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Characterisation and CPUE from 1989–90 to 2018–19 of jack mackerel off the west coast of New Zealand (JMA 7)

New Zealand Fisheries Assessment Report 2022/06

D.N. Webber,
P.J. Starr

ISSN 1179-5352 (online)
ISBN 978-1-99-102644-6 (online)

March 2022

New Zealand Government

Requests for further copies should be directed to:

Fisheries Science Editor
Fisheries New Zealand
Ministry for Primary Industries
PO Box 2526
Wellington 6140
NEW ZEALAND

Email: Fisheries-Science.Editor@mpi.govt.nz
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EXECUTIVE SUMMARY

Webber, D.N.[1]; Starr, P.J.[2] (2022). Characterisation and CPUE from 1989–90 to 2018–19 of jack mackerel off the west coast of New Zealand (JMA 7).

***New Zealand Fisheries Assessment Report 2022/06*. 65 p.**

Until the mid-1980s, only two jack mackerel species (both considered to be endemic) had been reported in New Zealand waters: the greenback horse mackerel (*Trachurus declivis*, JMD) and the yellowtail horse mackerel (*T. novaezelandiae*, JMN). A third species, the Chilean jack mackerel (T. *murphyi*, JMM), was first positively identified in 1986, but may have been present since 1984.

New Zealand's jack mackerel fisheries are managed as an aggregate complex of three species with no statutory requirement to report species specific catches. Consequently, commercial catches are reported as an aggregate of these three species (JMA).

The objectives of this project included to carry out a descriptive analysis of available data and literature to determine the species and stock structure of jack mackerel in JMA 7; to investigate methods to estimate the distribution of catch by species to develop species-specific CPUE series for JMD and JMN in JMA 7; and then to assess stock status of JMD and JMN in JMA 7 using the CPUE series as abundance indices.

The JMA 7 fishery is located off the west coast of the North and South islands of New Zealand and is the largest of the three JMA fisheries in terms of total catch. This document presents a descriptive analysis of the available JMA 7 data, including fishery independent trawl survey data, commercial catch and effort data, and observer data. However, the descriptive analysis of the data uncovered several issues, particularly with the observer data. These issues were deemed serious enough to prevent the development of reliable CPUE series by species and therefore prevented undertaking stock assessments of JMD and JMN in JMA 7.

Despite this setback, a set of combined species CPUE indices (i.e., the CPUE of JMD, JMM, and JMN combined) are presented that may be of some use to managers.

[1] Quantifish Ltd., New Zealand.
[2] Independent consultant.

1. INTRODUCTION

New Zealand's jack mackerel fisheries are managed as an aggregate complex of three species with no statutory requirement to report species specific catches. Consequently, commercial catches are reported as an aggregate of these three species (JMA). Until the mid-1980s, only two jack mackerel species (both considered to be endemic) had been reported in New Zealand waters: the greenback horse mackerel (*Trachurus declivis*, JMD) and the yellowtail horse mackerel (*T. novaezelandiae*, JMN). A third species, the Chilean jack mackerel (T. *murphyi*, JMM), was first positively identified in 1986, but may have been present since 1984 (McKenzie 2009).

JMA are found throughout New Zealand's Exclusive Economic Zone (EEZ), generally in less than 1000 m of water (Anderson et al. 1998, Hurst et al. 2000). Although there is a great deal of spatial overlap between the three species, JMD appears to be the most widespread of the three, JMN tends to occur more frequently in the waters off the North Island, and JMM tends to have a more southern distribution. The distribution of JMM is known to extend from the South American coastline to New Zealand and Tasmania and, at this scale, its distribution is largely driven by temperature and chlorophyll-a concentration (Bertrand et al. 2016).

In New Zealand, JMA are mainly caught by bottom trawl (BT), midwater trawl (MW), or purse seine (PS). There are four defined JMA Quota Management Areas (QMAs): JMA 1, JMA 3, JMA 7, and the nominal JMA 10 (Figure 1A). JMA 1 is managed by the Inshore Fisheries Management Team because most of the catch is taken by the domestic PS fleet. JMA in JMA 3 and JMA 7 are managed as part of New Zealand's deepwater fisheries. Prior to 1996, only JMA 7 was part of the Quota Management System (QMS), with a defined Total Allowable Commercial Catch (TACC) (Fisheries New Zealand 2020). JMA 1 and JMA 3 were brought into the QMS in 1996, with assigned TACCs and Total Allowable Catches (TACs).

The JMA 7 fishery is located off the west coasts of the North and South islands of New Zealand (Figure 1A and Figure 1B) and is the largest of the three JMA fisheries in terms of total catch. Most of the catch of JMA 7 is taken by chartered trawlers.

Although several studies have examined the species composition of JMA in New Zealand, these studies have mainly been limited to JMA 1 (Langley et al. 2016, Walsh et al. 2016). Walsh et al. (2016) focused on the species composition in commercial PS catches from 2009 to 2011 based on market sampling. They found that the majority (97%) of PS landings in JMA 1 in the study years were JMN. Langley et al. (2016) investigated species sampling of the JMA 1 catch that had been conducted since 1994 and concluded that the current sampling design was providing reliable estimates of catch for the three main jack mackerel species.

A pilot study to assess the feasibility of using an acoustic survey to obtain an abundance index of JMA in JMA 7 was conducted during summer 2012 (O'Driscoll et al. 2013). This pilot project concluded that it was "...feasible to survey jack mackerel using acoustics, but that it would be very difficult to do any kind of aggregation-based acoustic survey, because there are no concentrations of fish like those seen for southern blue whiting and hoki". The survey further concluded that "...it was not possible to separate the two major jack mackerel species (*T. novaezelandiae* and *T. declivis*) acoustically" and that "...[m]ark identification trawling was complicated because of our inability to target and capture individual schools. Jack mackerel were able to evade capture in short tows with small nets during the day and were observed on video swimming out of the net during hauling". Therefore, the primary outcome of this pilot survey was that it was considered impossible, given the level of technology in 2012, to acoustically survey the mixed jack mackerel populations in JMA 7.

Additionally, because JMD and JMN are mainly midwater species, with known diurnal vertical migration behaviour, fishery independent surveys using BT gear are also unlikely to reliably monitor these species. The 2012 acoustic pilot survey made 49 trawls to identify targets and collect biological samples. Twenty-eight of these tows were made with BT gear, six tows were made with MW gear, and the remaining 15 tows were made with a fine-mesh MW trawl. These trawls tended to catch both JMD and JMN because it was not possible to target individual schools. Because JMA made up 68% of the midwater catch (mesopelagic and MW) while accounting for only 11% of catch by BT, despite more BT than MW tows, it is reasonable to conclude that BT gear will not be a reliable monitoring tool for these species. Using midwater gear on mixed species schools is also not likely to be a reliable monitoring method, given the difficulty of conducting a random survey on actively moving schools.

This leaves commercial CPUE as the most likely source of information from which indices of abundance can be derived. However, using these data to create species-specific relative abundance series is hampered by the lack of species-specific information at the level of individual tows. To overcome this problem, McKenzie (2008) applied the average species composition calculated within several spatial strata to individual tows within the stratum using species identification made by on-board fishery observers (Rohan 2006). However, this procedure was unlikely to result in reliable estimates of species-specific abundance indices even if the average estimates of species composition were accurate. This is because standardised CPUE analyses use the variation of the catch for each tow relative to the average catch per tow to estimate the impact on catch rates of covariates (such as vessel or depth). Once the effect of the covariates has been removed, the remaining variation is assigned to each year and this 'year coefficient' is interpreted as resulting from changes in abundance. However, applying average species proportions across relatively large strata to individual tows instead of using the actual species proportions in the tow will reduce the variability in the analysis and will likely lead to biased coefficient estimates because the model does not have access to the real variation by species relative to the covariate values. Furthermore, this work did not critically examine the quality of the species estimates being made by the on-board fishery observers which have been determined to be unreliable (see below).

Taylor (1999) estimated species proportions for the component JMA species, used these estimates to prepare CPUE analyses for JMD and JMN, and then completed JMD and JMN stock assessments for JMA 7. However, these analyses were based on the observer species proportion estimates which are now considered unreliable, for reasons presented in Section 2.2.2 below.

Consequently, the JMD and JMN stock assessments for JMA 7 attempted by Taylor (1999) and McKenzie (2009), both of which were based on CPUE analyses which used unreliable observer species composition information, should not be used to inform the management of these two species in JMA 7.

This Fisheries Assessment Report documents Fisheries New Zealand project JMA2017-01. The overall objective of this project was "to carry out stock assessments for the main jack mackerel species in JMA 7, including estimating stock biomass and sustainable yields". Specifically, the project objectives were:

- to carry out a descriptive analysis of available data and literature to determine the stock structure of jack mackerel in JMA 7;
- to investigate methods to estimate the distribution of catch by species and develop species-specific CPUE series for JMD and JMN in JMA 7; and
- to assess stock status of JMD and JMN in JMA 7 where abundance indices are available.

To deal with the lack of catch and effort information specific to each JMA species, this project initially proposed to use trawl survey and scientific observer data to develop a spatio-temporal model that would be capable of predicting species proportion at any location and time in JMA 7. The proposal was to develop a statistical methodology to perform standardised CPUE analyses for mixed species fisheries with estimates of species composition derived from this spatio-temporal species proportion model. This methodology was to be applied to JMA 7, with the intent to use the species-specific CPUE abundance indices in stock assessments for JMD and JMN.

However, the descriptive analysis of the data uncovered several issues, particularly with the observer data, which appeared to have been unreliably collected against sampling standards that have changed over the years and which appear to have been poorly followed by the observers (see discussion of these issues in

Section 2.2.2 below). These issues were deemed serious enough to prevent the development of reliable species-specific CPUE series and therefore prevented undertaking stock assessments of JMD and JMN in JMA 7. However, a CPUE series for all three species combined using both the scientific observer data (COD) and the compulsory commercial catch and effort (EDW) data was developed which may be of use to managers.

Appendix I gives definitions of gear codes and species codes used in this report.

2. METHODS

2.1 Maps

The New Zealand inshore finfish statistical areas predate the QMS and unfortunately the QMA boundaries established at the inception of the QMS were not set to coincide with these inshore finfish statistical areas. Consequently, the JMA 7 QMA boundaries are so broad that they include areas that are likely to be independent from the main fishery off the west coast of New Zealand. For instance, JMA 7 includes parts of Statistical Areas 016, 017, and 018 which are situated in the eastern end of the Cook Strait. These eastern waters include an area around Kaikōura where an active PS fishery, targeted at kahawai in the early 1990s, captured some JMA. These three statistical areas were omitted from this analysis because they are on the east coast and account for only small amounts of current JMA catch. Statistical Areas 043 (Manukau Harbour) and 044 (Kaipara Harbour) are also part of JMA 7 but have been excluded from this study because the shallow nature of the harbours restricts the fishing methods to setnet and ringnet which catch only small amounts of JMA. Statistical Area 032, which is shared between JMA 3 and JMA 7, was included in its entirety in this analysis. For the purposes of this analysis, all west coast statistical areas from Statistical Area 032 in the south to Statistical Area 048 in the north were included (with the exception of Statistical Areas 043 and 044), extending into the western reaches of Cook Strait. The Statistical Areas included are:

- 032–048 (excluding 043 and 044)
- 101–104
- 701–706
- 801

These statistical areas are shown in Figure 1B.

2.2 Data

This analysis uses data from three different databases:

- the trawl survey database (trawl) (Mackay 2020);
- the Centralised Observer Database (COD) (Sanders & Fisher 2018);
- commercial catch and effort data from the Electronic Data Warehouse (EDW).

These data sets are described below.

2.2.1 Trawl survey data

The trawl survey database (trawl) contains information collected by research trawl surveys on research vessels and chartered commercial fishing vessels (Mackay 2020). These data were obtained from Fisheries New Zealand for 1 October 1986 to 30 September 2018 with no other restrictions (replog 12271). Although these data are collected in a such a manner that, for most fishing events, the JMA species identification has been done correctly and therefore should provide reliable estimates of the catch by species in each tow, they are spatially and temporally limited off the west coast of New Zealand, being either too close to shore or operating at times which are not optimal for JMA. These random stratified surveys are optimised for other species and mainly use BT gear, which sample JMA poorly, with MW gear only rarely used. Despite these issues, these data are presented to provide an approximate spatial distribution of the three species because this is the only data set where the species catch has been reliably recorded.

Acoustic survey indices cannot split JMA by species in the acoustic signal and it is nearly impossible to use trawl gear to deconstruct the species composition of the school (O'Driscoll et al. 2013). Consequently, these data cannot be used to inform JMA species distributions in JMA 7.

2.2.2 Centralised observer database (COD) data

The COD contains information collected by Fisheries Observers deployed at sea (Sanders & Fisher 2018). The COD data request obtained catch and effort data from bottom trawl and midwater trawl observer trips which captured any species of JMA anywhere in New Zealand by requesting data for trips that caught any of the four JMA species codes (JMA, JMD, JMM, JMN) in complete form. That is, if any single tow in a trip registered a JMA species, then all information for every tow from that trip was requested. Trips that never caught JMA in any of the tows were omitted. The COD data (replog 12225) were limited to:

- the fishing years 2006–07 to 2018–19 (1 October 2006 to 30 September 2019);
- the Scientific Observer Programme (SOP) origin code;
- start longitude and start latitude available and within JMA 7;
- core vessels which were defined as those vessels that caught JMA in at least three tows for five years or more;
- bottom or midwater trawl (codes: BT, MW, BPT, MPT, PSH, PRB, PRM);
- the top ten target species (JMA, BAR, HOK, EMA, TRE, TAR, KAH, SWA, WAR, RBT); and
- start bottom depth between 0 and 500 m.

The design of the COD data collection protocol includes provision for JMA species identification (see Appendix II for the observer instructions as of 5 March 2019). For this reason, these data were fundamental to developing a model to predict the catch of the three JMA species for all fishing events that caught JMA in the EDW data set. However, several major issues were discovered in the COD data that caused us to doubt the reliability of the species identification in this data set.

Three fields within two tables in the COD database should contain the information needed to estimate the species composition of an observed tow: species_weight, sample_weight, and catch_weight (Figure 2). Each of these fields are described below, as well as the problems encountered and why they were not used.

1. species_weight

Observers are not asked to record the JMA catch for each fishing event at the species level because this is not practical to achieve. Instead, the sampling protocol stipulates the recording of the total catch of JMA (i.e., JMD+JMM+JMN) for a fishing event in the species_weight field. Therefore, none of the species-specific codes (JMD, JMM, or JMN) should appear in the species_weight field in the greenweight tables (i.e., y_trw_observer _greenweight and y_trw_new_observer_greenweight).

However, upon looking at the data it was clear that some observers were recording catch at the species level (Table 1). This was confirmed by the Fisheries New Zealand Research Data Management team who noted "…observers do not speciate the catch to JMD, JMM and JMN as I am told this is not practical to achieve, speciating is done at the biological sampling level… The data supplied for job number 12225[3] is sourced solely from catch records. Looking at the data it is clear that some observers have been speciating mackerel i.e., there are 25,363 catch records where mackerels have been speciated and 56,111 records where they have not (i.e., reported as JMA)."

