)	3 (17)	160 (16)	–	3 (34)	–	–	–	–	–
1988	–	–	–	10 (22)	477 (32)	–	–	–	–	–	–	–	–	–
1989	–	–	–	5 (32)	251 (21)	13 (–)	148 (16)	68 (25)	8 (22)	2 (30)	–	–	–	–
1990	37 (14)	157 (16)	157 (16)	18 (46)	322 (13)	–	–	–	–	–	–	–	–	–
1991	–	–	–	–	–	40 (34)	216 (37)	142 (62)	13 (44)	1 (77)	–	–	–	–
1992	41 (28)	236 (12)	236 (12)	13 (21)	227 (35)	–	–	–	–	–	–	102 (29)	0 (–)	102 (29)
1993	–	–	–	17 (29)	374 (24)	–	–	–	–	–	265 (17)	–	–	–
1994	–	–	–	17 (13)	288 (17)	48 (27)	102 (47)	33 (47)	13 (39)	1 (63)	268 (31)	59 (26)	0.2 (100)	57 (27)
1995	–	–	–	–	–	–	–	–	–	–	170 (18)	27 (36)	0.3 (50)	27 (36)
1996	18 (22)	193 (44)	192 (44)	–	–	16 (15)	147 (15)	19 (38)	7 (19)	<0.5 (64)	172 (48)	–	–	–
1997	–	–	–	17 (21)	387 (18)	–	–	–	–	–	–	17 (31)	0.1 (100)	17 (31)
1998	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1999	–	–	172 (14)	–	–	–	–	–	–	–	–	–	–	–
2000	–	–	–	–	–	–	–	–	–	–	–	141 (16)	1.1 (75)	140 (16)

Table 2 (cont.): John dory biomass estimates from RV *Kaharoa* research trawl surveys. Coefficient of variation (c.v.) of biomass estimates are given in parentheses. All estimates taken from Horn et al. (1999), except WCSI (this study). WCNI, west coast North Island; ECNI, east coast North Island; WCSI, west coast South Island; Source: 1, Horn et al. 1999; 2, Morrison et al. 2001a; 3, Morrison et al. 2001b; 4, this study.

Region	Bay of Plenty			Hauraki Gulf		WCNI					ECNI	WCSI		
Area	JDO1E			JDO1E		JDO1W + JDO2W	JDO1W	JDO2W	JDO1W	JDO2W	JDO2E	JDO7		
Size group	Juv.	All	1+	Juv.		Juv.	All	All	Juv.	Juv.	Juv.	All	Juv.	Adult
	<33 cm	All	All	<30 cm	All	<29 cm	all	all	<29 cm	<29 cm	All	all	<29 cm	>28 cm
Season	Feb–Mar			Oct–Nov		Oct–Dec					Feb–Apr	Feb–Mar		
Source	1	1	2	1	1	3	1	1	1	1	1	4	4	4
2001	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2002	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2003	–	–	–	–	–	–	–	–	–	–	–	288 (19)	0.1 (100)	288 (19)
2004	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2005	–	–	–	–	–	–	–	–	–	–	–	222 (14)	0 (–)	222 (14)
2006	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2007	–	–	–	–	–	–	–	–	–	–	–	174 (26)	0.3 (73)	174 (26)
2008	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2009	–	–	–	–	–	–	–	–	–	–	–	269 (23)	0.8 (40)	268 (23)
2010	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2011	–	–	–	–	–	–	–	–	–	–	–	327 (18)	0.4 (78)	327 (18)

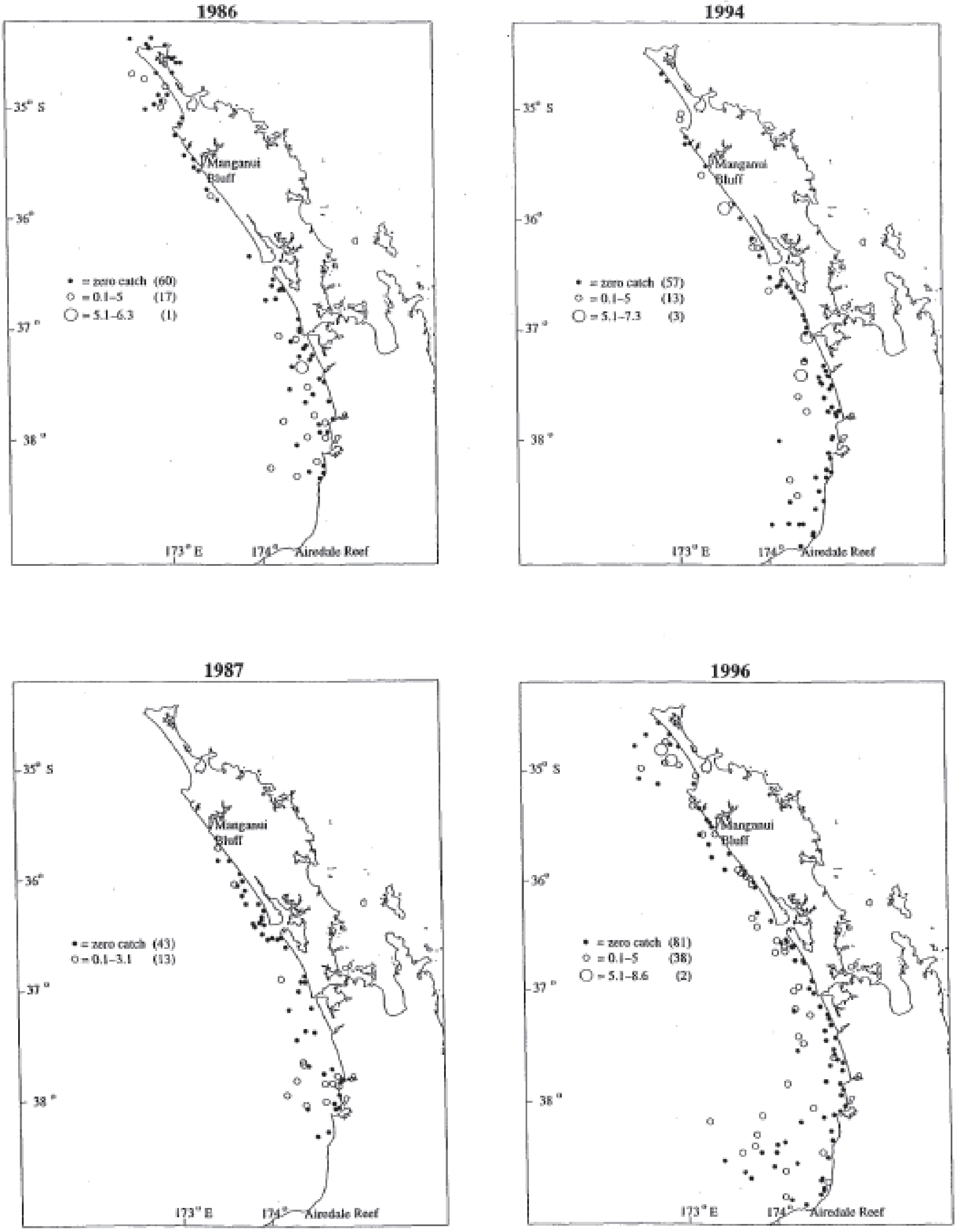


Figure 11: Research trawl catch rates of juvenile John dory during the west coast North Island trawl surveys, combined sexes, by year. Plotted circles are proportional to catch rate, which is kg km^{-1}. Juveniles were defined as John dory less than 29 cm total length. Numbers in parentheses give the number of stations within the given catch rate range. The years were selected at random from the trawl survey series. Reproduced from Stevenson (1998).

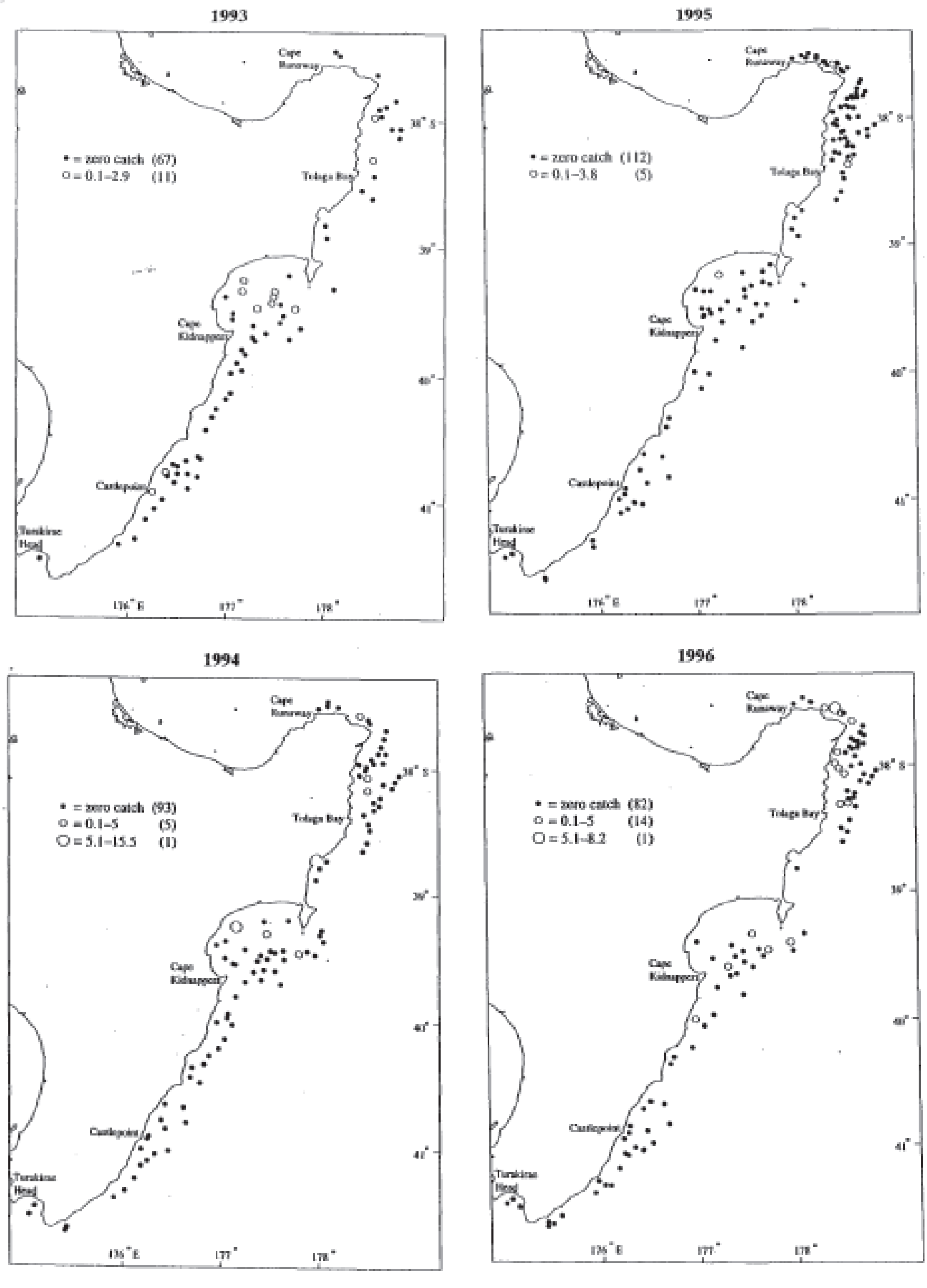


Figure 12: Research trawl catch rates of juvenile John dory during the east coast North Island trawl survyes, combined sexes, by year. Plotted circles are proportional to catch rate, which is kg km^{-1}. Juveniles were defined as John dory less than 34 cm total length. Numbers in parentheses give the number of stations within the given catch rate range. The years were selected at random from the trawl survey series. Reproduced from Stevenson (1998).

3.1.4 Commercial fishery catch and effort data

The most obvious pattern in John dory catches is the trend at the QMA level, where the official catches in JDO1 and JDO2 appear to have possibly contrasting peaks and troughs (Figure 13). The trend in JDO7 has some similarity to JDO2, with a pronounced increase in landings over 2000–2004. These trends suggest that catches in JDO2 may increase in years when catches in JDO1 decrease, implying perhaps a range extension or latitudinal movement of fish and, in some years, at least, a link between the QMAs. The Total Allowable Commercial Catch (TACC) limits for John dory have not been restrictive for JDO1 or JDO2 (Ministry for Primary Industries 2012).

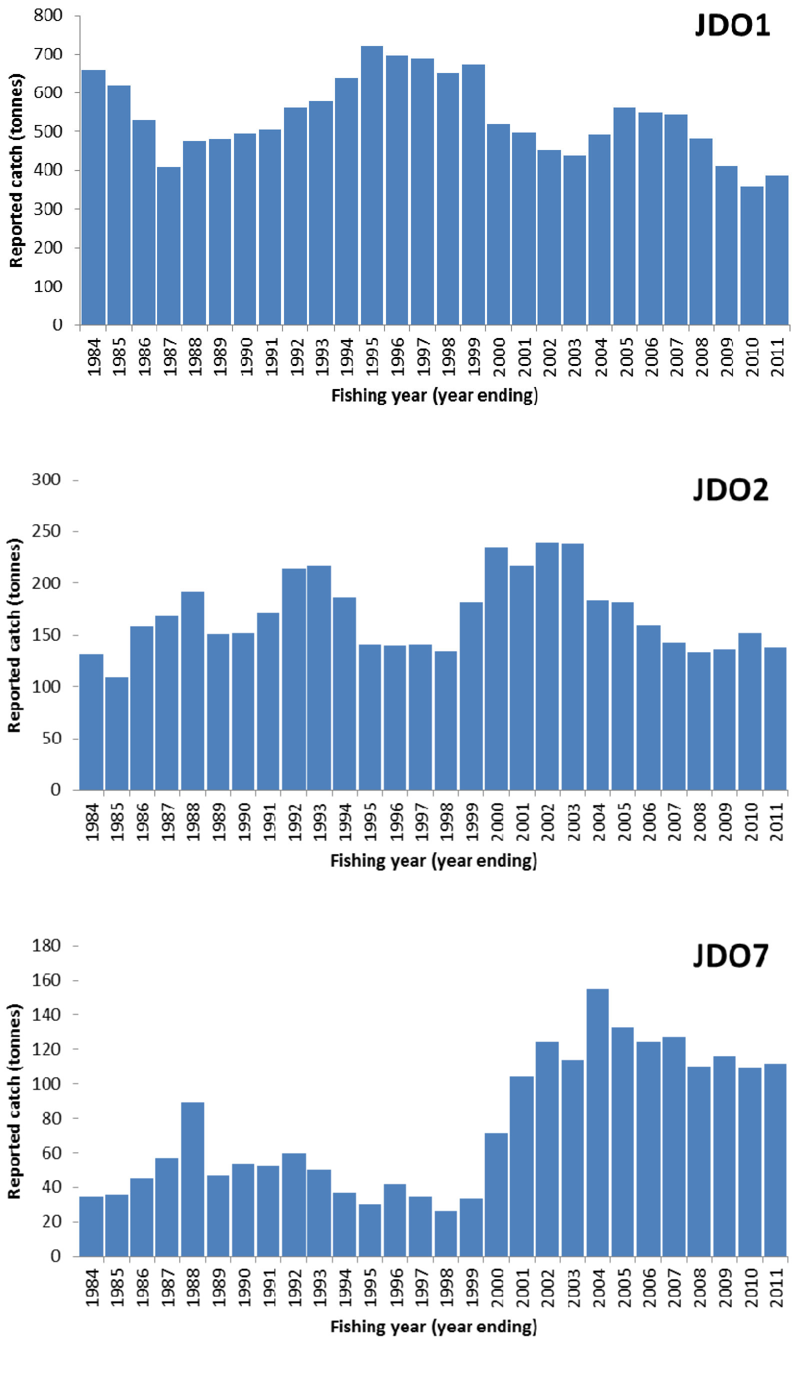


Figure 13: Reported landings of John dory by QMA (Ministry for Primary Industries 2012).

At the level of the statistical area, some John dory were caught almost everywhere around the North Island, with most catches coming from the northeast coast North Island into Hauraki Gulf (statistical areas 003, 005, and 006; Figure 14), the western end of the Bay of Plenty (008 and 009), Hawke's Bay (013), down the west coast of the North Island north of Taranaki Bight (041 to 045), and from the Kapiti coast west across the north of the South Island and especially Tasman and Golden Bays (036 to 039) (Figure 15). There were some seasonal patterns in catch, for example catches tended to be greatest in late spring and summer around Hauraki Gulf, in summer on the west coast North Island, and spring off the northern South Island (Figure 15).

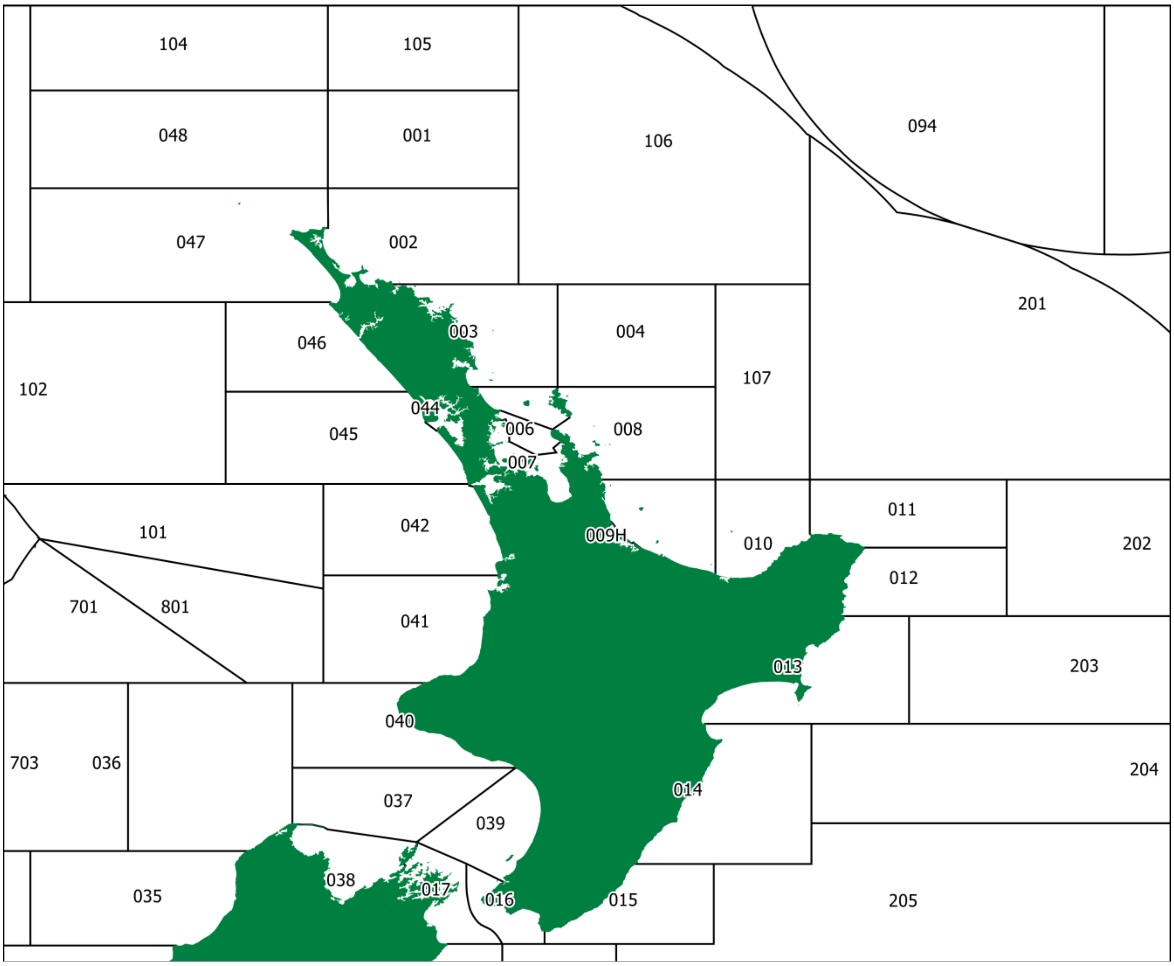


Figure 14: Location of Ministry for Primary Industries inshore fisheries management statistical areas (from www.nabis.govt.nz).

The increase in catches around the northern South Island and concomitant decline in JDO1 is apparent in the statistical areas 040, 037, and 039, where catches were taken during the early 1990s, and from 2000, but were rare in the period in between, and in 2008 and 2009 (Figure 15). This would be consistent with movement of fish south into this area from JDO1 into JDO2 in the early 1990s and 2000s. No such pattern was present on the east coast of the North Island, suggesting that range extension or latitudinal movement of John dory from JDO1 into JDO2 primarily took place on the west coast. Seasonal patterns in catches were apparent when monthly catches were normalised within statistical areas (Figure 16). Catches were taken all year but were usually greatest in summer in the Hauraki Gulf, Bay of Plenty, Hawke's Bay, and west coast North Island, but tended to be greatest in winter or spring off the north coast of the South Island. Whilst seasonality in catches was apparent, there were no patterns that suggest persistent movements or migrations between statistical areas: a similar pattern, with no suggestion of movements between statistical areas, was also found for bottom trawl raw CPUE (Figure 17).

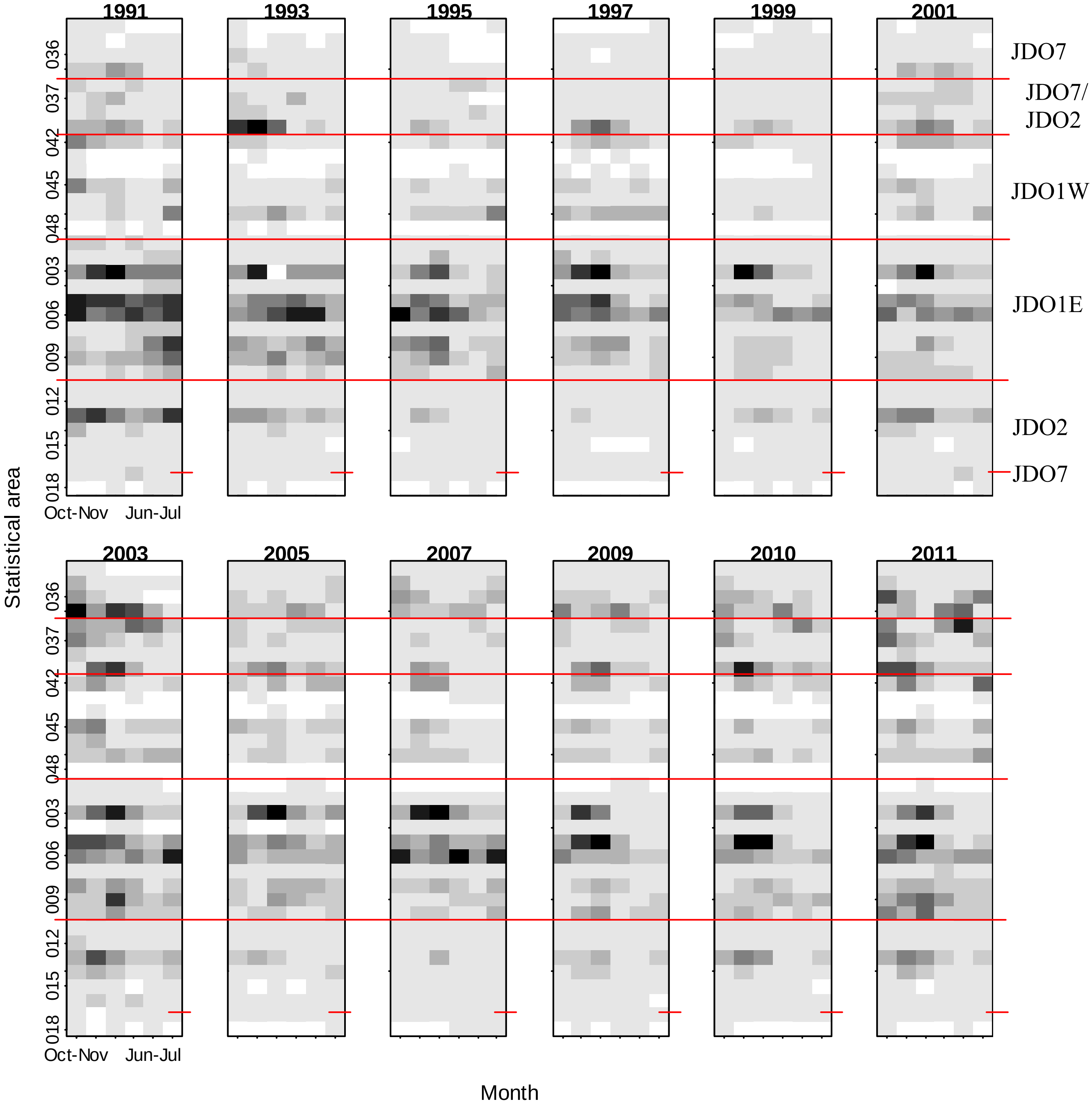


Figure 15: Image plot of the total catch of John dory for selected fishing years, by statistical area and bi-monthly groups. Darker cells indicate greater catches. From top to bottom, statistical areas are ordered numerically from south to north from the northern South Island up the west coast of the North Island, and then south down the east coast of the North Island. On the west coast, the areas are ordered 040, 037, 039, 038, 036, 035, 034. The top right panel is labelled with the splits between the quota management areas (note that statistical area 017, nominally within the JDO2 section, is actually in JDO7).

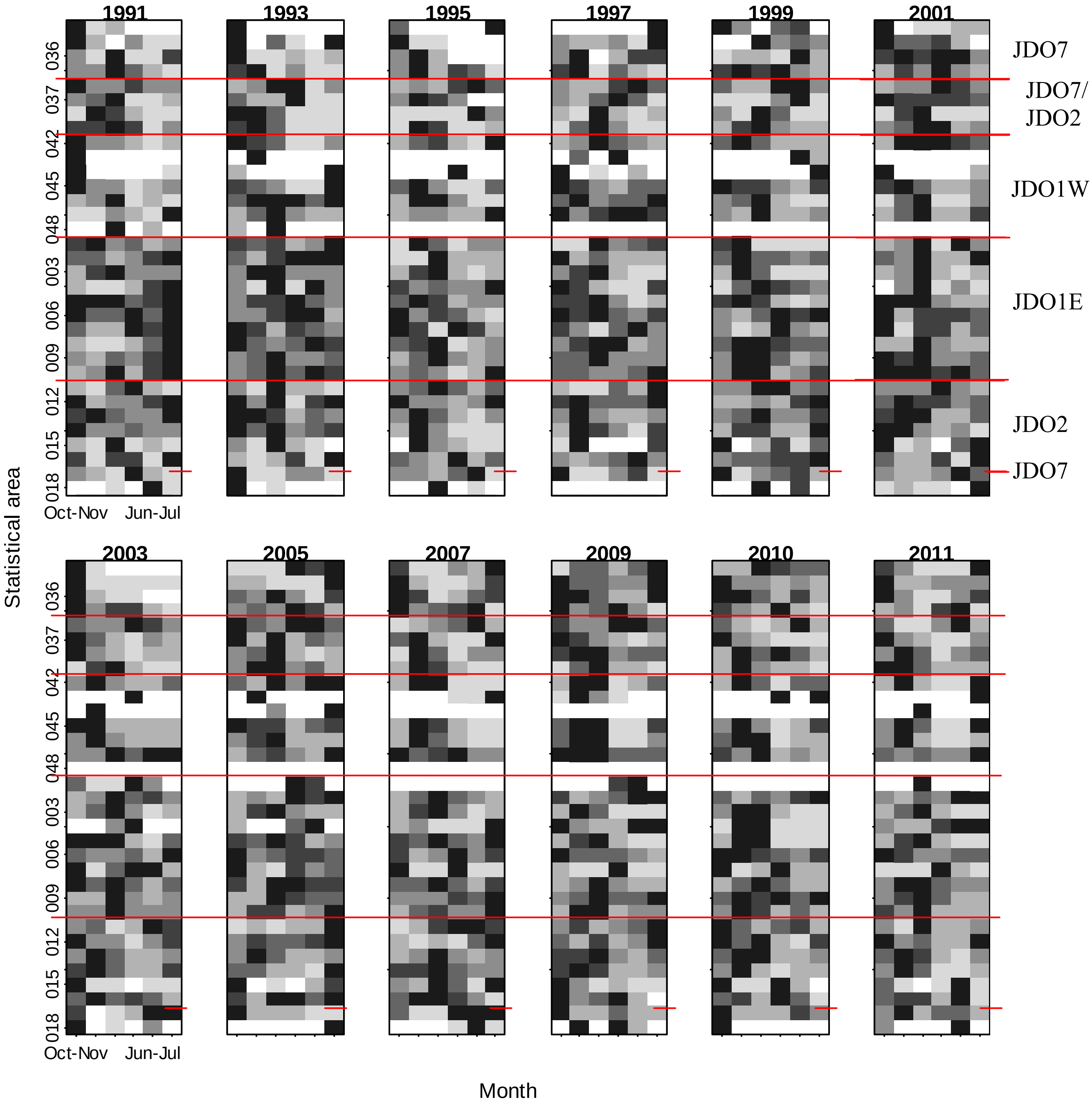


Figure 16: Image plot of the normalised catch of John dory within statistical areas, for selected fishing years, and by bi-monthly groups. Darker cells indicate greater relative catch within each statistical area. From top to bottom, statistical areas are ordered numerically from south to north from the northern South Island up the west coast of the North Island, and then south down the east coast of the North Island. On the west coast, the areas are ordered 040, 037, 039, 038, 036, 035, 034. The top right panel is labelled with the splits between the quota management areas (note that statistical area 017, nominally within the JDO2 section, is actually in JDO7).

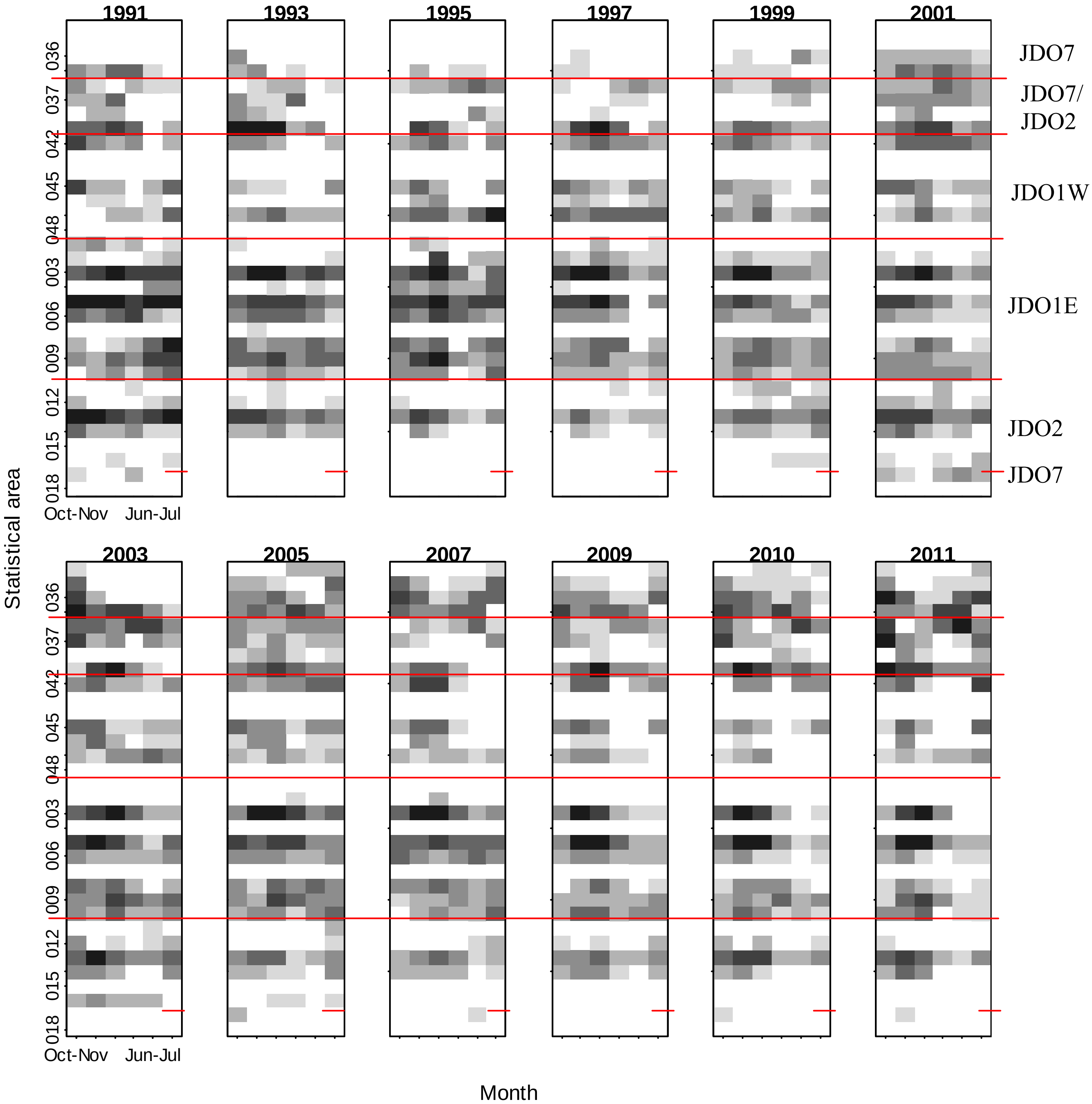


Figure 17: Image plot of the raw catch of John dory per unit effort (CPUE) by bottom trawlers within statistical areas, for selected fishing years, and by bi-monthly groups. CPUE is catch per hour for tows where John dory catches were reported. From top to bottom, statistical areas are ordered numerically from south to north from the northern South Island up the west coast of the North Island, and then south down the east coast of the North Island. On the west coast, the areas are ordered 040, 037, 039, 038, 036, 035, 034. The top right panel is labelled with the splits between the quota management areas (note that statistical area 017, nominally within the JDO2 section, is actually in JDO7).

Bottom trawl CPUE from tow-by-tow records and estimated catch provide greater detail on the distribution of John dory (Figures 18–25). Conclusions using tow-by-tow catch rates are tentative because of incomplete spatial and fleet coverage; the use of estimated catches means that a record with no catch does not necessarily mean the species was not caught (false negatives).

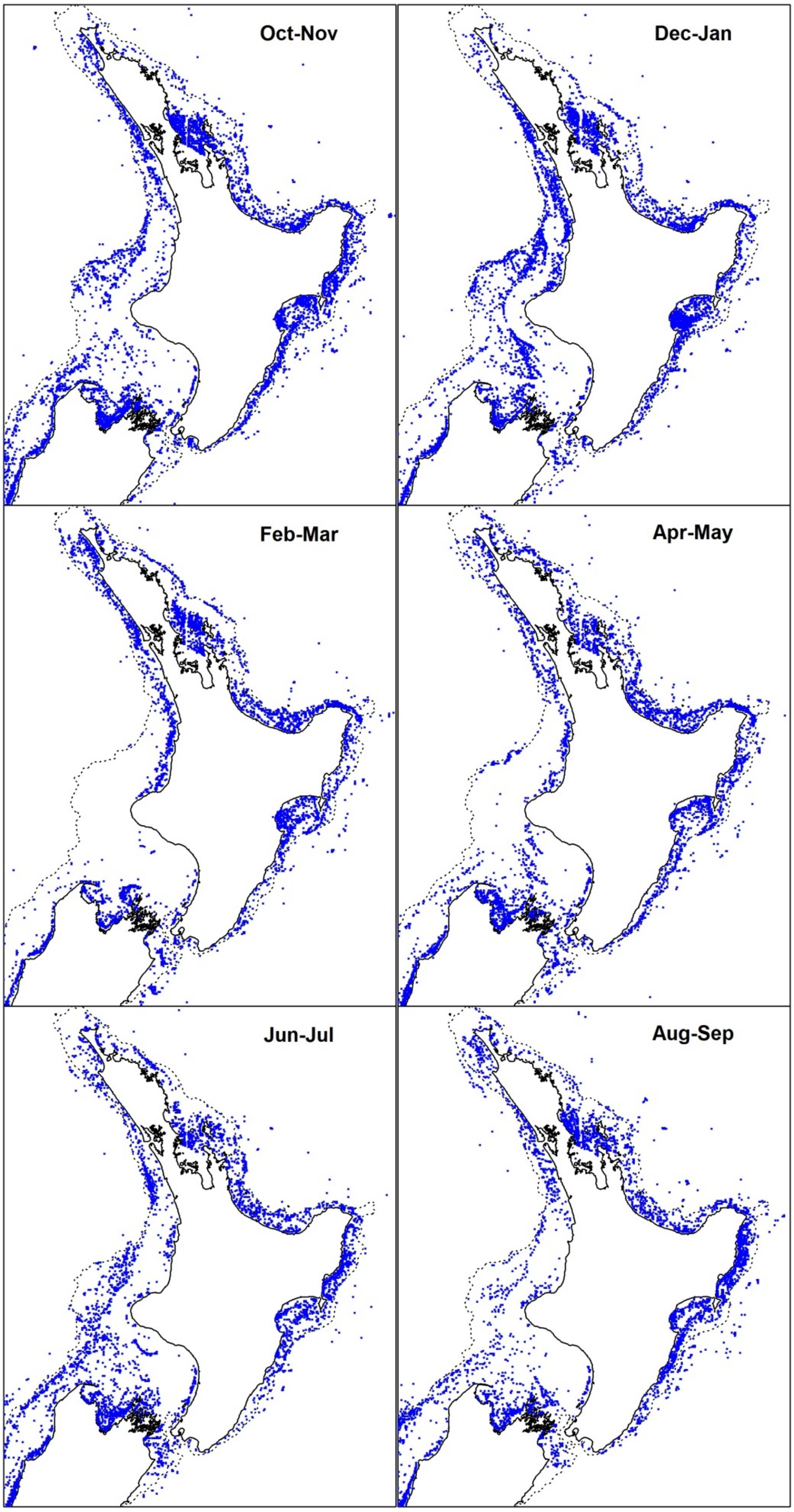


Figure 18: Location of bottom trawls from tow-by-tow data (points) in 2007–08, by bi-monthly groups.