[3] This replog was later updated with replog 12870 which included an additional year of data.

A meeting held on 17 May 2019 with Fisheries New Zealand staff further confirmed the above observations. Because it is not known how the observers arrived at their species-specific totals, JMA species-specific species_weight fields in the y_trw_observer_greenweight and y_trw_new_observer_greenweight tables were discarded. At this meeting, it was confirmed that observers were instructed to fill the species_weight field with the total JMA catch and were not asked to provide the component species catch, because this was not practical to achieve. Splitting the catch by species was designed to be covered through the biological sampling component of the protocol, expecting that the splitting of the JMA catch into species would be done analytically when the data were processed or analysed. Because there is no stated protocol given to the observers to undertake this procedure, they would be filling out these fields in an *ad hoc* manner and the fields must be considered unreliable.

2. sample_weight

The sample_weight field, within the y_lfs_general_catch_sample table, should contain the weight of JMD, JMN, and/or JMM examined for species identification within samples from a fishing event. The observer protocol stipulates that this field is used to report the weight by species for samples of JMA taken from the catch in the event. At the May 2019 meeting, Fisheries New Zealand staff stated that this field was likely to be accurate. However, this field may be unrepresentative of the entire catch in a tow if an observer took a single sample (i.e., a few bins of fish) at the beginning of unloading a tow. Observers are instructed to take one, two, or more samples, depending on the size of the tow, in various locations in the net (see Appendix II). A single sample taken at the beginning of unloading a tow may be unrepresentative of the total tow because JMA, in some circumstances, are capable of outrunning trawl gear (O'Driscoll et al. 2013) and larger fish will outrun the gear for longer than smaller fish. This could result in a gradient of small fish at the codend of the net to larger fish. Also, JMM tend to be larger than JMD and JMN, potentially leading to a gradient bias by species as well.

Furthermore, some observers attempt to estimate the catch by species within a net by eye rather than taking random samples throughout the net and scaling up. This adds yet another source of uncertainty to the data.

Given these considerations, there was a concern that an unknown proportion of the sample weights in the COD database was either unrepresentative or obtained incorrectly, resulting in unreliable information.

3. catch_weight

Finally, the catch_weight field, within the y_lfs_general_catch_sample table, gives the species (JMD, JMM, JMN) weight captured in the tow. A simple calculation should provide estimates of the species catch by scaling the sample_weight by the ratio of each species_weight relative to the sum of the sampled JMD+JMM+JMN. If α is the species_weight, β_s is the sample_weight for each species (s), then the catch_weight for each species (γ_s) should be calculated as:

$$\gamma_s = \alpha \frac{\beta_s}{\sum_s \beta_s}$$

However, when this calculation was made retrospectively, the values frequently did not align with the declared species_weight fields, indicating that the catch_weight field had been filled out incorrectly (Table 1).

There was a wide range of issues in the COD data set, with examples that include the following.

- Observers recording JMD, JMM, or JMN species_weight rather than JMA.
- Observers recording JMD, JMM, or JMN species_weight with no associated sample_weight and/or catch_weight.
- A mixture of JMA, JMD, JMM, and JMN recorded for species_weight. Sometimes the sum of JMD+JMM+JMN adds up to the JMA species_weight, sometimes it does not.

- Observers only filling out sample_weight.
- Observers only filling out catch_weight.
- Observers only reporting JMA in both tables (i.e., no species-specific estimates of sample_weight).
- Observers reporting JMA and JMN in catch_weight but JMD, JMM, and JMN in species_weight (and a variety of similar issues).

A summary of the proportion of erroneous records for a range of issues is provided in Table 1. Many of the identified issues appear to have become worse during the period extending from the mid-2000s to the mid-2010s before showing some improvement by the end of the 2010s (species weight errors: Figure 3, sample weight errors: Figure 4, catch weight errors: Figure 5). Of particular concern is the percentage of sample_weight proportions being different to the catch_weight proportions, overall 12% of records exhibit this error (Table 1), however, this increased to over 35% in 2009–10 and 2010–11 (Figure 4).

2.2.3 Commercial catch and effort (EDW) data

The commercial catch and effort data provided by Fisheries New Zealand are received in three tables: (1) estimated sub-catch, (2) fishing effort, and (3) landings. The first two tables contain the effort and estimated catches by event within a trip, while the landing table records all landing events for each trip, which will include multiple effort events depending on the length of the associated trip. This report has concentrated on the information in the estimated sub-catch and fishing effort tables because they contain the detailed descriptive data associated with each event, as well as the estimated catches that go with the event. The landing data have no spatial or capture method information which is inferred from the effort data by linking landings with the associated trip effort records. This step is necessary for species that are caught incidentally because only a limited number of species are reported in the estimated sub-catch table (usually only the top five to eight species per fishing event). However, because JMA is the primary target species in this fishery and should be nearly always captured among the top five species, there is confidence that the estimated catches can be used to characterise this fishery, both in terms of distribution and for CPUE estimation.

Commercial catch and effort data were obtained from the EDW in March 2020 (replog 12870, which updated an earlier data request under replog 12275 with an additional year of data). If a vessel caught, targeted, or landed JMA, every event for that trip was requested. All events in the trip, even those which might have fished outside JMA 7 (or caught no JMA) were needed so that the entire trip could be categorised. This was done so that the JMA 7 fishery boundaries could be redefined as required. Imputation of missing latitude and/or longitude was attempted before dropping those records. This involved identifying fishing events where latitude/longitude fields were missing and checking for latitude/longitude before and after that fishing event within a trip. If a before and after latitude and longitude was found, then the mean location was used, otherwise that fishing event was dropped. This imputation was only possible for 16 trips (of 702 902 trips missing latitude and/or longitude from a total of 4 311 620 trips). Statistical area was derived from location rather than the field provided in the EDW database.

All commercial catch and effort data used in this report were limited to:

- the fishing years 1989–90 to 2018–19 (1 October 1989 to 30 September 2019) and
- paired start longitude and start latitude, either in the data or after imputation.

This subset of the data was used to generate the maps that extended beyond the area of interest in this document. Tables and figures that present estimated catch were based on a smaller subset of the data that was limited to:

- those tows situated within the JMA 7 boundary defined in Section 2.1 and Figure 1B and
- those tows that caught JMA (most catch was reported as JMA, but some records reported JMD, JMM, or JMN, and these were changed to JMA).

Finally, the following filters were applied to the data used for the CPUE analysis:

- vessels that caught JMA in at least 50 tows for five years or more;
- BT or MW gear;
- the top ten target species (JMA, BAR, HOK, EMA, TRE, TAR, KAH, SWA, WAR, RBT);
- start bottom depth between 0 and 500 m;
- fishing duration between 0.5 and 10 hours;
- effort height between 0 and 130 m; and
- effort width between 0 and 330 m.

2.3 CPUE

Catch per unit effort (CPUE) series were developed for the COD and EDW data sets. CPUE was modelled as the total estimated catch weight (tonnes) of all three JMA species per tow ($\boldsymbol{Y}$) using a generalised linear model (GLM):

$$\boldsymbol{Y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}$$

where $\boldsymbol{X\beta}$ is the linear predictor composed of a matrix of independent variables ($\boldsymbol{X}$) and vector of estimated coefficients ($\boldsymbol{\beta}$), and $\boldsymbol{\varepsilon}$ is the error term vector. The error term was modelled using both the lognormal and gamma distributions. Three different series were modelled:

- EDW from 1989–90 to 2001–02 for BT fishing events
- EDW from 2000–01 to 2018–19 for MW fishing events
- COD from 2006–07 to 2018–19 for MW fishing events

The choices for these year ranges for each capture method were made with agreement from the Deepwater Working Group (DWWG), based on the amount of data for each capture method in each fishing year. All CPUE series were limited to those events targeting JMA. Only series that modelled positive catches were developed because the incidence of zero tows in this target fishery was extremely low. Fishing year was forced as the first explanatory variable. Different variables were offered to the EDW and COD series depending on what were available. Variables offered to the two EDW series are given below.

Variable	Type
Month	Categorical
Target species	Categorical
Vessel	Categorical
Statistical area	Categorical
Fishing speed (km/h)	Continuous
Fishing depth (m)	Continuous
Bottom depth (m) at the beginning of the tow	Continuous
Duration of the tow (hours)	Continuous
Effort height (m)	Continuous
Effort width (m)	Continuous

Variables offered to the COD series included the following.

Variable	Type
Month	Categorical
Target species	Categorical
Vessel	Categorical
Statistical area	Categorical
Duration of the tow (hours)	Continuous
Fishing speed (km/h)	Continuous

Each continuous explanatory variable was offered as a linear term, a second-degree polynomial, and a third-degree polynomial, allowing the model to choose the best term for the variable. Models were run using the *glm* function in R and variable selection was done using a two-step method which used the Akaike information criterion (AIC) to select variables in a step-wise manner and r^2 to determine the final model by permitting variables that explained at least 1% of the deviance to remain in the final model. The final model was then run again using the package *brms* in R. The *brms* package is a flexible package for running Bayesian GLMs and makes use of the Stan modelling language (Stan Development Team 2017). Markov chain Monte Carlo (MCMC) mixing was checked visually using MCMC trace plots. The leave-one-out information criterion (LOO IC) was used to select between lognormal and gamma models (Vehtari et al. 2017). The LOO IC works in the same way as AIC in that a smaller LOO IC represents a more parsimonious model.

An R package called *influ2* was developed to generate GLM diagnostic plots including influence plots and coefficient-distribution-influence (CDI) plots. This package is based on the original *influ* package developed Bentley et al. (2012). However, rather than processing output from the *glm* function, *influ2* processes output from the *brms* package. This R package is publicly available on GitHub (https://github.com/quantifish/influ2).

3. RESULTS

3.1 Trawl survey data

The trawl survey data should contain the most reliable species identification information because the surveys are staffed with biological scientists and technicians who are trained to identify species using a specified protocol. This can be seen in the summaries provided in Table 2 and Table 3, which show that most of the survey catch weight is recorded into the three component species and very little use the generic JMA code (Table 2, Table 3). These data show a higher concentration of JMD off the North Island within JMA 7 (left panel, Figure 6). JMM appear to have a more southerly distribution with few JMM in JMA 7 (central panel, Figure 6). JMN are largely mixed with JMD (right panel, Figure 6).

The three species exhibit different depth preferences, with JMN being caught in shallower water than JMD and JMM, while JMM occur in a wider range of depths compared to JMD and JMN (Figure 7).

Catch by jack mackerel species and year for JMA 7 in the trawl survey database is provided in Table 2. When these same data are summarised by capture method, almost all catch was made by BT, with only a very small amount of MW (Table 3). The small amount of catch and the reliance on the BT capture method indicate that these data are unlikely to provide reliable estimates of species composition or abundance.

3.2 COD data

JMA was caught in 98% of events that targeted JMA in the COD data set. This percentage was much higher than was reported in the EDW data, but the shortfall is likely due to poor reporting of small catches of JMA in the EDW data because the TCEPR (Trawl Catch, Effort Processing Return) deepwater forms only report the top five species by weight for any fishing event.

Although the estimates of JMA species catch from the COD data are considered unreliable, the spatial distribution of the catch for all three species combined is presented by capture method. The distribution of JMA caught by MW covers a smaller footprint when compared with BT, and most MW JMA catch is within the high catch rate region for BT (Figure 8). In recent years, the footprint of MW has spread, while the footprint for BT has contracted (Figure 9, Figure 10). Unsurprisingly, these observations mirror the equivalent observations based on the EDW data (see Section 3.3 below).

Over 96% of JMA catch in the COD data set was caught when targeting JMA (Table 4). A small amount of JMA was caught when targeting barracouta (BAR), otherwise there seemed to be little bycatch of JMA in JMA 7 when fishing for other species (Table 4). Most of the JMA catch reported in the COD data was caught in Statistical Areas 041, 037, and 040 (Table 5). JMA appeared to be caught year-round primarily by MW gear in the COD data set (Figure 11).

The level of observer coverage in the COD data was summarised by day of the year, depth, longitude, and latitude and was then compared with equivalent summaries from the EDW data. Such comparisons indicate the degree to which the observer data set is representative of the overall fishery (see Figure 42 to Figure 48 in Appendix III). These comparisons indicate that the coverage of the fishery has improved considerably between 1990–91 and 2018–19. From 1990–91 to 2000–01, observer coverage of the JMA 7 fishery catch (compared with the EDW catch) was poor but improved from in 2007–08. The coverage of the 2018–19 JMA 7 fishery was excellent (Figure 48).

3.3 Characterisation of the defined JMA 7 fishery based on the EDW data

As noted in Section 2.1, a custom definition was made for JMA 7 which only included relevant west coast statistical areas and dropped the east coast and harbour statistical areas (Figure 1B). It also added the straddling Statistical Area 032. When the estimated catches from this customised JMA 7 definition were summed, the annual totals approximated the equivalent landing sums based on landing destination code "L" (and codes "T" and "O" before 1998–99) and the Quota Management Reports / Monthly Harvest Returns (QMR/MHR) totals (Table 6, Figure 12). Although "L" is the primary code used to denote landings to a Licenced Fish Receiver (LFR), this code was not always used in the early years of the QMS, with codes "T" and "O" used for catches that were transhipped to foreign vessels which then left the New Zealand EEZ without going to a New Zealand port. Table 7 and Figure 13 show that the use of codes "T" and "O" was confined to the 1990s and needed to be included to match the QMR landings for these early fishing years. The "T" and "O" landings were not used after 1998–99, leaving the "L" code as the primary reporting code.

The EDW landing table also provides information on the processed state of JMA when delivered to the LFR. Figure 14 shows that most JMA were landed as GRE (green or whole) or DRE (dressed). The DRE conversion factor adds 60% to the processed weight to convert to greenweight; no conversion factor is required for GRE landings (Figure 15). Some of the landed state for JMA 7 is designated as MEA (mealed) which means that the catch had been damaged and could not be sold as green or dressed and was converted to fish meal. The conversion factor for MEA is 5.6 (Figure 15) which is large, but this landed state is not a large component of the catch, especially in recent years (Figure 14).

There has been a progression in the form types used to report JMA 7 catch. Table 8 shows that the majority of catch was reported on the deepwater TCEPR paper forms. These forms have been replaced in the deepwater fleet, beginning in 2017–18, with the electronic reporting system (ERS-Trawl) (Figure 16). There has been a negligible amount of reporting on the small vessel (< 28 m) daily (Catch Effort Landing Return, CELR) forms or event (Trawl Catch Effort Return, TCER) forms.

The majority of JMA 7 catch (about 87% over 30 years) has been made by MW gear (Table 9), with almost all of it targeted at JMA (Figure 17). Of the remaining 13% of the total JMA 7 catch, 12% was made by BT, again almost all of which is targeted at JMA.