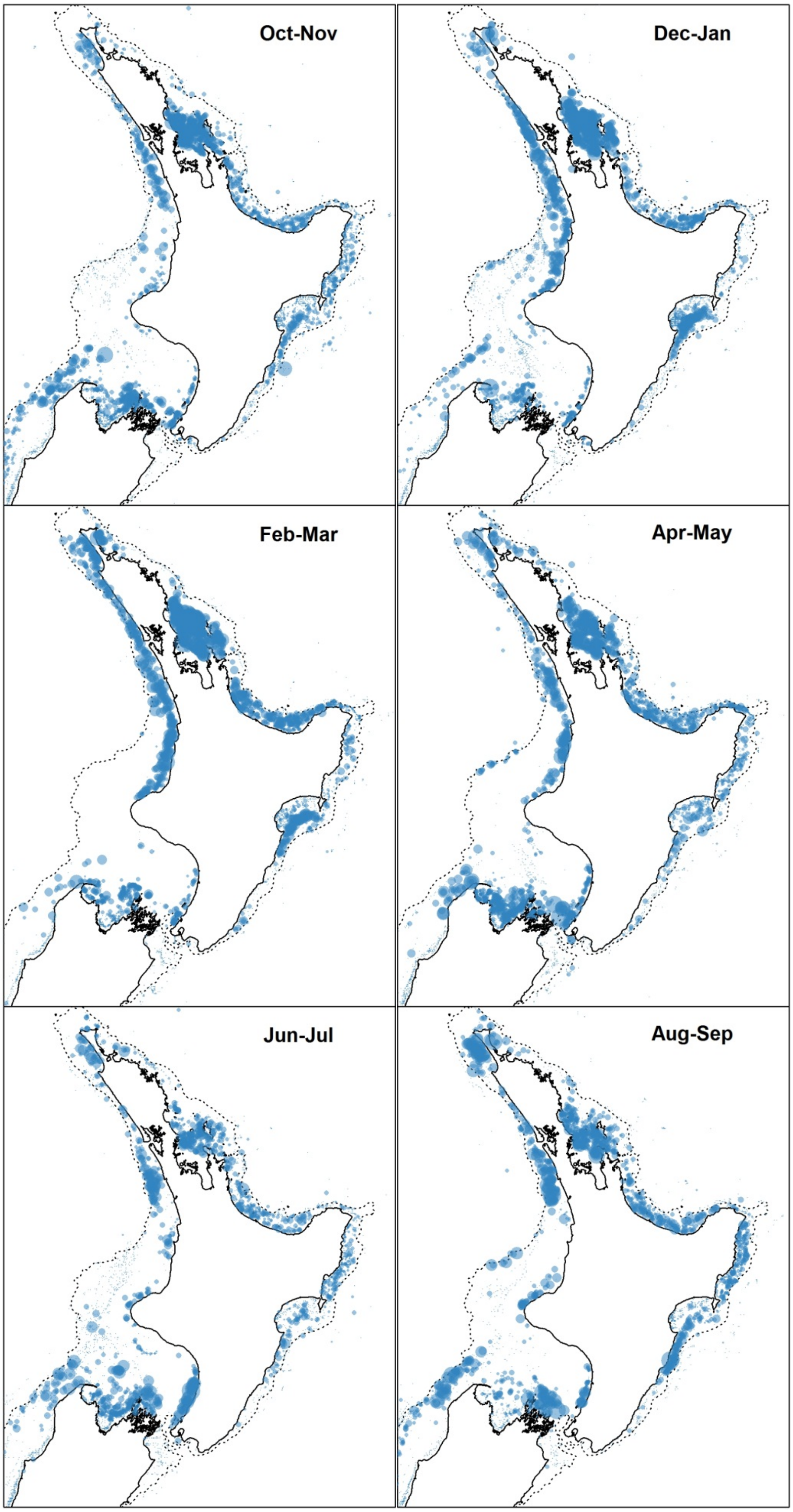


Figure 19: Catch of John dory per hour fished by bottom trawlers in 2007–08, by bi-monthly groups. Circle size is proportional to catch rate; the largest circle in each plot represents the largest catch rate in that two-month period. Dotted line, 200 m isobath.

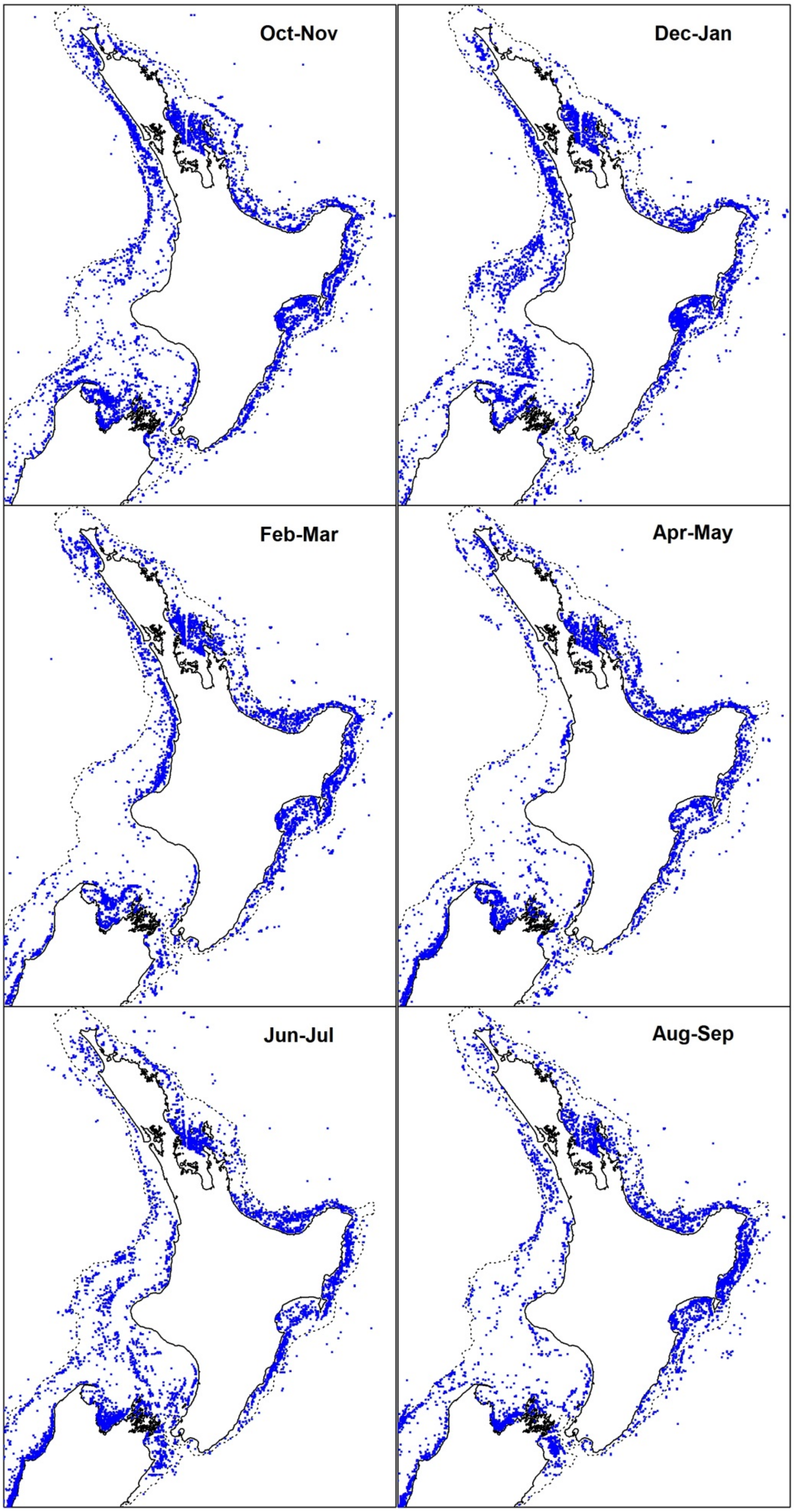


Figure 20: Location of bottom trawls from tow-by-tow data (points) in 2008–09, by bi-monthly groups.

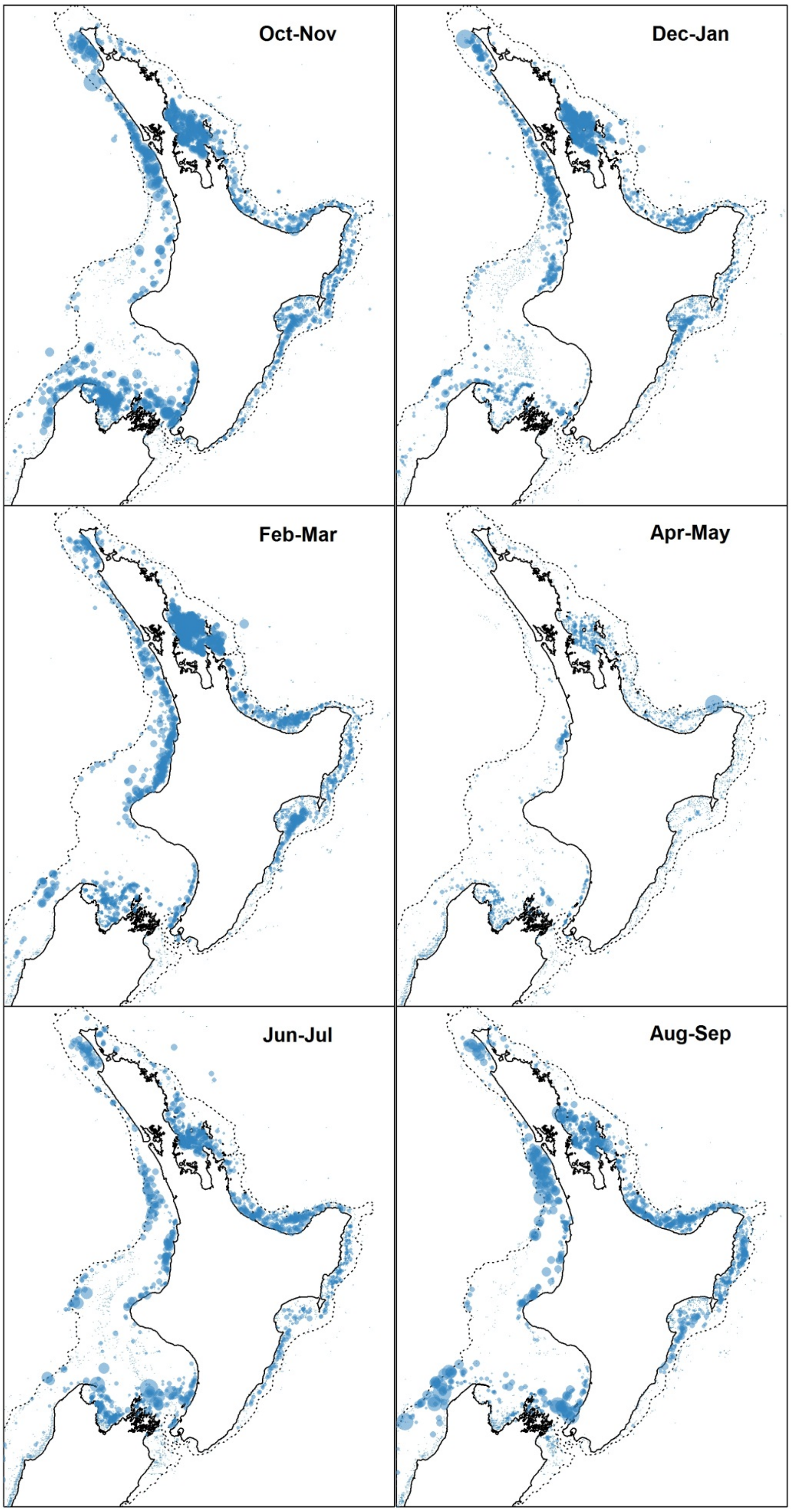


Figure 21: Catch of John dory per hour fished by bottom trawlers in 2008–09, by bi-monthly groups. Circle size is proportional to catch rate; the largest circle in each plot represents the largest catch rate in that two-month period. Dotted line, 200 m isobath.

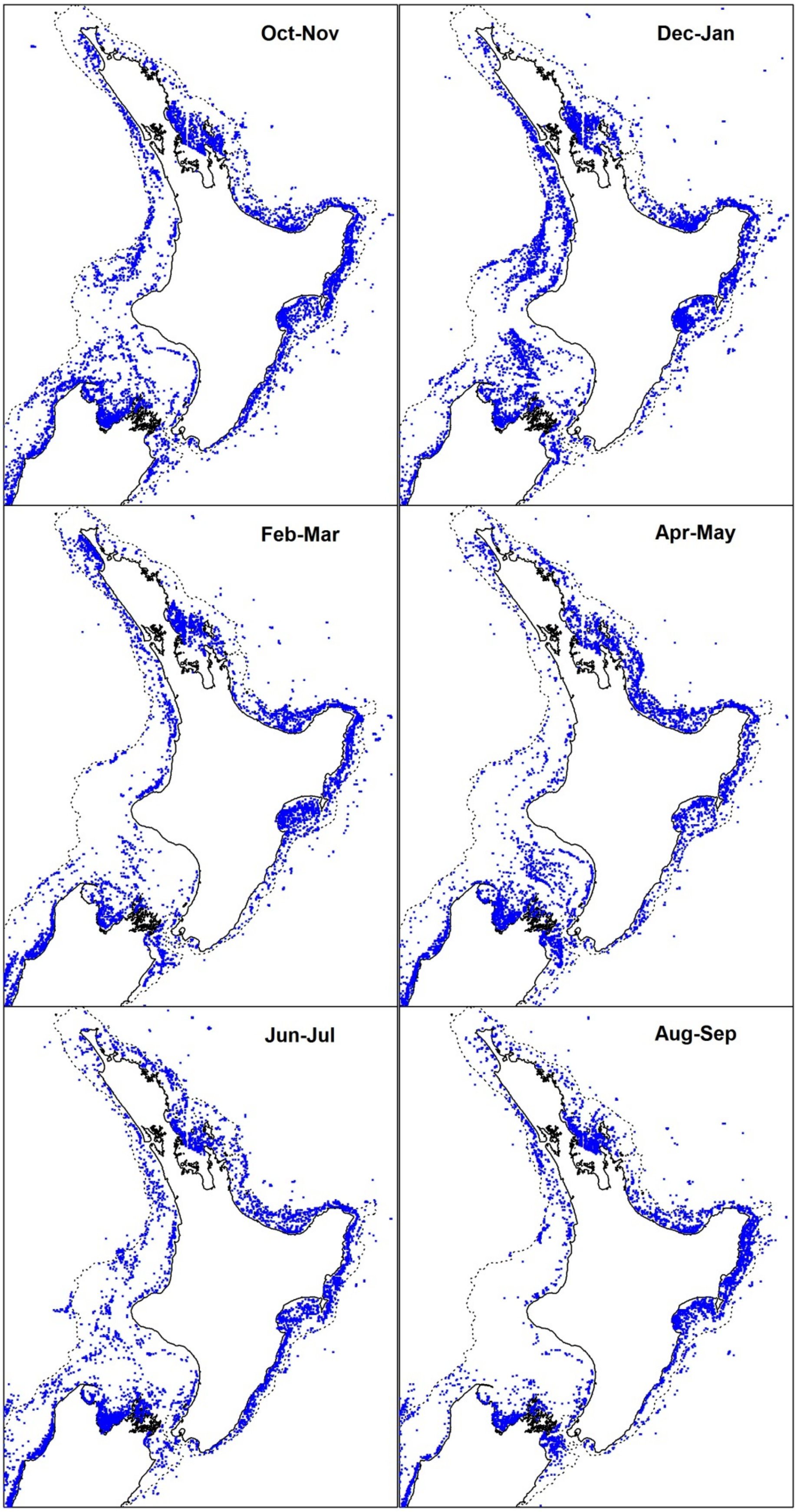


Figure 22: Location of bottom trawls from tow-by-tow data (points) in 2009–10, by bi-monthly groups.

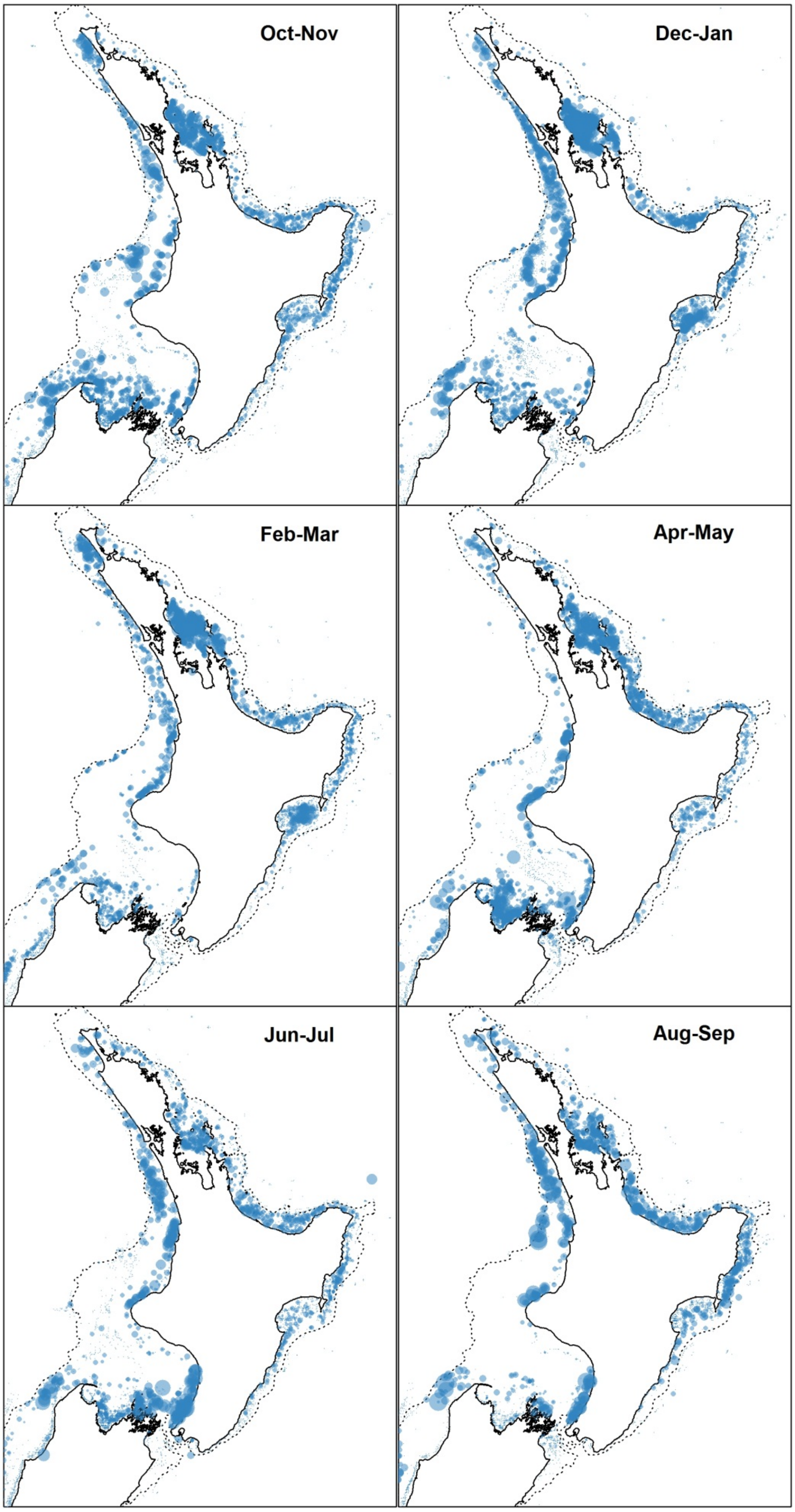


Figure 23: Catch of John dory per hour fished by bottom trawlers in 2009–10, by bi-monthly groups. Circle size is proportional to catch rate; the largest circle in each plot represents the largest catch rate in that two-month period. Dotted line, 200 m isobath.

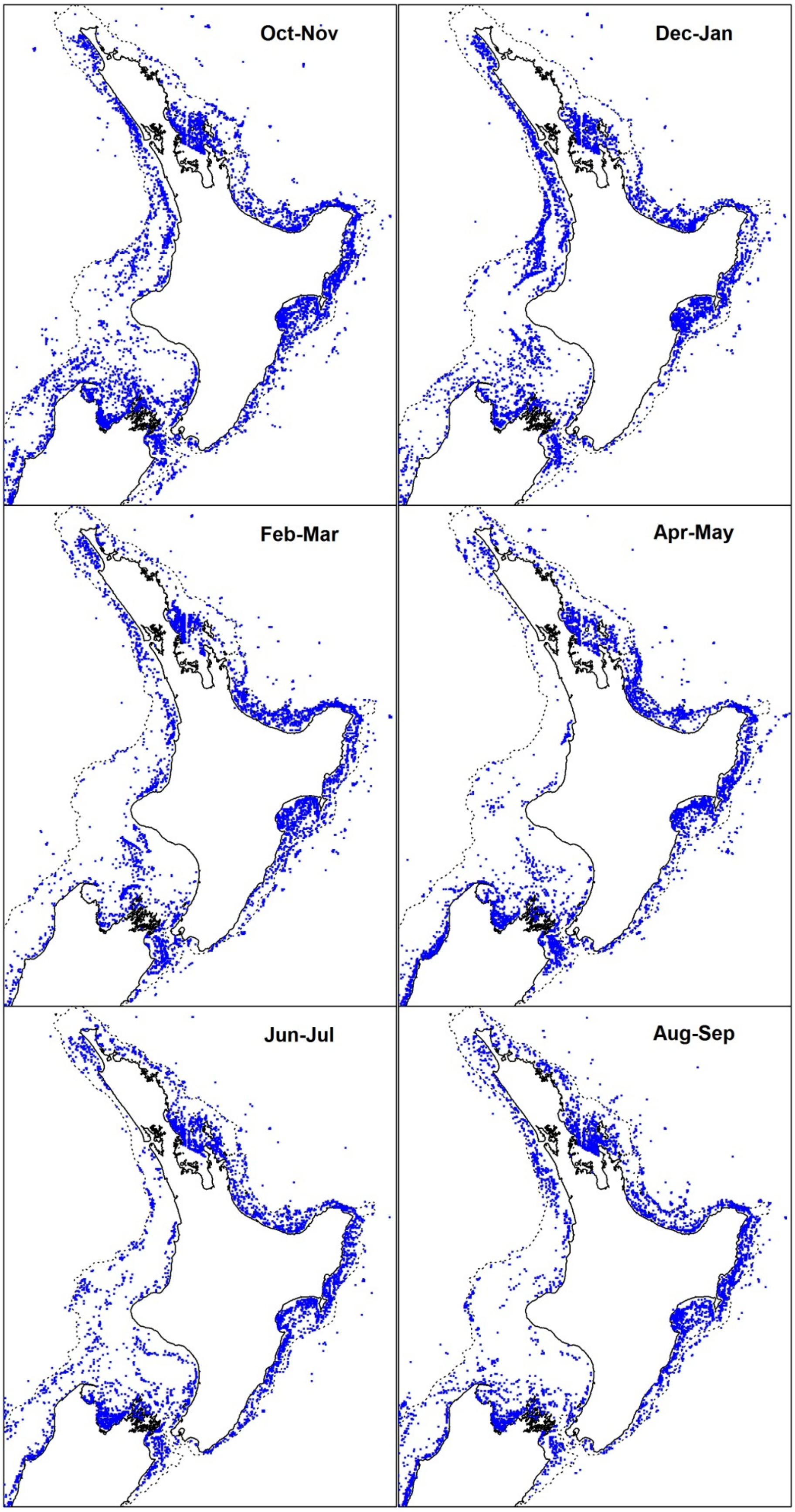


Figure 24: Location of bottom trawls from tow-by-tow data (points) in 2010–11, by bi-monthly groups.

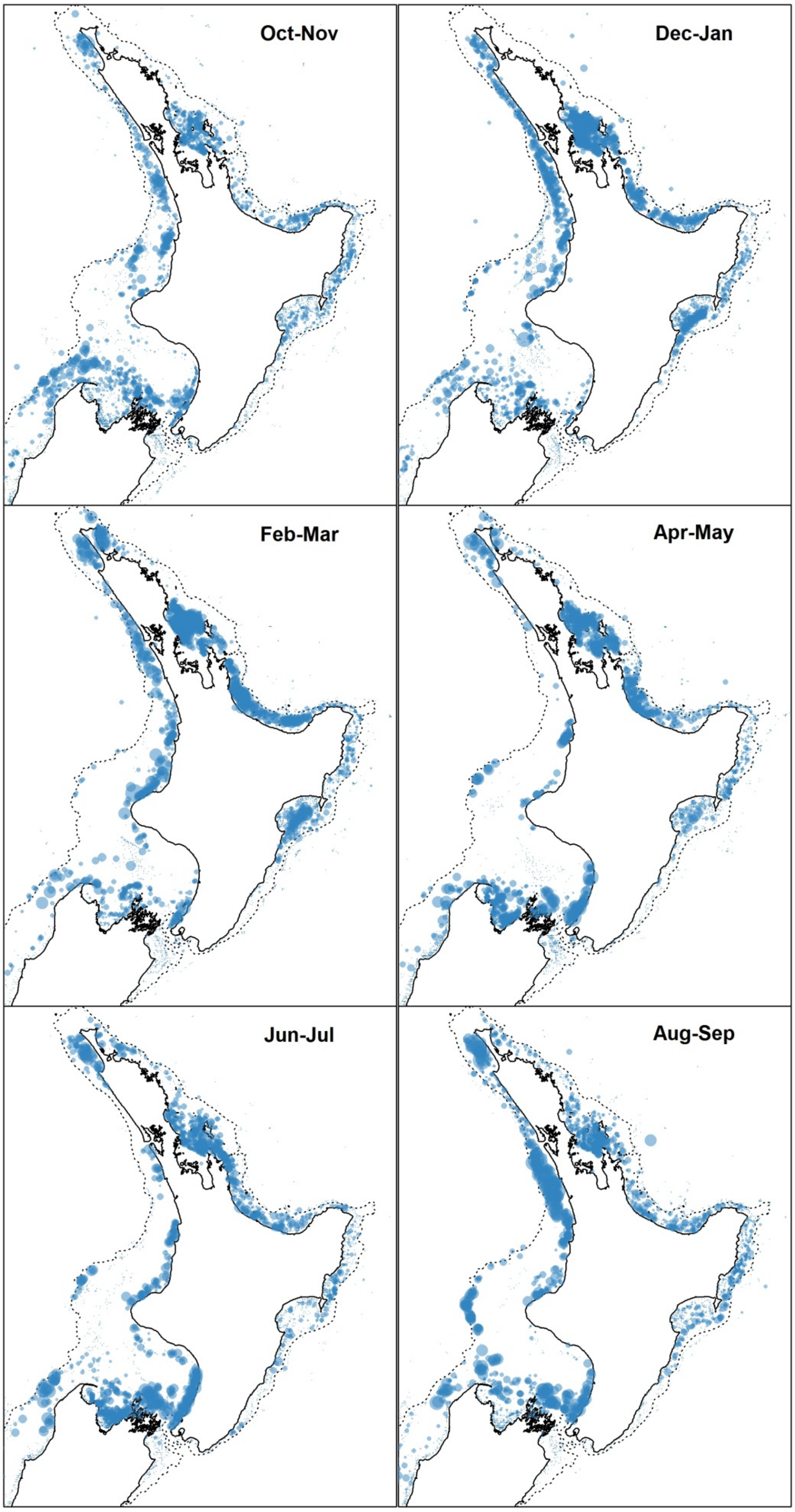


Figure 25: Catch of John dory per hour fished by bottom trawlers in 2010–11, by bi-monthly groups. Circle size is proportional to catch rate; the largest circle in each plot represents the largest catch rate in that two-month period. Dotted line, 200 m isobath.

The areas where catch rates were relatively high were stable across seasons and years, suggesting that no large scale movements took place (Figures 18–25). The catch rate data suggested a relatively complex spatial structure might occur. For example, the presence of 'patches' on the west coast North Island, for example around the far north of the North Island, off Manukau Harbour, and north of Taranaki Bight, could suggest localised aggregations. The relatively scarce fishing effort to the south of Taranaki Bight, and off northeast Northland, makes conclusions tentative for these regions.

The most pronounced seasonal movement of high catch rate areas was off the north of the South Island. The northern South Island represents the southern limit of common occurrence of John dory, and seasonal movements might be expected to be most pronounced at the edges of the species' range. Off the northern South Island, the centre of high catch rates generally moved from the northwest South Island (Tasman and Golden Bays) eastwards towards the southwest North Island (Kapiti coast) during winter. Whilst this suggests a seasonal movement of the higher catch rate area, and therefore a possible link between the two areas, there were some catches of John dory off the Kapiti coast, and northwest South Island, throughout the year.

In 2009–10 and 2010–11, there were more catches of John dory down the west coast of the South Island. There were also catches of John dory to the west of New Zealand close to the 200 m isobath throughout the year: these catches were predominantly from bottom trawl vessels targeting tarakihi.

3.1.5 CPUE analyses

The GLM of CPUE for John dory, from bottom trawls and inshore statistical areas, targeting snapper, tarakihi, John dory, trevally, gurnard, or barracouta, and combined at the trip–stratum level, explained 45.08% of the deviance (Table 3). All model terms were significant ($p < 0.001$).

Table 3: Summary of the lognormal GLM for catch rates of the John dory fishery, after application of data selection criteria, and without spatial stratification. Df, degrees of freedom. Poly, polynomial (order in parentheses).

	Df	Residual deviance	Deviance Explained. (%)
–	–	213 550	–
+ *fishing year*	21	211 413	0.98
+ *vessel key*	332	161 651	24.29
+ *target species*	5	154 508	27.63
+ poly(*day of year*, 3)	3	152 572	28.54
+ poly(log(*fishing duration*), 3)	3	117 260	45.08

Subsequent models included all of the terms in Table 3, plus an additional *fishstock* × *fishing year* interaction. In the simplest case, the *fishstock* was the QMA (Table 4). Including *fishstock* did improve the model (lower AIC). All additions of *fishstock* × *fishing year* predictors were highly significant ($p < 0.001$).

Compared to assuming QMA alone as the *fishstock*, adding the split in JDO1 into east and west explained an additional 0.515% of deviance (Table 4: compare runs 2 and 3), and splitting JDO1 east further into the Hauraki Gulf (and north) and Bay of Plenty explained a further 0.207% of deviance (Table 4: compare runs 3 and 4). Extending the Bay of Plenty stock to include the area around East Cape (statistical areas 011 and 012) proved to be a poor idea (Table 4). Moving data from the western statistical areas of JDO2 (037, 039, 040, 041) into JDO1 west was a good idea, and explained an additional 0.744% of deviance (Table 4: compare runs 6 and 4). Treating the entire east coast as a single stock was a relatively poor model (Table 4, Run 7).

Table 4: Summary of the lognormal GLM for catch rates of the John dory fishery, after application of data selection criteria, and without spatial stratification. The single area model is that described in Table 3. All subsequent models (numbered 2–9) have an additional *fishstock* × *fishing year* interaction term added to the model, with varying *fishstock* definitions. Dev. explained, total deviance explained; Dev. expl. gain, the gain in deviance explained, is relative to the single area model. Df, degrees of freedom; AIC, Akaike Information Criterion; Poly, polynomial (order in parentheses); HG, Hauraki Gulf; BoP, Bay of Plenty.

Fishstock assumption	*n* stocks	Df	AIC	Dev. explained (%)	Dev. expl. gain (%)
1. Single area	1	364	287 795	45.105	–
2. As 1, with QMA	4	422	283 672	47.511	2.406
3. As 2, JDO1east and west	5	444	282 791	48.026	2.921
4. As 3, JDO1e HG and BoP	6	466	282 461	48.233	3.128
5. As 3, JDO1e HG and BoP extended	6	466	283 253	47.794	2.689
6. As 4, JDO2W to JDO1W	6	466	281 104	48.977	3.872
7. As 3, JDO2W to JDO1W, JDO2E to JDO1E	5	444	284 079	47.307	2.202
8. As 4, JDO2W to JDO7 + JDO1W	6	466	282 233	48.359	3.254
9. As 4, JDO2W to JDO7 (039) + JDO1W	6	466	282 233	48.359	3.254
10. As 6, JDO7 to JDO1W	5	444	283 064	47.874	2.769
11. As 6, JDO1W split	7	488	280 848	49.140	4.035

Model runs moving data from the southern part of JDO2 into JDO7 did not improve the amount of deviance explained. With data from JDO2 statistical areas 037 and 039 moved into JDO7, and JDO2 statistical areas 040 and 041 moved into JDO1 west, the model explained 0.618% less deviance (Table 4: compare runs 6 and 8). A run with data from JDO2 statistical area 039 moved into JDO7, and JDO2 statistical areas 037, 040 and 041 moved into JDO1 west, produced a similar result (Table 4: run 9). Compared to the 'best' model (run 6, having the lowest AIC), moving JDO7 and JDO2W into JDO1W was a poor option and decreased the deviance explained by 1.103% (Table 4: run 10). However, allocation of data to particular QMAs in these 'boundary' regions is made difficult by catches from two (or potentially three) QMAs often being made in a single trip–stratum. In such cases, the accuracy of the allocation of catch and effort to QMA may be tolerable for fishery characterisation purposes, but may be dubious for these CPUE analyses.

Adding a further split in JDO1 west, into statistical areas 045–048 and the remainder, improved the deviance explained by 0.163 % (Table 4: compare runs 11 and 6). This split was essentially arbitrary, but in terms of additional deviance explained was similar in performance to the Hauraki Gulf and Bay of Plenty split. This is an interesting observation, as it supports the idea that splitting the fisheries into smaller and smaller units may continue to improve the overall model performance (in both deviance explained and AIC), simply because of spatial correlations in the catch rate data, even though the splits may have little other rationale in terms of stock structure.

Some of the year trends estimated by the model were substantially different for each assumed fishstock. For model 6 (see Table 4), the overall time-series CPUE trends in JDO1E east Northland and Bay of Plenty were steady declines, whereas CPUE was stable in JDO1W and JDO2W, increased around 2000–01 in JDO2E and JDO7, and remained relatively high after that in JDO7 (Figure 26).

3.1.6 Anecdotal information

Fishers in the Hauraki Gulf, Bay of Plenty, northern west coast (JDO1) and lower east coast of the North Island (JDO2) all reported catching John dory all year around at low levels, meaning "the odd one through the shot", "a scattering every shot", "just a bin here and there". Certain areas were noted as providing higher catches, including certain soft muddy bottom areas, around rocky outcrops and rocky reefs, and algal-covered banks. John dory were caught throughout Tasman and Golden Bay, Cook Strait and Cloudy Bay, with the main area being around Farewell Spit and Kahurangi Shoals, with catches often greater over rougher ground.

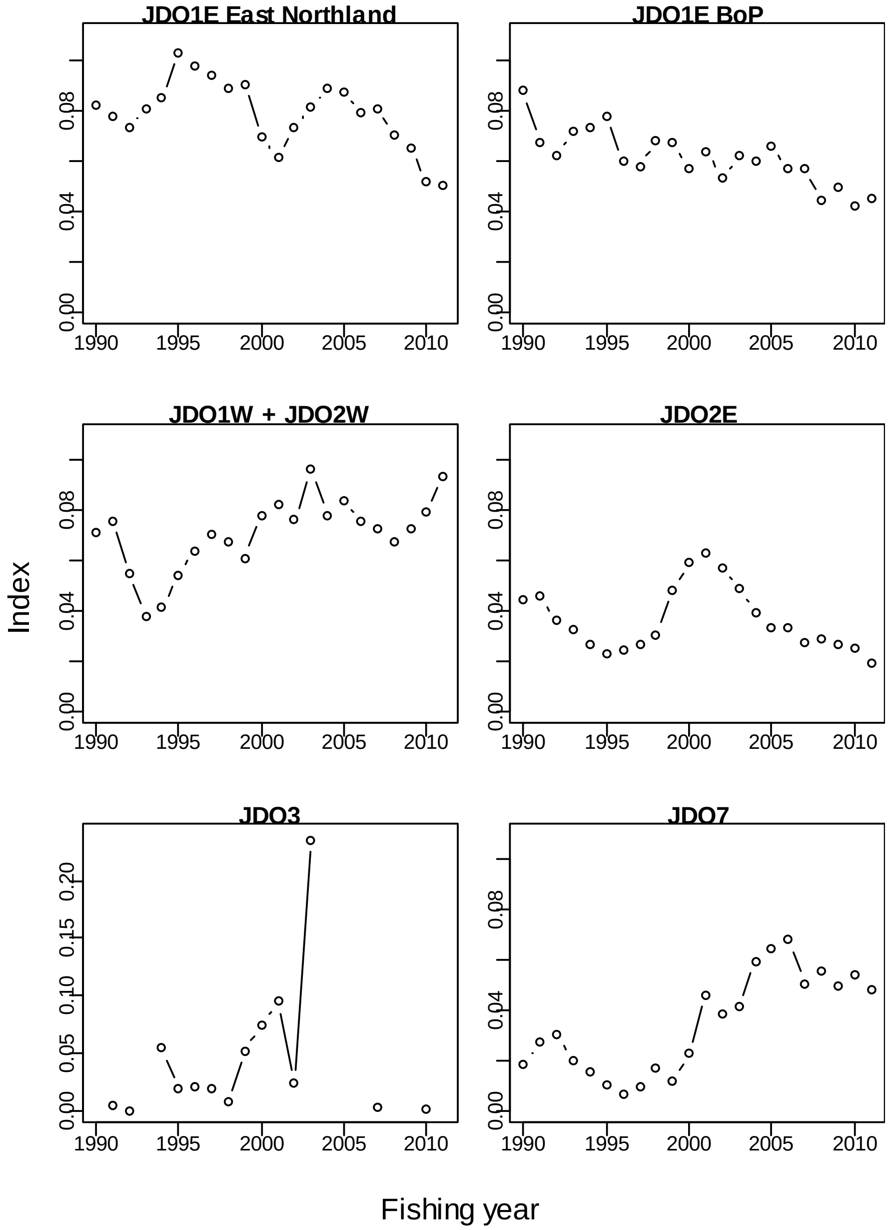


Figure 26: CPUE trends by fishstock estimated by GLM model 6 (see Table 4).