Table 10 indicates that 95% of all JMA 7 catch was targeted at JMA, with BAR and HOK target fishing accounting for 4% of the remaining 5% of the JMA 7 catch.

The majority of JMA caught in JMA 7 was caught in Statistical Areas (in descending order of importance) 041, 037, 040, and 042 (Table 11, Figure 18). Maps showing the spatial distribution of JMA catch for each gear type (Figure 19) indicate that, while the distribution of BT catch was much broader than for MW, they are concentrated in similar areas. The 'Other' gear type shows little pattern in the distribution of catch. The spatial distribution of the MW catch plotted in sequential five-year blocks (Figure 20) shows that, while the fishery has increased in intensity over time, it has operated in the same areas over the 30-year period. A similar sequential plot for BT shows that this fishery has reduced in intensity and covers a much broader area than the MW fishery (Figure 21). However, the reduction in intensity reflects the drop in the use of BT and the increase in MW when fishing for this species (see Figure 17). There is some suggestion that during the 1990s, the catch of JMA 7 was less concentrated and distributed further south. However, the concentration of catch seems to have increased off the North Island from about 2000–01 for the MW capture method (Figure 20, Figure 21).

A plot showing the monthly catch of JMA 7 over 30 years indicates that this species is captured throughout the year, but there seems to be more catch in the summer months (Figure 22).

The majority of JMA caught in JMA 7 has been caught between the 50–300m depth contours (Figure 23, Figure 24). There appear to be three modes in the distribution of depths at which JMA is caught (Figure 24) which may represent the three different species. Generally, MW gear is being fished at or near the bottom when targeting JMA (Figure 25).

The number of BT vessels that caught JMA in JMA 7 has declined by about 50% over the 30-year data period (Table 12). The number of MW vessels that caught JMA in JMA 7 has declined even more, dropping by about 70% over the same period. Recently, just under 50 BT vessels and under 20 MW vessels caught JMA in the JMA 7 fishery (Table 12).

3.4 CPUE

The distribution of the EDW data by vessel and fishing year for BT and MW was acceptable with 10 BT vessels and 10 MW vessels included in the CPUE analysis (Figure 26). Only 7 vessels were included in the COD CPUE analysis, but these vessels had excellent overlap by fishing year (Figure 27).

The final EDW BT series included vessel, month, and fishing duration specified as a third-degree polynomial in both the lognormal and gamma models (gamma model presented in Table 13). The final EDW MW and COD MW series both included fishing duration specified as a third-degree polynomial and statistical area in both the lognormal and gamma models (gamma models presented in Table 14 and Table 15).

Both the final lognormal and gamma models were taken to MCMC for all three series. MCMC mixing was excellent in all cases, although only the trace plots for the gamma models are presented in Figure 28, Figure 29, and Figure 30. The lognormal trace plots were very similar. According to the LOO IC, the gamma distribution fitted the data better than the lognormal model in all cases, so the lognormal models were discarded (Table 16). This is particularly apparent when comparing the density of the data with simulated replicates from the posterior distribution, with Figure 31, Figure 32, and Figure 33 all showing better fits for the gamma model.

For the EDW BT CPUE series, the influence of the vessel explanatory variable was minimal early in the time series, but there was greater influence in the latter part of the series when the number of vessels was greatly diminished (Figure 34). Month (Figure 35) and fishing duration (Figure 36) also had a greater influence on the series in these later years because of sparse data. This suggests that the last few years in the EDW BT series should be interpreted cautiously because of the reduction in the quantity of data.

Fishing duration was the most important explanatory variable in the EDW MW CPUE series. This variable had a consistently increasing influence in the standardisation model because the data indicated a trend towards longer tows (Figure 37). Statistical area made a few early adjustments to the series (i.e., in 2000–2004 fishing years), but its influence was trivial from 2005 on (Figure 38), indicating stability in the distribution of spatial data.

Fishing duration was also the most important explanatory variable in the COD MW CPUE series and again had a consistently increasing influence in the standardisation model because of the trend of increasing tow duration (Figure 39). Similarly, statistical area made a few early adjustments to the series (i.e., in 2007), but its influence was trivial from then on (Figure 40). Although these two data sets are not completely independent, their reporting is independent and it is reassuring that the two analyses are so similar in their diagnostics.

The standardised CPUE series for the EDW BT fishery from 1990–91 to 2002–03 shows a lot of interannual variability (Figure 41), and, as mentioned above, should be interpreted cautiously, especially in the last few years because of the loss of data at the end of the series. The EDW and COD MW series show less interannual variability and agree with each other in their overall trend and model diagnostics. Overall, JMA CPUE appears to be increasing steadily from the early to mid-2000s up to end of the series in 2018–19 (Table 17, Figure 41).

4. SUMMARY

The objectives of this project included: to carry out a descriptive analysis of available data and literature to determine the stock and species structure of jack mackerel in JMA 7; investigate methods to estimate the distribution of catch by species and develop species-specific CPUE series for JMD and JMN in JMA 7; and to assess stock status of JMD and JMN in JMA 7 where abundance indices are available.

This document presents a descriptive analysis of the available JMA 7 data. However, the descriptive analysis of the data uncovered several issues, particularly with the observer data. These issues were deemed serious enough to prevent the development of reliable CPUE series by species and therefore prevented undertaking stock assessments of JMD and JMN in JMA 7. The issues with the observer data are complex and required discussions with a fisheries observer to fully understand the severity of the issues. In short, the species-specific sampling of JMA in COD appears to be poorly collected against uncertain standards that have changed over the years. As well, the designated sampling standards were not always followed correctly; issues were identified with approximately 12% of records across all years. Many of the identified issues appear to have become worse during the period extending from the mid-2000s to the mid-2010s (with issues identified in over 35% of records during several years) before showing some improvement by the end of the 2010s. It should also be noted that this list of issues is not exhaustive and will not account for biases that arise from the sampling design. Therefore, the COD data are likely not sufficiently reliable for deriving species proportions by tow, which is what is required to develop a CPUE series to be used as an abundance index in a stock assessment.

This has important ramifications for several past studies that have relied on these data to develop species-specific distributions. For example, catch at age (e.g., Horn & Maolagain 2018) analyses require species proportions in order to weight the age frequencies properly. Previous stock assessments for JMA 7 were also based on these estimates.

Despite this, it is likely that using the COD data to derive the annual total catch of each species is not as badly compromised. For example, Penney et al. (2011) used monthly species proportion tables from 1985 to 2010 for JMA 3 and JMA 7 to split JMA catch into JMD, JMM, and JMN. Although the source of these data is uncertain and is simply accredited to "Paul Taylor, NIWA, pers comm", it is likely that these data were based on an analysis similar to that presented by Taylor (1999) and Rohan (2006). Although these analyses are not adequate for deriving tow by tow species proportions, the errors may average out at an annual level.

Future efforts might make use of the trawl survey data in combination with COD data, once the issues with the collection of COD data are remedied. In the meantime, the following two major recommendations are made.

1. Undertake a study to investigate the species representativeness of the observer sampling (i.e., the representativeness of a sample or samples from a tow for the entire tow).
2. Clearly specify the observer protocols and require the observers to follow them.

5. ACKNOWLEDGEMENTS

This work was funded under the Fisheries New Zealand research project JMA2017-01. Thanks to our colleagues at Fisheries New Zealand, especially David Foster, Richard Cropp, and Chris Dick for discussions relating to the observer data, Tiffany Bock for managing the jack mackerel fisheries, and Gretchen Skea for chairing the Deepwater Working Group meetings and managing the project. Thanks also to members of the Deepwater Working Group for thorough discussions.

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7. TABLES

Table 1: Summary of error checks done on the COD database. Each error check is based on the full data set, the same record can be included in more than one error category. This list of errors is not an exhaustive list.

Description of error		Percent of records
species_weight errors		
1.	species_weight for either JMD, JMM or JMN recorded but no associated sample_weight	6.31
2.	species_weight for either JMD, JMM or JMN recorded but no associated catch_weight	6.39
3.	species_weight for either JMD, JMM or JMN recorded but no associated sample_weight or catch_weight	6.45
4.	species_weight for either JMD, JMM or JMN recorded (should only be JMA)	11.83
5.	species_weight for JMA recorded as well as either JMD, JMM or JMN	2.43
6.	species_weight for JMA recorded as well as JMA in either sample_weight or catch_weight	0.00
7.	Any of the above errors	11.83
sample_weight errors		
1.	only sample_weight for either JMD, JMM or JMN reported (i.e., no species_weight or catch_weight to scale up by)	0.02
2.	sample_weight reports JMA (i.e., useless for splitting by species)	4.18
3.	sample_weight reports JMD but species_weight or catch_weight do not	7.08
4.	sample_weight reports JMM but species_weight or catch_weight do not	4.04
5.	sample_weight reports JMN but species_weight or catch_weight do not	5.33
6.	sample_weight proportions are different to the catch_weight proportions	11.72
7.	the total sample_weight (i.e., JMD+JMM+JMN) is larger than the total species_weight	7.19
8.	any of the above errors	12.40
catch_weight errors		
1.	only catch_weight reported (i.e., no species_weight or sample_weight)	0.00
2.	the catch_weights do not match the species weights	7.43
3.	the catch_weight for JMD is different to the species_weight for JMD	4.37
4.	the catch_weight for JMM is different to the species_weight for JMM	4.56
5.	the catch_weight for JMN is different to the species_weight for JMN	2.00
6.	any of the above errors	7.43

Table 2: Total catch (tonnes) by species and fishing year in JMA 7 in the trawl survey database (trawl). A "–" represents zero catch.

Fishing year	JMA	JMD	JMM	JMN	Total
1989–90	0.02	–	–	–	0.02
1990–91	2.15	19.24	0.03	42.02	63.44
1991–92	0.00	–	–	0.01	0.01
1992–93	0.60	0.24	0.31	0.83	1.98
1993–94	–	–	–	0.00	0.00
1994–95	–	0.00	–	0.14	0.14
1995–96	1.24	0.26	1.36	1.49	4.34
1996–97	–	0.12	0.00	0.23	0.35
1997–98	2.53	1.66	0.76	3.80	8.75
2000–01	–	0.98	0.11	1.37	2.46
2003–04	–	0.13	0.01	0.15	0.28
2005–06	–	0.18	0.02	0.25	0.44
2007–08	–	0.09	0.02	0.25	0.35
2009–10	–	0.10	0.01	0.64	0.75
2011–12	–	0.26	0.01	0.26	0.53
2012–13	–	0.91	0.03	0.55	1.49
2013–14	–	0.22	0.01	0.09	0.33
2015–16	–	0.04	0.00	0.47	0.52
2016–17	–	0.02	0.01	0.00	0.02
2017–18	–	0.08	–	0.43	0.51

Table 3: Total catch (tonnes) by species and fishing gear method in JMA 7 in the trawl survey database (trawl) across all years in Table 2.

Gear	JMA	JMD	JMM	JMN	Total
Bottom trawl (BT)	–	2.71	1.95	4.68	9.34
High opening bottom trawl	6.53	21.45	0.23	48.16	76.37
Midwater trawl (MW)	0.00	0.36	0.52	0.13	1.01

Table 4: Percentage of observed JMA catch in defined JMA 7 (Figure 1B), by fishing year and target species in the COD database. A "–" represents zero catch.

Fishing year	JMA	BAR	HOK	EMA	TRE	TAR	KAH	SWA	WAR	Other	Total
1987–88	2.684	0.001	0.001	–	–	0.001	–	–	–	0.003	2.689
1988–89	1.368	0.016	0.007	–	–	–	–	–	–	0.017	1.407
1989–90	0.805	0.023	0.017	–	–	–	–	–	–	0.003	0.848
1990–91	1.097	0.017	0.041	–	–	–	–	0.000	–	0.000	1.155
1991–92	0.686	0.017	0.070	0.001	–	–	–	–	0.001	0.000	0.775
1992–93	0.642	0.010	0.046	–	–	–	–	0.000	0.000	0.001	0.699
1993–94	1.165	0.025	0.007	–	–	–	–	0.000	–	0.001	1.197
1994–95	1.256	0.033	0.078	–	–	–	–	0.000	0.000	0.001	1.369
1995–96	0.682	0.003	0.107	–	–	–	–	–	–	0.000	0.792
1996–97	0.242	0.011	0.110	–	–	–	–	–	–	0.004	0.368
1997–98	0.954	0.021	0.031	–	–	–	–	–	–	0.000	1.007
1998–99	1.139	0.000	0.017	0.000	–	–	–	–	–	0.000	1.157
1999–00	0.787	0.008	0.010	–	–	–	–	–	–	0.001	0.805
2000–01	0.266	–	0.013	–	–	0.000	–	–	–	0.001	0.281
2001–02	0.710	0.001	0.001	–	–	–	–	–	0.000	0.000	0.713
2002–03	0.431	0.000	0.000	0.000	–	0.000	–	–	–	0.000	0.432
2003–04	0.700	0.001	0.002	–	–	–	–	–	–	0.003	0.705
2004–05	0.720	0.008	0.024	–	–	–	–	–	–	0.000	0.751
2005–06	3.025	0.073	0.016	0.000	–	–	–	0.000	–	0.000	3.114
2006–07	2.629	0.032	0.002	0.021	0.002	0.000	–	0.000	–	0.000	2.685
2007–08	2.617	0.068	0.001	0.002	0.000	0.000	–	0.000	0.000	0.000	2.689
2008–09	3.491	0.040	0.001	0.001	–	0.000	–	0.005	–	0.000	3.538
2009–10	3.587	0.037	0.008	0.023	0.000	0.000	–	0.000	0.000	0.004	3.660
2010–11	3.001	0.006	0.000	0.000	–	0.000	–	0.000	–	0.000	3.008
2011–12	2.562	0.003	0.000	–	–	–	–	0.000	–	0.000	2.565
2012–13	7.279	0.005	0.000	0.043	–	–	–	–	–	0.000	7.328
2013–14	9.154	0.064	0.006	0.057	0.000	0.000	–	–	–	0.018	9.299
2014–15	9.389	0.310	0.000	0.050	0.000	0.000	–	0.000	–	0.001	9.750
2015–16	8.677	1.009	0.023	0.011	0.000	0.000	–	0.001	0.001	0.003	9.726
2016–17	8.327	0.234	0.008	0.000	0.001	0.000	0.000	0.001	–	0.001	8.572
2017–18	7.201	0.165	0.019	0.006	0.001	0.002	0.000	–	–	0.000	7.393
2018–19	8.821	0.611	0.044	0.042	–	0.000	–	–	–	0.002	9.521
Total	96.092	2.851	0.713	0.259	0.004	0.004	0.000	0.008	0.003	0.066	100.000

Table 5: Percentage of observed JMA catch in defined JMA 7 (Figure 1B), by fishing year and statistical area in the COD database. A “-” represents zero catch.