There were times of the year when catches were usually greater, but this varied by area. In the Hauraki Gulf, highest catches were usually in the cooler months either side of summer and in early winter, although abundance was reported as very variable. Fishers believed variability in John dory catches was mainly related to the abundance of prey (baitfish: sardines and pilchards, maybe juvenile snapper), for which the John dory would aggregate, sometimes in great densities. One fisher recalled a very dense mark that produced a false seabed echo on the sonar, and fishing over a period of weeks caught about 15 tonnes of John dory. Late winter, spring and early summer (Aug/Sept and Nov/Dec) were good months on the west coast of the North Island, whereas in the western Bay of Plenty, highest catches were thought to occur in autumn. In the Hawke's Bay region, trawl catches were generally highest in mid-summer, between mid-January and mid-March. Summer was also reported as the time for higher catches in JDO 7 (Golden and Tasman Bay), over a 3–4 month window, and at depths of 20–25 m.

Most fishers commented on how John dory were quite unpredictable and could "just turn up" and disappear very quickly. Those fishing in the Hauraki Gulf (Danish seiners) believed fish were moving through their fishing area, and movements were related to the presence of prey. Fishers in other areas didn't believe John dory moved far, but catches were reduced when the fish moved off the bottom, making them unavailable to the trawl or Danish seine nets. In the western Bay of Plenty, John dory were caught with stomachs full of "red-coloured eel-like fish, around 10–12cm long" (probably red bandfish *Cepola haasti*; Peter McMillan, pers.comm.), and the fisher believed John dory descended to the seafloor at certain times of the day to feed on these. It was also thought that John dory may move into shallower water at some times of the year and onto hard ground, with their presence noted around wharf piling, in shallow bays and their observed abundance at reef sites such as Waihi Bluffs in the Bay of Plenty, Clive Hard, Hawke Bay, and around Kapiti Island. One fisher reported being able to pick up adult live John dory from the beach, believing that they accidently became beached following baitfish into the shallows. All fishers believed the John dory were likely to be resident in the areas where they fished, and thought absence in catches was due to moving to localised areas or into mid-water, where they were less available.

Some fishers were unable to comment on presence of spawning fish as they landed John dory whole. Others reported ripe John dory in the western Bay of Plenty in Autumn, in spring (Nov/Dec) on the west coast of the North island, and in the summer months from the end of December onwards along the east coast of the North island (JDO2 east). No regular and important spawning sites were identified for John dory, although one fisher believed they did "school up to spawn". On the west coast, spawning fish were thought to move into shallower water and were caught all along the coast.

Fishers in all areas reported catching small John dory (Hauraki Gulf, western Bay of Plenty, south east coast of the North Island, northern west coast of the South Island and Golden and Tasman Bays). In most cases, fishers described catching small numbers of juvenile John dory, although on the west coast of the North Island one fisher reported catching "heaps and heaps", observing small fish falling out of the cod end meshes and being picked off by seagulls. The smallest John dory described were generally 4–5" (10–15cm), although one mentioned catching fish 3–4 cm long. One fisher reported catching small (15–30 cm) fish in deeper water (180 m) at night, with larger adults caught in shallower depths (60–79 m). Most fishers reported that the juveniles were caught along with adult fish, but some areas were highlighted as possible nursery grounds. For example, in the Hauraki Gulf an area about 5 miles north of The Noises, in 40–50 m depth was identified. In the western Bay of Plenty, an area near Great Mercury Island was highlighted. On the east coast North Island (JDO 2), the bays along the coast towards Cape Turnagain were identified, although one fisher commented that "you don't catch many small fish in Area 2". Another area was on the southwest coast North Island, north of Kapiti Island and "on the edge of the weedline". In the Golden and Tasman Bays region, fishers observed an increase in John dory, starting in 1999–2000 with increasing numbers of smaller fish (5–10 cm), initially caught in dredges, and then in subsequent years larger numbers of medium sized (about 35 cm), and then larger fish, being caught.

There was also a perceived decline in John dory abundance in recent years in the Hauraki Gulf, and along the east coast of the North island. Several fishers commented that they used to occasionally be able to catch "a big bag of John Dory" when they schooled up, presumably to feed. Such profitable catches were less common now, and this was thought to be due to a reduction in the abundance of prey species such as pilchards, caused by increased pressure on those stocks. On the west coast North Island, in contrast to some east coast areas, one fisher who had recently returned to the west coast inshore fishery perceived an increase in abundance of John dory compared to about ten years ago. Further south, in JDO 7, the increased abundance of John dory in the early 2000s and initial lack of TACC required fishers to avoid catching or landing John dory. In addition, several fishers commented on an increase in snapper abundance in both the Hauraki Gulf and west coast of the North Island, which made it hard to target and/or reach the quota for John dory. Snapper were described as "a plague", and "a nuisance". Whereas previously in the Hauraki Gulf, snapper would "vanish around May and turn up again at the end of September", now they were present on the fishing grounds all year around.

3.1.7 Stock structure hypotheses

3.1.7.1 Large-scale stock structure hypotheses

Is there stock separation between JDO1 west and JDO1 east?

The evidence that tends to support there being separation between the west and east coasts of the northern North Island is that (a) both areas have spawning grounds and adjacent nursery grounds, (b) there were different patterns in age frequency and length frequency distributions, (c) there were persistent centres of relatively high catches on both coasts, (d) separating the areas increased the amount of deviance explained in CPUE analyses, and (e) the limited (four years) research trawl surveys showed different biomass trends in Hauraki Gulf compared to the west coast. The only evidence against stock separation was the largely continuous distribution of John dory around the North Island, although the distribution through northeast Northland is equivocal through lack of data. On balance, the evidence tends to supports an assumption of stock separation between the west and east coasts of the northern North Island.

Are JDO1 west and JDO2 west the same stock?

The evidence that tends to support JDO1 west and JDO2 west being the same stock is that (a) the historical catches generally increased in JDO2 when they decreased in JDO1 implying possible movement, (b) the distribution of John dory in research trawl surveys was continuous between JDO1 west and the northern part of JDO2 west, and (c) merging the areas increased the amount of deviance explained in CPUE analyses. The evidence against merging the two stocks is that there were spawning and adjacent nursery grounds found in both areas. The research trawl survey biomass indices were treated as equivocal, in that the trend over the first three years compared was the same, but the fourth year differed. On balance, the evidence tends to supports an assumption of no stock separation between JDO1 west and JDO2 west.

Is JDO2 east a separate stock from JDO2 west, and from JDO1 east?

The evidence that tends to support JDO2 east being a separate stock from the adjacent areas is that (a) there are spawning and adjacent nursery grounds around Hawke's Bay, (b) there is a persistent centre of higher catches around Hawke's Bay, with very few catches south of that area, and (c) CPUE analyses indicate that the Bay of Plenty and adjacent areas of JDO2 should not be aggregated. The only evidence against stock separation is the largely continuous distribution of John dory from the north. Anecdotal evidence corroborates a local stock that spawns and has nursery grounds in JDO2 east. On balance, the evidence tends to supports an assumption of stock separation between JDO1 east and JDO2 east.

Is there a separate stock in JDO7?

The evidence that tends to support JDO7 being a separate stock is that (a) the John dory in JDO7 include unusually large fish not seen elsewhere, (b) there are spawning grounds (albeit one occurrence) and adjacent nursery grounds in the area, (c) there is a persistent centre of higher catches across the north of the South Island and especially Tasman and Golden Bays, and (d) CPUE analyses favour separation of JDO7 from JDO2 west, or from a combined JDO1 west and JDO2 west stock. The evidence against stock separation is the continuous distribution of John dory in JDO7 with JDO2, especially to the southwest coast of the North Island. The apparent 'gap' in occurrence between the Kapiti coast (southwest North Island) and further north is caused by infrequent fishing effort in the area, so this separation is equivocal. On balance, the evidence tends to supports an assumption of stock separation between JDO7 and JDO2.

There is little evidence to suggest substantial numbers of John dory extend further south than JDO 7, on either coasts of the South Island. It is not entirely clear, however, where a boundary might be drawn between JDO7 and areas to the north and east. The tow-by-tow catch data suggest that the JDO7 stock may overwinter in areas towards the Cook Strait, potentially including the southwest coast of the North Island. If these two areas were aggregated, an appropriate boundary on the west coast might be at 40°S. However, analyses with CPUE did not support aggregating catch and effort data from the southern statistical areas of JDO2 with those from JDO7. If JDO2 and JDO7 were not aggregated, the existing QMA boundary would be appropriate.

3.1.7.2 Smaller-scale stock structure hypotheses

Both observational and anecdotal evidence suggest that John dory may have locally restricted ranges, and therefore stocks may be smaller than the regional scale (e.g., QMA scale). However, the observational data to argue for smaller-scale stocks of John dory are sparse. Whilst sufficient data may exist to argue for separate stocks in Hauraki Gulf and the Bay of Plenty, similar-scale stocks may exist elsewhere but little or no data were available to detect them. There is no simple answer to smaller-scale stock structure questions without additional data and analyses being completed. At present, arguments for smaller-scale stocks are as follows:

Are there separate stocks in JDO1 east in the Hauraki Gulf (and further north) and Bay of Plenty?

The evidence that tends to support the hypothesis that Hauraki Gulf and Bay of Plenty support separate stocks is that (a) spawning fish, and nursery grounds, are known in both areas, (b) research trawl survey biomass trends are different (albeit only three years could be compared), (c) CPUE analyses indicate that separation may be supported (just), and (d) the previous analysis of Kendrick & Bentley (2011) assumed separate stocks. The evidence against stock separation is (a) the continuous distribution of John dory throughout the Hauraki Gulf and Bay of Plenty, and (b) similar length compositions for the two areas (age composition data being equivocal because of high c.v.s). Anecdotal evidence suggests that John dory were always present in Hauraki Gulf, but fishers also suggest that John dory 'pass through' their fishing grounds in this area and so could move into the Bay of Plenty. On balance, the evidence tends to supports an assumption of the Hauraki Gulf and Bay of Plenty containing separate stocks.

3.1.7.3 Final stock structure assumptions

The Inshore Fisheries Assessment Working Group agreed on five stocks:

Hauraki Gulf and east Northland (JDO1) – defined here by the statistical areas 001, 002, 003, 004, 005, 006, 007, and 106.

Bay of Plenty (JDO1) – defined here by the statistical areas 008, 009, 010, 107, and 201.

West coast North Island (JDO1 and northern part of JDO2) – defined here by the statistical areas 040, 041, 801, 701, 101, 102, 042, 043, 044, 045, 046, 047, 048, 103, and 104.

Southeast North Island (JDO2) – defined here by the statistical areas 011, 012, 013, 014, 015, 016, 205, 204, 203, 202, and 201.

Northern South Island (JDO7 and southern part of JDO2) – defined here by the statistical areas 039, 037, 038, 017, 034, 035, 036, 703, 704, 701, 033, 706, 705, and 702.

3.2 Fishery characterisation and standardised CPUE

3.2.1 Overall catch and effort trends

Diagnostics from the grooming and "roll-up" of the catch and effort data are given in Appendix 1. The capture of John dory by bottom longline was restricted to northern and east Northland south to the Bay of Plenty, and with relatively low catches from the last four fishing years (Figure 27). Catches of John dory from bottom pair trawl were only consistently taken from the east and west coasts of Nouth Island, although catches off Coromandel and east Northland were reduced after 1997–98. Total catches from bottom pair trawl were reduced from the late 1990s.

Catches of John dory have been greatest, and most consistent, from bottom trawls (Figure 27). Bottom trawls caught John dory in almost all areas, and catches increased in Tasman and Golden Bay and the west coast South Island around the year 2000–01, but with no obvious decreases in catches elsewhere. There appeared to be temporal cycles in catch size around Hawke Bay, and a similar trend but to a lesser extent in the Bay of Plenty, with catches peaking about every 10 years. Catches of John dory from Danish Seine were almost entirely from the Hauraki Gulf, but some catches also started in Tasman and Golden Bay in 2008–09, and also in Hawke bay in the last three years.

The catches of John dory from midwater trawls were substantialy higher from 2000–01, although remaining relatively small. Midwater trawl catches of John dory increased from the west coast North island, centred around Taranaki Bight, and decreased off the west coast South Island. In a few years around 1999–2000, John dory were also caught in midwater trawls off the east coast of the North Island, mostly south of Napier.

Catches of John dory by set net were largely from the inner Hauraki Gulf and Firth of Thames. Catches by set nets were relatively high during the 1990s, and relatively low over the last four fishing years, with much of the decline occurring off Northland.

Catches of John dory in the fishery targeting barracouta (BAR) were relatively high between about 2000 and 2005, with most of this catch being taken off south Taranaki, Tasman and Golden Bay, and the west coast South Island. Despite a declining catch in recent years this spatial pattern has persisted (Figure 28). Catches of John dory in the flatfish (FLA) target fishery were spatially distinct, and restricted to Tasman and Golden Bays since the catches in this area increased in about 1999–2000. The spatial distribution of John dory catches in the fishery targeting gurnard (GUR) has not changed much over time, with most caught in Hawke's Bay, and the west coast North Island north of Taranaki Bight.

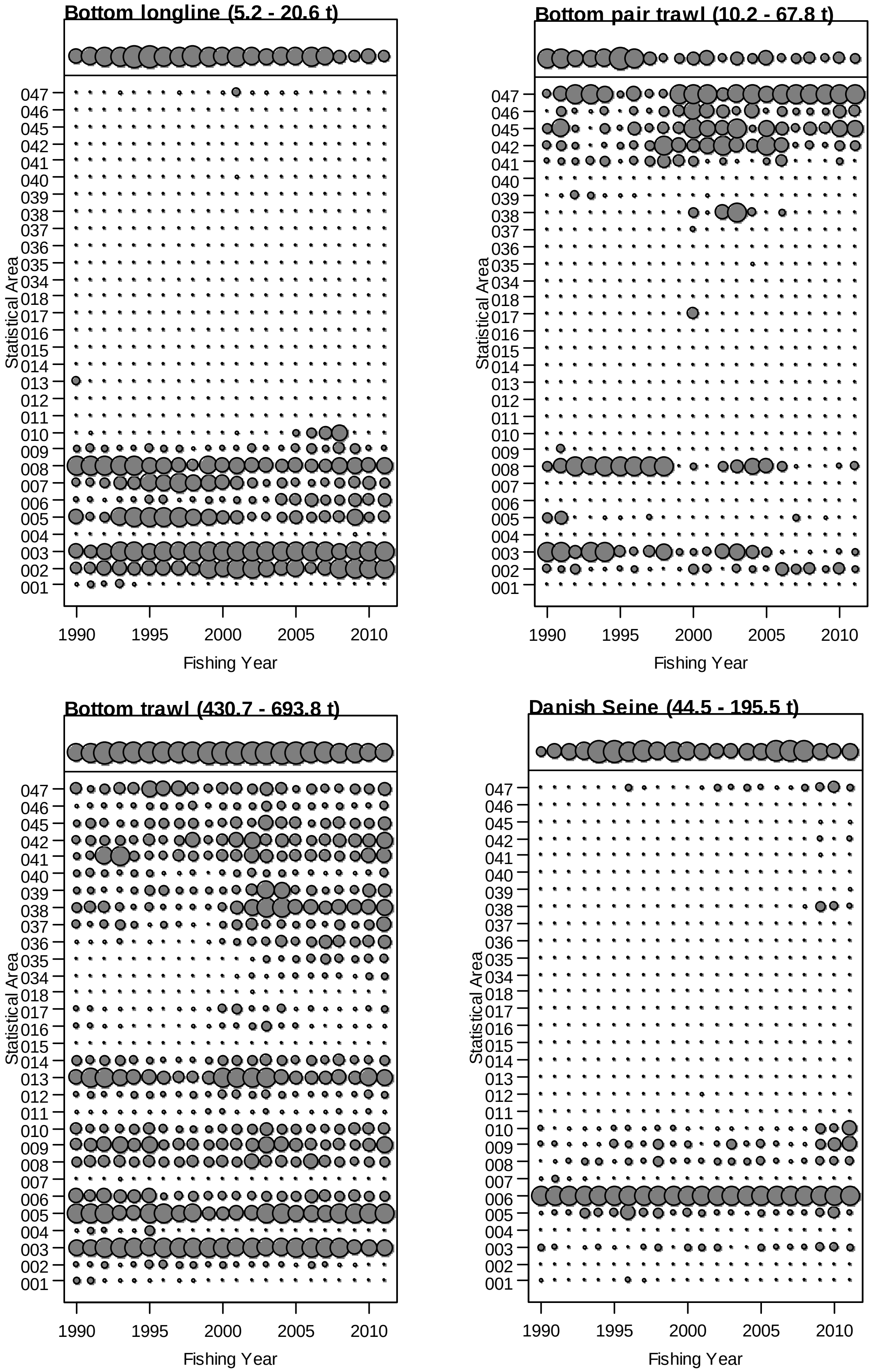
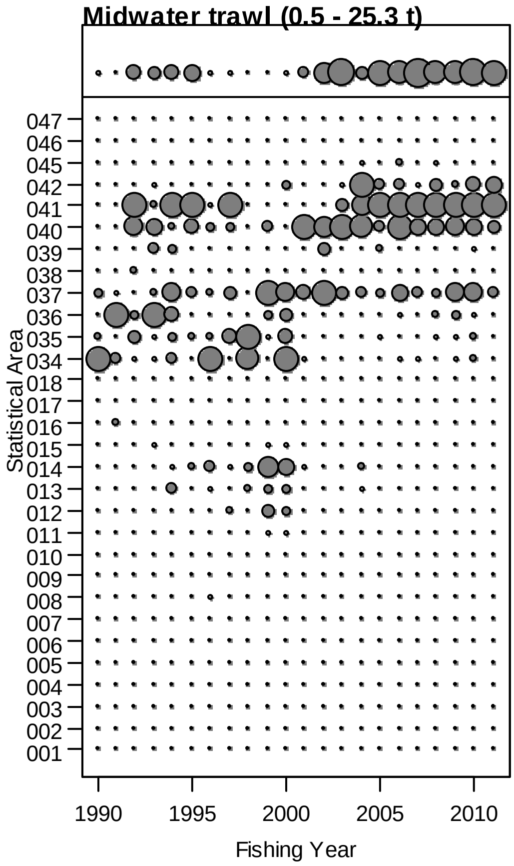


Figure 27: Bubble plots of John dory catch by method, statistical area, and fishing year. Bubble area is proportional to catch size. Catches by area are normalised within each year. The top panel shows the catch by year, with bubble sizes varying between the catch sizes shown in the title. Fishing year is labelled as the year ending.



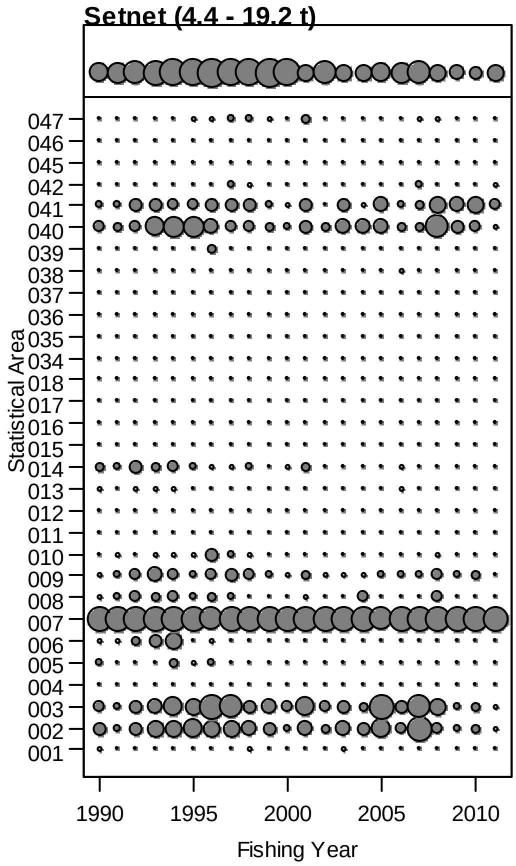


Figure 27 (cont.): Bubble plots of John dory catch by method, statistical area, and fishing year. Bubble area is proportional to catch size. Catches by area are normalised within each year. The top panel shows the catch by year, with bubble sizes varying between the catch sizes shown in the title. Fishing year is labelled as the year ending.

The John dory catches from the target fishery for John dory were largely from east Northland and the Hauraki Gulf, with catches decreasing over the last four years (Figure 28). Catches of John dory from the fishery targeting jack mackerel (JMA) were relatively high for 1991–92 and 1992–93 but low in other years, and were largely from the west coast North Island and off the northwest corner of the South Island. Catches of John dory in the fishery targeting snapper (SNA) were largely on the east coast North Island from Northland through the Hauraki Gulf to the Bay of Plenty, with larger catches from the mid–1990s to the mid–2000s. Catches of John dory from the tarakihi (TAR) fishery were relatively widespread, but largely in Hawke Bay and the surrounding areas, and off the northwest South Island from the early 2000s. Catches of John dory from the trevally (TRE) fishery were mostly off the west coast of the North Island north of Taranaki Bight, plus the Bay of Plenty since the late 1990s.

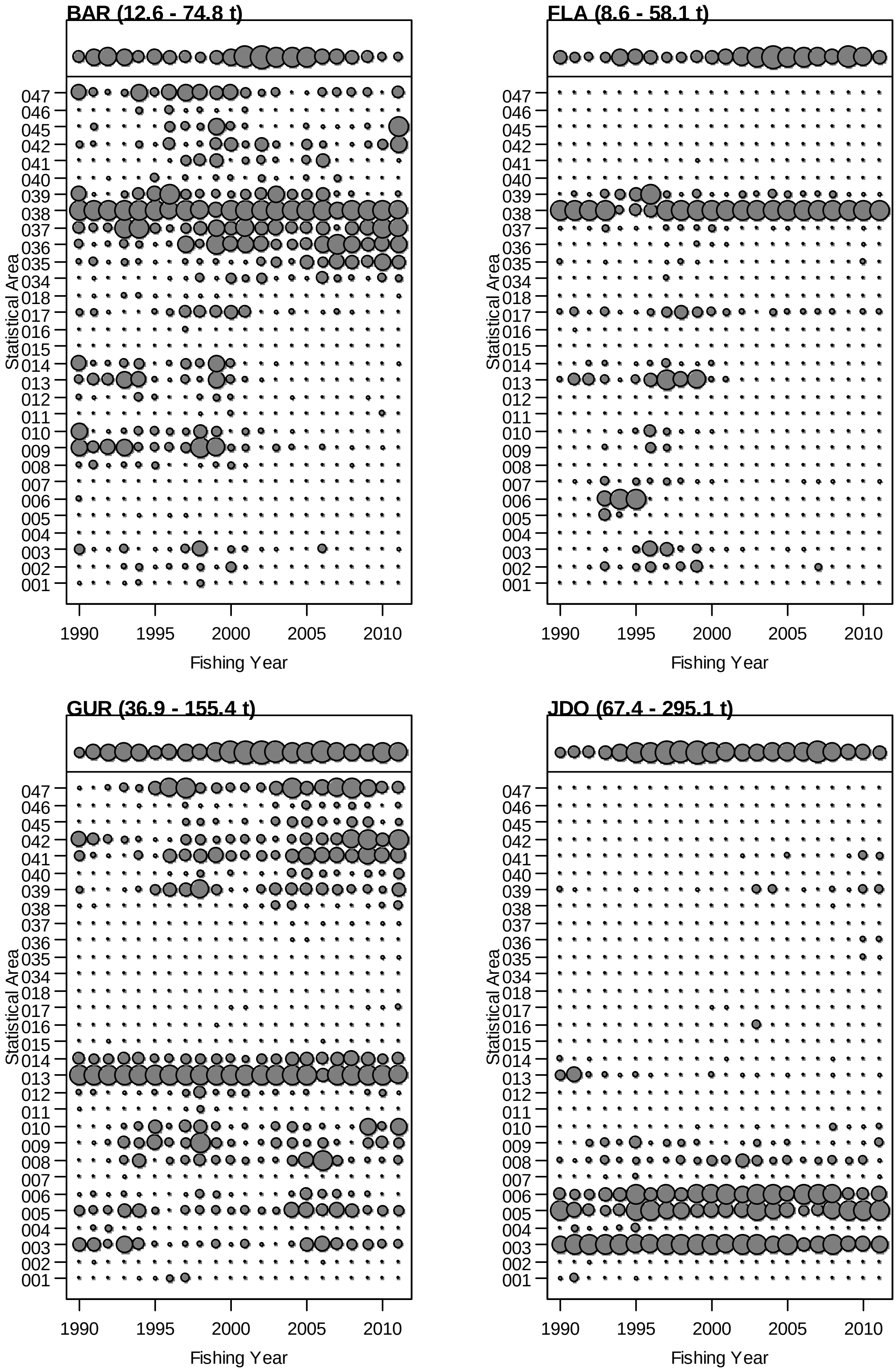


Figure 28: Bubble plots of John dory catch by target species, statistical area, and fishing year. Bubble area is proportional to catch size. Catches by area are normalised within each year. The top panel shows the catch by year, with bubble sizes varying between the catch sizes shown in the title. Fishing year is labelled as the year ending.

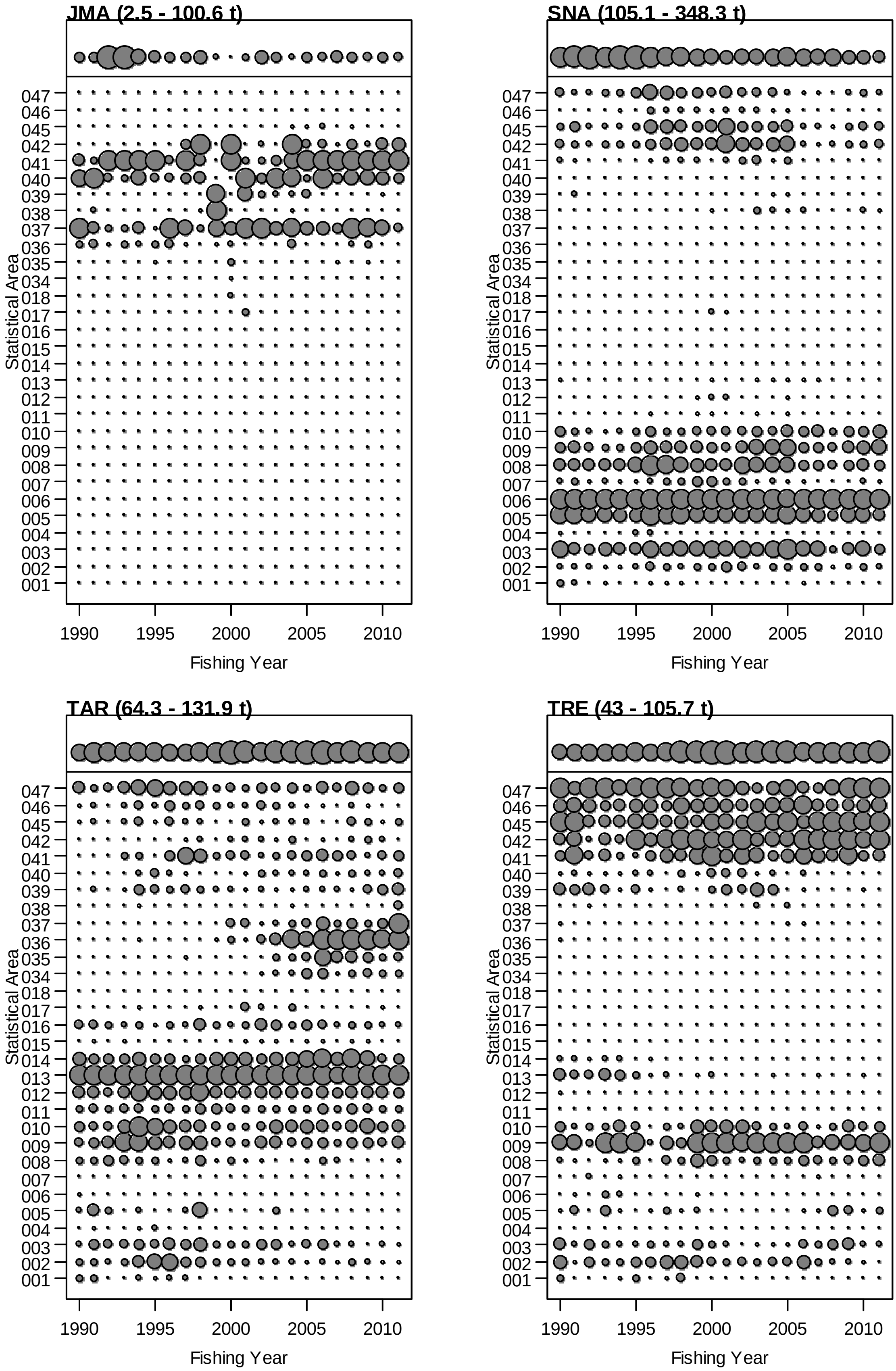


Figure 28 (cont.): Bubble plots of John dory catch by target species, statistical area, and fishing year. Bubble area is proportional to catch size. Catches by area are normalised within each year. The top panel shows the catch by year, with bubble sizes varying between the catch sizes shown in the title. Fishing year is labelled as the year ending.

3.2.2 Standardised CPUE indices

3.2.2.1 Hauraki Gulf and east Northland (JDO1)

The tow-by-tow data set is summarised in Table 5. There were no strong trends in median tow duration, bottom depth, or seasonality of the fishery. The number of vessels decreased in the early 2000s. The proportion of the fishery catch represented in this data set was variable over time, but less than half (typically about a third) of the reported catch in years before 2007–08. There was little data for the first two years in the series (1993–94 and 1994–95), so these were excluded from subsequent analyses.

Table 5: Statistics of the tow-by-tow catch and effort data set for Hauraki Gulf and east Northland, after applying the target species and vessel selection criteria. Tow duration, bottom depth, and date of the fishing year are all medians (interquartile range in parentheses); % in index, the estimated catch divided by the stock catch (Catch); % zero, the percentage of tows with zero catch of John dory.

Fishing year	No. tows	Est. catch (t)	Catch (t)	% in index	Tow duration (hr)	Bottom depth (m)	Date	No. vessels	% zero
1993–94	119	2.5	402	1	2.2 (1.6–3.3)	90 (50–109)	198 (191–252)	4	54
1994–95	516	13.4	379	4	2 (1.5–3)	50 (45–90)	197 (147–260)	8	44
1995–96	3 322	103.1	361	29	2.2 (1.5–3)	50 (41–75)	184 (125–278)	20	35
1996–97	3 802	129.1	371	35	1.8 (1.2–3)	49 (40–65)	135 (70–175)	23	34
1997–98	4 523	120.5	345	35	2 (1.2–3)	50 (44–80)	159 (95–223)	22	33
1998–99	4 052	131.7	395	33	2 (1.5–3)	55 (45–100)	163 (68–272)	19	31
1999–2000	4 097	93.1	285	33	2.5 (1.6–3)	65 (50–100)	137 (55–244)	19	38
2000–01	4 127	109.9	243	45	2.5 (1.8–3.5)	60 (48–98)	144 (60–248)	21	30
2001–02	3 678	104.9	220	48	2.5 (1.8–3.2)	55 (46–80)	113 (44–189)	19	28
2002–03	2 956	84.4	200	42	2 (1.8–3)	56 (48–79)	126 (54–220)	18	26
2003–04	2 729	70.9	254	28	1.8 (1.5–2.5)	54 (49–80)	149 (70–277)	16	26
2004–05	2 189	49.0	286	17	1.8 (1.5–2.5)	50 (48–72)	115 (64–215)	13	29
2005–06	2 290	53.7	334	16	2 (1.5–3.2)	54 (50–100)	124 (64–256)	11	33
2006–07	2 910	76.3	339	23	2.2 (1.6–3)	54 (49–88)	156 (78–291)	11	27
2007–08	3 968	139.7	273	51	3 (2–3.6)	60 (50–85)	143 (69–238)	14	23
2008–09	4 225	127.6	204	63	2.8 (1.9–3.5)	55 (49–75)	153 (73–258)	12	27
2009–10	4 088	101.1	169	60	3 (1.9–3.5)	54 (48–80)	156 (76–274)	12	27
2010–11	3 944	84.2	142	59	2.5 (1.6–3.2)	54 (47–80)	163 (78–284)	13	31

Different target species had different seasonal catch patterns, with snapper and trevally taken steadily throughout the year and John dory, tarakihi, and gurnard largely caught before May (Figure 29). Because the effort by target species varied over time (Table 6), a target species by season interaction was tested in the model. There were no strong trends in the seasonality of the overall fishery over time; the two years where catches were taken later in the year (those to the right of the plot) were the years excluded in subsequent analyses (1993–94 and 1994–95) (Figure 30).

The final models included the predictors *fishing year*, *target species*, *vessel*, *fishing duration*, *fishing day*, and *statistical area* (Tables 7 and 8). The fit of the models was reasonable (Figure 31). While most of the data fitted the models, the departures towards the ends of the normal quantile plot indicated that the models did not describe all of the extremes of the catch rate, for small catches in the binomial model, and both small and large catches in the lognormal model.

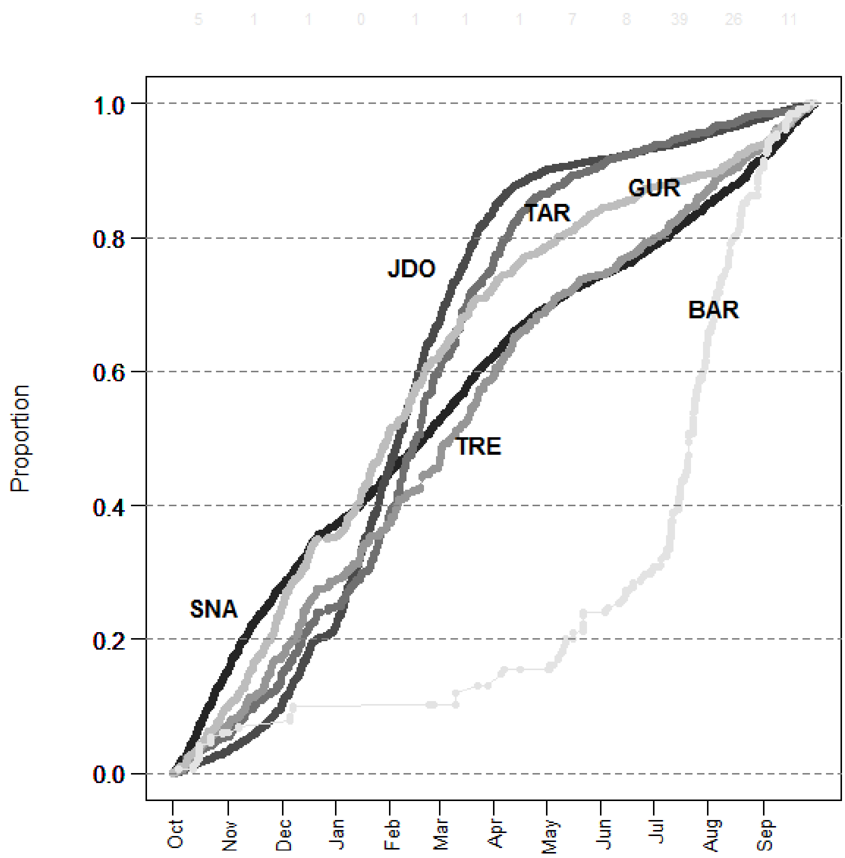


Figure 29: Cumulative catches of John dory in Hauraki Gulf and east Northland, by target species, by day of fishing year from 1995–96 to 2010–11, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year.

Table 6: Proportion of the number of tows by fishing year and target species code for Hauraki Gulf and east Northland, after applying the target species and vessel selection criteria.

Fishing year	BAR	SNA	JDO	TAR	GUR	TRE
1995–96	0.01	0.68	0.20	0.09	0.00	0.02
1996–97	0.01	0.60	0.27	0.08	0.01	0.03
1997–98	0.01	0.65	0.23	0.08	0.01	0.03
1998–99	0.00	0.59	0.28	0.08	0.03	0.02
1999–2000	0.01	0.47	0.33	0.11	0.05	0.03
2000–01	0.02	0.37	0.39	0.11	0.08	0.03
2001–02	0.01	0.42	0.35	0.08	0.11	0.03
2002–03	0.00	0.40	0.37	0.09	0.08	0.05
2003–04	0.01	0.49	0.27	0.06	0.12	0.06
2004–05	0.00	0.55	0.11	0.11	0.15	0.08
2005–06	0.02	0.44	0.14	0.17	0.16	0.06
2006–07	0.00	0.43	0.26	0.13	0.10	0.08
2007–08	0.00	0.38	0.36	0.13	0.06	0.07
2008–09	0.00	0.44	0.35	0.10	0.03	0.08
2009–10	0.00	0.41	0.36	0.12	0.07	0.04
2010–11	0.00	0.48	0.29	0.10	0.06	0.07

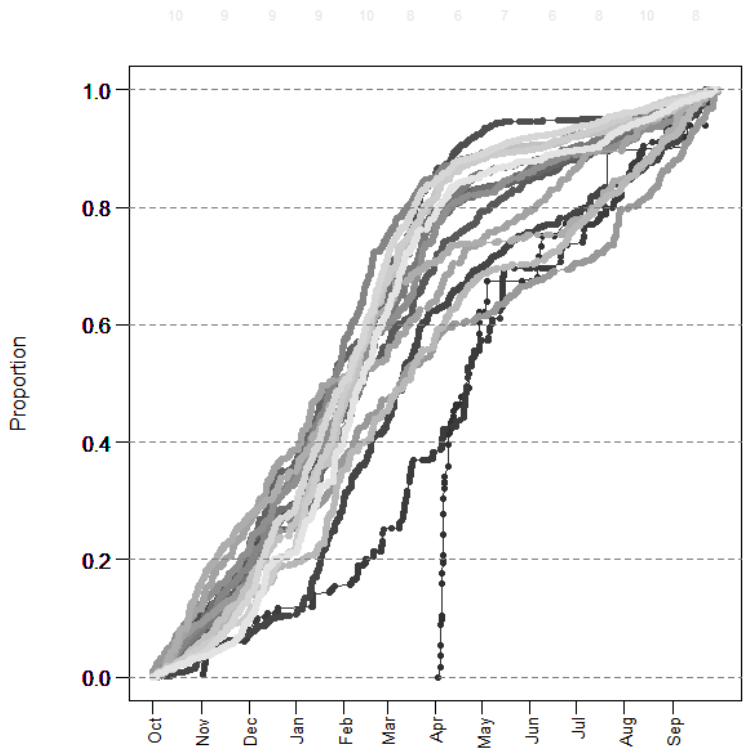


Figure 30: Cumulative catches of John dory in Hauraki Gulf and east Northland, by fishing year, by day of fishing year, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year. Fishing years are shown by the degree of shading, with the earliest year in black (1993–94), through to the most recent year in light grey (2010–11)

Table 7: Predictor and percentage of deviance explained for the final binomial model fit for the Hauraki Gulf and east Northland index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
*Fishing year **	1	14	69 092	0.6	0.6
*Target species **	2	5	55 768	19.8	19.2
*Vessel **	3	31	50 242	27.8	8.0
*Fishing duration **	4	3	49 588	28.8	1.0
*Fishing day **	5	3	48 785	30.0	1.2
Depth	6	3	48 168	30.9	0.9
*Target species * Fishing day*	7	15	47 820	31.4	0.5
Stat area	8	7	47 501	31.9	0.5
Form type	9	1	47 501	31.9	0.0

The binomial model index showed an increase in the proportion of tows catching John dory during the time series. The lognormal model showed a decrease in the non-zero catch rate, and the combined index showing an overall decline but with a period of low catch rates around the year 2000 (Figure 32).

The estimated predictor effects all seemed reasonable (Figure 32). The probability of catching John dory, and the non-zero catch rate, were highest for tows reported as targeting John dory, with the catch rate of tows targeting other species being much the same. Catch rate increased with longer tow duration, and during summer. The seasonality of catch rates was most pronounced in John dory target fishing, and least pronounced for snapper target fishing. There was a roughly two-fold variability in the vessel coefficients. Plots investigating the influence of the predictor variables are shown in Appendix 2.

The combined index had c.v.s of 16% (Table 9).

Table 8: Predictor and percentage of deviance explained for the final lognormal model fit for the Hauraki Gulf and east Northland index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
Fishing year *	1	14	406 130	2.1	2.1
Fishing duration *	2	3	398 769	18.6	16.5
Target species *	3	5	393 670	28.4	9.8
Fishing day *	4	3	390 813	33.4	5.0
Vessel *	5	31	388 194	37.7	4.3
*Target species * Fishing day* *	6	15	386 695	40.0	2.3
Stat area *	6	7	387 502	40.9	0.8
Depth	7	3	387 171	39.3	0.5
Form type	8	1	387 160	39.3	0.0

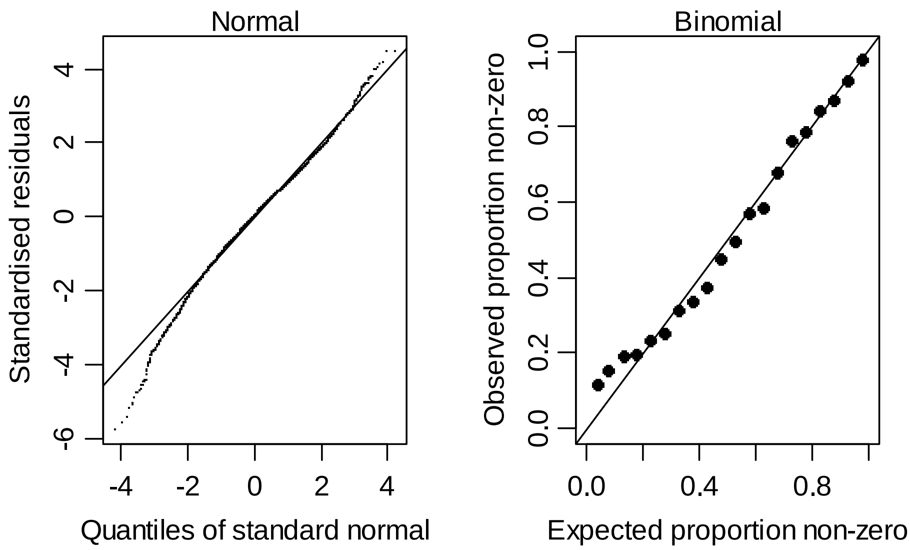


Figure 31: Q–Q plots for the fit of the Hauraki Gulf and east Northland index.

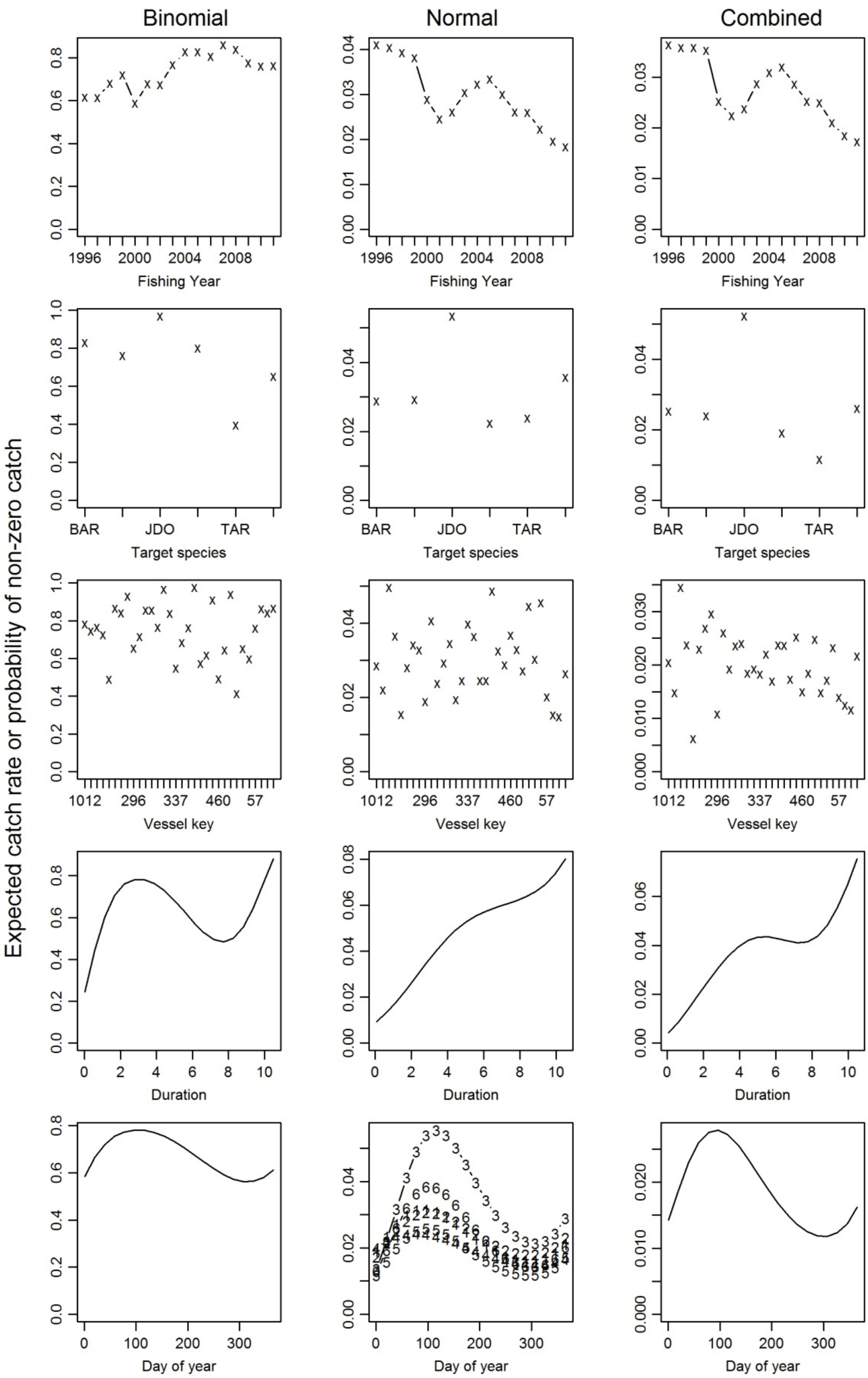


Figure 32: Model predictions for the Hauraki Gulf and east Northland index, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) target species, vessel key, tow duration, day of year, and statistical area, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values. The day of year × target species interaction is shown in the centre bottom panel: 1 BAR; 2 GUR; 3 JDO; 4 SNA; 5 TAR; 6 TRE.

Table 9: Combined (binomial plus normal) CPUE index and c.v.s for the Hauraki Gulf and east Northland stock.

Fishing year	Index	c.v.
1995–96	1.00	0.16
1996–97	0.99	0.16
1997–98	0.96	0.16
1998–99	0.93	0.16
1999–2000	0.70	0.16
2000–01	0.60	0.16
2001–02	0.64	0.16
2002–03	0.74	0.16
2003–04	0.79	0.16
2004–05	0.81	0.16
2005–06	0.73	0.16
2006–07	0.64	0.16
2007–08	0.63	0.16
2008–09	0.54	0.16
2009–10	0.48	0.16
2010–11	0.45	0.16

3.2.2.2 Bay of Plenty (JDO1)

The tow-by-tow data set is summarised in Table 10. The target species barracouta (BAR) was excluded by Kendrick & Bentley (2011), but included in this analysis in agreement with the Hauraki Gulf and east Northland analysis; catches of John dory whilst reportedly targeting BAR were greater in the Bay of Plenty than in the Hauraki Gulf and east Northland.

The data were sparse for the years before 1995–96 and described very little of the reported catch, and also tended to have relatively long tow duration, and catches later in the year than in subsequent years (Table 10). Data before 1995–96 were therefore excluded from standardised CPUE analyses. From 1995–96, there were no strong trends in the fishery statistics. The proportion of the fishery catch represented in this data set was variable over time, but was about 45% on average. The proportion of tows catching John dory was about 50%, and higher than for Hauraki Gulf and East Northland.

Different target species had different seasonal catch patterns, with John dory in the snapper fishery taken steadily throughout the year, barracouta largely in autumn, and others, including John dory, largely during summer and autumn (Figure 33). Because the effort by target species varied over time (Table 11), a target species by season interaction was tested in the model. There were no strong trends in the seasonality of the overall fishery over time (Figure 34).

The final models included the predictors *fishing year*, *depth*, *vessel*, *target species*, *fishing day*, and *fishing duration* (Tables 12 and 13). The fit of the models was good (Figure 35), with departures only at the extremes of the catch rate.

The binomial index showed a slight increase in the proportion of tows catching John dory during the time series. The lognormal index showed a slow decrease in the non-zero catch rate. The combined index had an initial decline and then remained roughly flat (Figure 36).

The estimated predictor effects all seemed reasonable (Figure 35). The probability of catching John dory, and the non-zero catch rate, were highest for tows reported as targeting John dory, with the catch rate of tows targeting other species being much the same as each other. Catches peaked at about 90 m depth, increased with tow length up to about 6 hours, and varied with vessel by a factor of about four.

The seasonality of catch rates was most pronounced in John dory target fishing, and least pronounced for snapper target fishing, with barracouta having the lowest catch rate at the start of the fishing year. Influence plots are shown in Appendix 2.

The combined index had c.v.s of 3–4% (Table 14).

Table 10: Statistics of the tow-by-tow catch and effort data set for Bay of Plenty, after applying the target species and vessel selection criteria. Tow duration, bottom depth, and date of the fishing year are all medians (interquartile range in parentheses); % in index, the estimated catch divided by the stock catch (Catch); % zero, the percentage of tows with zero catch of John dory.

Fishing year	No. tows	Est. catch (t)	Catch (t)	% in index	Tow Duration (hr)	Bottom depth (m)	Date	No. vessels	% zero
1989–90	50	1.1	87	1	3.3 (3–4)	67 (43–84)	356 (349–358)	3	56
1990–91	16	0.9	108	<1	3.3 (2.8–3.9)	63 (548–77)	345 (344–348)	1	25
1991–92	30	2.5	129	2	3.2 (2.7–3.5)	65 (49–83)	349 (277–355)	2	33
1992–93	19	0.4	144	<1	4 (3.1–4.4)	80 (69–108)	240 (232–242)	3	79
1993–94	592	6.9	151	5	3 (2.5–4)	81 (50–140)	252 (223–318)	12	63
1994–95	1 067	29.0	200	14	3 (2–4)	90 (50–125)	253 (143–325)	14	45
1995–96	2 199	38.9	118	33	2.8 (2–3.5)	53 (30–110)	180 (126–276)	26	51
1996–97	2 738	45.5	122	37	2.2 (1.6–3.2)	60 (35–108)	169 (106–241)	24	51
1997–98	2 698	52.5	132	40	2.9 (2–3.8)	98 (56–120)	193 (109–281)	27	50
1998–99	3 583	60.6	133	46	2.7 (2–3.5)	99 (59–117)	211 (119–294)	21	52
1999–2000	3 131	40.6	113	36	2.5 (1.8–3.2)	90 (50–105)	157 (72–230)	18	53
2000–01	3 871	45.9	90	51	2.5 (2–3.5)	71 (45–110)	146 (68–230)	23	61
2001–02	3 638	47.1	111	42	2.9 (2–3.8)	88 (50–112)	148 (74–252)	20	56
2002–03	4 007	48.7	119	41	3 (2–3.8)	100 (50–110)	179 (104–264)	21	58
2003–04	4 396	55.9	116	48	3 (2.1–3.8)	95 (52–110)	201 (116–283)	20	54
2004–05	4 465	65.5	139	47	3 (2.2–3.8)	90 (50–103)	181 (109–253)	19	53
2005–06	3 602	40.1	118	34	3 (2.2–3.8)	100 (52–120)	183 (102–251)	18	56
2006–07	2 725	44	92	48	3 (2.2–3.7)	85 (50–112)	176 (88–240)	14	50
2007–08	3 475	50.9	88	58	3 (2.2–4)	90 (50–120)	184 (103–257)	19	45
2008–09	3 760	51.6	88	59	3 (2.2–4)	100 (53–120)	194 (114–266)	19	45
2009–10	3 709	44.2	87	51	3 (2.2–4)	95 (52–126)	183 (102–257)	17	53
2010–11	3 408	44.8	105	43	2.8 (2–3.7)	86 (50–120)	163 (84–241)	16	53

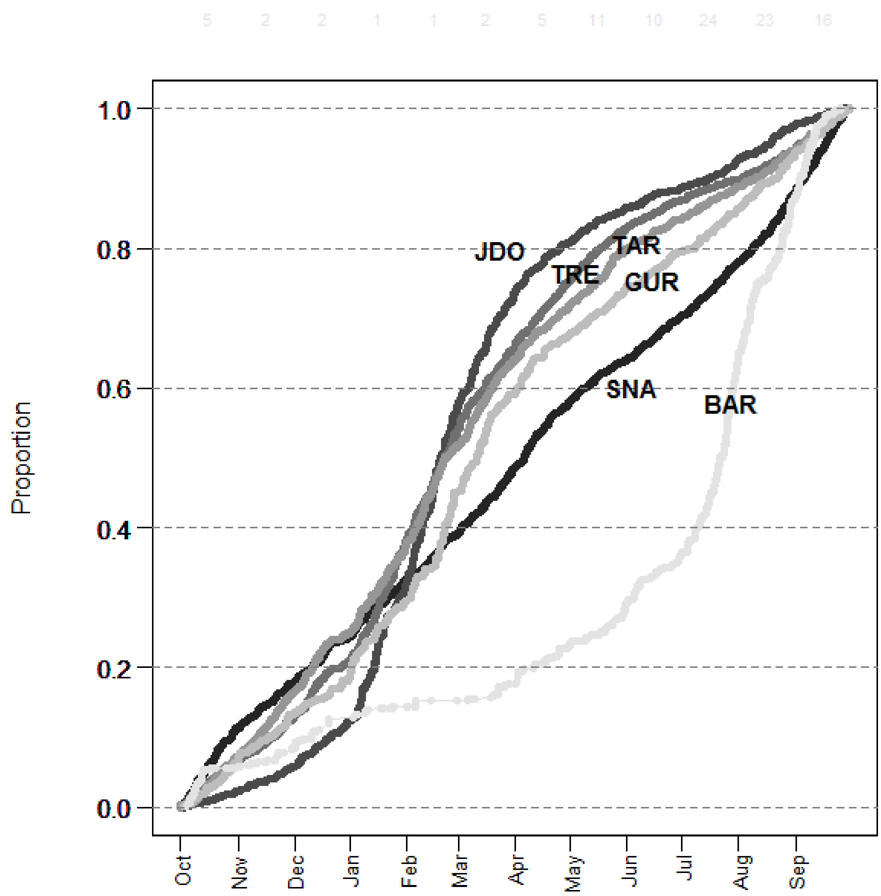


Figure 33: Cumulative catches of John dory in Bay of Plenty, by target species, by day of fishing year and for 1995–96 to 2010–11, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year.

Table 11: Number of tows by fishing year and target species for Bay of Plenty, after applying the target species and vessel selection criteria.

Fishing year	BAR	SNA	JDO	TAR	GUR	TRE
1995–96	80	1 437	124	22	497	39
1996–97	89	1 250	340	130	670	259
1997–98	175	1 097	365	77	826	158
1998–99	210	1 549	187	55	798	784
1999–2000	93	1 286	229	75	688	760
2000–01	253	746	205	358	737	1 572
2001–02	108	982	190	406	829	1 123
2002–03	136	974	146	352	1 123	1 276
2003–04	128	1 411	62	349	1 110	1 336
2004–05	8	1 427	161	319	1 373	1 177
2005–06	52	808	82	340	1 282	1 038
2006–07	14	890	159	166	945	551
2007–08	31	1 026	309	73	1 220	816
2008–09	3	955	274	175	1 448	905
2009–10	12	814	278	155	1 487	963
2010–11	0	786	195	34	1 238	1 155

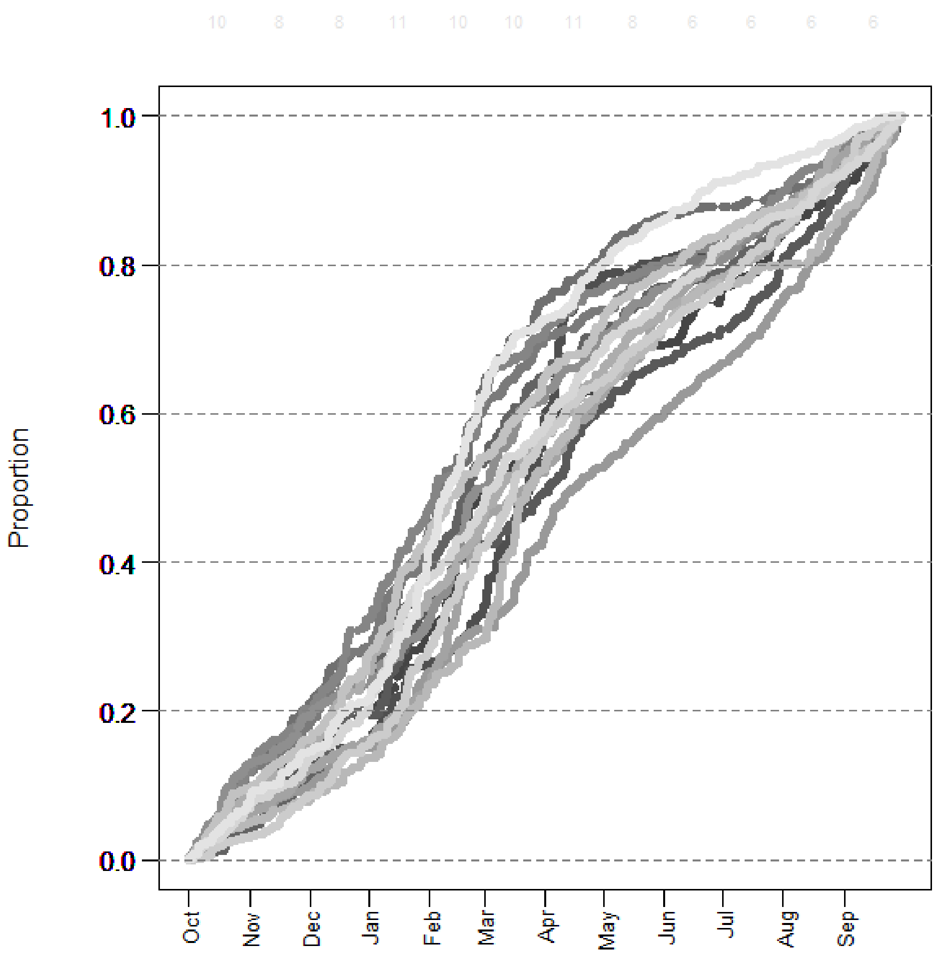


Figure 34: Cumulative catches of John dory in Bay of Plenty, by fishing year, by day of fishing year, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year. Fishing years are shown by the degree of shading, with the earliest year in black (1995–96), through to the most recent year in light grey (2010–11).

Table 12: Predictor and percentage of deviance explained for the final binomial model fit for the Bay of Plenty index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
Fishing year *	1	14	76 085	0.5	0.5
Depth *	2	3	67 950	11.2	10.7
Vessel *	3	36	64 184	16.2	5.0
Target species *	4	5	62 224	18.8	2.6
Form type	5	1	61 548	19.6	0.9
Stat area	6	3	60 967	20.4	0.8
Fishing duration	7	3	60 374	21.2	0.8
Fishing day	8	3	60 298	21.3	0.1
Target species × Fishing day	9	15	60 192	21.7	0.4

Table 13: Predictor and percentage of deviance explained for the final lognormal model fit for the Bay of Plenty index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
Fishing year *	1	14	250 597	1.7	1.7
Vessel *	2	36	247 138	14.2	12.5
Target species *	3	5	245 306	20.0	5.9
Fishing day *	4	3	244 507	22.4	2.4
Target species × Fishing day *	5	15	243 536	25.4	2.9
Fishing duration *	6	3	242 773	27.5	2.2
Depth *	7	3	242 260	29.0	1.4
Stat area	8	3	242 110	29.4	0.4
Form type	9	1	242 073	29.5	0.1

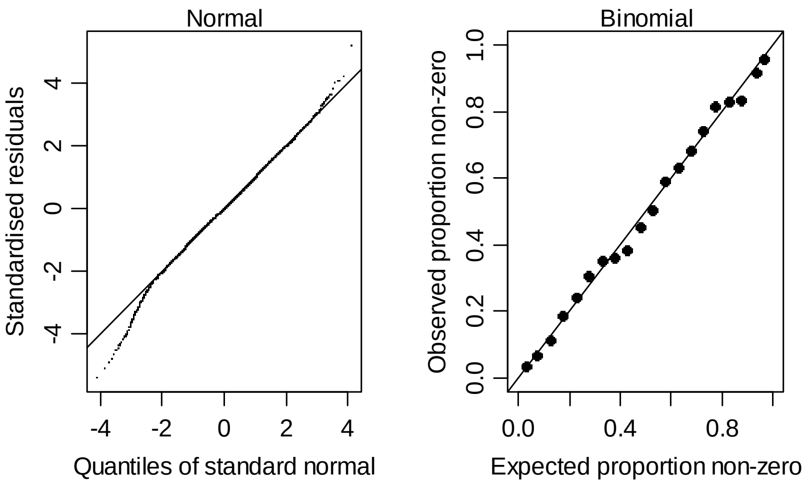


Figure 35: Q–Q plots for the fit of the Bay of Plenty index.

Table 14: Combined (binomial plus normal) CPUE index and c.v.s for the Bay of Plenty stock.

Fishing year	Index	c.v.
1995–96	0.96	0.04
1996–97	0.91	0.04
1997–98	1.00	0.03
1998–99	0.85	0.03
1999–2000	0.71	0.03
2000–01	0.59	0.04
2001–02	0.62	0.03
2002–03	0.65	0.03
2003–04	0.69	0.03
2004–05	0.72	0.03
2005–06	0.65	0.03
2006–07	0.82	0.03
2007–08	0.74	0.03
2008–09	0.76	0.03
2009–10	0.62	0.03
2010–11	0.71	0.03

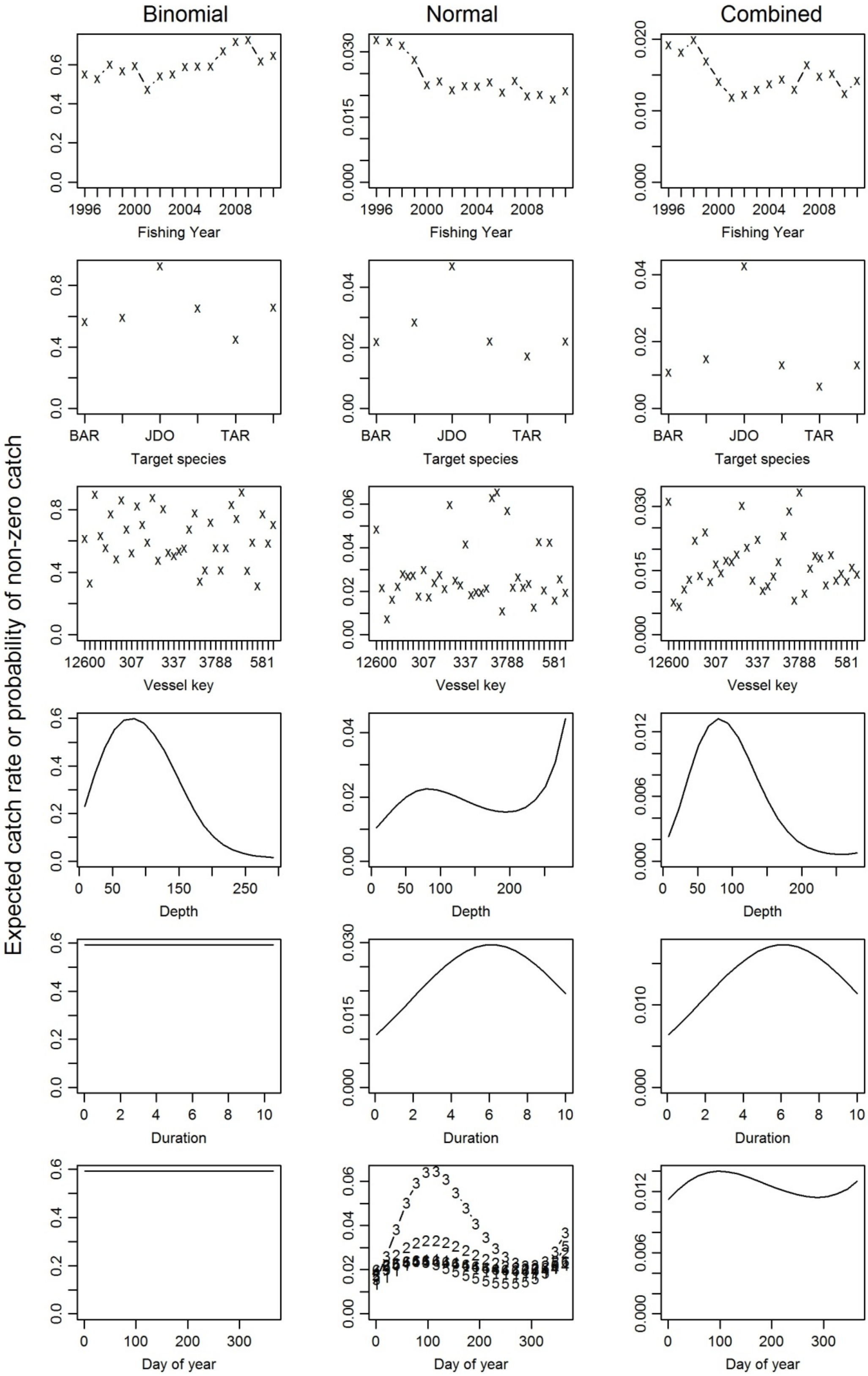


Figure 36: Model predictions for the Bay of Plenty index, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) and other selected predictors, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values. The day of year × target species interaction is shown in the centre bottom panel: 1 BAR; 2 GUR; 3 JDO; 4 SNA.

3.2.2.3 West coast North Island (JDO1 and northern part of JDO2)

The data were sparse for the years before 1994–95 and described very little of the reported catch, and also tended to have catches earlier in the year than in subsequent years (Table 15). Data before 1994–95 were therefore excluded from standardised CPUE analyses. From 1994–95, the number of vessels declined over the time series, and the proportion of tows catching John dory increased, but there were otherwise no strong trends in the fishery statistics. The proportion of the fishery catch represented in this data set was variable over time, but about 54% on average.

Table 15: Statistics of the tow-by-tow catch and effort data set for West Coast North Island, after applying the target species and vessel selection criteria. Tow duration, bottom depth, and date of the fishing year are all medians (interquartile range in parentheses); % in index, the estimated catch divided by the stock catch (Catch); % zero, the percentage of tows with zero catch of John dory.

Fishing year	No. tows	Est. catch (t)	Catch (t)	% in index	Tow duration (hr)	Bottom depth (m)	Date	No. vessels	% zero
1989–90	170	2.9	91	3	2.8 (1.9–3.3)	70 (54–83)	43 (27–159)	4	76
1990–91	190	5.2	95	5	2.5 (2.1–2.9)	65 (47–80)	26 (15–136)	2	59
1991–92	435	8.1	144	6	2.7 (2.1–3.2)	50 (39–68)	62 (32–118)	3	72
1992–93	1 415	12.8	134	10	2.7 (2.2–3.2)	37 (28–54)	94 (48–134)	4	84
1993–94	839	8.5	111	8	2.7 (2.1–3)	53 (40–70)	72 (43–122)	11	83
1994–95	1 359	42.9	125	34	3 (2.5–3.5)	70 (45–97)	133 (91–293)	12	68
1995–96	2 620	57	146	39	3 (2.5–4)	50 (35–96)	142 (70–225)	22	66
1996–97	3 883	97	169	58	3 (2.5–3.7)	58 (40–90)	148 (67–269)	22	61
1997–98	4 148	87.1	159	55	3 (2.5–3.5)	57 (40–78)	129 (61–224)	22	65
1998–99	3 333	53.1	127	42	2.8 (2.2–3.2)	52 (40–76)	118 (56–174)	18	66
1999–2000	3 350	62.6	147	43	3.2 (2.8–4)	60 (45–91)	148 (88–203)	18	67
2000–01	3 791	87.2	160	55	3.5 (2.9–4)	53 (39–82)	155 (92–240)	20	53
2001–02	3 492	86.8	164	53	3.5 (3–4)	55 (34–90)	150 (72–233)	18	52
2002–03	3 015	78.8	125	63	3.8 (3–4.2)	55 (38–85)	142 (69–224)	17	57
2003–04	3 660	75.7	124	61	3.6 (3–4)	55 (40–80)	118 (55–199)	17	57
2004–05	3 669	112	175	64	3.8 (3–4.2)	59 (40–87)	160 (83–280)	17	48
2005–06	2 710	61.1	109	56	3.8 (3–4.2)	59 (41–85)	137 (64–213)	15	54
2006–07	2 441	64.3	118	55	3.5 (3–4)	53 (38–75)	125 (73–200)	12	51
2007–08	3 329	81.7	129	63	3.5 (3–4)	56 (41–86)	162 (104–242)	14	48
2008–09	2 939	81.7	133	62	3.5 (3–4)	56 (41–88)	149 (85–241)	12	41
2009–10	2 104	64.9	118	55	3.5 (3–3.9)	50 (40–81)	141 (91–194)	9	36
2010–11	1 948	68.3	130	52	3.2 (2.7–4)	55 (43–83)	124 (63–217)	9	31

Different target species had different seasonal catch patterns, with John dory catches tending to be taken relatively steadily through the year in tarakihi, gurnard, and snapper target tows, more often during the summer in the trevally and John dory target tows, and in the autumn in the barracouta tows (Figure 37).

Because the effort by target species varied over time (Table 16), a target species by season interaction was tested in the model. There were no strong trends in the seasonality of the overall fishery over time (Figure 38). The year where 80% of the catch was taken early, by early March, was 2006–07, and the year where less than 70% of the catch was still not taken by late July was 1994–95.

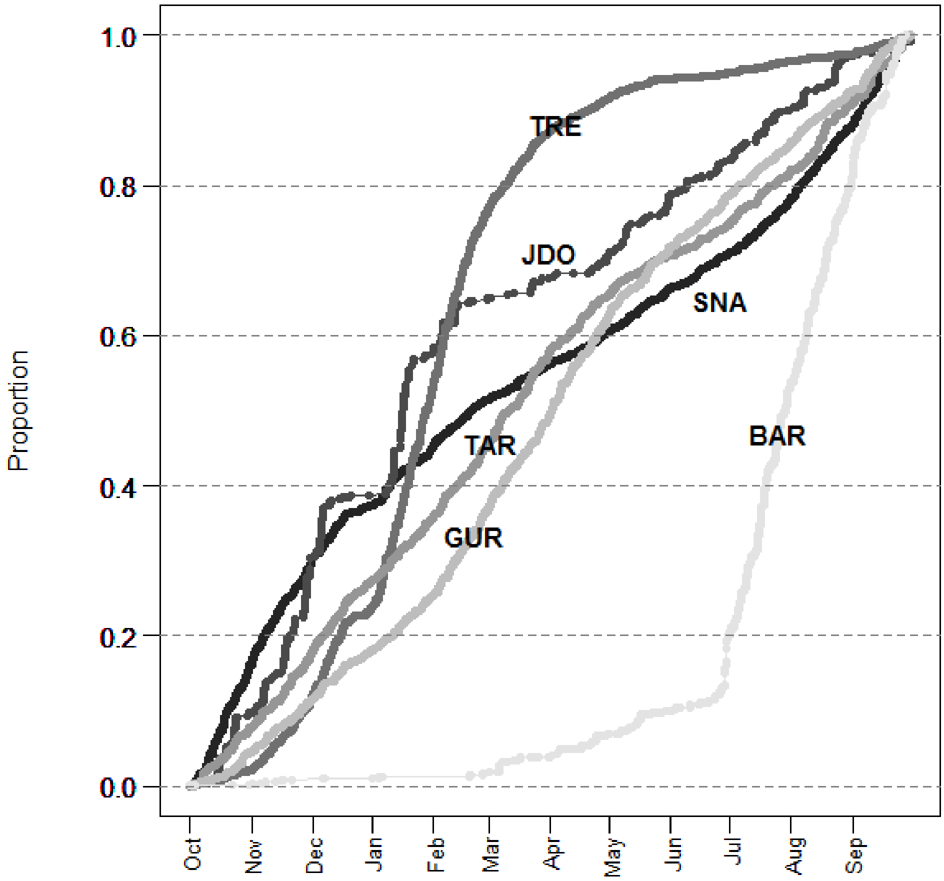


Figure 37: Cumulative catches of John dory in West Coast North Island, by target species, by day of fishing year and for 1994–95 to 2010–11, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year.

Table 16: Number of tows by fishing year and target species for West Coast North Island, after applying the target species and vessel selection criteria.