	Statistical Area																				
Fishing year	032	033	034	035	036	037	038	039	040	041	042	045	046	047	103	701	702	703	704	705	801	Total
1987–88	–	0.000	0.002	0.026	0.250	1.014	0.006	0.044	0.674	0.509	0.098	0.000	0.001	–	–	–	0.000	0.000	–	–	0.066	2.689
1988–89	–	–	0.005	0.030	0.129	0.494	–	0.024	0.352	0.263	–	–	–	–	–	–	0.000	–	–	–	0.110	1.407
1989–90	–	0.000	0.031	0.062	0.156	0.142	–	0.004	0.216	0.165	0.012	–	–	–	–	–	0.000	–	–	–	0.059	0.848
1990–91	0.000	0.000	0.054	0.026	0.083	0.655	–	0.065	0.054	0.217	–	–	–	–	–	–	0.000	0.000	–	0.000	–	1.155
1991–92	–	–	0.059	0.048	0.032	0.452	–	0.008	0.175	0.001	–	–	–	–	–	–	–	0.000	–	–	–	0.775
1992–93	–	–	0.052	0.042	0.099	0.116	0.001	0.000	0.100	0.274	–	0.000	0.000	0.000	–	0.000	0.000	0.000	–	–	0.015	0.699
1993–94	–	–	0.153	0.100	0.022	0.188	–	–	0.239	0.494	–	–	–	–	–	–	–	0.000	0.000	–	–	1.197
1994–95	0.000	0.000	0.133	0.142	0.256	0.370	–	0.160	0.093	0.213	–	–	–	–	–	–	–	0.000	–	–	0.003	1.369
1995–96	–	–	0.100	0.009	0.005	0.229	–	0.001	0.163	0.284	–	–	–	–	–	–	–	0.000	–	–	0.000	0.792
1996–97	–	–	0.130	0.014	0.007	0.124	–	0.000	0.080	0.010	0.002	–	–	–	–	–	0.000	–	–	0.000	–	0.368
1997–98	–	–	0.142	0.068	0.004	0.449	–	–	0.192	0.073	0.075	–	–	–	–	–	–	–	–	–	0.004	1.007
1998–99	–	0.000	0.114	0.012	0.001	0.176	–	–	0.317	0.235	0.301	–	–	–	–	–	0.000	0.000	0.000	-	–	1.157
1999–00	–	–	0.094	0.170	0.075	0.276	–	0.021	0.170	–	–	–	–	–	–	–	–	0.000	–	0.000	–	0.805
2000–01	–	0.000	0.028	0.009	0.048	0.127	–	–	0.066	0.000	0.001	0.000	0.000	0.000	–	–	–	0.000	–	0.000	0.000	0.281
2001–02	–	–	0.017	0.025	0.068	0.349	–	0.010	0.243	0.000	–	–	–	–	–	–	–	–	–	–	–	0.713
2002–03	–	–	0.038	0.007	0.055	0.189	–	–	0.142	–	–	0.000	0.000	0.000	-	–	-	0.000	–	–	0.001	0.432
2003–04	–	0.000	0.003	0.013	0.096	0.256	–	0.078	0.257	0.002	–	0.000	0.000	-	0.000	–	-	0.000	–	–	–	0.705
2004–05	–	0.000	0.074	0.001	0.000	0.010	–	–	0.041	0.049	0.432	0.120	–	0.000	0.000	–	-	0.000	–	–	0.024	0.751
2005–06	–	–	0.016	0.022	0.412	0.422	–	0.282	0.186	0.843	0.689	0.240	–	–	–	–	–	–	–	–	0.002	3.114
2006–07	–	–	0.006	0.017	0.042	0.573	–	0.009	1.030	0.846	0.113	0.004	0.001	0.000	–	–	–	–	–	–	0.044	2.685
2007–08	0.000	0.000	0.090	0.113	0.190	0.555	0.004	0.066	0.559	0.789	0.105	0.010	0.000	0.000	–	–	–	–	–	–	0.208	2.689
2008–09	–	–	0.028	0.114	0.088	0.263	0.000	0.001	0.572	1.964	0.244	0.040	0.000	0.000	0.000	–	–	–	–	–	0.225	3.538
2009–10	–	0.000	0.233	0.039	0.272	0.659	–	0.027	0.604	1.296	0.181	0.100	0.000	0.000	0.000	–	–	–	–	–	0.251	3.660
2010–11	–	–	0.000	0.013	0.049	0.462	0.000	0.024	0.579	1.347	0.433	0.023	–	–	–	–	–	–	–	–	0.079	3.008
2011–12	–	–	0.085	0.010	0.240	0.416	–	0.020	0.452	0.559	0.614	0.011	–	0.000	0.000	–	–	–	–	–	0.159	2.565
2012–13	–	–	0.072	0.144	0.091	1.497	–	0.114	1.361	2.697	0.706	0.184	0.000	0.000	0.000	–	0.000	0.000	–	–	0.463	7.328
2013–14	–	–	0.112	0.284	0.562	2.290	0.009	0.186	1.854	2.599	1.118	0.153	0.000	0.000	–	–	–	0.000	0.000	–	0.133	9.299
2014–15	0.000	0.000	0.118	0.633	0.880	1.685	–	0.252	1.449	2.678	1.178	0.153	0.000	0.000	0.000	–	–	0.000	–	–	0.724	9.750
2015–16	–	–	0.216	1.179	0.403	2.120	0.000	0.069	0.953	2.754	1.559	0.144	0.000	0.000	0.000	–	–	0.000	–	0.000	0.329	9.726
2016–17	–	0.000	0.246	0.887	0.377	1.941	0.000	0.131	0.886	2.446	1.396	0.088	0.000	0.001	–	–	0.000	0.009	–	–	0.163	8.572
2017–18	–	–	0.267	0.723	0.603	1.837	–	0.162	1.997	1.454	0.171	0.001	0.000	0.002	–	–	–	–	–	–	0.177	7.393
2018–19	–	0.000	0.571	0.980	0.677	2.838	–	0.159	1.462	1.859	0.582	0.250	0.000	0.000	–	–	–	0.000	–	–	0.145	9.521
Total	0.000	0.000	3.286	5.962	6.272	23.174	0.019	1.915	17.517	26.922	10.010	1.522	0.003	0.005	0.000	0.000	0.000	0.009	0.000	0.000	3.384	100.000

Table 6: Total catch (tonnes) of JMA in JMA 7 by fishing year showing the estimated catch, landings [destination codes L, T (Transferred to another vessel), and O (Conveyed outside NZ)], MHR/QMR totals, and the TACC. Catches are rounded to the nearest tonne. A "–" represents missing information. The fishing year for estimated catch is derived from the *start_date* field and landings are derived from the *landing_date* field. The same information is presented in Figure 12. Note that the 'Estimated catch' totals only include catches from the defined JMA 7 statistical areas (Figure 1B).

Fishing year	Estimated catch	Landings	MHR/QMR	TACC
1986–87	–	–	19 816	20 000
1987–88	–	–	17 879	22 698
1988–89	–	–	17 403	26 008
1989–90	13 160	11 076	21 776	32 027
1990–91	11 990	14 672	17 786	32 069
1991–92	23 332	28 496	25 880	32 069
1992–93	21 448	24 952	24 659	32 537
1993–94	19 389	18 393	22 377	32 537
1994–95	16 085	19 527	18 912	32 537
1995–96	10 111	11 031	12 269	32 537
1996–97	10 844	10 821	12 056	32 537
1997–98	14 335	13 893	14 291	32 537
1998–99	12 305	12 564	13 629	32 537
1999–00	7 128	8 128	7 889	32 537
2000–01	14 843	14 168	15 703	32 537
2001–02	21 362	21 602	22 338	32 537
2002–03	25 201	26 497	26 084	32 537
2003–04	27 558	27 663	28 888	32 537
2004–05	35 185	37 598	36 507	32 537
2005–06	26 902	27 502	27 782	32 537
2006–07	30 620	29 773	32 039	32 537
2007–08	32 563	34 699	34 059	32 537
2008–09	27 268	28 523	28 828	32 537
2009–10	29 651	31 818	31 152	32 537
2010–11	26 713	28 101	28 177	32 537
2011–12	26 559	27 334	28 266	32 537
2012–13	29 238	32 724	31 776	32 537
2013–14	32 891	35 096	35 175	32 537
2014–15	31 772	33 937	33 970	32 537
2015–16	28 319	30 853	30 875	32 537
2016–17	30 783	33 684	33 802	32 537
2017–18	31 947	34 200	34 190	32 537
2018–19	30 015	31 772	31 752	32 537
Total	699 517	741 097	762 887	–

Table 7: **Total landings (tonnes) of JMA in JMA 7 by fishing year and destination type in the EDW landings table. Catches are rounded to the nearest tonne. A "-" represents zero catch and 0 represents less than 0.5 of a tonne. Codes represent: A = accidental loss, B = bait stored for later use, D = discarded (non-ITQ), E = eaten, EOY = Landings balanced at the end of the fishing year, F = landed under government approval, J = returned to sea, L = landed in New Zealand (to LFR), LR = landed in New Zealand (to LFR) and previously recorded as 'R', NP = Null, O = conveyed outside New Zealand, R = retained on board, S = seized by crown, T = transferred to another vessel, U = bait used on board, and W = sold at wharf.**

Fishing year	A	B	D	E	EOY	J	L	F	LR	NP	O	R	S+U+W	T	Total
1989–90	–	0	–	–	–	–	3 246	–	–	–	314	1 601	0	7 516	12 677
1990–91	4	0	33	–	–	–	4 912	–	–	–	565	1 855	0	9 195	16 564
1991–92	–	1	7	–	–	–	8 841	–	–	–	123	2 159	–	19 532	30 662
1992–93	17	–	18	1	–	–	8 557	–	–	–	1 126	2 531	–	15 268	27 518
1993–94	4	–	6	6	–	–	10 088	–	–	–	1 480	3 902	–	6 825	22 311
1994–95	10	0	71	4	–	–	13 429	–	–	0	547	944	–	5 551	20 556
1995–96	5	–	49	55	–	–	8 698	–	–	–	0	409	0	2 333	11 549
1996–97	8	–	83	2	–	–	9 094	–	–	21	5	272	0	1 722	11 206
1997–98	–	–	172	3	–	–	13 076	–	–	0	176	422	–	641	14 489
1998–99	0	–	9	3	–	–	12 246	–	–	–	311	477	–	7	13 053
1999–00	0	0	–	1	–	–	8 127	–	–	–	0	77	–	1	8 205
2000–01	0	–	6	1	–	–	14 168	–	–	–	–	50	0	0	14 226
2001–02	1	0	5	3	–	–	21 602	–	–	–	–	118	–	–	21 728
2002–03	0	–	0	3	–	–	26 497	–	–	0	–	205	–	–	26 706
2003–04	–	–	0	4	–	–	27 663	–	–	0	–	649	–	–	28 317
2004–05	7	–	–	5	–	–	37 595	–	–	–	3	760	–	–	38 370
2005–06	3	–	–	5	–	–	27 502	0	–	–	–	726	–	–	28 235
2006–07	3	–	0	5	–	–	29 773	–	–	–	–	26	0	–	29 807
2007–08	1	–	–	7	–	–	34 699	–	–	–	–	1 143	0	–	35 849
2008–09	0	0	–	8	–	–	28 523	0	–	–	–	275	0	0	28 806
2009–10	4	–	0	7	–	–	31 816	0	–	–	3	546	1	–	32 377
2010–11	2	–	–	7	–	–	28 101	0	–	0	–	114	1	–	28 226
2011–12	7	–	–	11	–	–	27 334	0	–	0	–	399	2	–	27 754
2012–13	11	–	–	13	–	–	32 724	0	–	–	–	188	0	–	32 935
2013–14	17	–	–	14	–	0	35 096	0	–	–	–	12	2	–	35 141
2014–15	1	0	–	11	–	1	33 937	0	–	–	–	302	0	–	34 253
2015–16	5	0	–	9	–	5	30 853	0	–	–	–	15	0	–	30 887
2016–17	0	–	–	12	–	4	33 684	0	–	–	–	1	0	–	33 700
2017–18	3	–	–	13	–	18	34 200	–	104	–	–	218	–	–	34 556
2018–19	0	–	–	12	25	0	31 772	–	0	0	–	95	–	–	31 904

Table 8: Percentage of estimated JMA catch in defined JMA 7 (Figure 1B), by fishing year and form type in the EDW effort table. A "–" represents zero catch. Codes represent: CELR = Catch Effort Landing Return, ERS - Trawl = electronic reporting for trawl, TCEPR = Trawl Catch Effort Processing Return, and TCER = Trawl Catch Effort Return. Estimated catch totals can be found in Table 6.

Fishing year	CELR	ERS - Trawl	TCEPR	TCER	Total
1989–90	0.013	–	1.868	–	1.881
1990–91	0.021	–	1.692	–	1.714
1991–92	0.034	–	3.301	–	3.335
1992–93	0.218	–	2.847	–	3.065
1993–94	0.126	–	2.645	–	2.771
1994–95	0.057	–	2.241	–	2.299
1995–96	0.021	–	1.424	–	1.445
1996–97	0.011	–	1.539	–	1.550
1997–98	0.066	–	2.012	–	2.078
1998–99	0.016	–	1.741	–	1.757
1999–00	0.011	–	1.008	–	1.019
2000–01	0.011	–	2.110	–	2.121
2001–02	0.015	–	3.038	–	3.053
2002–03	0.034	–	3.568	–	3.602
2003–04	0.068	–	3.870	–	3.938
2004–05	0.030	–	4.998	–	5.028
2005–06	0.007	–	3.837	–	3.845
2006–07	0.008	–	4.368	–	4.376
2007–08	0.009	–	4.637	0.007	4.654
2008–09	0.004	–	3.881	0.012	3.897
2009–10	0.005	–	4.219	0.014	4.238
2010–11	0.001	–	3.803	0.013	3.818
2011–12	0.001	–	3.785	0.010	3.796
2012–13	0.011	–	4.152	0.015	4.179
2013–14	0.012	–	4.676	0.013	4.701
2014–15	0.000	–	4.528	0.013	4.541
2015–16	0.142	–	3.890	0.015	4.047
2016–17	0.000	–	4.390	0.010	4.399
2017–18	0.000	4.052	0.503	0.010	4.566
2018–19	0.000	4.282	–	0.008	4.290
Total	0.952	8.334	90.572	0.141	100.000

Table 9: Percentage of estimated JMA catch in defined JMA 7 (Figure 1B), by fishing year and fishing method in the EDW effort table. A "–" represents zero catch. Codes represent: bottom pair trawl (BPT), bottom trawl (BT), hand line (HL), midwater trawl (MW), precision seafood bottom trawl (PRB), precision seafood midwater trawl (PRM), purse seine (PS), and set net (SN). Estimated catch totals can be found in Table 6.