Fishing year	SNA	BAR	TAR	TRE	JDO	GUR
1994–95	620	56	166	510	5	2
1995–96	1 476	94	476	481	10	83
1996–97	2 061	121	546	795	38	322
1997–98	2 261	34	481	1 208	58	106
1998–99	2 010	66	408	664	4	181
1999–2000	1 122	126	420	1 466	4	212
2000–01	1 550	167	495	1 238	21	320
2001–02	1 189	300	513	1 102	45	343
2002–03	1 100	117	570	767	14	447
2003–04	1 374	30	640	1 105	14	497
2004–05	912	136	580	1 153	47	841
2005–06	391	67	584	813	15	840
2006–07	338	11	408	1 110	15	559
2007–08	397	51	650	1 281	15	935
2008–09	331	44	568	1 231	29	736
2009–10	139	9	391	703	95	767
2010–11	78	26	369	679	89	707

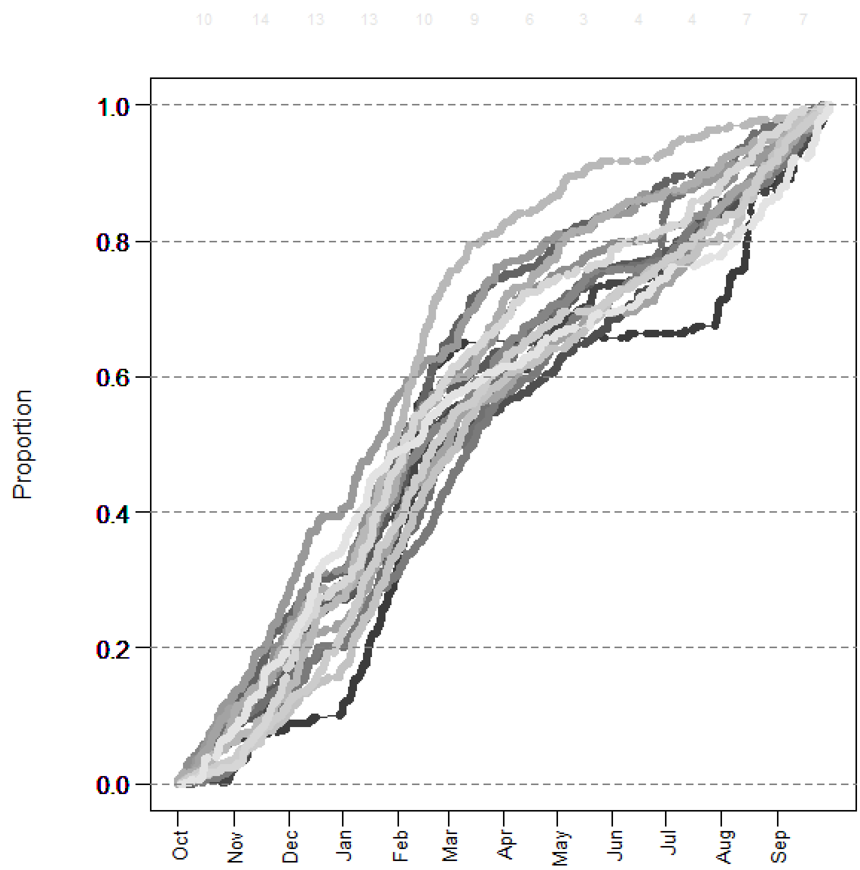


Figure 38: Cumulative catches of John dory in West Coast North Island, by fishing year, by day of fishing year, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year. Fishing years are shown by the degree of shading, with the earliest year in black (1994–95), through to the most recent year in light grey (2010–11).

The final models included the predictors *fishing year*, *depth*, *vessel*, *statistical area*, *target species*, and *fishing duration* (Tables 17 and 18). The fit of the models was good (Figure 39), with departures only at of the extremes of the catch rate.

The binomial index showed an increase in the proportion of tows catching John dory during the time series. The lognormal model showed a decrease in the non-zero catch rate. The combined index showed an initial decline and then remained roughly flat (Figure 40).

The estimated predictor effects all seemed reasonable (Figure 40). Relatively high catch rates were estimated for tows reported as targeting John dory, and in statistical area 801 (offshore off Taranaki Bight). Catch rates peaked at about 100 m depth, increased with tow length up to about 5 hours, and varied with vessel by a factor of roughly 2.5. Influence plots are shown in Appendix 2.

The combined index had c.v.s of 3–6% (Table 19).

Table 17: Predictor and percentage of deviance explained for the final binomial model fit for the West Coast North Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
*Fishing year **	1	15	69 225	2.8	2.8
*Vessel **	3	32	65 657	7.9	5.1
*Depth **	2	3	63 666	10.7	2.8
*Stat area**	4	11	62 919	11.8	1.1
Target species	5	5	62 316	12.7	0.9
Fishing duration	6	3	62 018	13.1	0.4
Form type	7	1	61 820	13.4	0.3
Fishing day	8	5	61 776	13.4	0.1
*Target species * Fishing day*	9	15	61 337	14.0	0.6

Table 18: Predictor and percentage of deviance explained for the final lognormal model fit for the West Coast North Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
*Fishing year **	1	15	58 801	3.6	3.6
*Vessel **	2	32	52 469	26.7	23.1
*Depth **	3	3	51 182	30.6	3.9
*Target species **	4	5	50 647	21.2	1.6
*Stat area **	5	10	50 167	33.7	1.4
*Fishing duration **	6	3	49 762	34.8	1.2
Form type	7	1	49 694	35.0	0.2
Fishing day	8	3	49 636	35.2	0.2
Target species × Fishing day	9	15	49 465	35.7	0.6

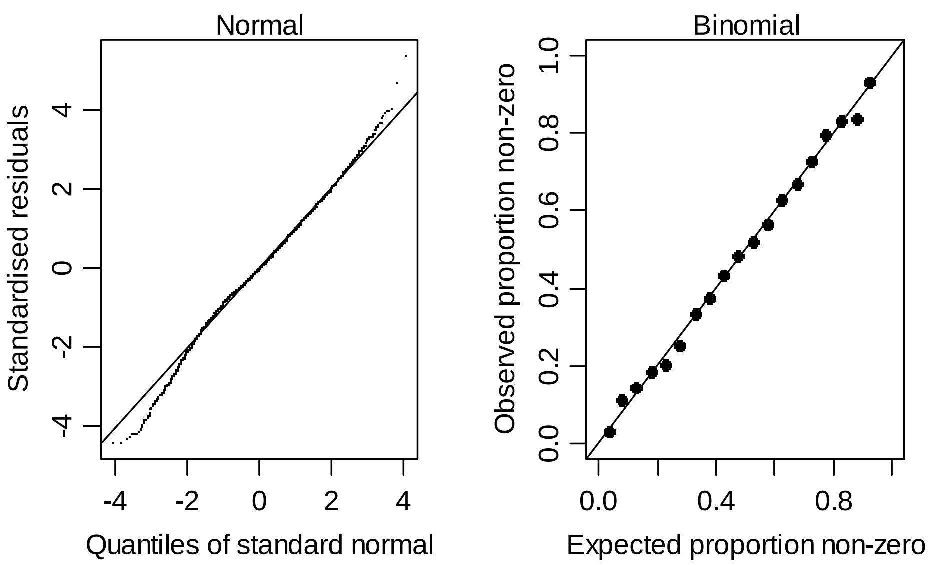


Figure 39: Q–Q plots for the fit of the West Coast North Island index.

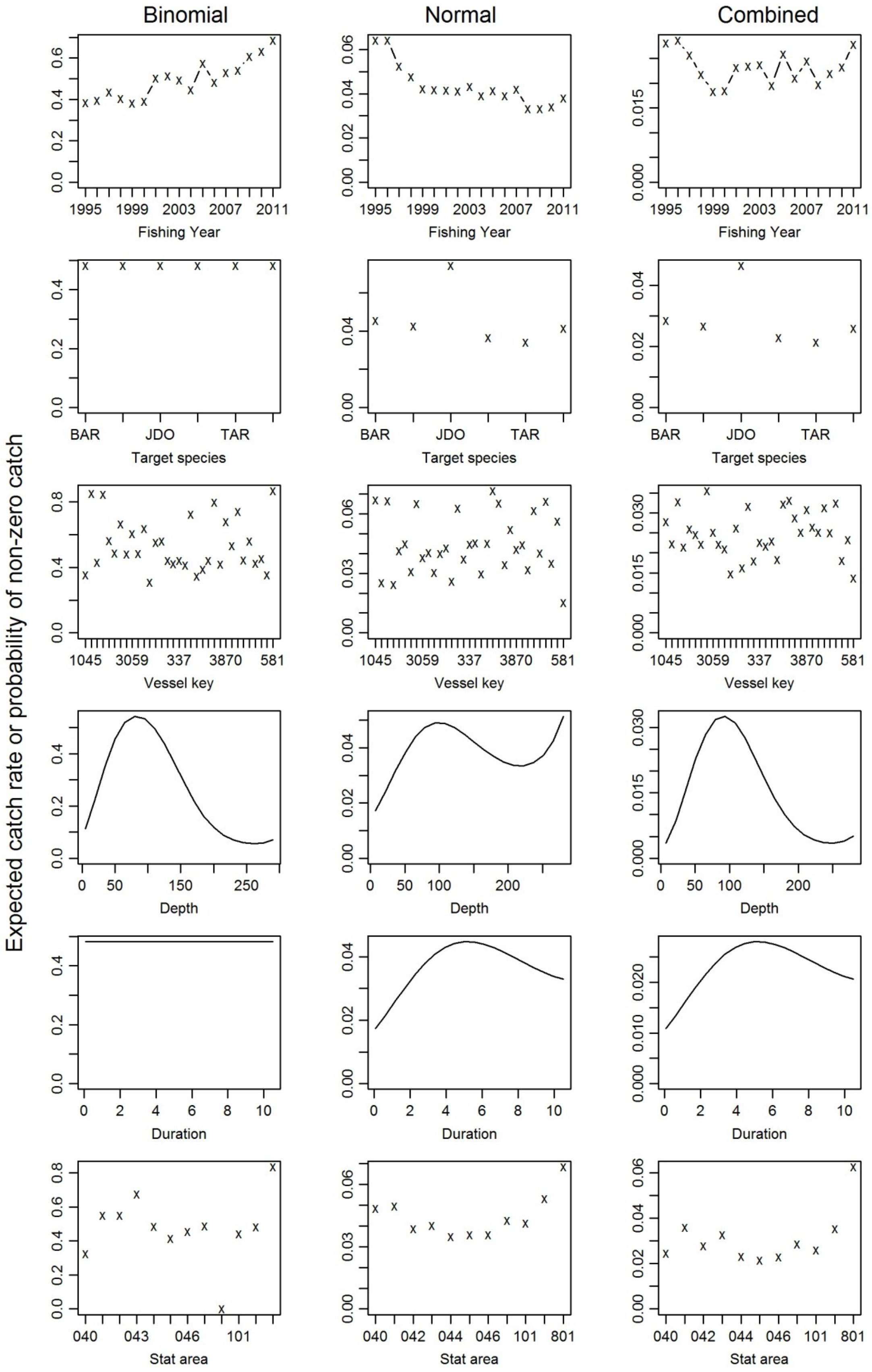


Figure 40: Model predictions for the West Coast North Island index, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) and other selected predictors, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values.

Table 19: Combined (binomial plus normal) CPUE index and c.v.s for the West Coast North Island stock.

Fishing year	Index	c.v.
1994–95	0.98	0.06
1995–96	1.00	0.05
1996–97	0.89	0.04
1997–98	0.76	0.05
1998–99	0.64	0.05
1999–2000	0.64	0.05
2000–01	0.81	0.05
2001–02	0.82	0.04
2002–03	0.83	0.04
2003–04	0.68	0.05
2004–05	0.90	0.03
2005–06	0.73	0.05
2006–07	0.85	0.04
2007–08	0.69	0.04
2008–09	0.76	0.04
2009–10	0.81	0.04
2010–11	0.97	0.04

3.2.2.4 Southeast North Island (JDO2 east)

The tow-by-tow data set is summarised in Table 20. The total data set listed John dory caught in fishing events targeting 79 species. To reduce the number of target species, catch and effort data were excluded when the target species accounted for less than 30 t of John dory over the entire time series; the analysis data set therefore included the target species barracouta (BAR), flatfish (FLA), gurnard (GUR), John dory (JDO), snapper (SNA), tarakihi (TAR), trevally (TRE), and warehou (WAR). The data set included on average 70% of the reported catch (Table 20). John dory were caught by 16 different gear types (gear codes), but 98.8% of the catch was reported to bottom trawl. As a result, only bottom trawl catch and effort data were included in the standardised CPUE analyses.

Different target species had different seasonal catch patterns, with John dory catches in most target species fisheries taken steadily throughout the year, and barracouta and warehou fisheries taken largely in autumn (Figure 41). Although the effort by target species varied over time (Table 21), in particular for flatfish targeting, the changes were amongst species that had a similar seasonal fishery, and therefore a target species by season interaction was not tested in the model. There was notably little trend in the seasonality of the overall fishery over time (Figure 42).

The final models included the predictors *fishing year*, *fishing duration*, *vessel*, *target species*, and *fishing day* (Tables 22 and 23). The fit of the models was good (Figure 43), with departures only at the extremes of the catch rate.

The binomial index showed moderate variability, but no trend, in the proportion of tows catching John dory during the time series. The lognormal model showed large changes in the non-zero catch rate, and the combined index had peaks at the start of the time series and around 2000–01 (Figure 44). The estimated predictor effects all seemed reasonable (Figure 44). The probability of catching John dory, and the non-zero catch rate, were highest for tows reported as targeting John dory, with the catch rate of tows targeting other species being much the same. Catches increased with tow duration, peaked in early summer, and varied with vessel roughly by a factor of eight.

Influence plots are shown in Appendix 2. The combined index had c.v.s of 7–8% (Table 24).

Table 20: Statistics of the tow-by-tow catch and effort data set for Southeast North Island, after applying the target species and vessel selection criteria. Tow duration and date of the fishing year are medians (interquartile range in parentheses); % in index, the catch included in the index (Catch) divided by the reported stock catch; % zero, the percentage of records with zero catch of John dory.

Fishing year	No. tows	Catch (t)	% in index	Tow duration (hr)	Date	No. vessel	% zero
1989–90	3 370	41.6	56	8.5 (6–15)	180 (111–276)	17	41
1990–91	4 382	50.7	47	10 (6–18.4)	186.5 (75.5–298)	18	30
1991–92	5 243	49.3	44	9 (6–15.5)	164.5 (79–253)	21	35
1992–93	5 664	44	47	9 (6–16)	188 (101–277)	22	40
1993–94	5 621	46.1	56	9 (6–16)	186 (76–280)	22	42
1994–95	5 316	43.4	66	9 (6–14)	176 (73–264)	23	43
1995–96	5 509	41.9	68	9 (6–15.4)	178 (75–263)	21	44
1996–97	5 134	39.3	67	9 (6–16.5)	171 (81–267)	21	40
1997–98	6 158	47.7	72	9 (6–18.2)	179 (79.5–273.5)	23	39
1998–99	6 632	84.2	73	9.4 (6–20)	178 (91–267)	22	32
1999–2000	5 978	108.9	69	10 (6.8–22)	170 (81–264)	20	19
2000–01	5 808	96.6	72	9 (6–19.2)	186 (101–272)	23	22
2001–02	6 230	96	76	9 (6–18.3)	188.5 (86.8–268)	23	27
2002–03	6 194	75.7	65	9 (6–18.1)	170 (76–260)	24	28
2003–04	5 930	64.9	76	10 (6.3–19)	174 (79–253)	24	33
2004–05	7 379	74.7	85	9.7 (6.2–22)	174 (83–271)	24	36
2005–06	7 348	61.3	79	9 (6–19.6)	170 (89–272)	25	42
2006–07	7 604	57.4	85	9 (6–20.8)	175 (86–257)	23	39
2007–08	7 301	59.4	82	8.3 (4–19.3)	154 (74–249)	24	37
2008–09	7 391	55.6	87	8.7 (4–18)	161 (79–252)	22	35
2009–10	7 816	60.9	83	8.5 (4.1–18.5)	167 (79–260)	22	38
2010–11	7 565	45.1	88	8.2 (4–18.5)	163 (73.5–255)	22	43

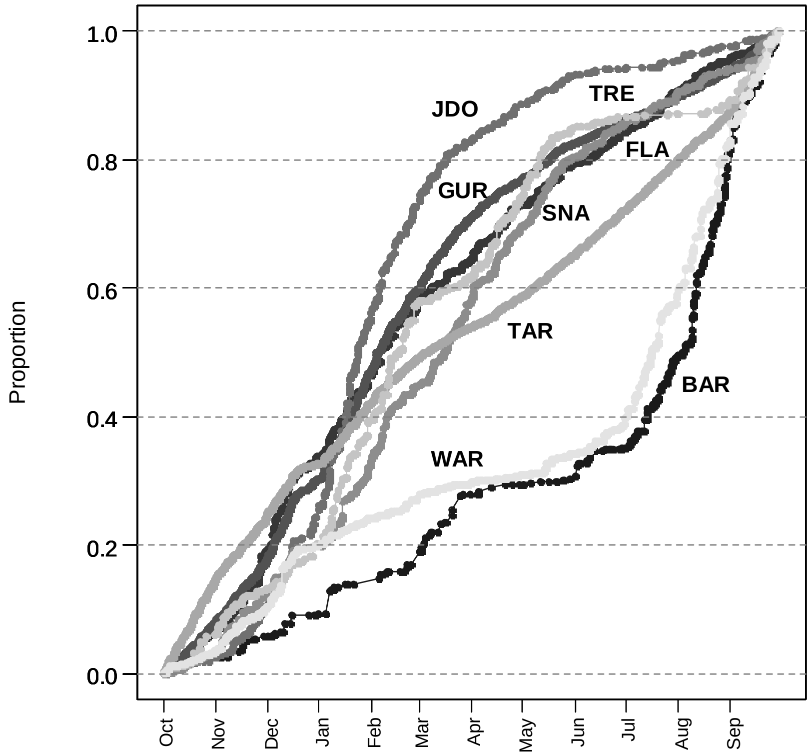


Figure 41: Cumulative catches of John dory in Southeast North Island, by target species, by day of fishing year and for 1989–90 to 2010–11, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year.

Table 21: Proportion of the number of fishing events by fishing year and target species for Southeast North Island, after applying the target species and vessel selection criteria.

Fishing year	BAR	FLA	GUR	JDO	SNA	TAR	TRE	WAR
1989–90	0.01	0.20	0.22	0.02	0.03	0.43	0.05	0.03
1990–91	0.02	0.13	0.31	0.03	0.02	0.46	0.02	0.02
1991–92	0.00	0.21	0.31	0.01	0.01	0.41	0.02	0.03
1992–93	0.03	0.25	0.22	0.02	0.02	0.38	0.04	0.04
1993–94	0.05	0.17	0.33	0.02	0.04	0.33	0.04	0.02
1994–95	0.03	0.19	0.32	0.02	0.03	0.34	0.03	0.04
1995–96	0.03	0.25	0.30	0.02	0.02	0.32	0.01	0.05
1996–97	0.04	0.24	0.24	0.01	0.01	0.39	0.03	0.04
1997–98	0.03	0.24	0.30	0.01	0.01	0.36	0.01	0.04
1998–99	0.02	0.15	0.35	0.02	0.04	0.35	0.01	0.06
1999–2000	0.01	0.09	0.43	0.03	0.02	0.35	0.01	0.06
2000–01	0.01	0.04	0.48	0.02	0.02	0.33	0.01	0.09
2001–02	0.01	0.03	0.53	0.01	0.01	0.31	0.02	0.07
2002–03	0.01	0.04	0.46	0.01	0.03	0.36	0.01	0.07
2003–04	0.01	0.03	0.38	0.01	0.06	0.43	0.01	0.07
2004–05	0.01	0.07	0.41	0.01	0.03	0.40	0.01	0.06
2005–06	0.00	0.12	0.37	0.01	0.03	0.41	0.01	0.06
2006–07	0.01	0.12	0.35	0.00	0.04	0.42	0.01	0.04
2007–08	0.00	0.07	0.36	0.01	0.02	0.47	0.01	0.05
2008–09	0.01	0.07	0.34	0.00	0.03	0.48	0.02	0.05
2009–10	0.00	0.05	0.44	0.00	0.02	0.44	0.01	0.03
2010–11	0.00	0.10	0.41	0.01	0.01	0.43	0.00	0.04

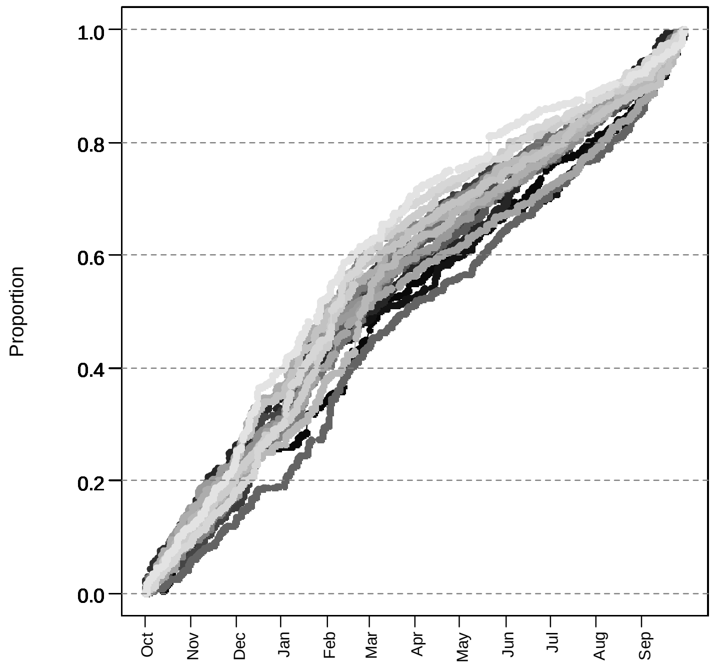


Figure 42: Cumulative catches of John dory in Southeast North Island, by fishing year, by day of fishing year, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year. Fishing years are shown by the degree of shading, with the earliest year in black (1989–90), through to the most recent year in light grey (2010–11).

Table 22: Predictor and percentage of deviance explained for the final binomial model fit for the Southeast North Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
*Fishing year **	1	20	44 994	1.5	1.5
*Fishing duration **	2	3	41 244	9.7	8.2
*Vessel **	3	35	38 904	15.0	5.3
*Target species **	4	7	38 140	16.7	1.7
Stat area	5	9	37 773	17.5	0.8
Fishing day	6	3	37 682	17.8	0.2
No. stratum records	7	3	37 647	17.9	0.1

Table 23: Predictor and percentage of deviance explained for the final lognormal model fit for the Southeast North Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
*Fishing year **	1	20	82 883	2.6	2.6
*Vessel **	2	35	74 047	34.5	31.9
*Fishing duration **	3	3	69 316	47.0	12.5
*Target species **	4	7	68 272	49.5	2.4
*Fishing day **	5	3	67 801	50.5	1.1
Stat area	6	8	67 409	51.4	0.9
Form type	7	2	67 395	51.4	0.0
No. stratum records	8	3	67 393	51.5	0.0

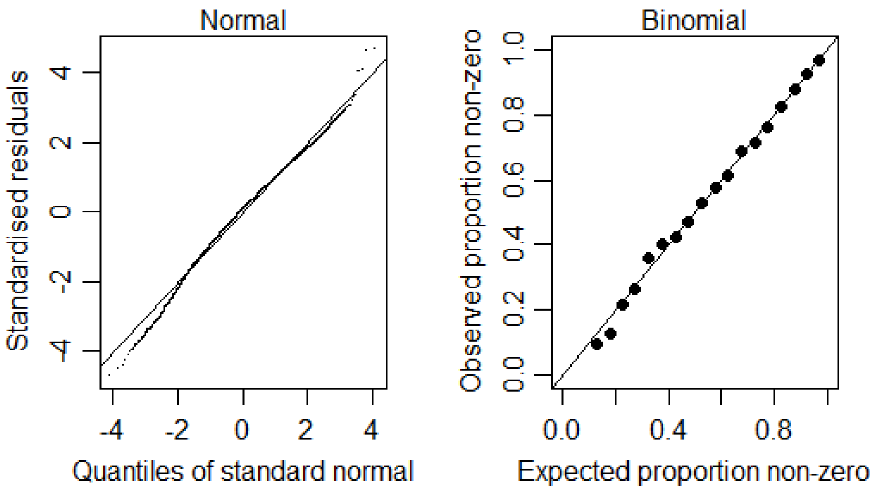


Figure 43: Q–Q plots for the fit of the Southeast North Island index.

Table 24: Combined (binomial plus normal) CPUE index and c.v.s for the Southeast North Island stock.

Fishing year	Index	c.v.
1989–90	0.74	0.08
1990–91	0.73	0.08
1991–92	0.59	0.08
1992–93	0.46	0.08
1993–94	0.39	0.08
1994–95	0.37	0.07
1995–96	0.37	0.08
1996–97	0.45	0.07
1997–98	0.43	0.07
1998–99	0.69	0.07
1999–2000	0.94	0.07
2000–01	1.00	0.07
2001–02	0.89	0.07
2002–03	0.69	0.07
2003–04	0.55	0.07
2004–05	0.46	0.07
2005–06	0.53	0.07
2006–07	0.39	0.07
2007–08	0.38	0.07
2008–09	0.37	0.07
2009–10	0.36	0.07
2010–11	0.25	0.07

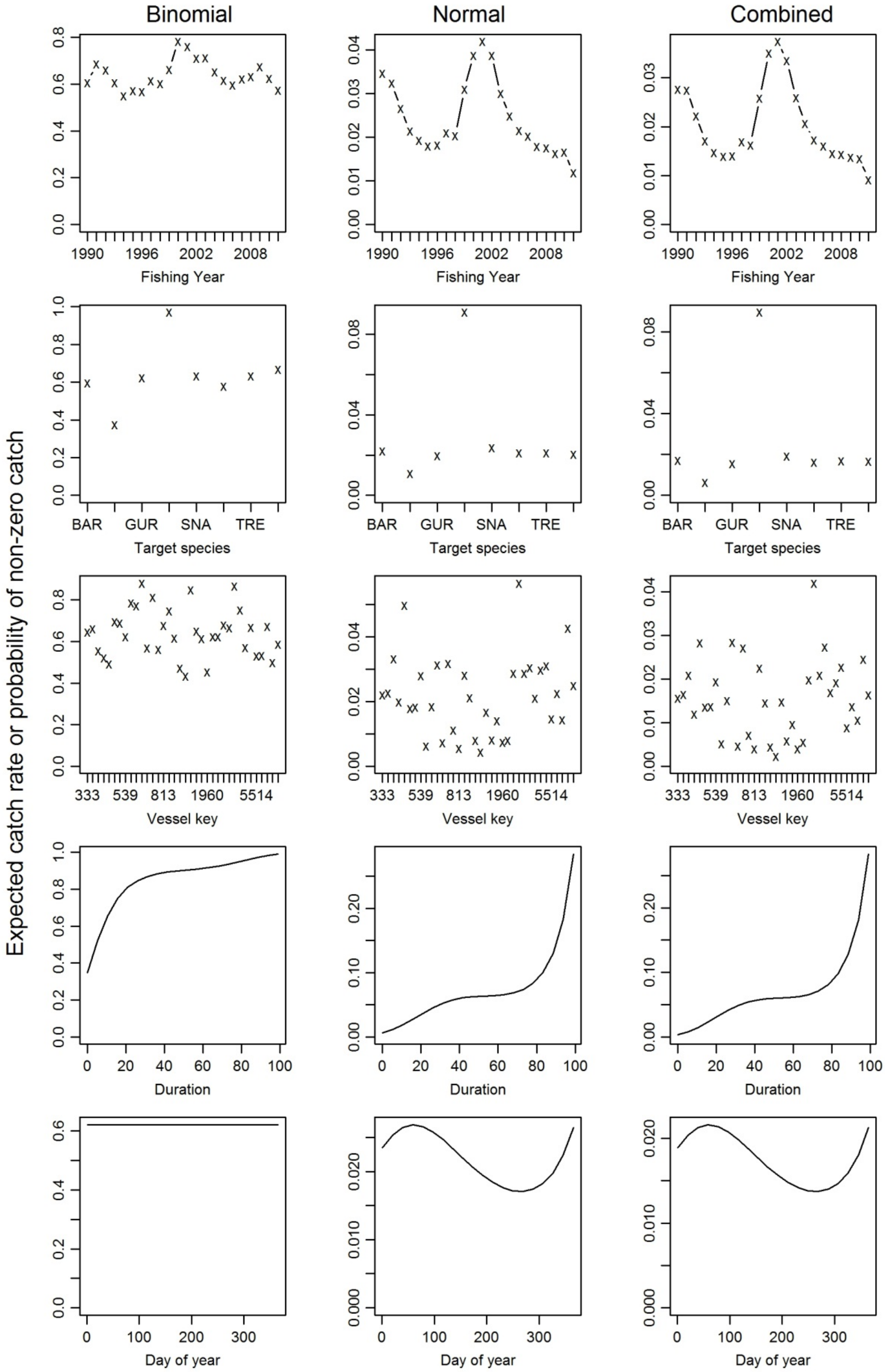


Figure 44: Model predictions for the Southeast North Island index, by fishing year (labelled as year ending, i.e., 1991 means 1990–91) and other selected predictors, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values. The target species are labelled in ascending alphabetical order; John dory is between the GUR and SNA labels.

3.2.2.5 Northern South Island (JDO7 and southern part of JDO2)

The tow-by-tow data set is summarised in Table 25. The total data set listed John dory caught in fishing events targeting 83 species. To reduce the number of target species, catch and effort records were excluded where the target species accounted for less than a total of 60 t of John dory over the entire time series; the analysis data set subsequently included the target species barracouta (BAR), flatfish (FLA), gurnard (GUR), John dory (JDO), jack mackerel (JMA), red cod (RCO), and tarakihi (TAR).

The catch and effort data were particularly sparse for the first two years (Table 25), and these years were therefore excluded from standardised CPUE analyses. The data set from 1991–92 to 2010–11 included on average 51% of the reported catch. Bottom trawls accounted for 96% of the catch, and therefore only bottom trawl catch and effort data were included in the analyses.

Different target species had different seasonal catch patterns, with John dory catches in most fisheries taken between December and June, but more often in spring in barracouta and tarakihi target tows (Figure 45). The effort by target species varied over time (Table 26), in particular for barracouta targeting, therefore a target species by season interaction was tested in the model. There were no strong trends in the seasonality of the overall fishery over time, except that the accumulation of catches tended to be steadier through the year in more recent years (Figure 46).

Table 25: Statistics of the tow-by-tow catch and effort data set for Northern South Island, after applying the target species and vessel selection criteria. Tow duration and date of the fishing year are medians (interquartile range in parentheses); % in index, the catch included in the index (Catch) divided by the reported stock catch; % zero, the percentage of records with zero catch of John dory.

Fishing year	No. tows	Catch (t)	% in index	Tow duration (hr)	Date	No. vessel	% zero
1989–90	1 200	2.9	7	11 (8–19)	166.5 (102.5–242)	8	45
1990–91	1 077	5.7	14	12 (8–20)	178 (78.5–254)	9	51
1991–92	1 985	12	27	12.9 (8–23.7)	167 (77.8–246.2)	11	41
1992–93	2 640	12.1	31	12.2 (9–24)	151 (72–223)	12	45
1993–94	2 659	13.3	39	10 (6.5–21)	160 (69–223)	14	33
1994–95	2 585	23.3	56	10 (7–20)	178.5 (78–243)	15	32
1995–96	3 372	23.2	64	12 (6–23)	169 (65.5–234.5)	17	50
1996–97	3 943	13	39	13 (8–21)	169 (65–238)	17	46
1997–98	3 016	15.8	52	15 (8–24)	207 (71.5–257)	16	45
1998–99	3 629	22.9	52	12 (7–25)	161.5 (69.8–233.2)	16	38
1999–2000	3 520	30.9	46	18.5 (10–28)	180 (98–252)	13	33
2000–01	4 199	57.4	57	18 (10–32)	154 (68.5–239)	15	39
2001–02	4 246	64	52	19 (10.5–32)	175 (74–251)	16	37
2002–03	4 288	67.6	54	18 (12–32)	161 (57.5–248)	16	38
2003–04	4 409	96.8	57	16 (10–29.3)	190 (69–263)	18	32
2004–05	5 642	77.6	59	20 (11.5–33)	188 (111–280)	17	36
2005–06	5 030	69.2	56	18 (9–32)	180 (81–271)	17	36
2006–07	5 128	60.8	53	18 (9.5–31)	179 (73–268.2)	15	33
2007–08	5 146	62.7	67	10.2 (4.8–24.1)	178 (70–260)	16	39
2008–09	4 683	68	71	10.2 (4.5–22.1)	185 (78.5–257)	15	39
2009–10	4 874	59.2	61	9 (4–20.5)	183 (70–260)	16	43
2010–11	4 602	64.1	67	8.5 (4–16.8)	171.5 (59–255)	16	43

The final models included the predictors *fishing year*, *statistical area*, *fishing duration*, *vessel*, and *target species* (Tables 27 and 28). The fit of the models was good (Figure 47), with departures only at the extremes of the catch rate.

The binomial index showed an increase in the proportion of tows catching John dory from the mid-1990s. The lognormal model showed large changes in the non-zero catch rate, and the combined index increased after 1998–99 and peaked in 2003–04 (Figure 48).

The estimated predictor effects all seemed reasonable (Figure 48). The probability of catching John dory, and the non-zero catch rate, were highest for tows reported as targeting John dory, with the catch rate of tows targeting other species being much the same. Catch rates increased with tow duration, were greatest in statistical areas across the top of the South Island including Tasman and Golden Bays, and varied with vessel roughly by a factor of five.

Table 26: Percentage of the number of records by target species and fishing year for Northern South Island. Fishing year as year ending (1990 means 1989–90).

Fishing year	BAR	FLA	GUR	JDO	JMA	RCO	TAR
1992	43.9	30.6	5.9	0.3	0.0	8.8	10.5
1993	50.8	32.3	1.7	0.1	0.0	11.7	3.4
1994	36.2	45.8	1.2	0.1	0.1	6.0	10.6
1995	40.1	40.7	4.8	1.3	0.1	3.8	9.3
1996	43.5	36.9	5.1	0.7	0.2	4.3	9.4
1997	41.6	38.6	5.1	0.4	0.0	5.1	9.3
1998	26.8	48.1	7.6	1.4	0.0	8.9	7.3
1999	32.3	39.1	5.7	2.5	0.1	8.6	11.8
2000	43.6	36.7	5.0	0.9	0.3	3.2	10.4
2001	48.5	27.9	7.0	0.4	0.4	5.3	10.6
2002	35.1	40.5	6.7	0.5	0.0	10.0	7.1
2003	29.9	40.6	11.6	0.7	0.0	8.5	8.7
2004	33.7	41.0	4.3	1.6	0.1	8.4	10.9
2005	27.4	49.5	3.7	0.5	0.0	11.4	7.5
2006	14.4	52.8	4.3	2.0	0.1	14.9	11.5
2007	15.3	57.0	2.4	2.6	0.0	11.1	11.6
2008	20.2	46.5	3.2	3.5	0.0	13.0	13.6
2009	12.8	47.2	4.7	1.1	0.0	9.0	25.1
2010	7.7	46.9	9.6	1.8	0.0	7.4	26.7
2011	7.2	35.9	12.3	2.8	0.0	9.9	31.9

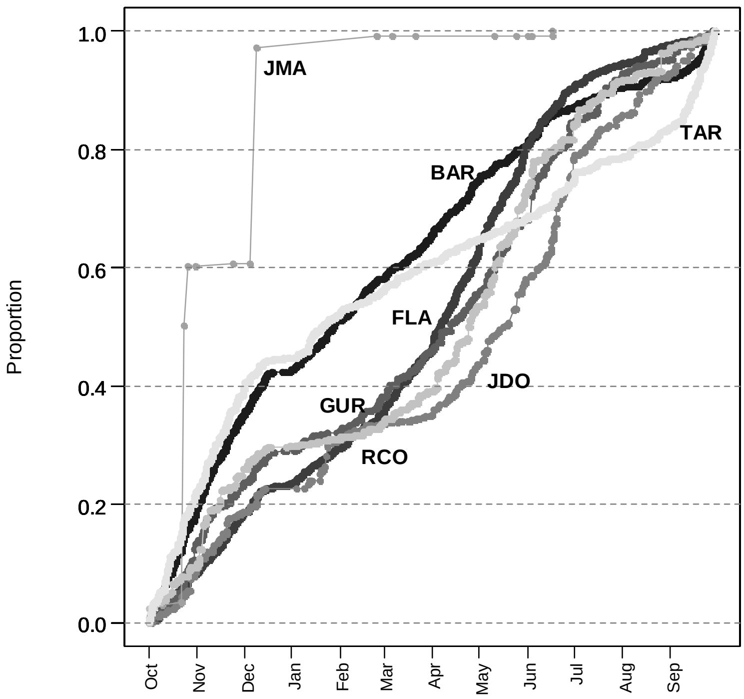


Figure 45: Cumulative catches of John dory in Northern South Island, by target species, by day of fishing year and for 2007–08 to 2010–11, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year.

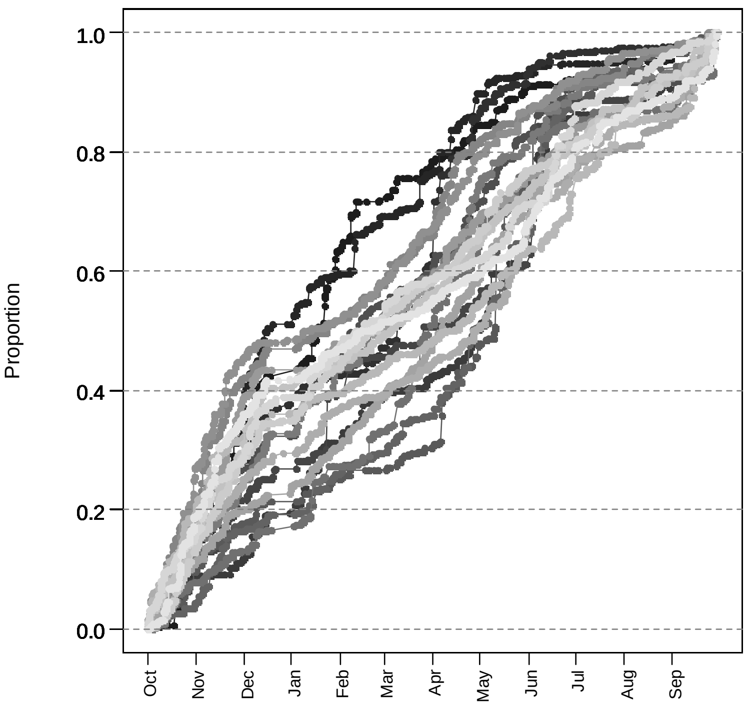


Figure 46: Cumulative catches of John dory in Northern South Island, by fishing year, by day of fishing year, after applying the target species and vessel selection criteria. Catches are summed in chronological order through the fishing year. Fishing years are shown by the degree of shading, with the earliest year in dark grey (1991–92), through to the most recent year in light grey (2010–11).

Table 27: Predictor and percentage of deviance explained for the final binomial model fit for the Northern South Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
Fishing year *	1	18	19 296	0.7	0.7
Stat area *	2	9	17 722	8.9	8.2
Fishing duration *	3	3	17 280	11.2	2.3
Vessel *	4	22	16 810	13.9	2.6
Target species	5	6	16 640	14.8	0.9
Fishing day	6	3	16 565	15.2	0.4
Form type	7	2	16 565	15.3	<0.1

Table 28: Predictor and percentage of deviance explained for the final lognormal model fit for the Northern South Island index. Df, degrees of freedom; AIC, Aikake Information Criterion; % dev. expl., % of deviance explained; Add % dev. expl., additional % deviance explained; *, predictor included in final model.

Predictor	Step	Df	AIC	% dev. expl	Add % dev. expl.
Fishing year *	1	18	35 138	8.5	8.5
Stat area *	2	9	33 720	22.3	13.7
Fishing duration *	3	3	32 144	35.0	12.8
Vessel *	4	22	31 310	41.2	6.2
Target species *	5	6	30 915	43.8	2.7
Fishing day	6	3	30 845	44.3	0.5
Number of records	7	3	30 835	44.4	0.1
Form type	8	2	30 833	44.4	<0.1

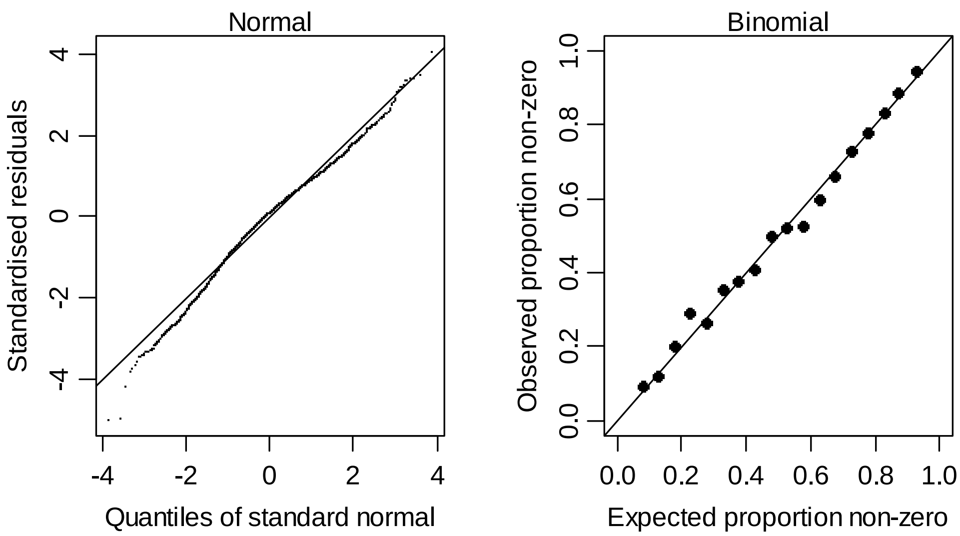


Figure 47: Q–Q plots for the fit of the Northern South Island index.

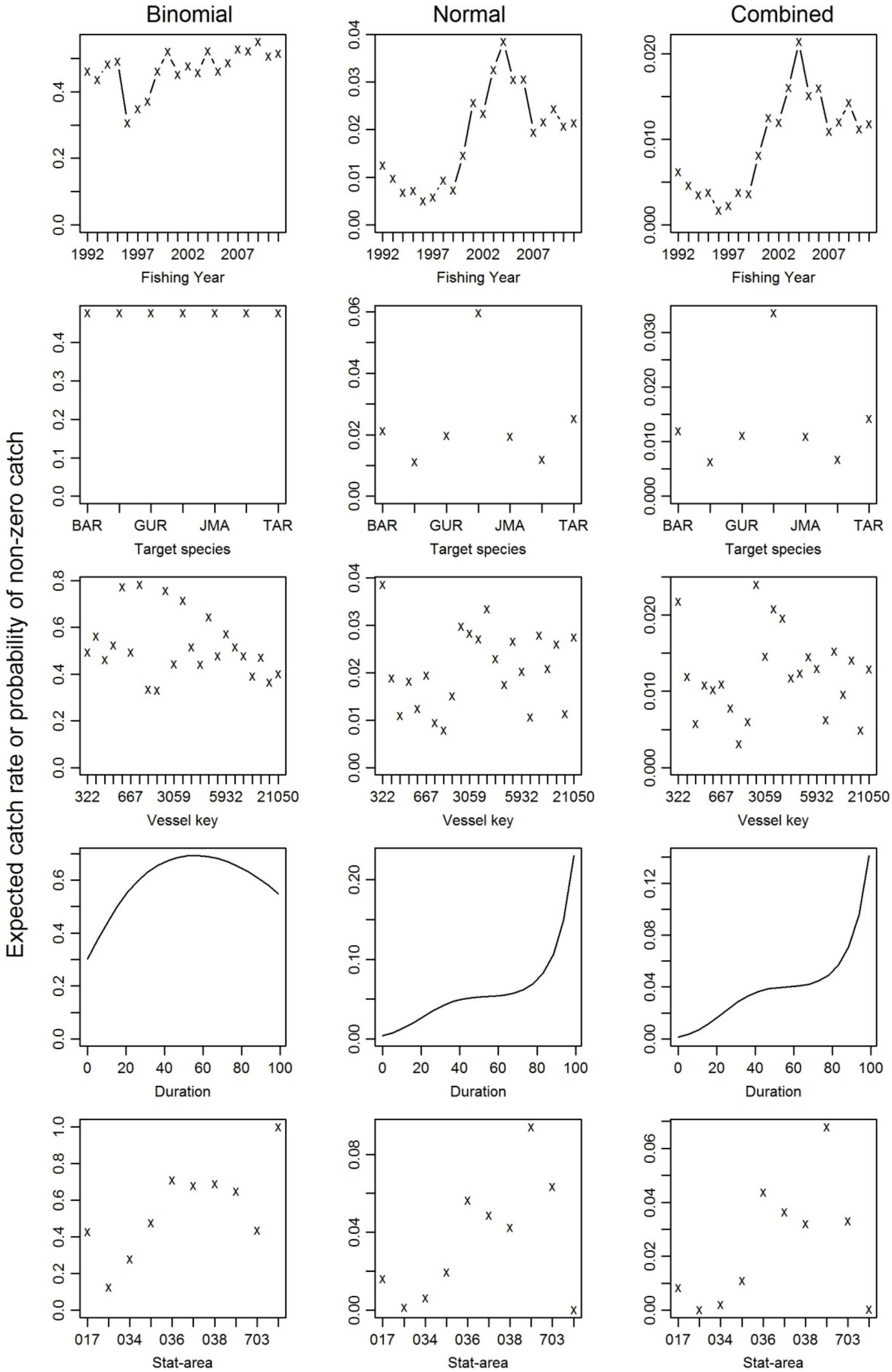


Figure 48: Model predictions for the northern South Island index, by fishing year (labelled as year ending, i.e., 1995 means 1994–95) and other selected predictors, for the binomial, normal and combined model, made with all other predictors set to the median (fixed) values. The target species are labelled in ascending alphabetical order; John dory is between the GUR and JMA labels.

Table 29: Combined (binomial plus normal) CPUE index and c.v.s for the Northern South Island stock.

Fishing year	Index	c.v.
1991–92	0.29	0.18
1992–93	0.22	0.17
1993–94	0.17	0.17
1994–95	0.18	0.18
1995–96	0.08	0.19
1996–97	0.10	0.18
1997–98	0.18	0.18
1998–99	0.17	0.17
1999–2000	0.38	0.17
2000–01	0.58	0.17
2001–02	0.56	0.16
2002–03	0.75	0.16
2003–04	1.00	0.15
2004–05	0.71	0.16
2005–06	0.75	0.15
2006–07	0.51	0.15
2007–08	0.56	0.16
2008–09	0.67	0.16
2009–10	0.52	0.17
2010–11	0.55	0.16

4. DISCUSSION

Whilst the evidence supported separation of John dory into several stocks around New Zealand, no split was entirely compelling. This is not unexpected, because the data sets examined were all indefinite measures of stock separation. The veracity of the stock assumption depends on the level of demographic connectivity. Some movement between areas is likely, but provided this is below some threshold (perhaps below 10% per generation; Waples & Gaggiotti 2006), then the assumption of separate stocks will be valid. The evidence for stock separation is probably strongest for separating the east and west coasts of the North Island, and then separating out the northern South Island, and probably weakest for the separation between the Hauraki Gulf and Bay of Plenty. Commercial fishery catch distribution, CPUE analyses, length and age compositions, spawning and nursery grounds, and research trawl survey biomass trends, all provide evidence to separate the northeast and northwest coasts of the North Island (JDO1). The evidence to separate the northern South Island from stocks to the north included the occurrence of unusually large fish on the northwest South Island, commercial fishery catch distribution and CPUE analyses. The distribution of John dory on the west coast North Island was continuous between JDO1 and the northern part of the west coast JDO2, and the combination of these areas was supported by CPUE analyses. A separate stock of John dory on the southeast coast of the North Island (east coast JDO2) was supported by the presence of spawning and nursery grounds, commercial fishery catch distribution, and CPUE analyses. Although geographically close and demographically similar, the separation of Hauraki Gulf and Bay of Plenty into two stocks was supported by the presence of spawning and nursery grounds, research trawl biomass trends, and CPUE analyses. John dory were very rarely reported from around the northeast, central, or southern South Island, and no stock was assumed to occur in these areas.

In the Mediterranean Sea, John dory have a preference for waters warmer than 16.5°C (Maravelias et al. 2007). Surveys of the east coast of the South Island of New Zealand rarely encountered temperatures above 15°C (Beentjes & Stevenson 2001), explaining the rarity of John dory around the central and southern South Island. Relatively warm water extends further down the west coast of the South Island (Figure 49), but it seems unlikely that John dory stocks will permanently occur further south than about 42°S under current oceanographic conditions.

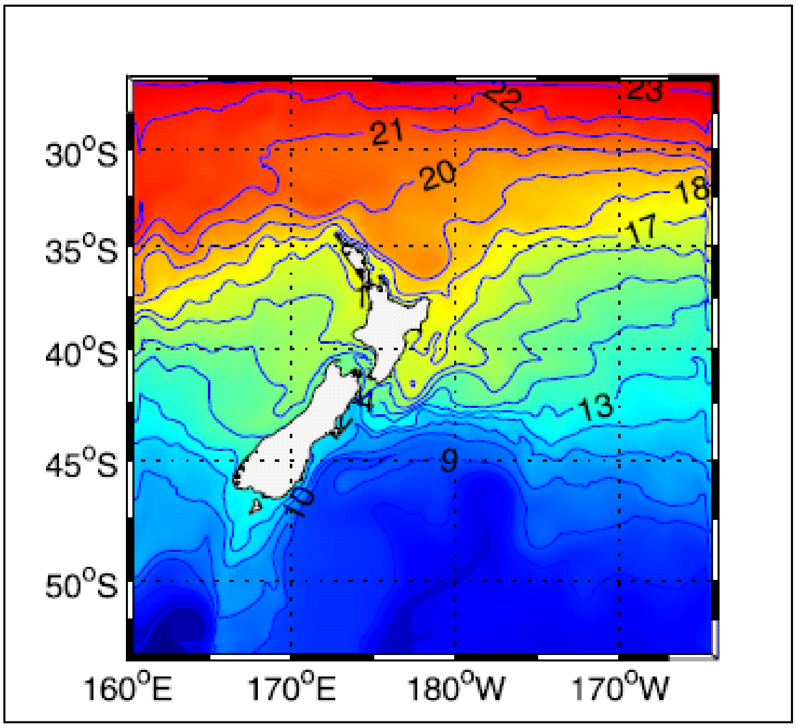


Figure 49: Average sea surface temperature from the New Zealand Regional Simulation Model (Chiswell & Rickard 2006).

The catch data suggest that John dory stocks may have shifted southward in around 2000, and then the fishery in JDO7 increased in subsequent years. It may be that fish from JDO2 'seeded' the JDO7 fishery at around that time. Because John dory are at the southern limit of their range on the north coast of the South Island, it seems likely that stock size and distribution, and so commercial catches in JDO7, will have a pronounced response to climatic conditions and be more variable than catches around the northern North Island.

The standardised CPUE analyses had year trends in accordance with anecdotal reports of catch and CPUE trends. The anecdotal reports also helped to provide information corroborating the analyses of stock structure and fisheries patterns, allowing more confidence in the conclusions.

Validation of the stock structure hypotheses presented here could be achieved with tagging or genetic studies. Tagging provides specific data, but might not be cost effective because of typically small catches; requiring extended tagging programmes, and if completed in collaboration with commercial fishing also the purchase of relatively expensive fish. Either tagging or genetics would directly allow the veracity of our conclusions to be examined.

5. MANAGEMENT IMPLICATIONS

The holistic analysis favoured the assumption of five stocks: (1) Hauraki Gulf and east Northland, (2) Bay of Plenty, (3) West coast North Island, (4) Southeast North Island, and (5) Northern South Island. John dory have been caught around most of the North Island and northern South Island of New Zealand, indicating that the boundaries between the assumed stocks were not distinct.

CPUE trends were estimated for use as indices of stock biomass. The catch rate for Hauraki Gulf and east Northland between 1995–96 and 2010–11 showed an overall decline, but with a period of low catch rates around 1999–2000. The catch rate for the Bay of Plenty between 1995–96 and 2010–11 showed an initial decline to around 1999–2000, and then remained roughly flat. The catch rate for the West Coast North Island between 1994–95 and 2010–11 showed an initial decline to 1998–99, and then remained roughly flat. The catch rates for the Southeast North Island between 1989–90 and 2010–11 had peaks at the start of the time series, and then around 2000–01. The catch rate for the Northern South Island from 1991–92 to 2010–11 increased after 1998–99, and peaked in 2003–04. The standardised CPUE trends were in general accordance with reports from commercial fishers.

6. ACKNOWLEDGMENTS

This study was funded by the Ministry for Primary Industries project INS2001/03. We acknowledge the critical review by members of the Ministry of Primary Industries Inshore Stock Assessment Working Groups. We thank Graham Rickard (NIWA) for providing the sea surface temperature figure, and Mike Stevenson (NIWA) for providing the updated biomass estimates for the west coast South Island research trawl survey. We thank Steve Brouwer for helpful comments on the draft report.

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APPENDIX 1

Diagnostic results from the grooming and "roll-up" of the catch and effort data (see Section 2.5).

A1.1 Results for JDO1

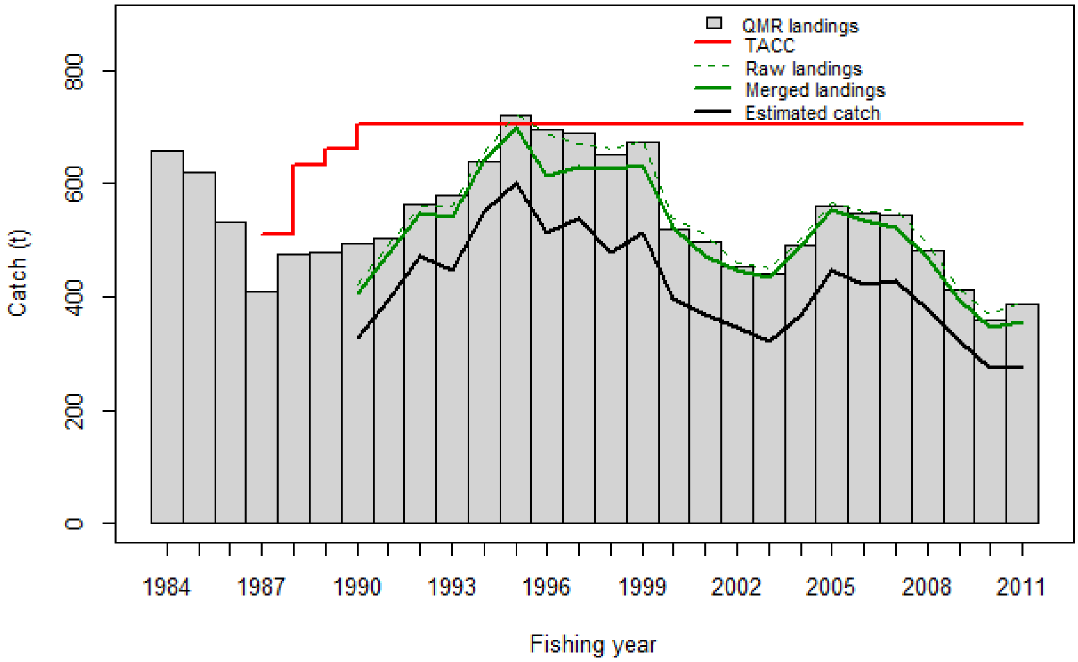

Figure A1.1: John dory official (Quota Management Reports: QMR) landings and TACC, and the raw, merged, and estimated catches in the catch-effort dataset, for JDO1.

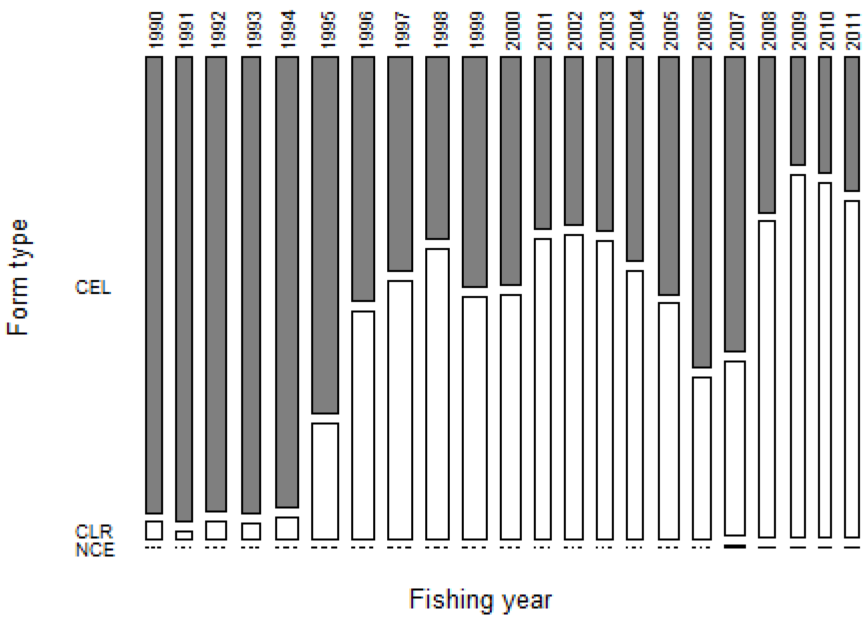

Figure A1.2: The proportion of reported landings of John dory by form type for JDO 1. Calculated from estimated greenweight. CEL, Catch Effort Landing Return; CLR, Catch Landing Return (for TCP and TCEPR forms); NCE, Netting Catch, Effort and Landing Return (for set nets, inshore drift nets, or pair set nets).

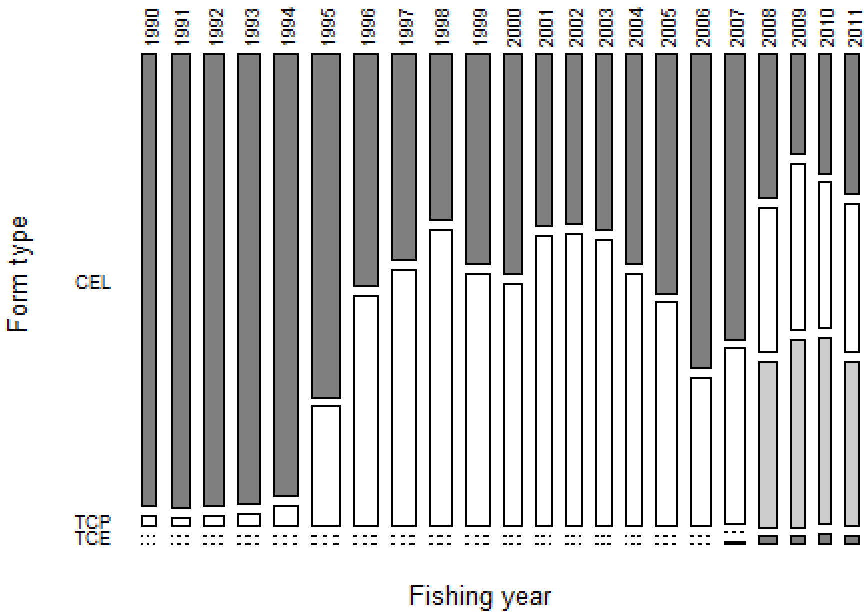

Figure A1.3: The proportion of estimated catches of John dory by form type for JDO 1. CEL, Catch Effort Landing Return; TCP, – Trawl Catch Effort Processing Return (for vessels >28 m in length); TCE, Trawl Catch Effort Return (for vessels 6–28 m in length).

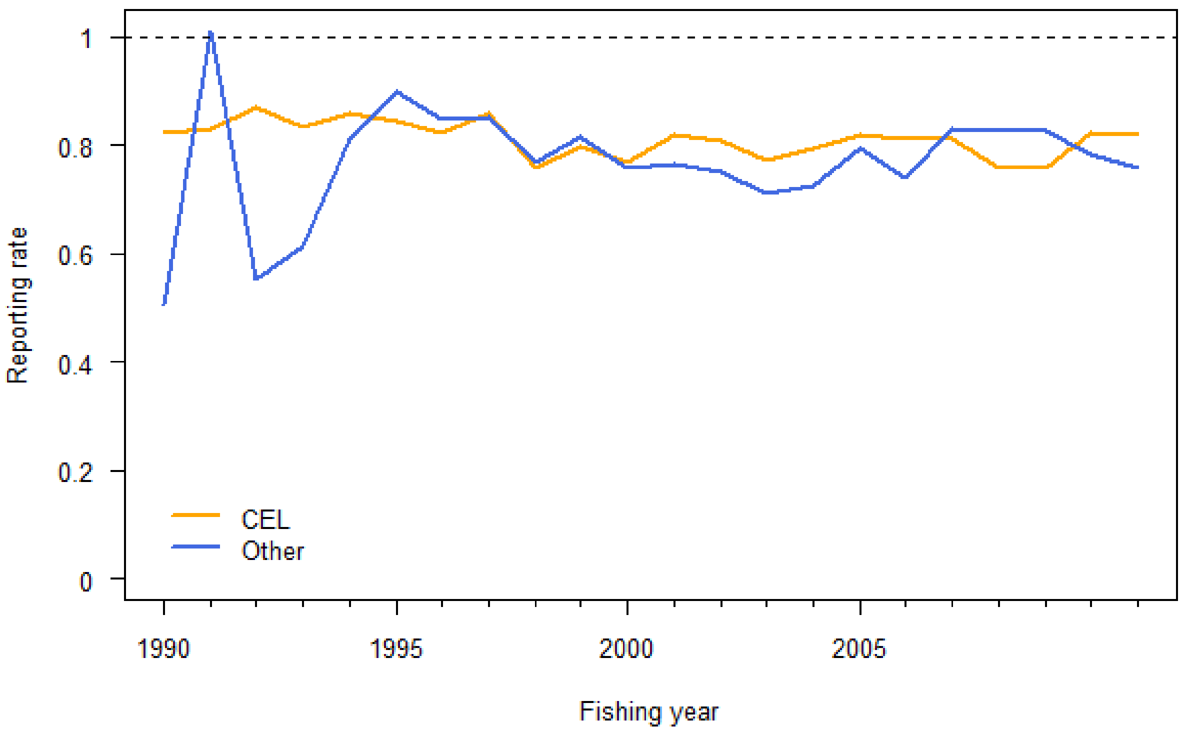

Figure A1.4: The reporting rate of John dory by form type for JDO 1. CEL, Catch Effort Landing Return. The reporting rate is the estimated catch divided by the trip-stratum (i.e., QMR) catch.

A1.2 Results for JDO2

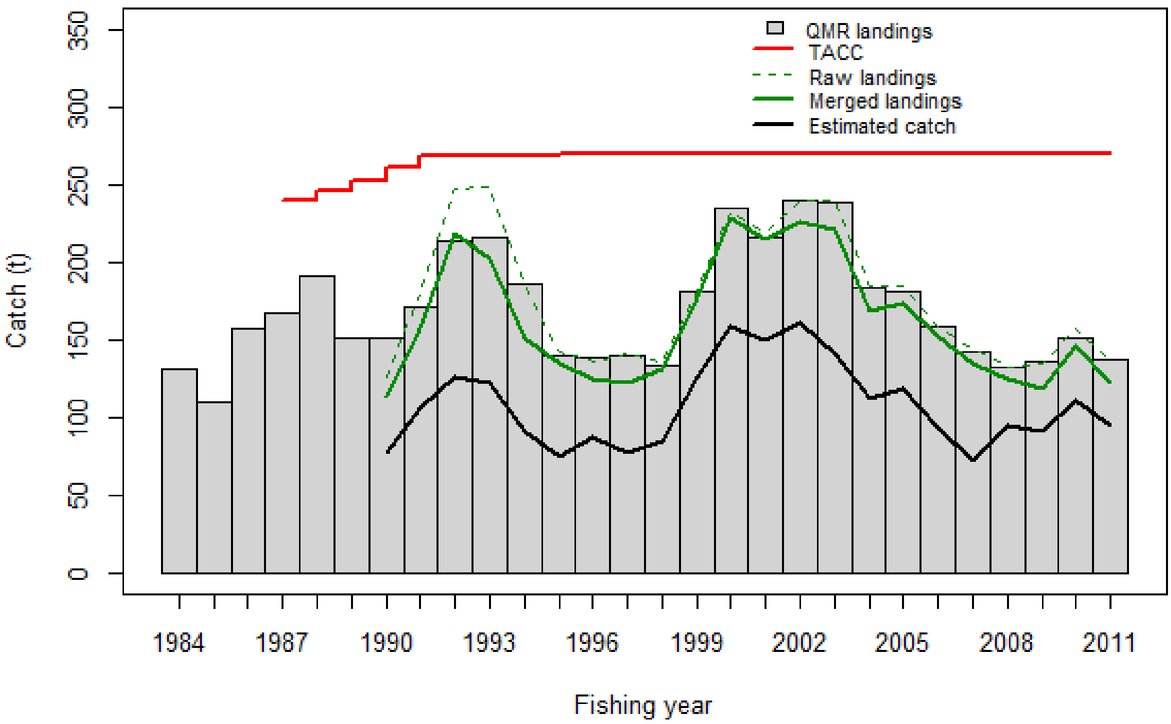

Figure A1.5: John dory official (Quota Management Reports: QMR) landings and TACC, and the raw, merged, and estimated catches in the catch-effort dataset, for JDO2.

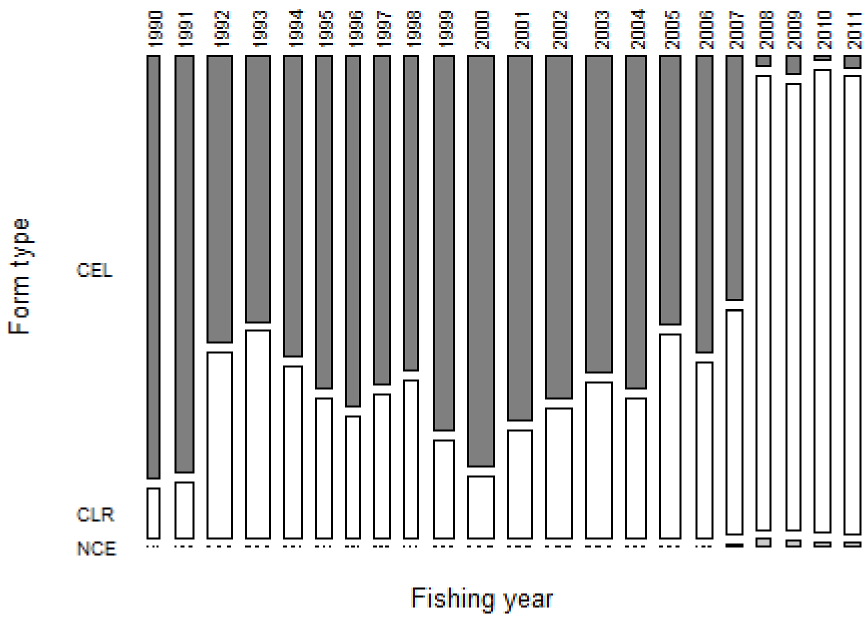

Figure A1.6: The proportion of reported landings of John dory by form type for JDO 2. Calculated from estimated greenweight. CEL, Catch Effort Landing Return; CLR, Catch Landing Return (for TCP and TCEPR forms); NCE, Netting Catch, Effort and Landing Return (for set nets, inshore drift nets, or pair set nets).

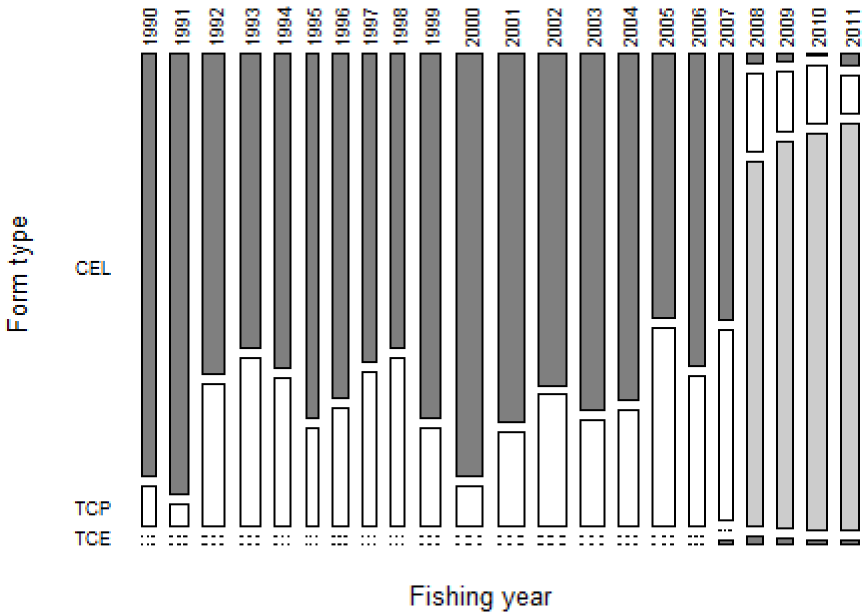

Figure A1.7: The proportion of estimated catches of John dory by form type for JDO 2. CEL, Catch Effort Landing Return; TCP, – Trawl Catch Effort Processing Return (for vessels >28 m in length); TCE, Trawl Catch Effort Return (for vessels 6–28 m in length).

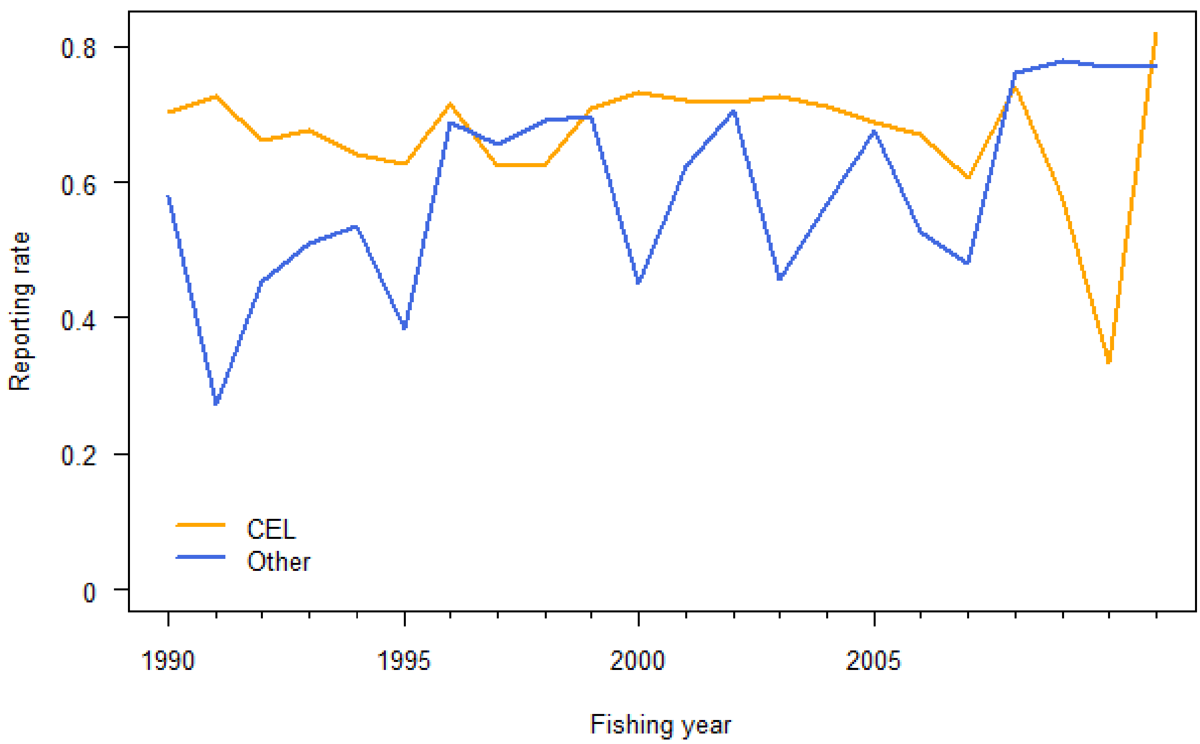

Figure A1.8: The reporting rate of John dory by form type for JDO 2. CEL, Catch Effort Landing Return. The reporting rate is the estimated catch divided by the trip-stratum (i.e., QMR) catch.

A1.3 Results for JDO3

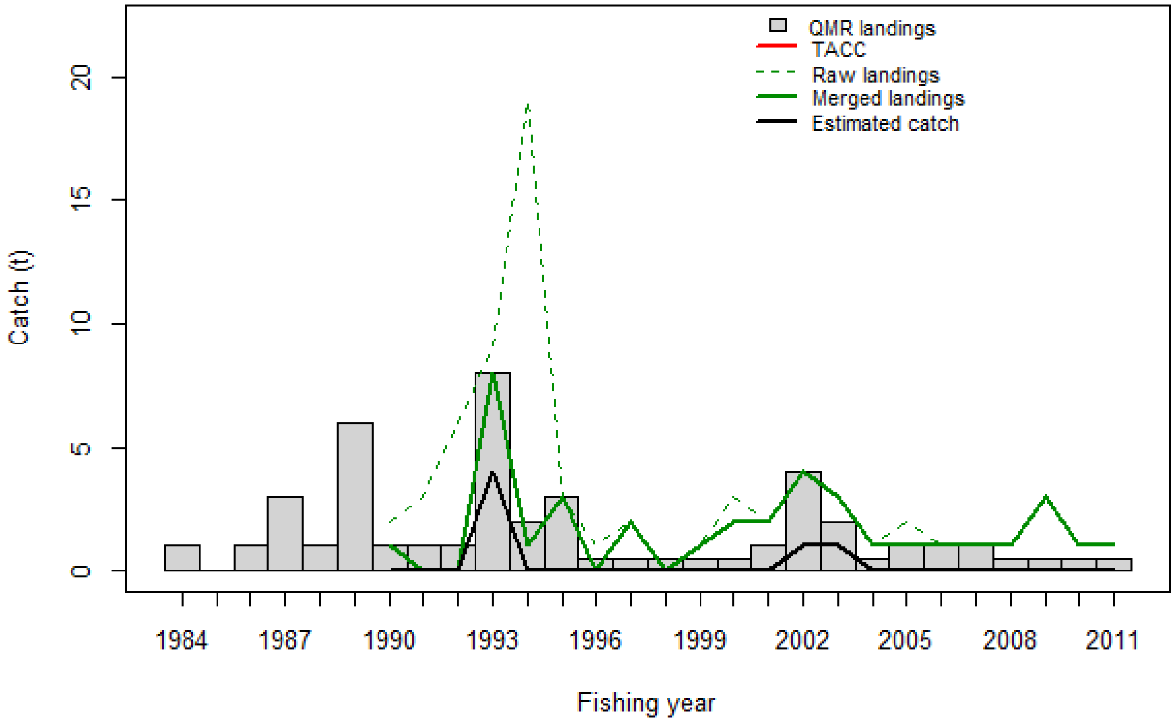

Figure A1.9: John dory official (Quota Management Reports: QMR) landings and TACC, and the raw, merged, and estimated catches in the catch-effort dataset, for JDO3.