Fishing year	BPT	BT	HL	MW	PRB	PRM	PS	SN	Unknown	Total
1989–90	0.002	1.589	–	0.282	–	–	0.008	–	–	1.881
1990–91	0.004	1.132	–	0.572	–	–	0.005	0.000	–	1.714
1991–92	0.002	1.735	–	1.572	–	–	0.026	0.000	–	3.335
1992–93	0.001	2.062	–	0.799	–	–	0.204	0.000	–	3.065
1993–94	0.001	1.443	–	1.210	–	–	0.117	–	–	2.771
1994–95	0.002	0.456	–	1.795	–	–	0.046	–	–	2.299
1995–96	0.001	0.593	–	0.835	–	–	0.011	–	0.005	1.445
1996–97	0.000	0.479	–	1.070	–	–	0.000	–	0.001	1.550
1997–98	0.000	1.334	–	0.680	–	–	0.062	0.000	0.003	2.078
1998–99	0.000	0.409	–	1.344	–	–	0.003	0.000	–	1.757
1999–00	0.001	0.053	–	0.963	–	–	0.002	–	–	1.019
2000–01	0.000	0.196	–	1.925	–	–	0.001	–	0.000	2.121
2001–02	0.000	0.254	–	2.798	–	–	0.001	–	–	3.053
2002–03	0.000	0.043	–	3.538	–	–	0.021	–	–	3.602
2003–04	0.000	0.032	–	3.849	–	–	0.057	–	–	3.938
2004–05	0.001	0.048	–	4.964	–	–	0.016	–	–	5.028
2005–06	0.001	0.015	0.000	3.824	–	–	0.005	–	–	3.845
2006–07	0.000	0.066	–	4.306	–	–	0.004	–	–	4.376
2007–08	0.000	0.140	–	4.504	–	–	0.009	–	–	4.654
2008–09	0.000	0.045	–	3.848	–	–	0.003	–	–	3.897
2009–10	0.001	0.021	–	4.211	–	–	0.005	–	–	4.238
2010–11	0.001	0.025	–	3.791	–	–	0.001	–	–	3.818
2011–12	–	0.020	0.000	3.775	–	–	0.001	–	–	3.796
2012–13	–	0.019	–	4.148	–	–	0.011	–	–	4.179
2013–14	–	0.015	0.000	4.674	–	–	0.012	–	–	4.701
2014–15	0.000	0.026	0.000	4.515	–	–	0.000	–	0.000	4.541
2015–16	–	0.019	–	3.885	0.001	–	0.142	–	0.000	4.047
2016–17	–	0.012	0.000	4.386	0.001	–	0.000	–	–	4.399
2017–18	–	0.012	–	4.552	0.002	–	0.000	–	–	4.566
2018–19	0.000	0.023	–	4.266	0.000	0.000	0.000	–	0.000	4.290
Total	0.019	12.314	0.000	86.881	0.004	0.000	0.774	0.000	0.008	100.000

Table 10: Percentage of estimated JMA catch in defined JMA 7 (Figure 1B), by fishing year and target species in the EDW effort table. A "–" represents zero catch. Estimated catch totals can be found in Table 6.

Fishing year	JMA	BAR	HOK	EMA	TRE	TAR	KAH	SWA	WAR	Other	Total
1989–90	1.712	0.096	0.050	–	0.001	0.000	0.008	0.005	0.000	0.008	1.881
1990–91	1.513	0.047	0.126	0.003	0.006	0.001	0.005	0.002	0.001	0.011	1.714
1991–92	3.118	0.027	0.160	0.004	0.006	0.002	0.010	0.001	0.000	0.006	3.335
1992–93	2.840	0.046	0.061	0.065	0.004	0.002	0.040	0.002	0.000	0.004	3.065
1993–94	2.356	0.090	0.306	–	0.004	0.002	0.002	0.002	0.000	0.009	2.771
1994–95	1.863	0.143	0.262	0.004	0.006	0.002	0.001	0.000	0.000	0.018	2.299
1995–96	1.099	0.072	0.255	–	0.003	0.002	0.004	0.001	0.003	0.007	1.445
1996–97	1.299	0.097	0.136	0.000	0.006	0.003	0.000	0.000	0.001	0.008	1.550
1997–98	1.992	0.032	0.033	0.001	0.004	0.006	–	0.000	0.001	0.010	2.078
1998–99	1.641	0.037	0.026	0.021	0.004	0.003	0.000	0.003	0.001	0.022	1.757
1999–00	0.970	0.011	0.014	–	0.008	0.005	0.002	0.001	0.000	0.007	1.019
2000–01	2.075	0.023	0.002	0.000	0.008	0.003	0.000	0.000	0.001	0.009	2.121
2001–02	2.979	0.053	0.002	0.000	0.003	0.002	0.000	0.001	0.000	0.012	3.053
2002–03	3.559	0.009	0.016	0.001	0.003	0.003	–	0.000	0.001	0.009	3.602
2003–04	3.856	0.027	0.036	–	0.004	0.002	–	0.002	0.001	0.012	3.938
2004–05	4.750	0.249	0.005	0.001	0.004	0.002	0.000	0.004	0.002	0.011	5.028
2005–06	3.786	0.032	0.001	0.004	0.004	0.004	–	0.000	0.002	0.011	3.845
2006–07	4.290	0.068	0.001	0.003	0.003	0.001	–	0.004	0.001	0.005	4.376
2007–08	4.587	0.035	0.001	0.002	0.003	0.003	–	0.009	0.002	0.012	4.654
2008–09	3.811	0.055	0.000	0.005	0.002	0.004	0.002	0.006	0.001	0.010	3.897
2009–10	4.203	0.014	0.000	0.003	0.003	0.003	0.000	0.003	0.002	0.007	4.238
2010–11	3.790	0.010	0.000	0.000	0.004	0.004	–	0.001	0.002	0.006	3.818
2011–12	3.760	0.012	0.000	0.013	0.001	0.004	–	0.000	0.001	0.005	3.796
2012–13	4.089	0.022	0.000	0.031	0.001	0.005	0.001	0.000	0.003	0.027	4.179
2013–14	4.470	0.196	0.000	0.018	0.001	0.002	–	0.000	0.003	0.010	4.701
2014–15	4.075	0.451	0.001	–	0.001	0.003	–	0.000	0.005	0.005	4.541
2015–16	3.865	0.161	0.008	0.001	0.001	0.005	0.000	–	0.002	0.005	4.047
2016–17	4.320	0.052	0.017	–	0.000	0.003	–	–	0.001	0.006	4.399
2017–18	4.286	0.247	0.017	0.006	0.002	0.004	–	0.000	0.002	0.003	4.566
2018–19	4.177	0.070	0.004	0.012	0.002	0.006	–	–	0.001	0.018	4.290
Total	95.128	2.484	1.540	0.197	0.101	0.089	0.076	0.049	0.042	0.293	100.000

Table 11: Percentage of estimated JMA catch in defined JMA 7 (Figure 1B), by fishing year and statistical area in the EDW effort table. A "–" represents zero catch. Estimated catch totals can be found in Table 6.

	Statistical Area																						
Fishing year	032	033	034	035	036	037	038	039	040	041	042	045	046	047	048	101	701	703	704	705	706	801	Total
1989–90	–	0.002	0.113	0.157	0.160	0.576	0.010	0.288	0.304	0.246	0.009	0.000	0.001	0.001	–	–	–	0.002	0.001	0.002	–	0.008	1.881
1990–91	–	0.003	0.151	0.133	0.174	0.598	0.010	0.183	0.327	0.114	0.002	0.002	0.001	0.001	–	–	0.000	0.002	–	0.000	–	0.013	1.714
1991–92	0.000	0.006	0.336	0.189	0.721	0.397	0.007	0.041	0.480	1.036	0.001	0.004	0.001	0.004	0.001	–	–	0.002	0.003	–	–	0.106	3.335
1992–93	–	0.003	0.144	0.195	0.272	0.626	0.026	0.079	0.480	1.006	0.054	0.035	0.029	0.085	–	–	0.000	0.000	–	–	0.001	0.031	3.065
1993–94	–	0.000	0.329	0.331	0.389	0.479	0.024	0.080	0.325	0.636	0.015	0.002	0.001	0.081	0.000	0.001	–	0.002	0.000	0.000	0.001	0.077	2.771
1994–95	–	0.001	0.689	0.493	0.212	0.276	0.038	0.086	0.214	0.256	0.002	0.003	0.002	0.006	–	0.000	–	0.000	-	0.000	0.000	0.022	2.299
1995–96	–	0.001	0.527	0.208	0.132	0.400	0.009	0.005	0.093	0.046	0.009	0.003	0.007	0.003	–	–	–	0.001	0.000	-	0.000	0.001	1.445
1996–97	0.000	0.003	0.500	0.270	0.019	0.351	0.008	0.050	0.145	0.154	0.039	0.002	0.002	0.001	–	–	–	0.000	0.001	0.000	–	0.003	1.550
1997–98	–	0.002	0.266	0.237	0.049	0.495	0.004	0.251	0.332	0.174	0.252	0.007	0.004	0.007	–	0.000	–	0.001	–	–	–	0.000	2.078
1998–99	–	0.004	0.299	0.306	0.283	0.507	0.014	0.184	0.144	0.003	0.001	0.001	0.009	0.002	–	0.000	–	–	–	–	–	–	1.757
1999–00	–	0.001	0.104	0.079	0.309	0.330	0.004	0.004	0.152	0.014	0.012	0.002	0.004	0.002	–	0.000	-	0.000	-	0.002	0.000	0.000	1.019
2000–01	–	0.002	0.085	0.118	0.443	0.591	0.002	0.070	0.726	0.077	0.002	0.002	0.001	0.001	–	–	–	-	–	–	–	0.003	2.121
2001–02	–	0.002	0.094	0.220	0.416	1.244	0.005	0.049	0.846	0.069	0.013	0.004	0.001	0.001	–	–	–	0.001	–	–	–	0.089	3.053
2002–03	–	0.003	0.104	0.125	0.350	0.841	0.006	0.132	0.965	0.641	0.250	0.034	0.000	0.001	–	–	–	0.000	–	–	–	0.150	3.602
2003–04	–	0.002	0.078	0.005	0.077	0.248	0.005	0.022	0.492	0.939	1.604	0.282	0.001	0.048	–	0.003	–	–	–	–	–	0.133	3.938
2004–05	–	0.001	0.017	0.035	0.414	0.435	0.013	0.269	0.572	1.613	1.065	0.557	0.001	0.001	–	-	-	0.000	–	–	–	0.034	5.028
2005–06	–	0.001	0.051	0.024	0.105	0.790	0.006	0.074	1.026	1.170	0.417	0.119	0.001	0.000	–	0.002	-	0.001	–	–	–	0.058	3.845
2006–07	0.000	0.001	0.085	0.214	0.232	0.910	0.002	0.071	0.752	1.292	0.382	0.140	0.000	0.001	–	–	–	–	–	–	–	0.294	4.376
2007–08	0.000	0.000	0.091	0.093	0.178	0.803	0.003	0.034	1.039	1.716	0.252	0.051	0.000	0.001	–	–	–	–	–	–	–	0.393	4.654
2008–09	–	0.002	0.110	0.076	0.205	0.820	0.004	0.022	0.675	1.370	0.267	0.051	0.000	0.002	–	–	–	–	–	–	–	0.293	3.897
2009–10	0.000	0.002	0.003	0.033	0.123	0.939	0.008	0.094	0.789	1.612	0.508	0.022	0.000	0.001	–	–	–	–	–	–	–	0.104	4.238
2010–11	0.000	0.004	0.117	0.058	0.151	0.758	0.002	0.091	0.646	1.202	0.675	0.024	0.000	0.001	–	–	–	–	–	0.000	-	0.088	3.818
2011–12	0.000	0.003	0.049	0.070	0.077	0.811	0.002	0.068	0.740	1.264	0.375	0.105	0.000	0.000	–	–	–	–	–	0.000	-	0.232	3.796
2012–13	0.000	0.008	0.052	0.115	0.277	0.960	0.002	0.074	0.786	1.139	0.551	0.127	0.000	0.000	–	–	–	–	–	–	0.000	0.088	4.179
2013–14	0.000	0.006	0.056	0.365	0.441	0.793	0.001	0.114	0.751	1.252	0.546	0.068	0.000	0.000	–	–	–	–	–	–	–	0.306	4.701
2014–15	0.000	0.007	0.095	0.506	0.164	0.988	0.001	0.057	0.505	1.310	0.702	0.054	0.000	0.000	–	–	–	–	–	–	–	0.150	4.541
2015–16	0.000	0.007	0.116	0.466	0.195	0.850	0.001	0.045	0.416	1.104	0.607	0.063	0.097	0.001	–	–	–	0.000	–	–	0.000	0.078	4.047
2016–17	0.000	0.005	0.279	0.525	0.491	0.939	0.001	0.084	1.120	0.764	0.079	0.000	0.000	0.001	–	–	–	–	–	–	–	0.112	4.399
2017–18	0.000	0.005	0.287	0.441	0.335	1.490	0.001	0.081	0.720	0.788	0.243	0.103	0.001	0.001	–	–	–	–	–	–	–	0.069	4.566
2018–19	0.000	0.006	0.137	0.463	0.276	1.104	0.000	0.007	0.579	1.042	0.303	0.200	0.001	0.002	–	–	–	–	–	–	–	0.169	4.290
Total	0.001	0.090	5.363	6.551	7.670	21.347	0.219	2.708	17.140	24.048	9.237	2.067	0.168	0.256	0.001	0.005	0.001	0.012	0.005	0.004	0.003	3.104	100.000

Table 12: Number of vessels catching JMA in defined JMA 7 (Figure 1B) by fishing year and fishing method in the EDW effort table.

Fishing year	BT	MW	Other	Total
1989–90	82	49	2	133
1990–91	82	55	4	141
1991–92	87	49	5	141
1992–93	82	27	7	116
1993–94	71	44	5	120
1994–95	80	54	4	138
1995–96	75	47	5	127
1996–97	83	60	6	149
1997–98	85	52	7	144
1998–99	85	45	3	133
1999–00	60	26	1	87
2000–01	61	27	3	91
2001–02	71	22	2	95
2002–03	68	27	4	99
2003–04	57	23	4	84
2004–05	59	19	3	81
2005–06	41	15	5	61
2006–07	58	20	4	82
2007–08	65	11	2	78
2008–09	57	15	4	76
2009–10	61	13	3	77
2010–11	68	14	4	86
2011–12	63	9	3	75
2012–13	55	13	2	70
2013–14	58	15	7	80
2014–15	58	25	3	86
2015–16	54	22	5	81
2016–17	48	16	1	65
2017–18	43	20	1	64
2018–19	45	16	3	64

Table 13: The explanatory variables in the order that they were accepted into the EDW BT model (1989–90 to 2001–02) that assumed a gamma distribution. Degrees of freedom (DF), residual deviance, Akaike information criterion (AIC), deviance explained (r^2), and if the explanatory variable was included in the final model.