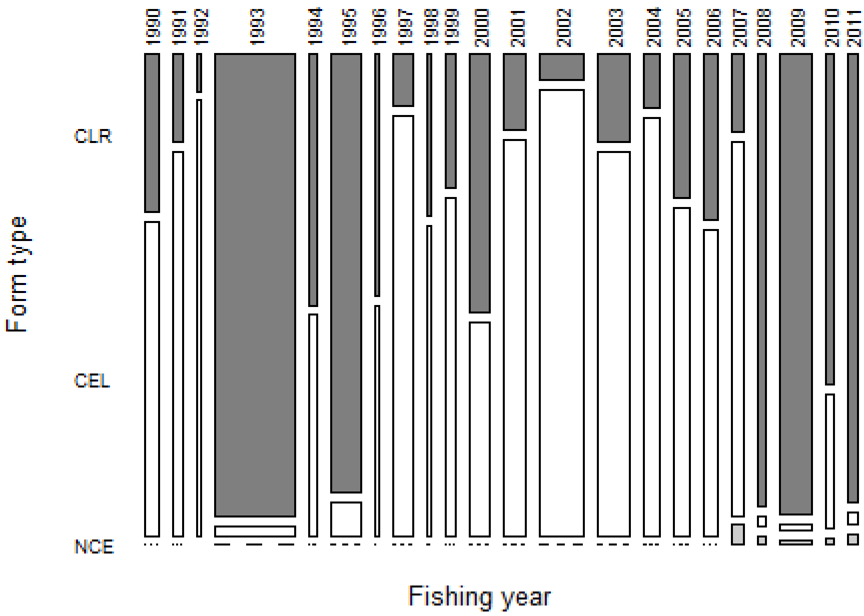

Figure A1.10: The proportion of reported landings of John dory by form type for JDO 3. Calculated from estimated greenweight. CEL, Catch Effort Landing Return; CLR, Catch Landing Return (for TCP and TCEPR forms); NCE, Netting Catch, Effort and Landing Return (for set nets, inshore drift nets, or pair set nets).

Figure A1.11: The proportion of estimated catches of John dory by form type for JDO 3. CEL, Catch Effort Landing Return; TCP, – Trawl Catch Effort Processing Return (for vessels >28 m in length); TCE, Trawl Catch Effort Return (for vessels 6–28 m in length).

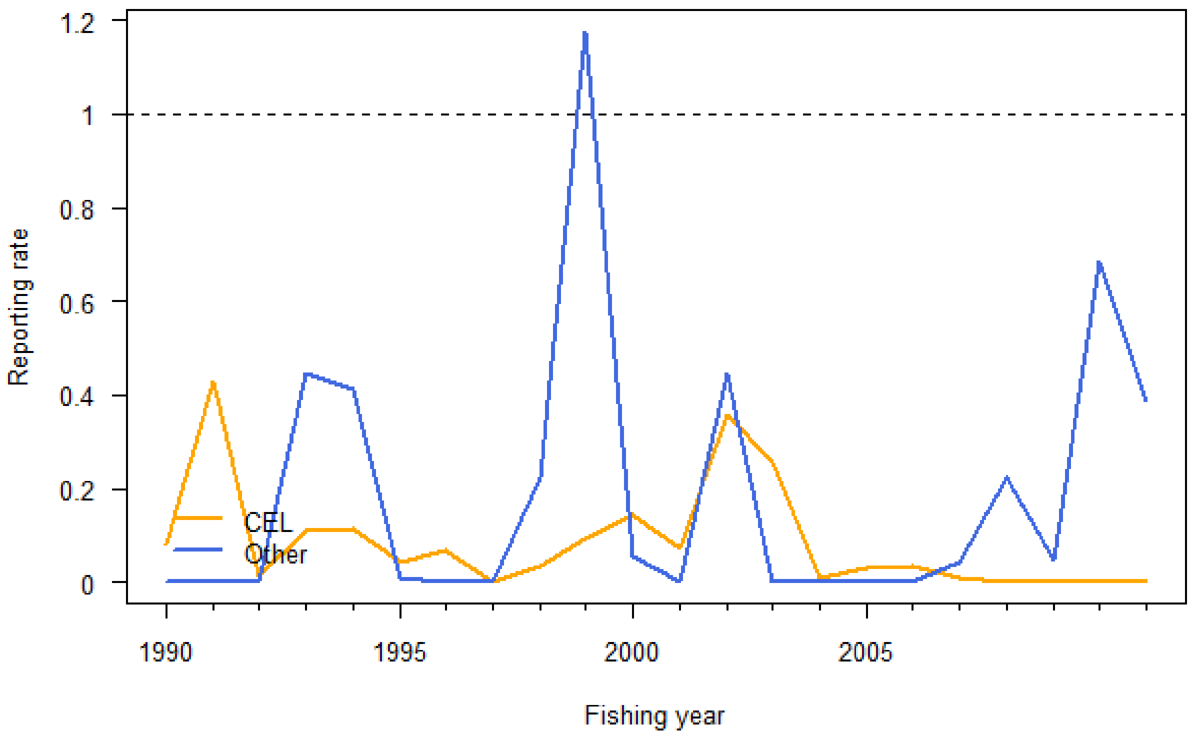

Figure A1.12: The reporting rate of John dory by form type for JDO 1. CEL, Catch Effort Landing Return. The reporting rate is the estimated catch divided by the trip-stratum (i.e., QMR) catch.

A1.4 Results for JDO7

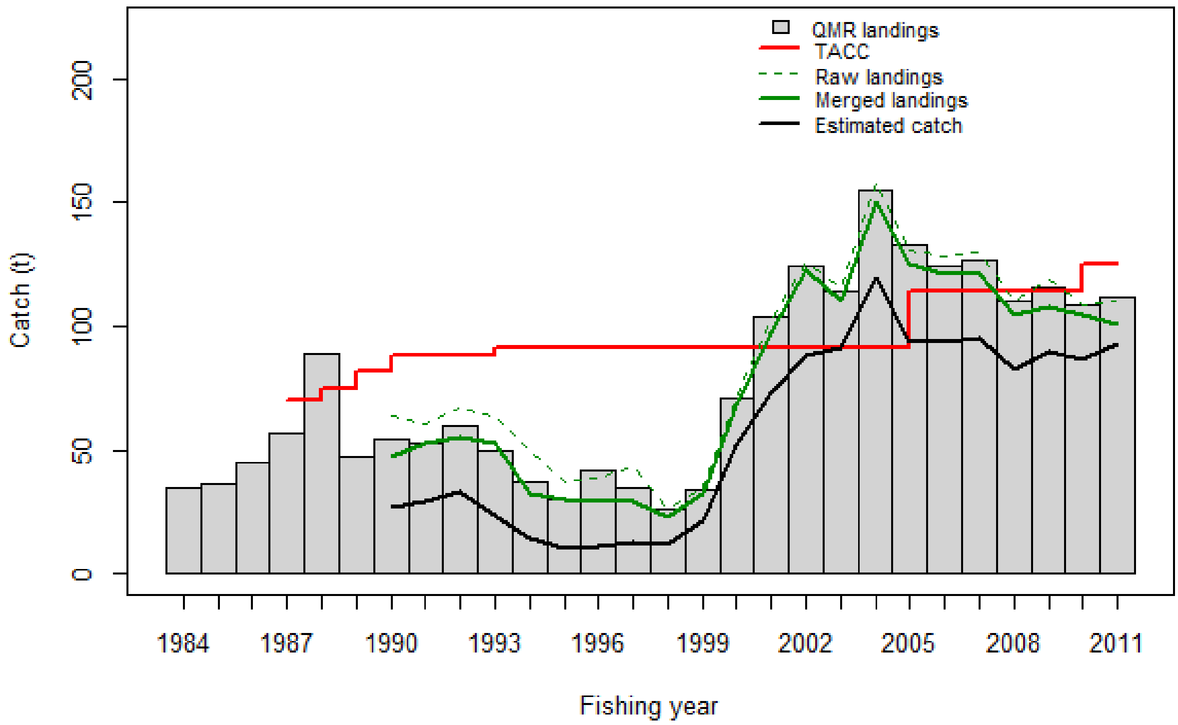

Figure A1.13: John dory official (Quota Management Reports: QMR) landings and TACC, and the raw, merged, and estimated catches in the catch-effort dataset, for JDO7.

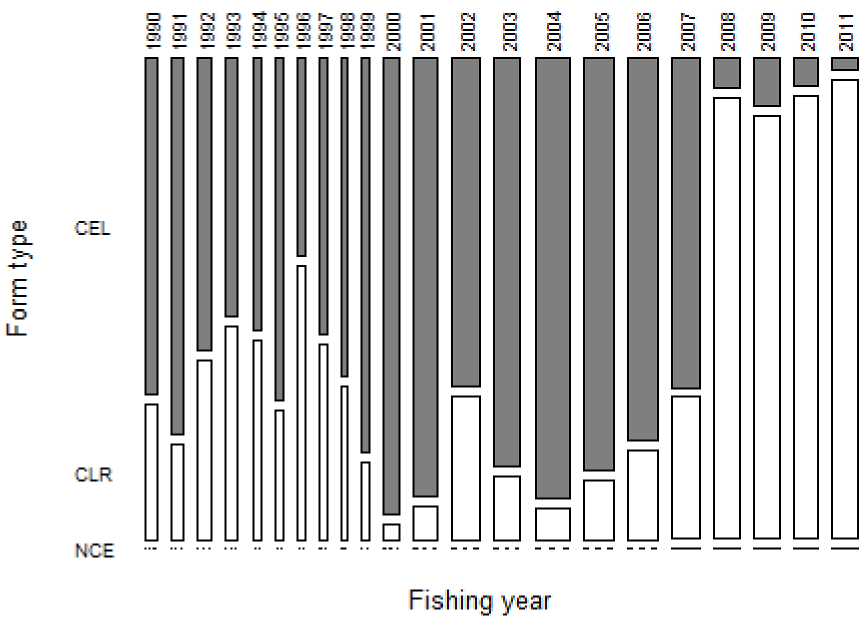

Figure A1.14: The proportion of reported landings of John dory by form type for JDO 7. Calculated from estimated greenweight. CEL, Catch Effort Landing Return; CLR, Catch Landing Return (for TCP and TCEPR forms); NCE, Netting Catch, Effort and Landing Return (for set nets, inshore drift nets, or pair set nets).

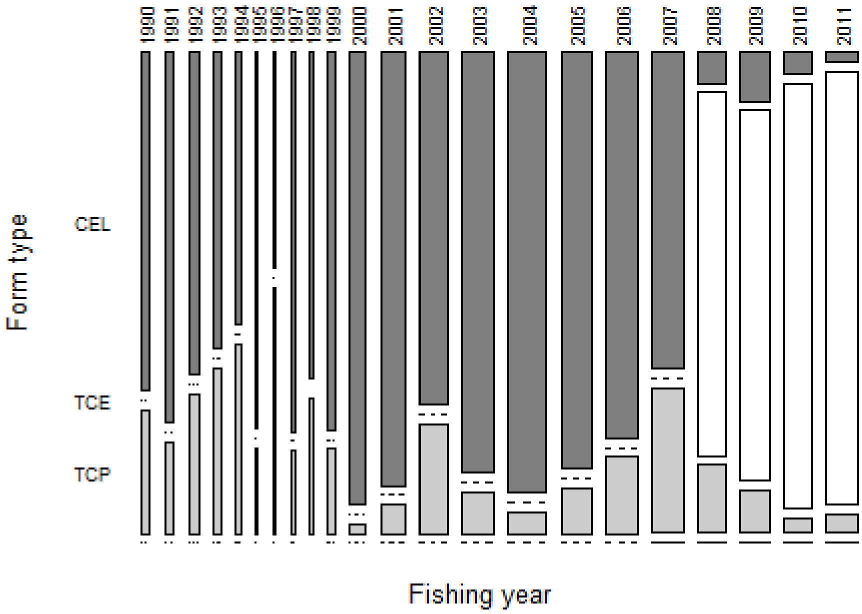

Figure A1.15: The proportion of estimated catches of John dory by form type for JDO 7. CEL, Catch Effort Landing Return; TCP, – Trawl Catch Effort Processing Return (for vessels >28 m in length); TCE, Trawl Catch Effort Return (for vessels 6–28 m in length).

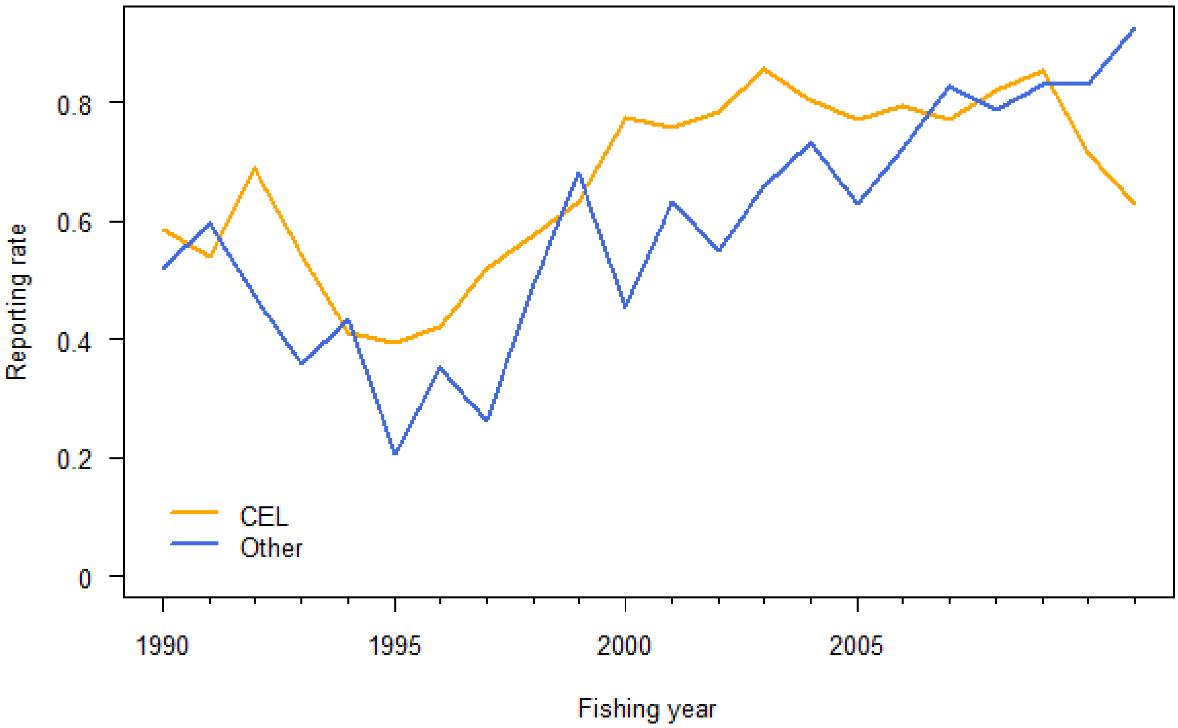

Figure A1.16: The reporting rate of John dory by form type for JDO 7. CEL, Catch Effort Landing Return. The reporting rate is the estimated catch divided by the trip-stratum (i.e., QMR) catch.

APPENDIX 2

Results exploring the influence of final selected predictors for the lognormal models in the standardised catch per unit effort (CPUE) analyses (Bentley et al. 2012).

A2.1 Results for Hauraki Gulf and east Northland (JDO1)

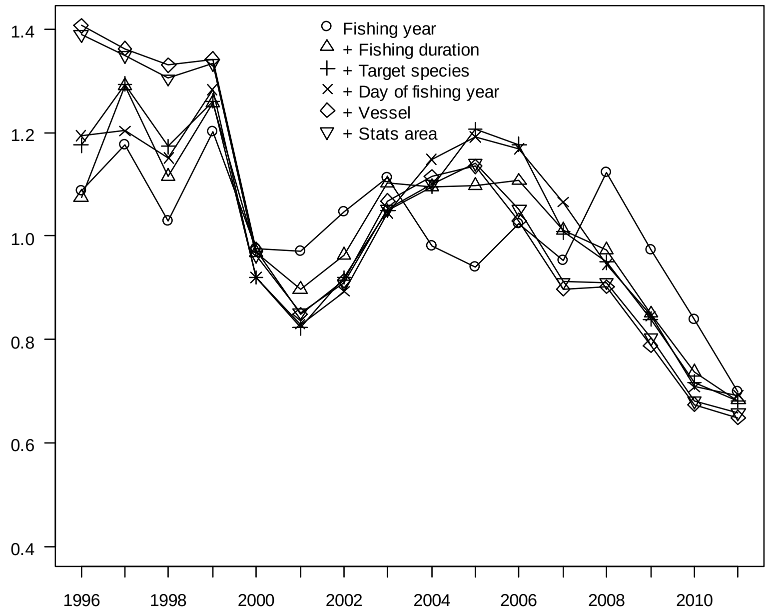

Figure A2.1: Annual CPUE indices for the Hauraki Gulf and east Northland stock normal model at each step in the variable selection process.

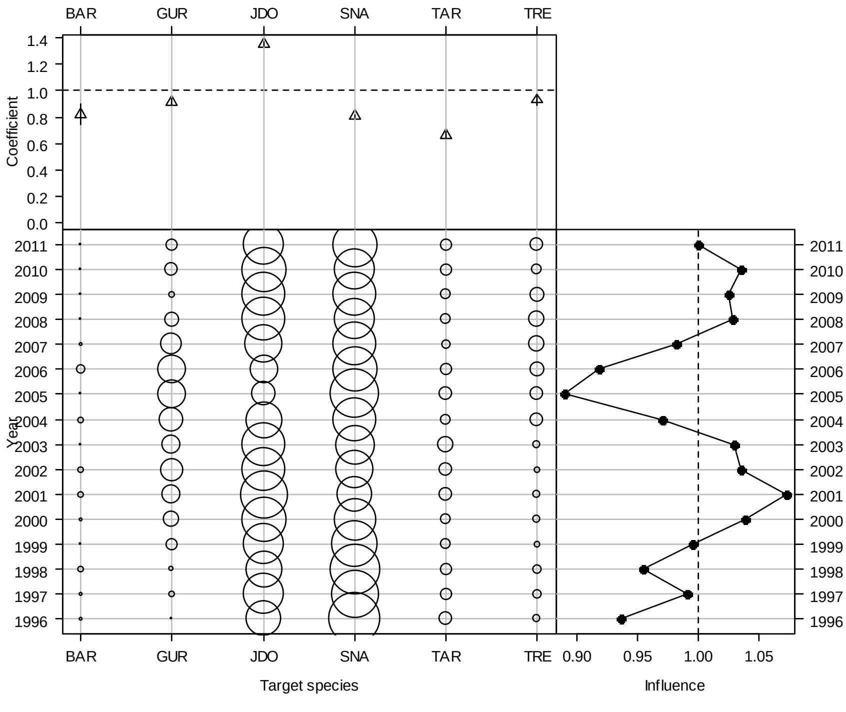

Figure A2.2: Effect and influence of target species in the Hauraki Gulf and east Northland CPUE normal model. Top: relative effect by level of variable; Bottom left, relative distribution of variables by fishing year; Bottom right, influence of variable on unstandardized CPUE by fishing year.

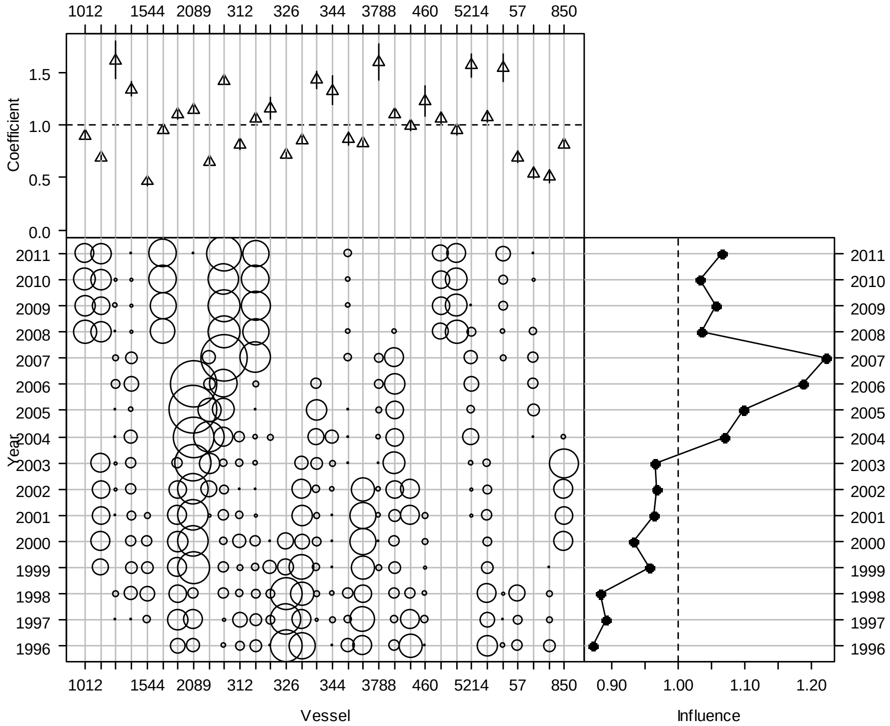

Figure A2.3: Effect and influence of vessel in the Hauraki Gulf and east Northland CPUE normal model. Top: relative effect by level of variable; Bottom left, relative distribution of variables by fishing year; Bottom right, influence of variable on unstandardized CPUE by fishing year.

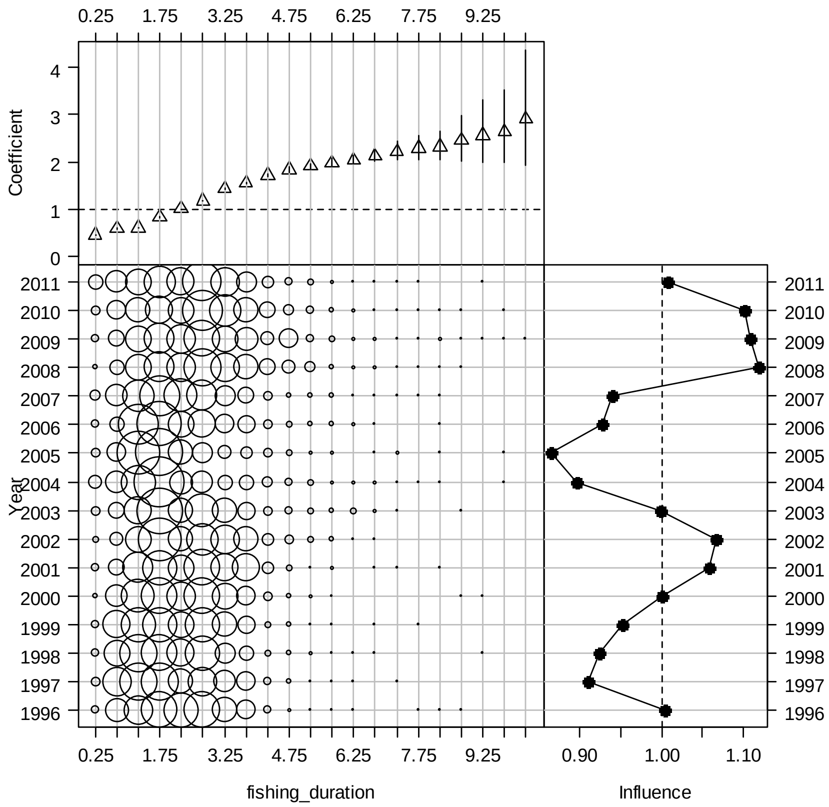

Figure A2.4: Effect and influence of fishing duration in the Hauraki Gulf and east Northland CPUE normal model. Top: relative effect by level of variable; Bottom left, relative distribution of variables by fishing year; Bottom right, influence of variable on unstandardized CPUE by fishing year.

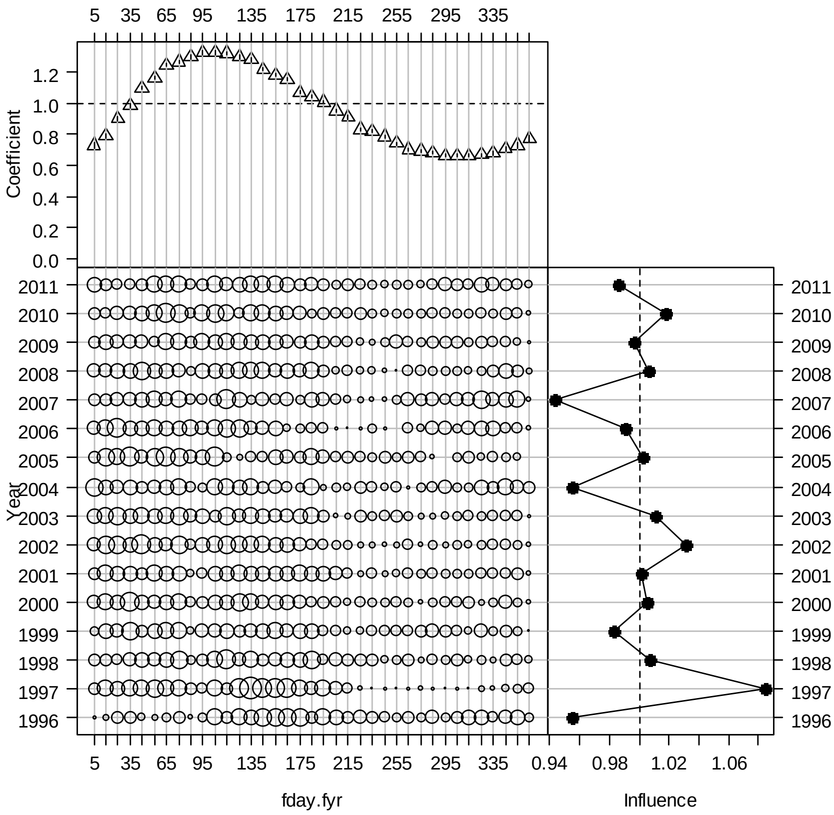

Figure A2.5: Effect and influence of fishing day (labelled here as fday.fyr: day of the fishing year) in the Hauraki Gulf and east Northland CPUE normal model. Top: relative effect by level of variable; Bottom left, relative distribution of variables by fishing year; Bottom right, influence of variable on unstandardized CPUE by fishing year.

A2.2 Results for Bay of Plenty (JDO1)

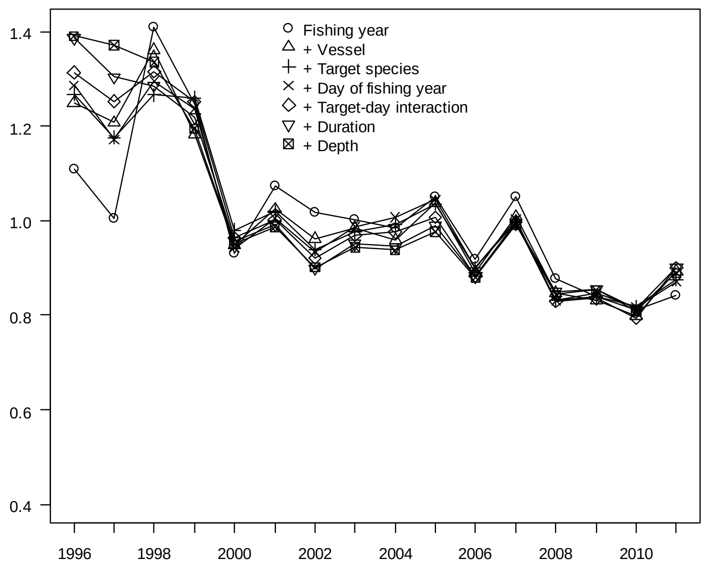

Figure A2.6: Annual CPUE indices for the Bay of Plenty stock normal model at each step in the variable selection process.

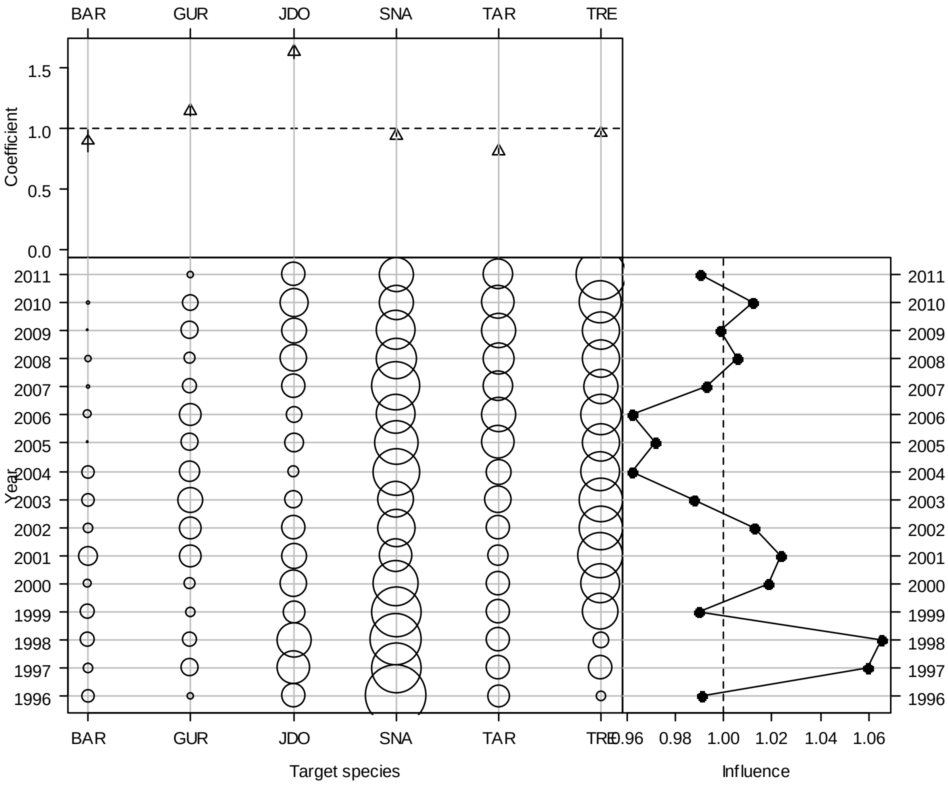

Figure A2.7: Effect and influence of target species in the Bay of Plenty CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

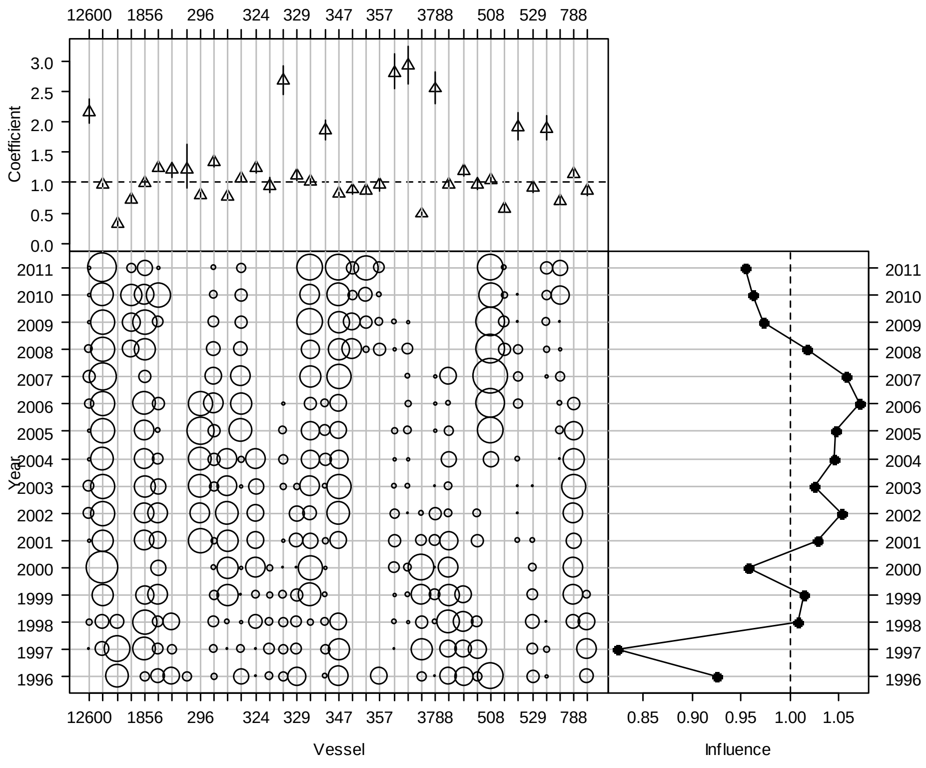

Figure A2.8: Effect and influence of vessel in the Bay of Plenty CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

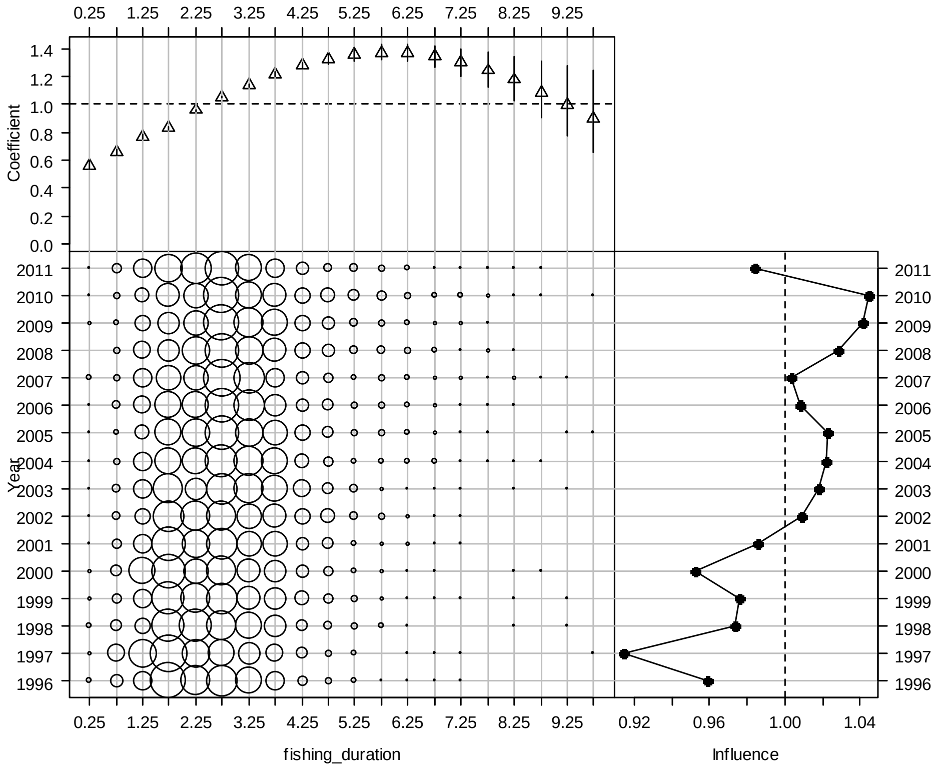

Figure A2.9: Effect and influence of fishing duration in the Bay of Plenty CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

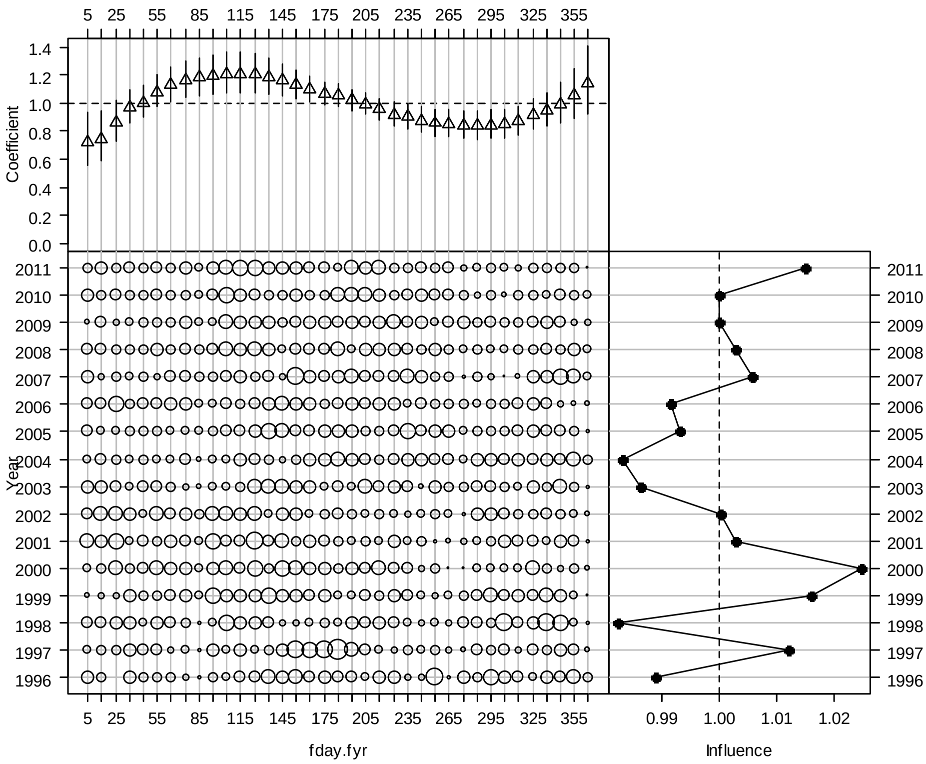

Figure A2.10: Effect and influence of fishing day (labelled here as fday.fyr: day of the fishing year) in the Bay of Plenty CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

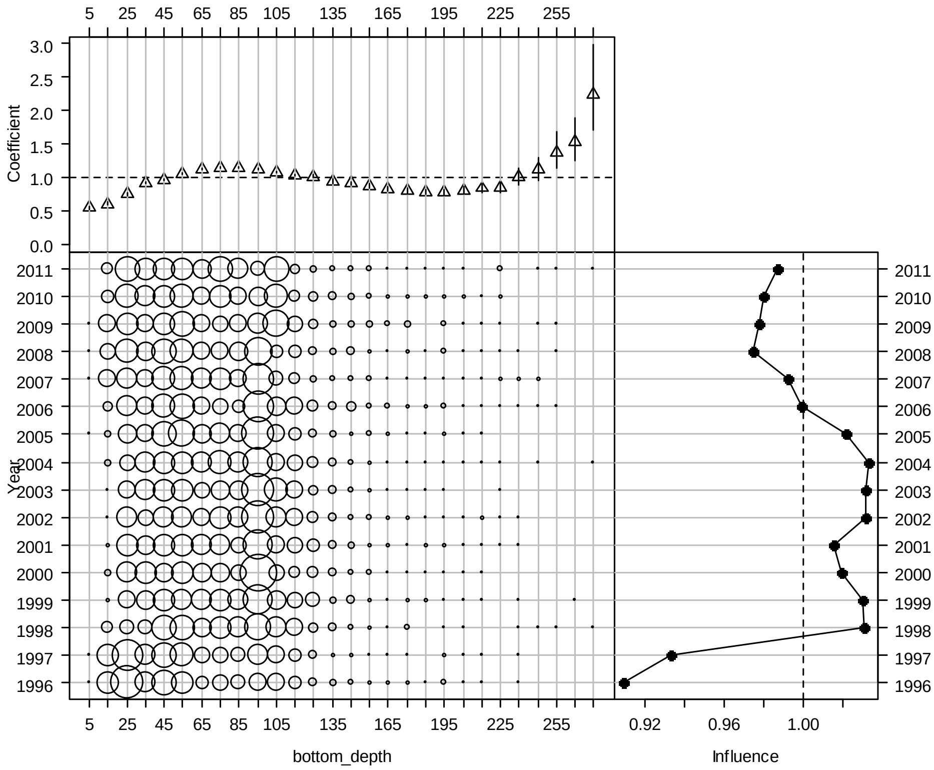

Figure A2.11: Effect and influence of bottom depth in the Bay of Plenty CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

A2.3 Results for West Coast North Island (JDO1 and northern part of JDO2)

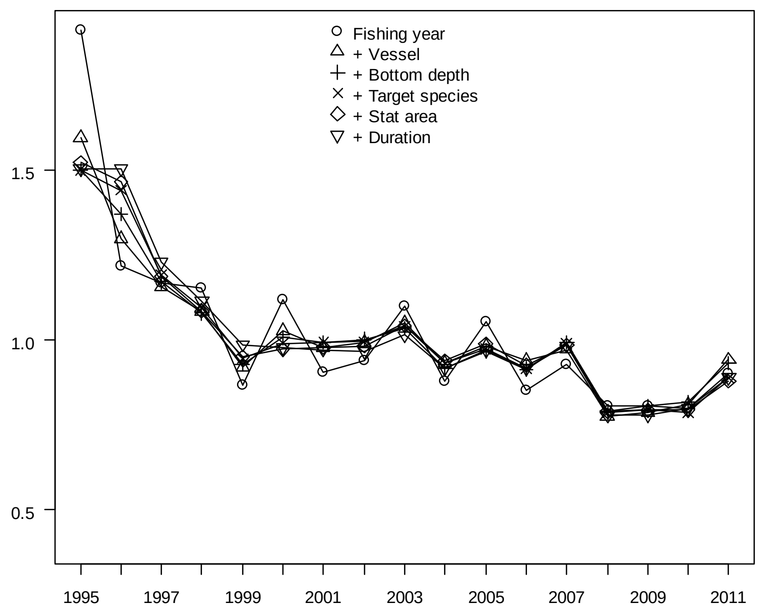

Figure A2.12: Annual CPUE indices for the West coast North Island stock normal model at each step in the variable selection process.