Term	DF	Deviance	AIC	r^2	Final
none	0	6672	39820	0.000	✓
year	12	6182	39240	0.074	✓
vessel	9	5873	38860	0.120	✓
month	11	5632	38560	0.156	✓
poly(duration, 3)	3	5466	38340	0.181	✓
statistical area	8	5412	38280	0.189	
poly(speed, 2)	2	5401	38260	0.190	

Table 14: The explanatory variables in the order that they were accepted by into the EDW MW model (2001–02 to 2018–19) that assumed a gamma distribution. Degrees of freedom (DF), residual deviance, Akaike information criterion (AIC), deviance explained (r^2), and if the explanatory variable was included in the final model.

Term	DF	Deviance	AIC	r^2	Final
none	0	26530	165300	0.000	✓
year	18	25630	164400	0.034	✓
poly(duration, 3)	3	25070	163800	0.055	✓
statistical area	9	24700	163400	0.069	✓
month	11	24570	163300	0.074	
vessel	7	24370	163100	0.081	
effort height	1	24230	162900	0.087	

Table 15: The explanatory variables in the order that they were accepted into the COD MW model (2006–07 to 2018–19) that assumed a gamma distribution. Degrees of freedom (DF), residual deviance, Akaike information criterion (AIC), deviance explained (r^2), and if the explanatory variable was included in the final model.

Term	DF	Deviance	AIC	r^2	Final
none	0	14230	78680	0.000	✓
year	12	13930	78430	0.021	✓
poly(duration, 3)	3	13600	78140	0.045	✓
statistical area	9	13360	77950	0.061	✓
month	11	13250	77870	0.069	
vessel	6	13220	77850	0.071	
poly(speed, 3)	3	13190	77830	0.073	

Table 16: Leave-one-out information criterion (LOO IC) for each Bayesian model run.

		LOO IC	
Model	Distribution	Estimate	SE
EDW BT	lognormal	39 536.1	187.2
	gamma	38 235.8	163.1
EDW MW	lognormal	166 155.3	353.9
	gamma	163 123.3	294.5
COD MW	lognormal	81 352.5	246.2
	gamma	77 782.2	199.8

Table 17: Standardised CPUE indices (i.e., relative year effects, each series is rescaled to have a geometric mean of 1) from 1989–90 to 2018–19. The mean and CV for each series are provided.

	EDW BT		EDW MW		COD MW	
Fishing year	**CPUE**	**CV**	**CPUE**	**CV**	**CPUE**	**CV**
1989–90	1.264	0.167	–	–	–	–
1990–91	1.088	0.166	–	–	–	–
1991–92	0.929	0.167	–	–	–	–
1992–93	0.873	0.168	–	–	–	–
1993–94	0.785	0.169	–	–	–	–
1994–95	0.653	0.174	–	–	–	–
1995–96	0.717	0.170	–	–	–	–
1996–97	1.323	0.175	–	–	–	–
1997–98	1.330	0.169	–	–	–	–
1998–99	1.042	0.183	–	–	–	–
1999–00	0.756	0.232	–	–	–	–
2000–01	1.780	0.230	0.898	0.075	–	–
2001–02	0.986	0.212	0.887	0.071	–	–
2002–03	–	–	0.771	0.069	–	–
2003–04	–	–	0.809	0.071	–	–
2004–05	–	–	0.980	0.071	–	–
2005–06	–	–	0.918	0.071	–	–
2006–07	–	–	0.859	0.070	0.707	0.110
2007–08	–	–	0.904	0.071	0.813	0.092
2008–09	–	–	0.942	0.071	0.931	0.089
2009–10	–	–	0.874	0.071	0.807	0.095
2010–11	–	–	0.966	0.073	0.906	0.094
2011–12	–	–	0.955	0.072	0.929	0.085
2012–13	–	–	1.031	0.073	1.046	0.085
2013–14	–	–	0.899	0.074	0.870	0.085
2014–15	–	–	1.209	0.075	1.074	0.085
2015–16	–	–	1.218	0.075	1.170	0.086
2016–17	–	–	1.495	0.078	1.380	0.088
2017–18	–	–	1.243	0.079	1.271	0.087
2018–19	–	–	1.497	0.082	1.373	0.091

8. FIGURES

(A) (B)

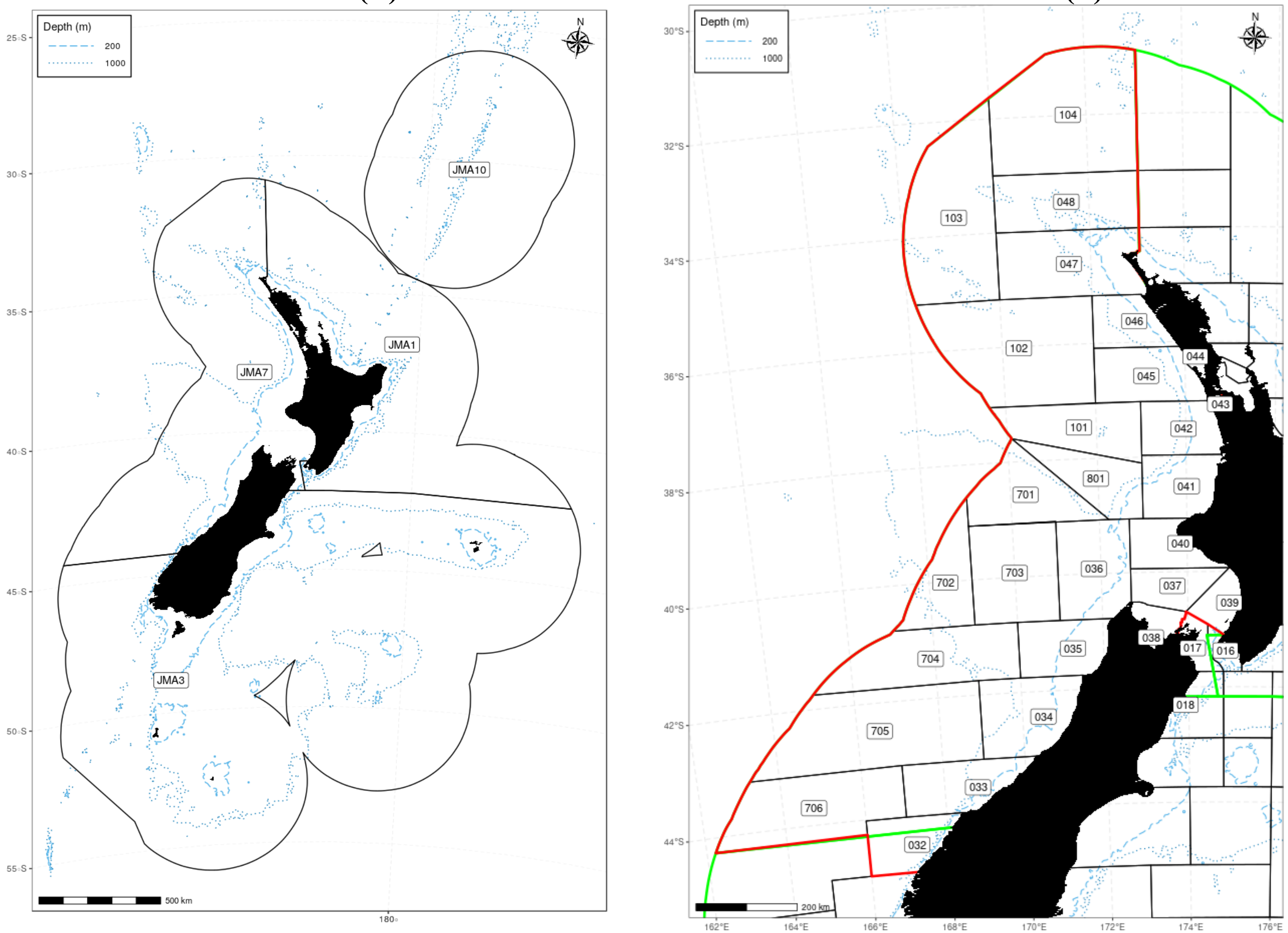

Figure 1: (A): Map showing the four jack mackerel Quota Management Areas (QMAs): JMA 1, JMA 3, JMA 7, and JMA 10; (B) Map showing the statistical areas within the statutory JMA QMA boundaries (green lines), and the defined JMA 7 (Figure 1B) stock boundary (red line). Statistical Areas 016, 017, 018, and 032 are straddling areas which extend beyond the statutory JMA 7 QMA boundary. Statistical Areas 016, 017, 018, 043, and 044 were excluded from the defined JMA 7 stock boundary and Statistical Area 032 was included. The 200-m and 1000-m depth contours are shown as dashed and dotted blue lines, respectively. These same depth contours are used in maps throughout this document.

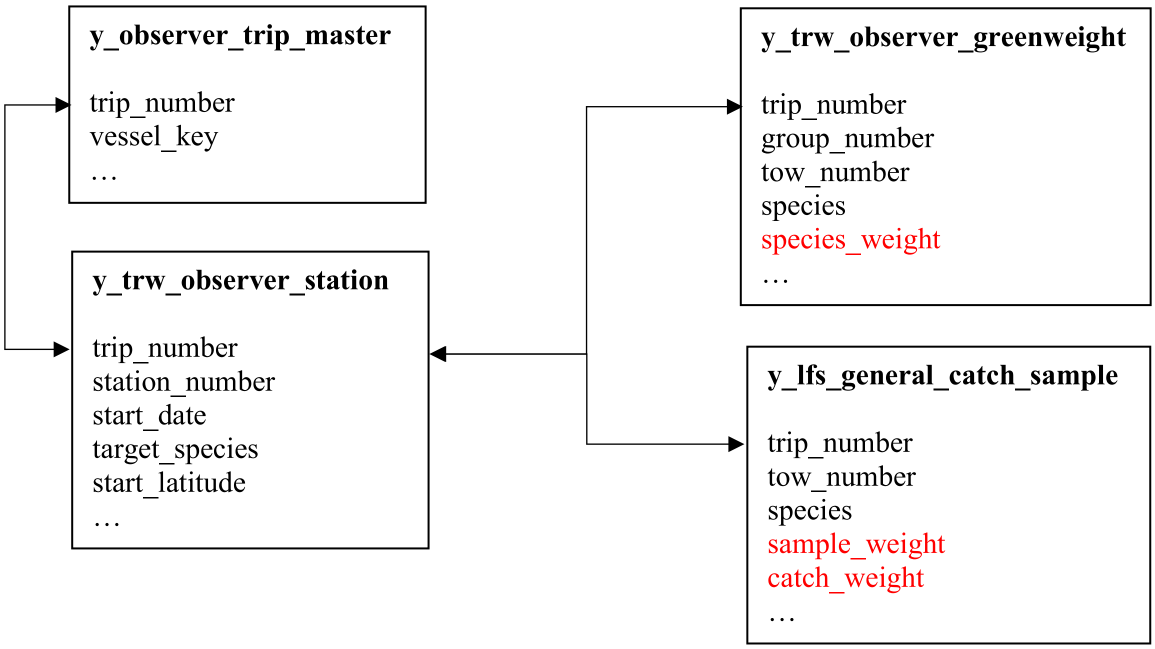

Figure 2: A simplified entity relationship diagram (ERD) of the centralised observer database (COD) tables and a subset of fields that were used in this analysis. The full ERD is given by Sanders & Fisher (2018).

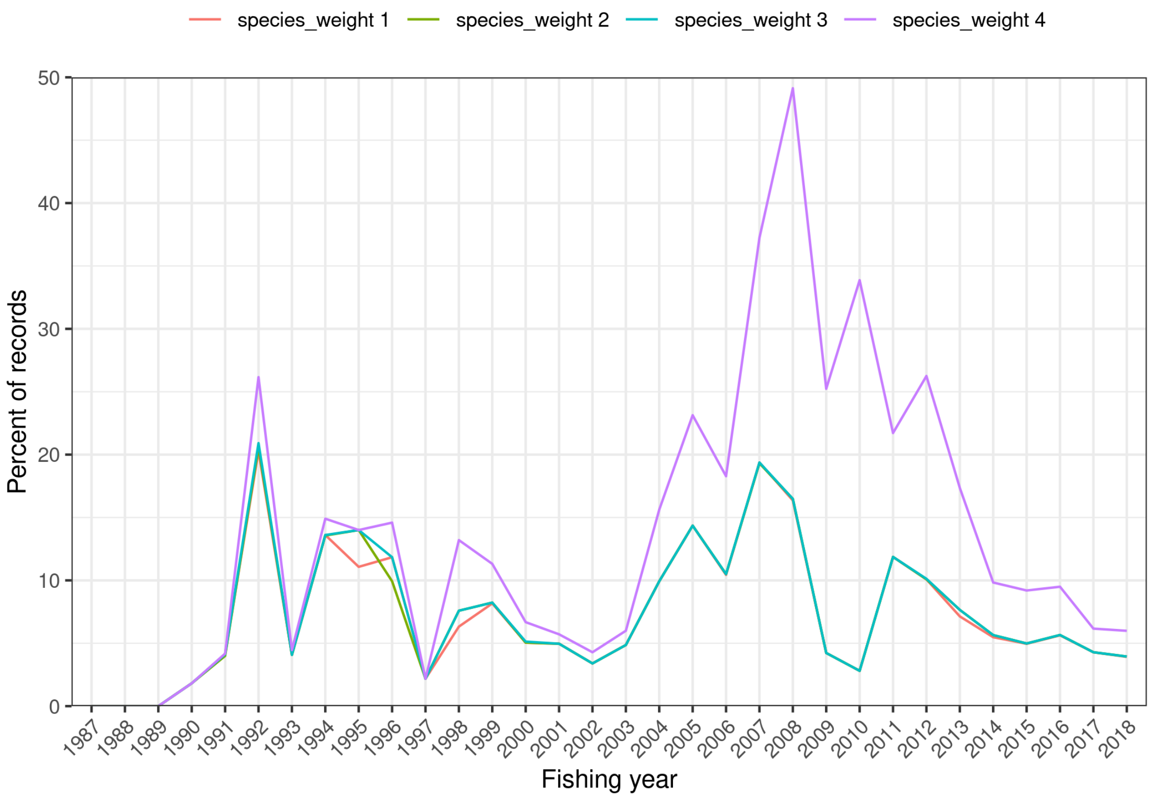

Figure 3: Percentage of records with one of the species_weight errors by fishing year. The overall percentage for each error is provided in Table 1 as well as the definitions for each of the errors. Note that fishing year has been labelled with the first year of the pair.