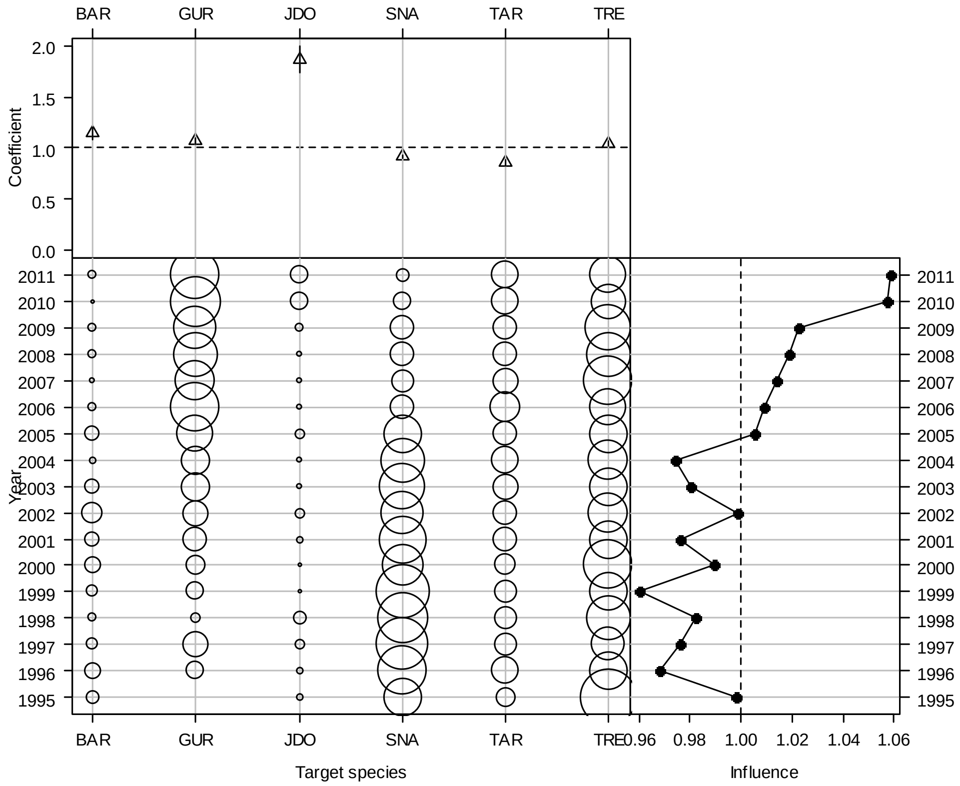

Figure A2.13: Effect and influence of target species in the West coast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

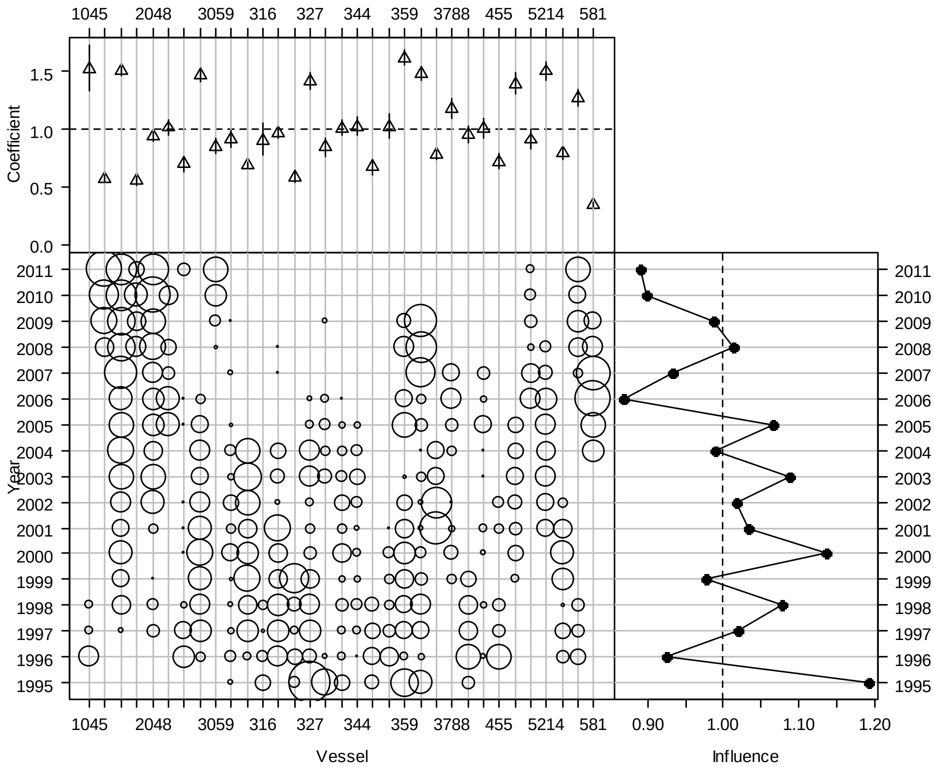

Figure A2.14: Effect and influence of vessel in the West coast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

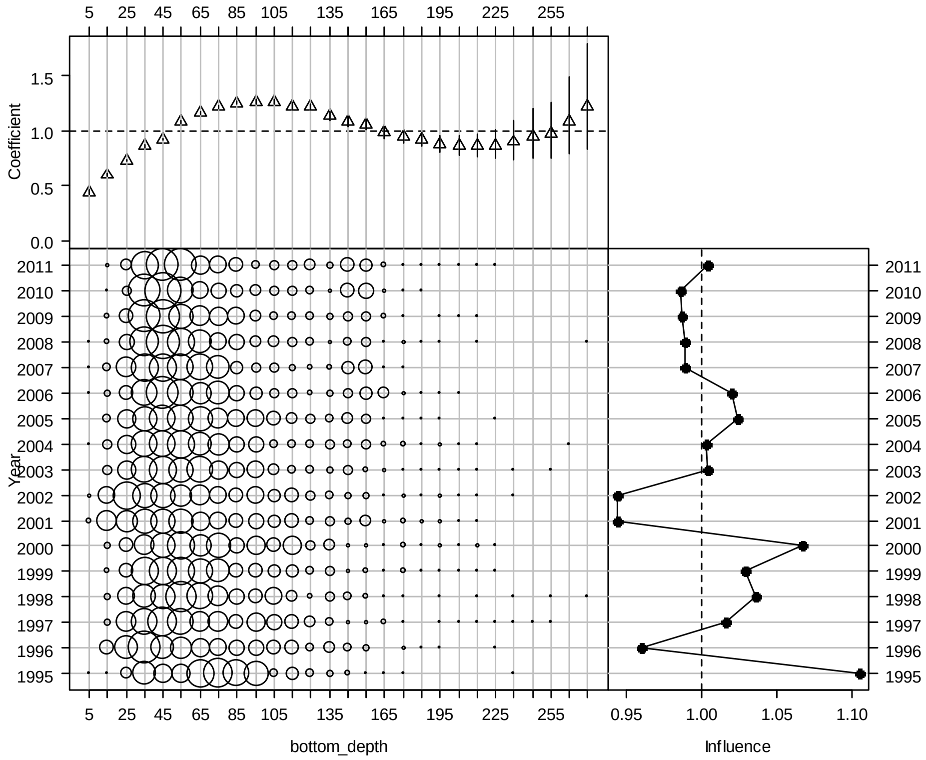

Figure A2.15: Effect and influence of bottom depth in the West coast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

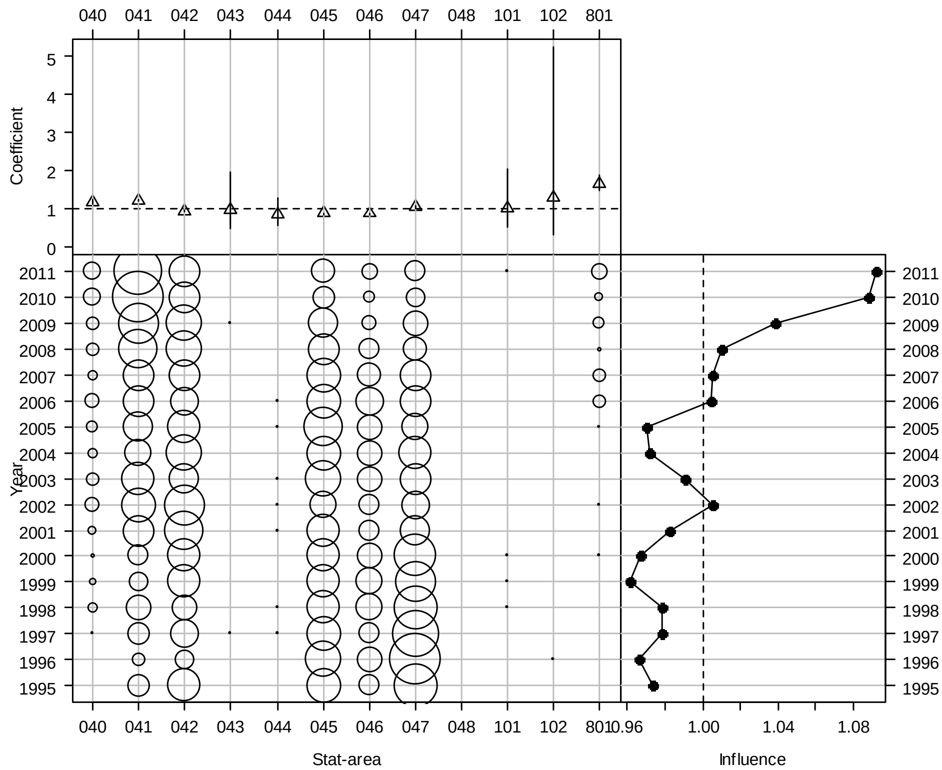

Figure A2.16: Effect and influence of statistical area in the West coast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

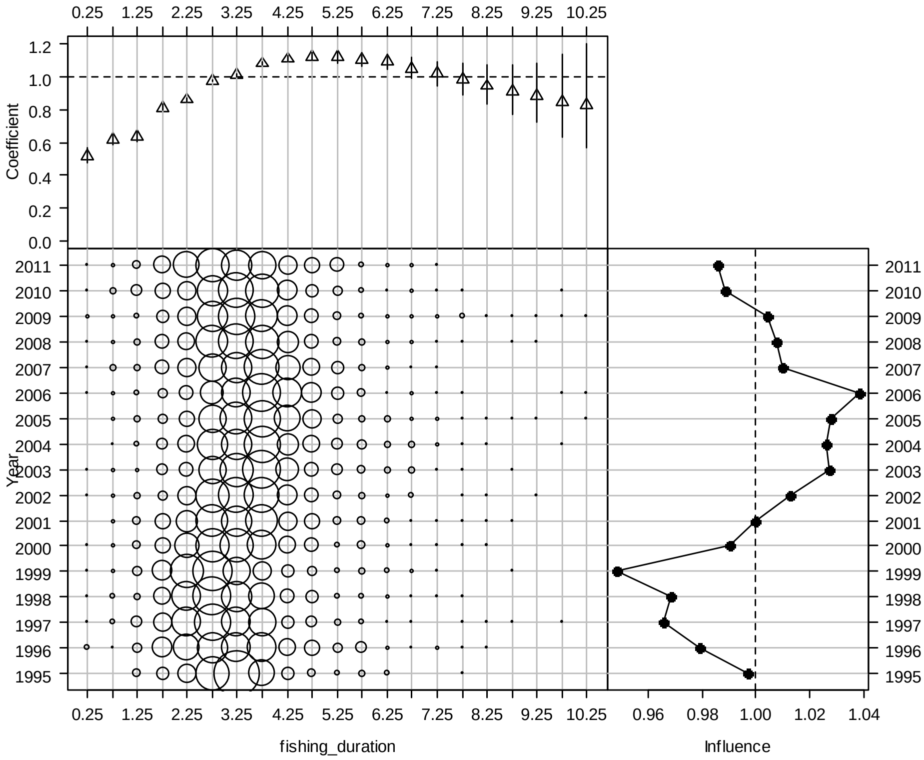

Figure A2.17: Effect and influence of fishing duration in the West coast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

A2.4 Results for Southeast North Island (JDO2 east)

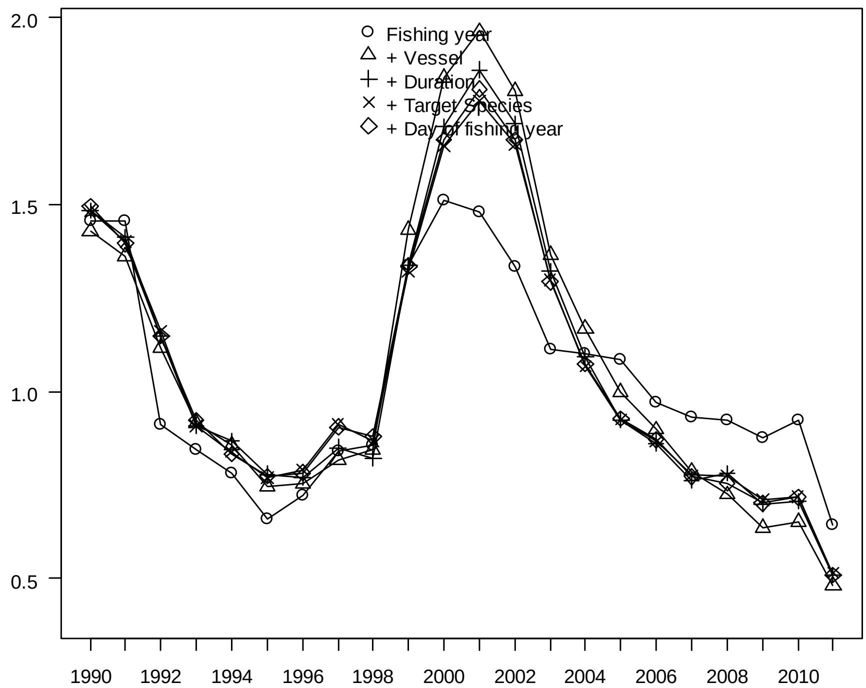

Figure A2.18: Annual CPUE indices for the Southeast North Island stock normal model at each step in the variable selection process.

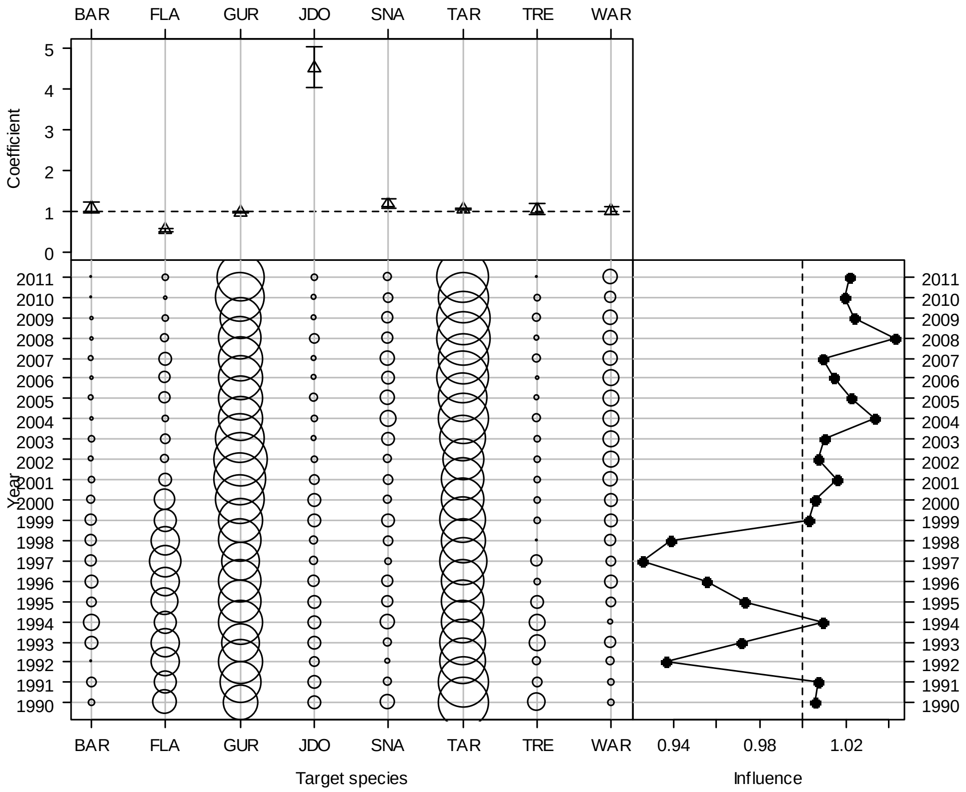

Figure A2.19: Effect and influence of target species in the Southeast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

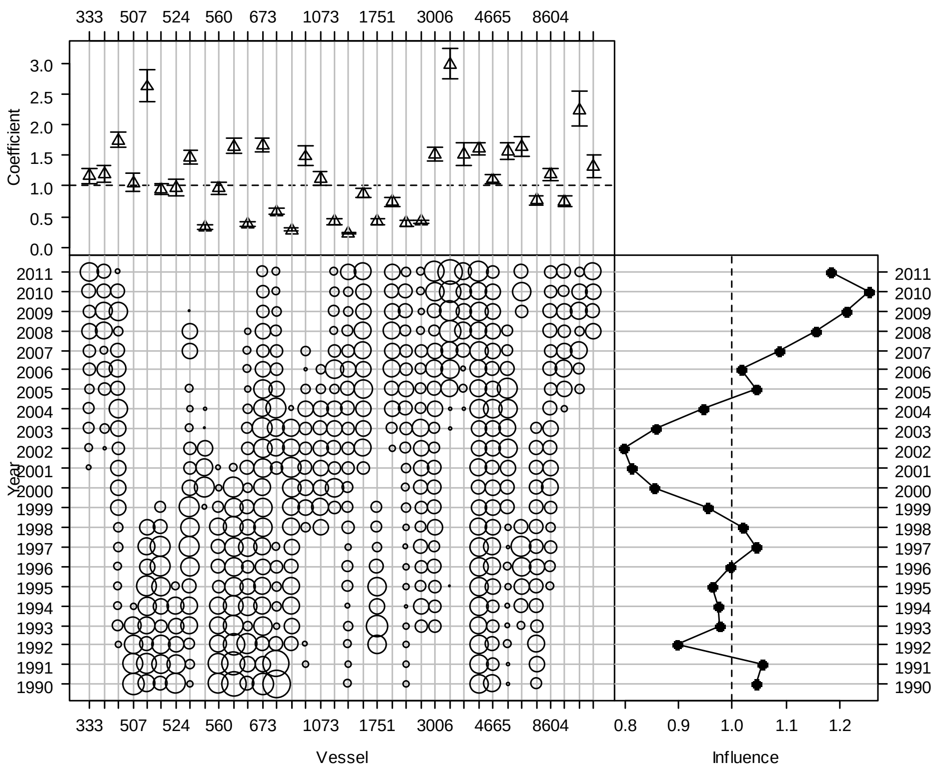

Figure A2.20: Effect and influence of vessel in the Southeast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

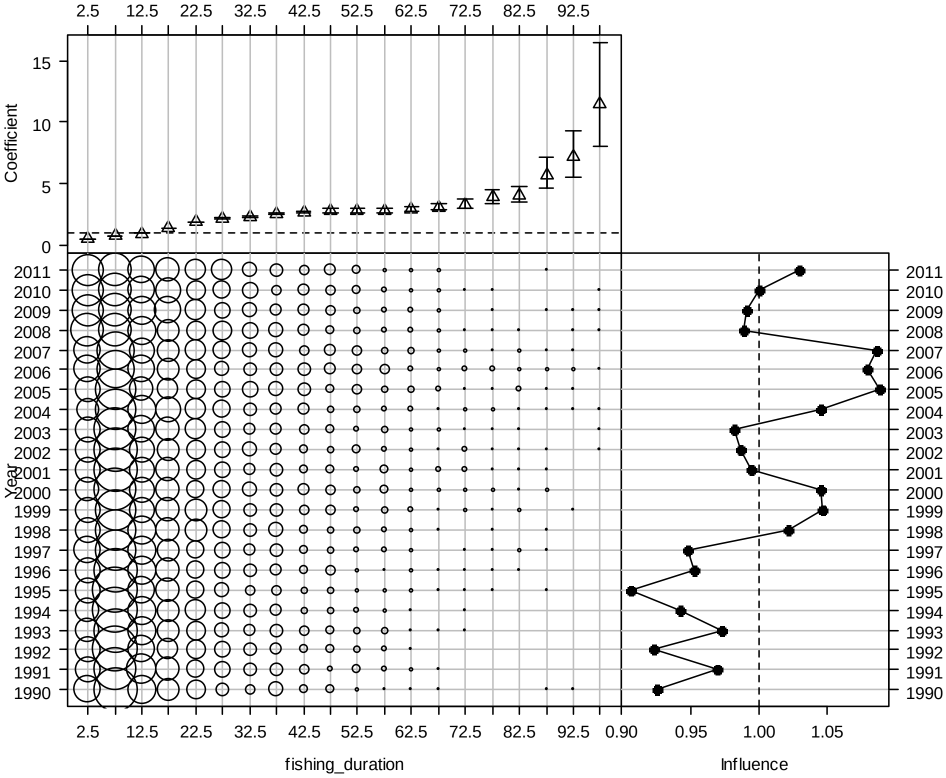

Figure A2.21: Effect and influence of fishing duration in the Southeast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

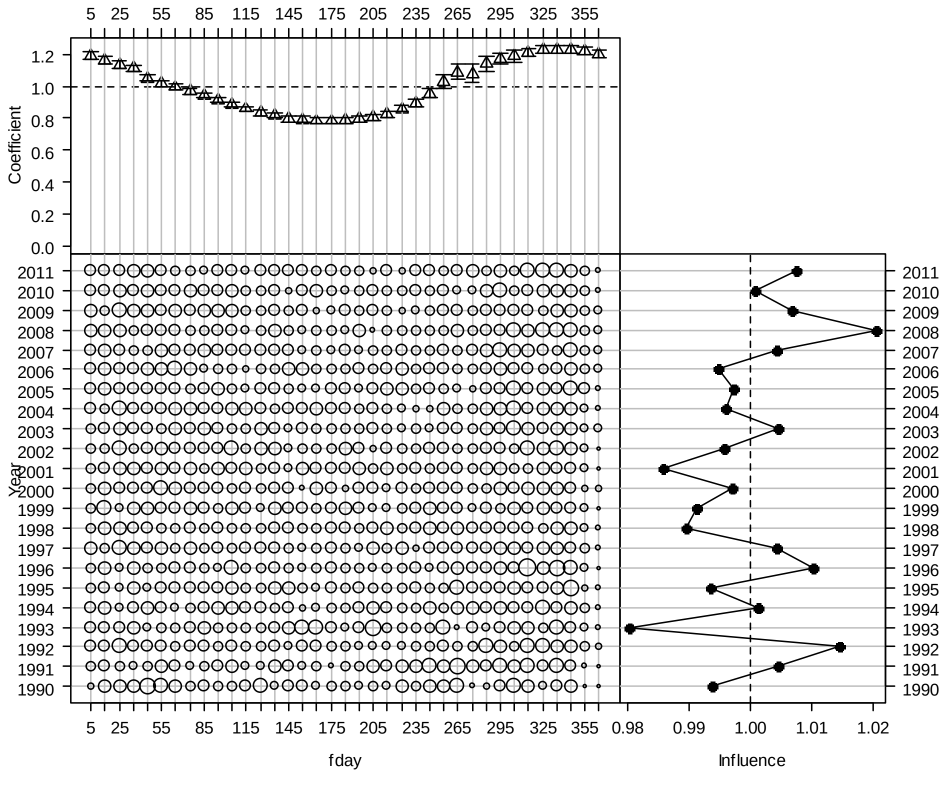

Figure A2.22: Effect and influence of day of the fishing year in the Southeast North Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

A2.5 Results for West Coast North Island (JDO1 and northern part of JDO2)

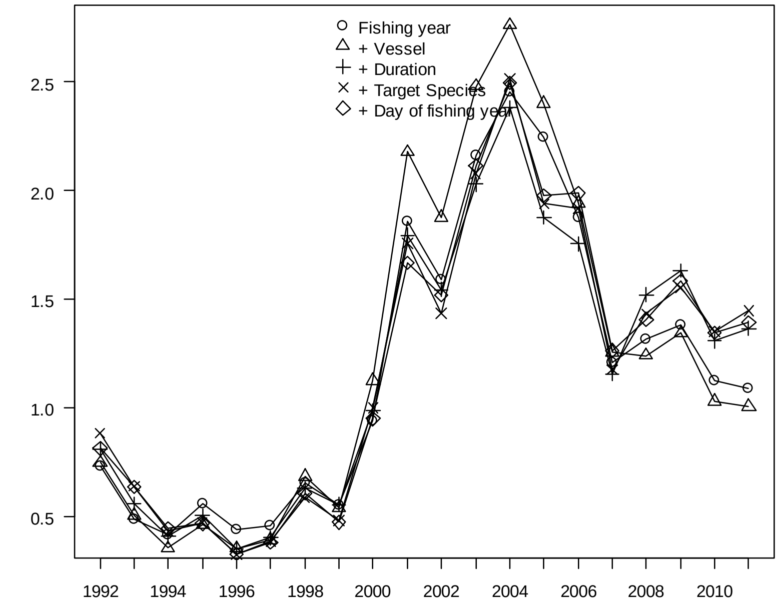

Figure A2.23: Annual CPUE indices for the Northern South Island stock normal model at each step in the variable selection process.

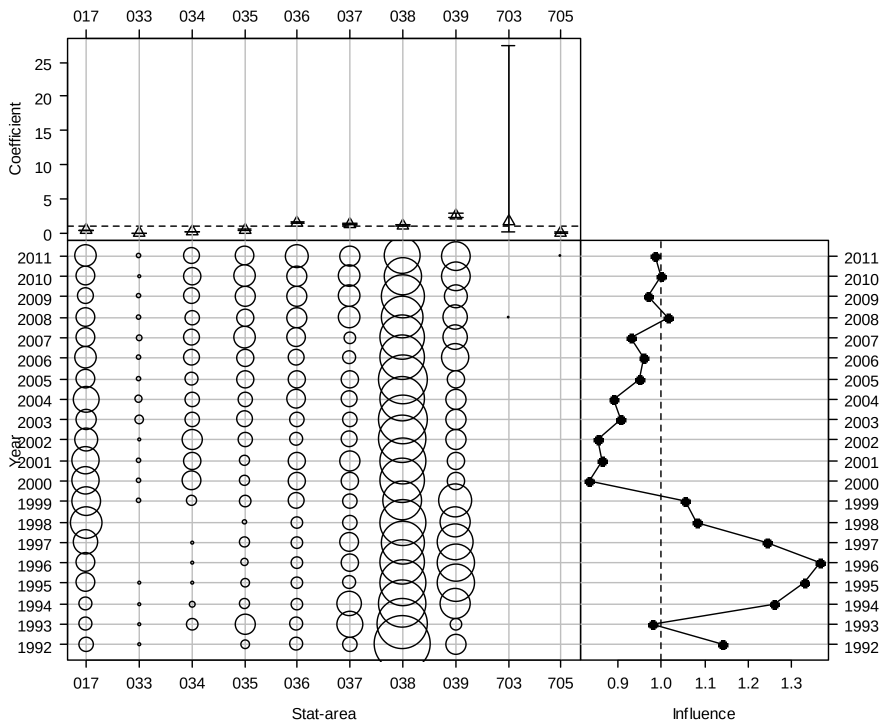

Figure A2.24: Effect and influence of statistical area in the northern South Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

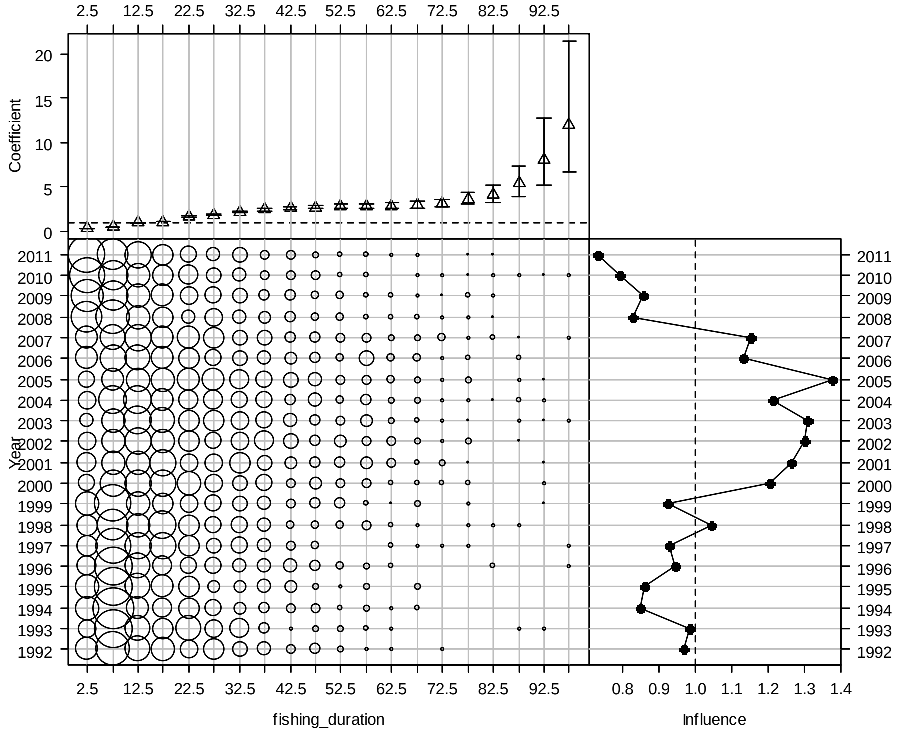

Figure A2.25: Effect and influence of fishing duration in the northern South Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

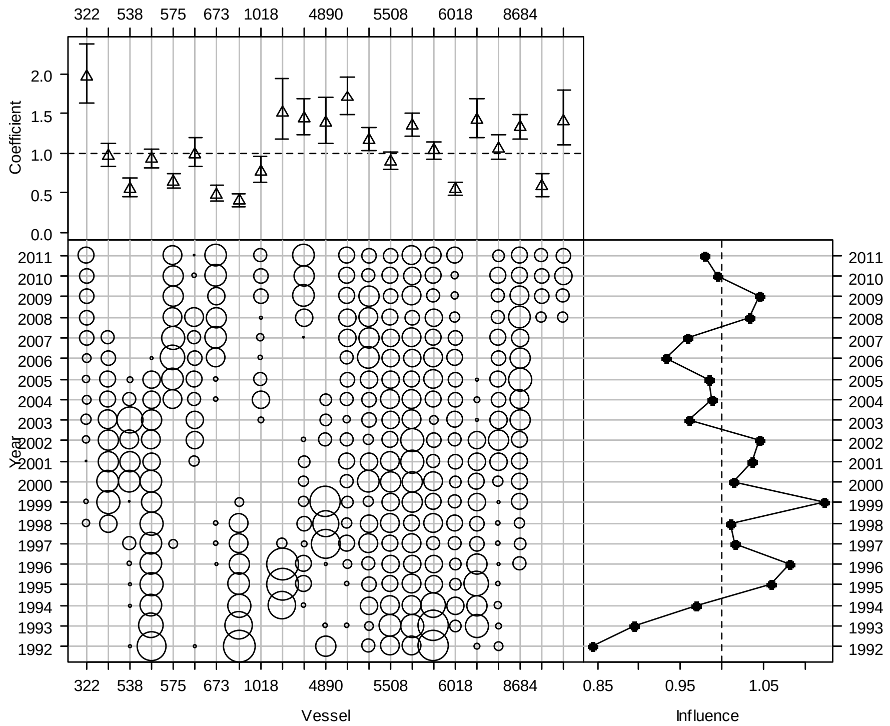

Figure A2.26: Effect and influence of vessel in the northern South Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.

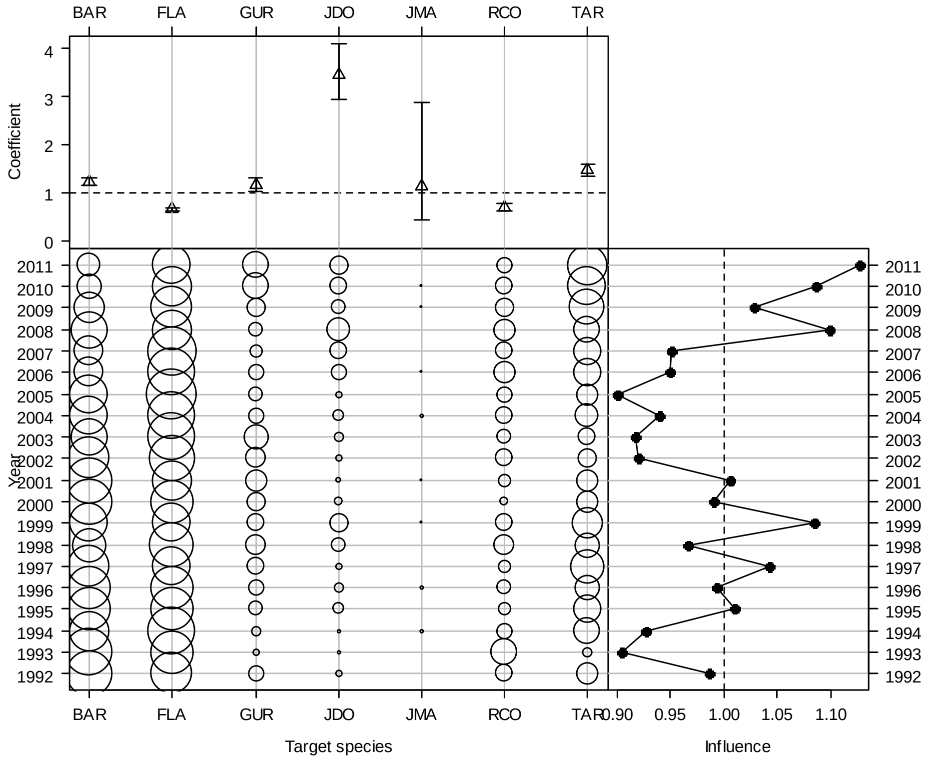

Figure A2.27: Effect and influence of target species in the northern South Island CPUE normal model. Top: relative effect by level of variable; Bottom-left, relative distribution of variables by fishing year; Bottom-right, influence of variable on unstandardized CPUE by fishing year.