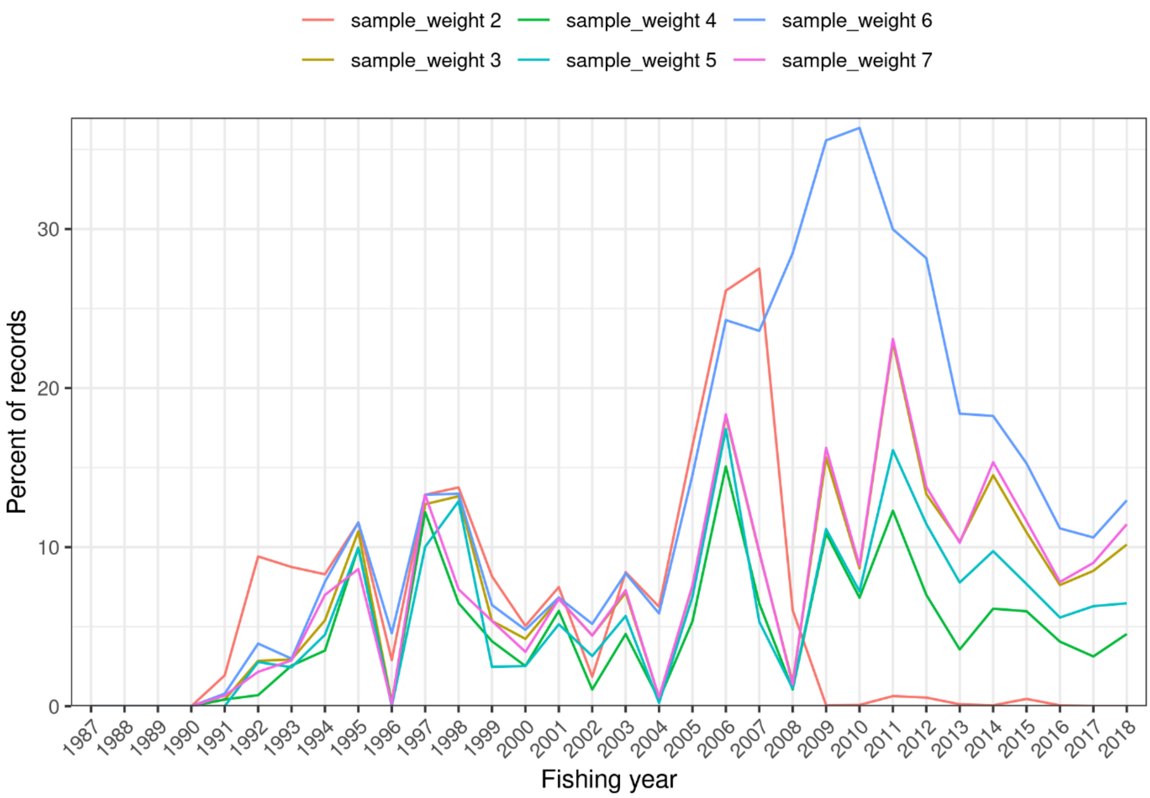

Figure 4: Percentage of records with one of the sample_weight errors by fishing year. The overall percentage for each error is provided in Table 1 as well as the definitions for each of the errors. Note that fishing year has been labelled with the first year of the pair.

Figure 5: Percentage of records with one of the catch_weight errors by fishing year. The overall percentage for each error is provided in Table 1 as well as the definitions for each of the errors. Note that fishing year has been labelled with the first year of the pair.

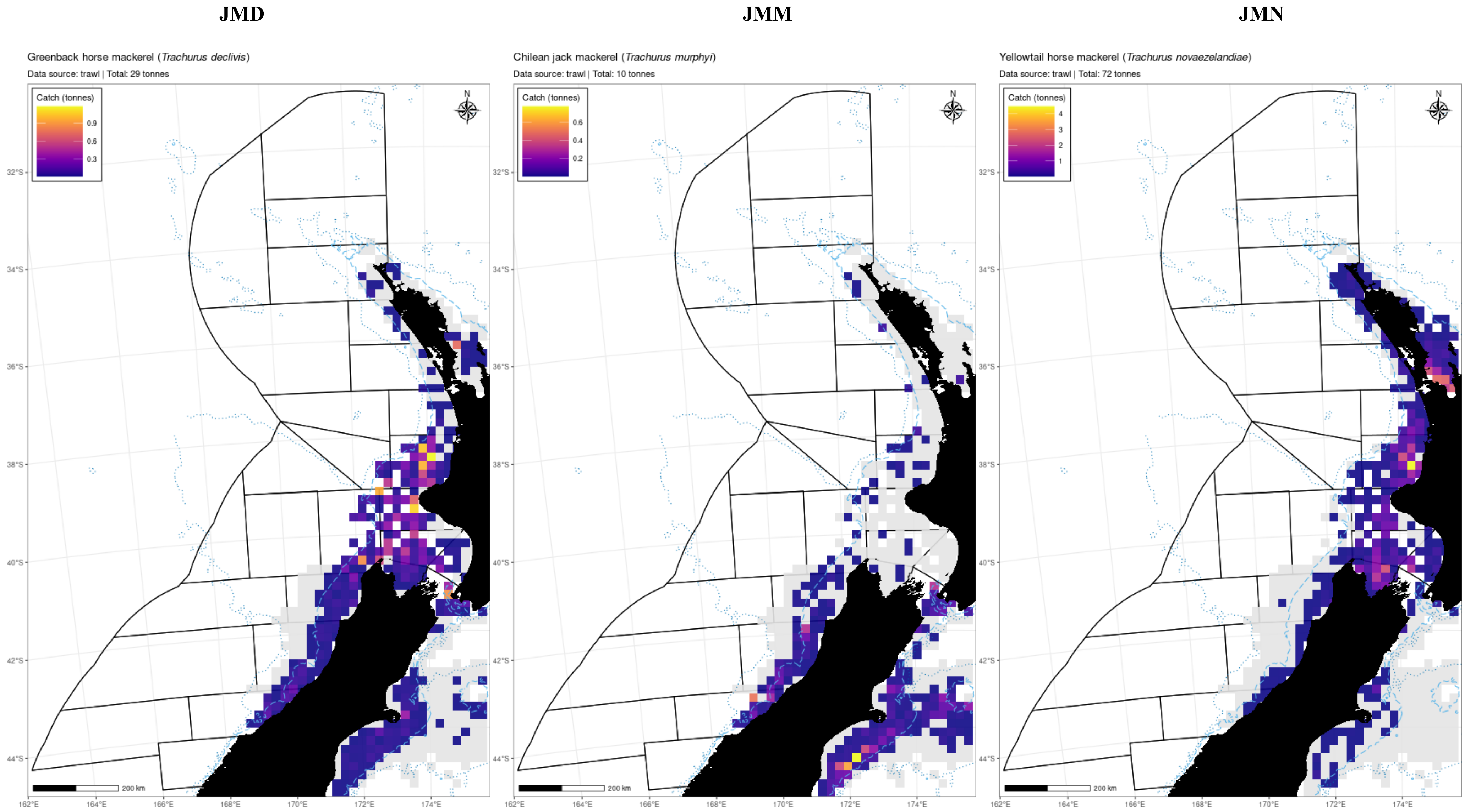

Figure 6: Total catch (tonnes) of JMD (left panel), JMM (central panel) and JMN (right panel) by any fishing gear between 1 October 1986 and 30 September 2019 in the trawl survey database for the waters surrounding the west coast of New Zealand, including beyond the New Zealand EEZ. Grey cells represent areas where there has been effort but no jack mackerel species caught in the appropriate species panel. The defined JMA 7 (Figure 1B) boundary is shown in black.

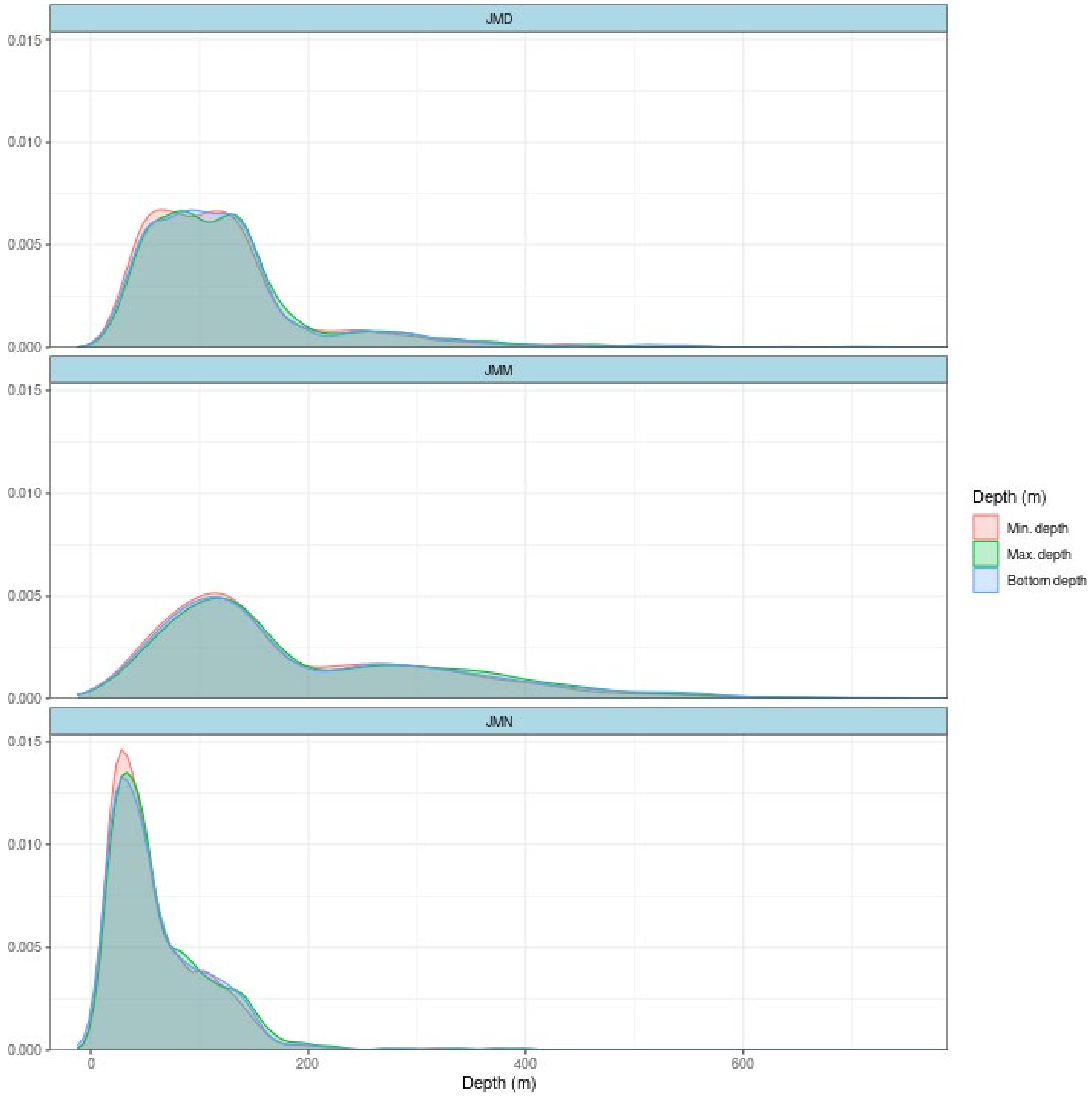

Figure 7: Distribution of depth (m) of JMD, JMM and JMN by any fishing gear between 1 October 1986 and 30 September 2019 in the trawl survey database for the waters surrounding the west coast of New Zealand, including beyond the New Zealand EEZ. The minimum fishing depth (Min. depth), maximum fishing depth (Max. depth), and bottom depth by event are indicated.

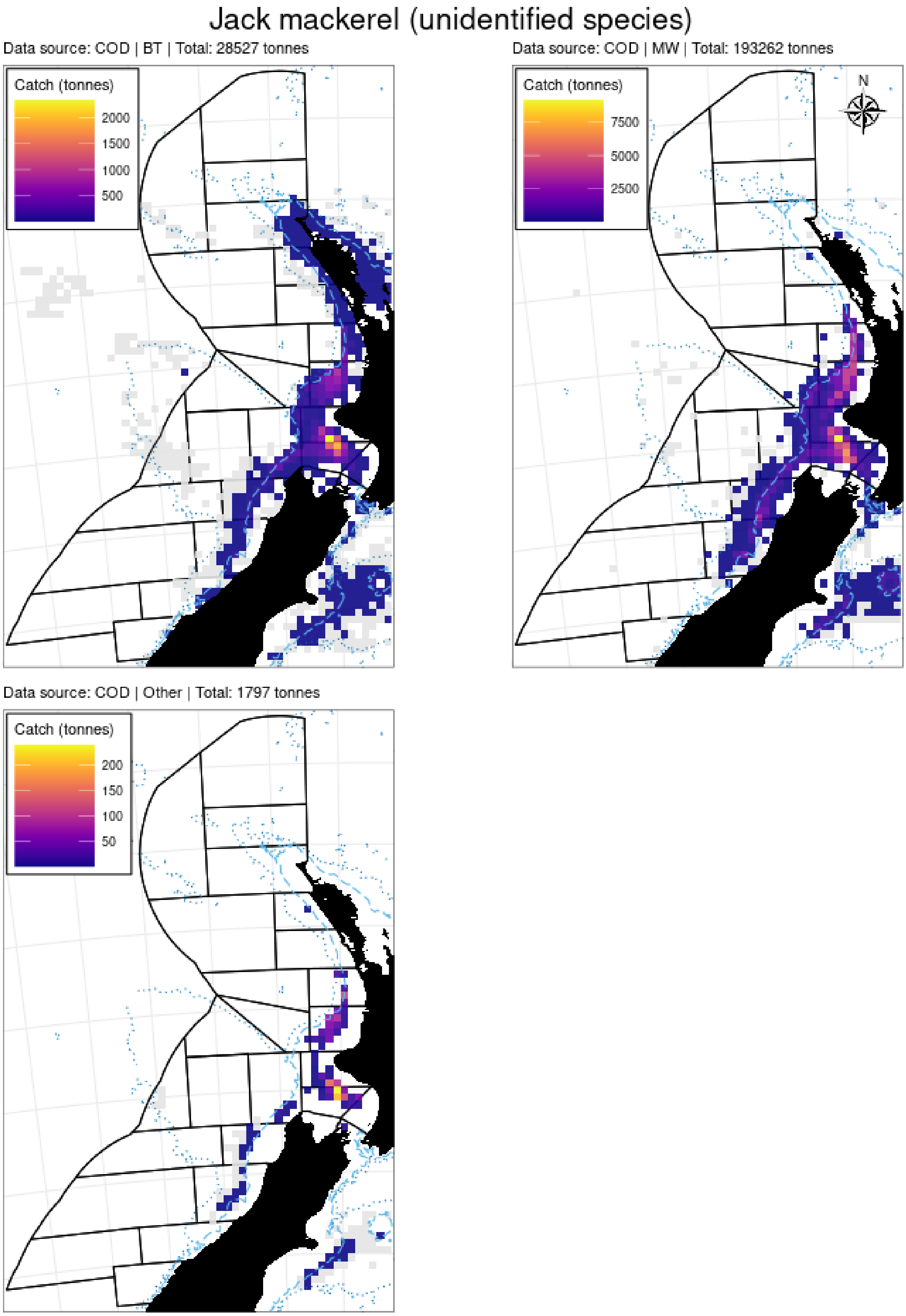

Figure 8: Total catch (tonnes) reported by observers of all JMA species by fishing gear for all fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there was effort but no JMA were recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from COD.

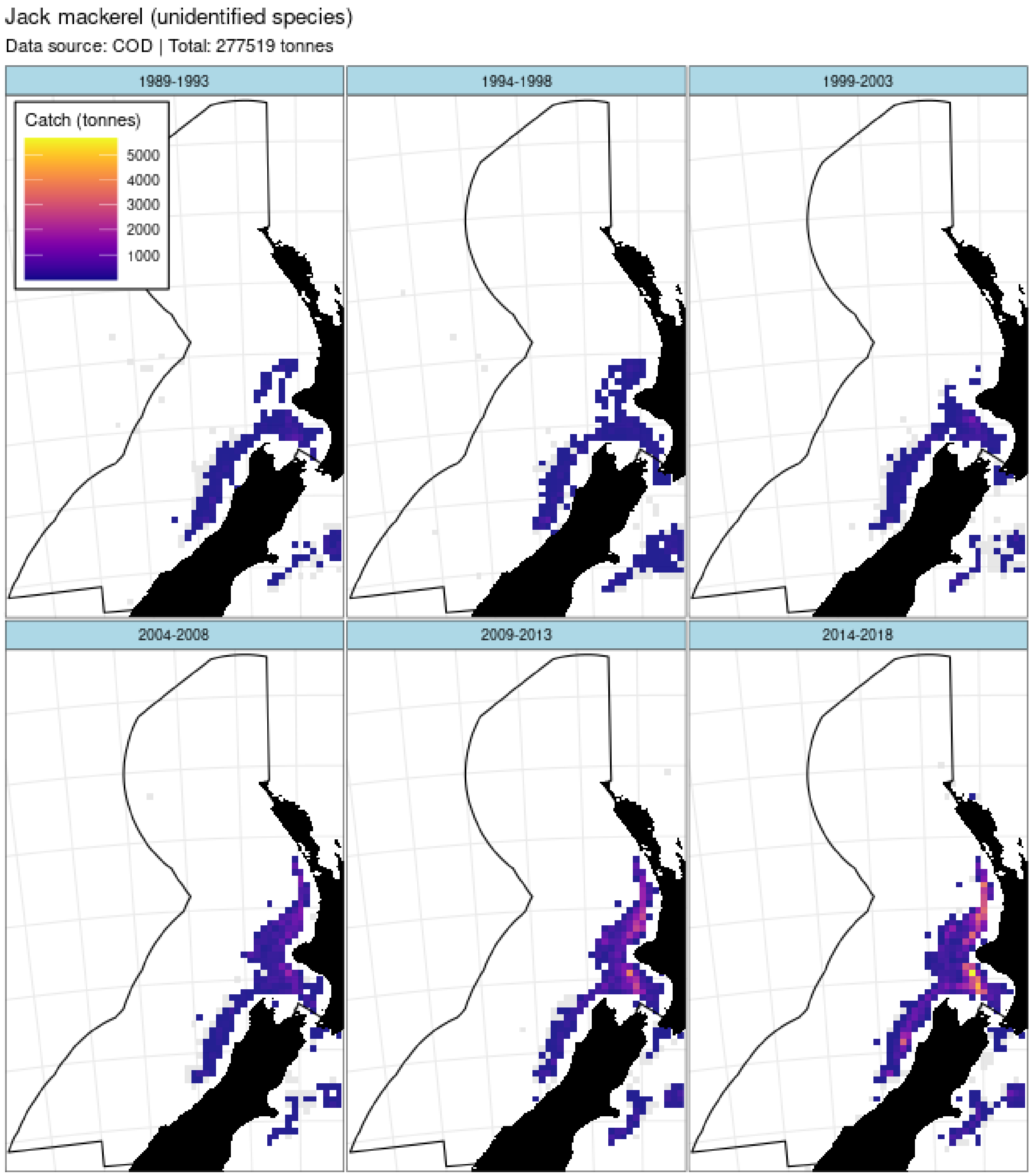

Figure 9: Total catch (tonnes) reported by observers of all JMA species caught by MW split into five-year blocks of fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there has been effort but no JMA recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from COD.

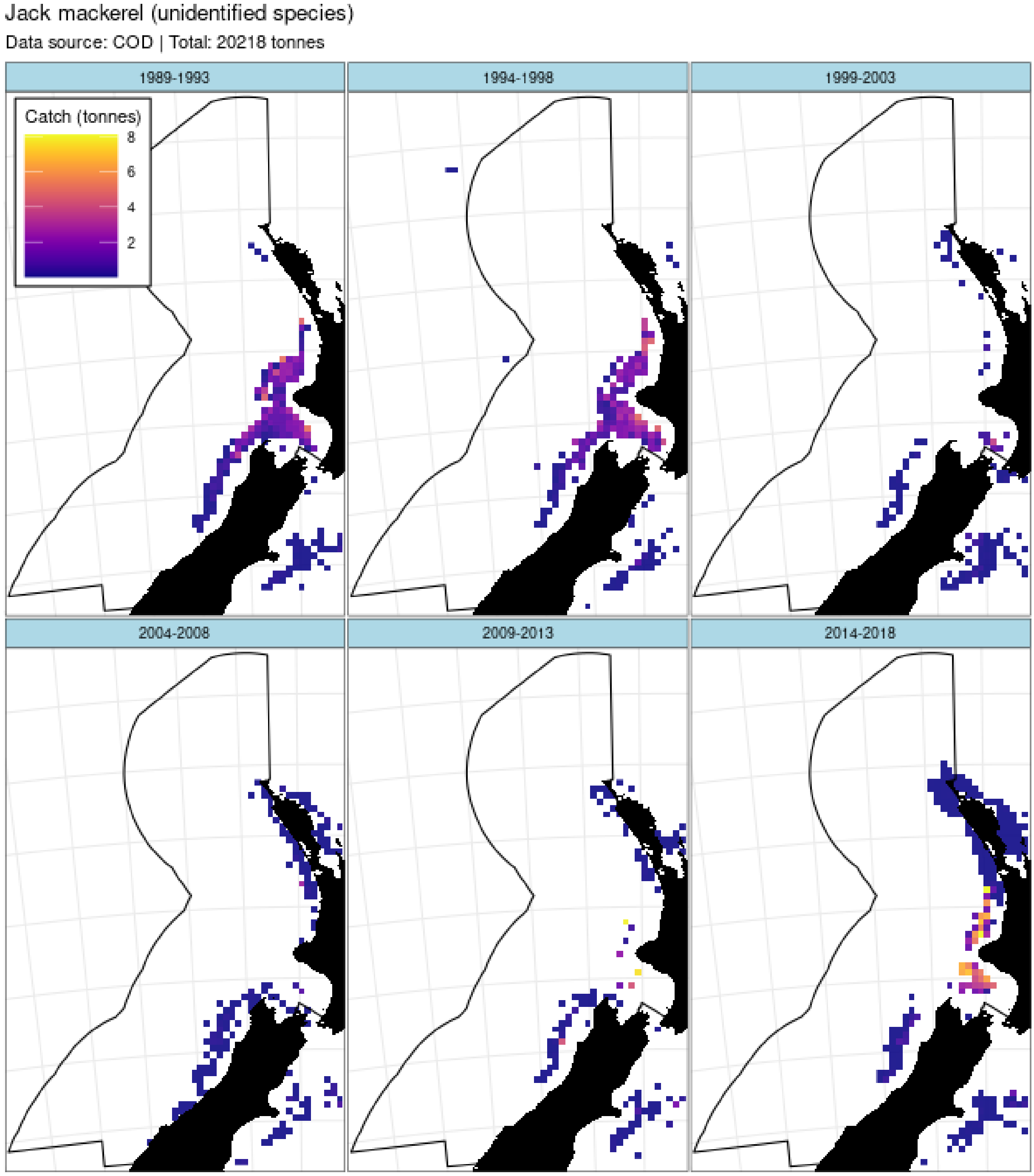

Figure 10: Total catch (tonnes) reported by observers of all JMA species caught by BT split into five-year blocks of fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there has been effort but no JMA recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from COD.

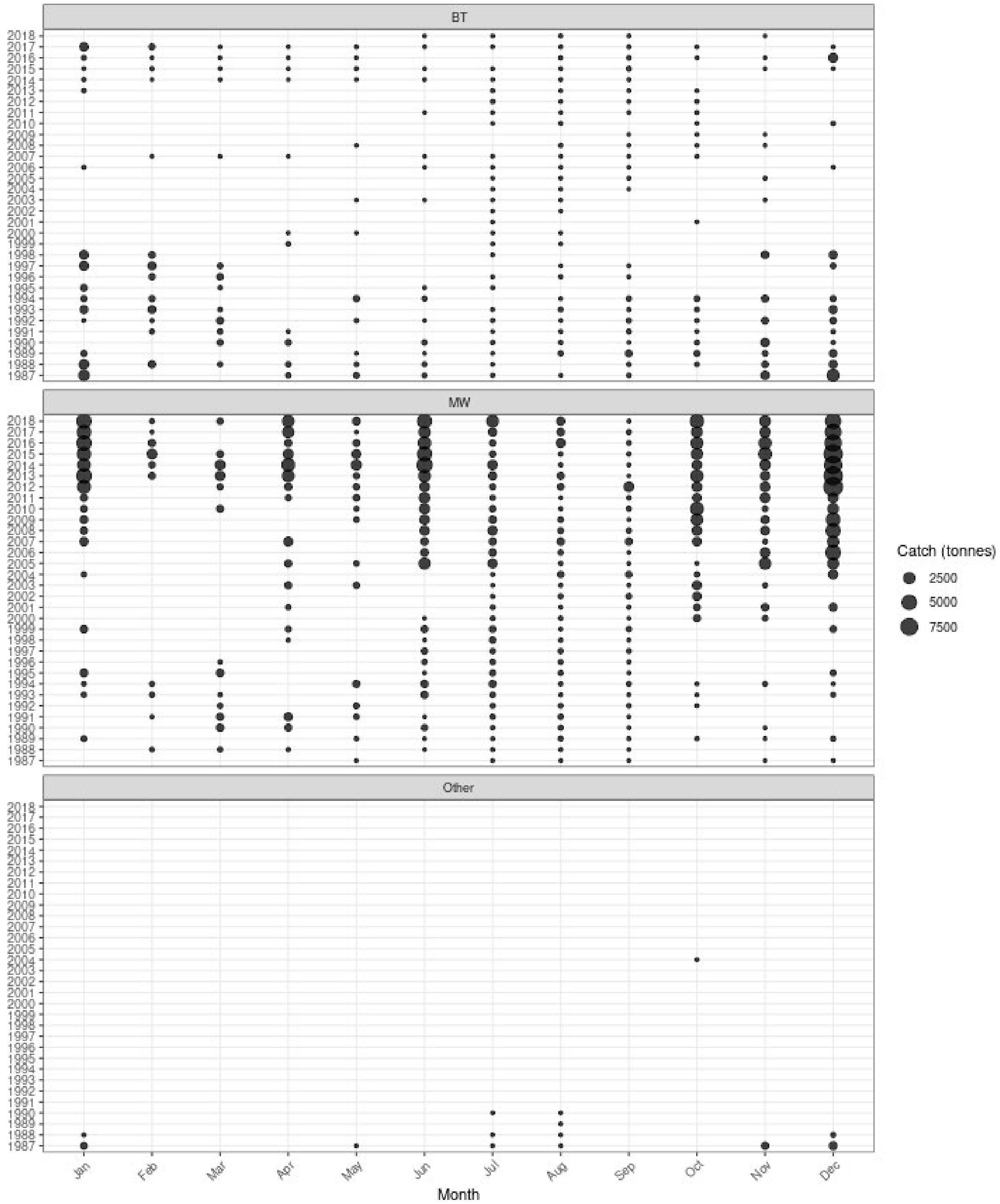

Figure 11: Catch (tonnes) reported by observers by fishing method (BT = bottom trawl, MW = midwater trawl), month, and fishing year from 1987–88 to 2018–19. These data are derived from COD. Note that fishing year has been labelled with the first year of the pair.

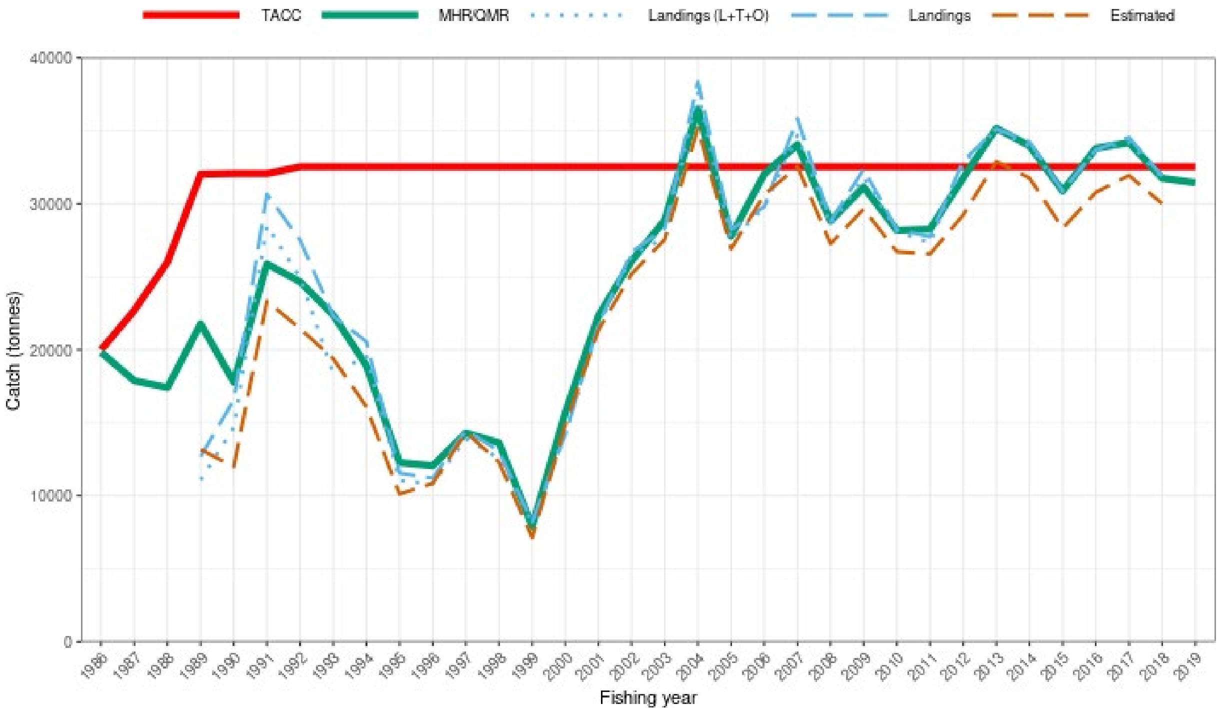

Figure 12: Commercial catch (tonnes) by fishing year from 1989–90 to 2018–19. 'Landings' includes all destination codes, and 'Landings (L+T+O)' includes destination codes L, T, and O. Also shown in Table 6. Note that fishing year has been labelled with the first year of the pair.

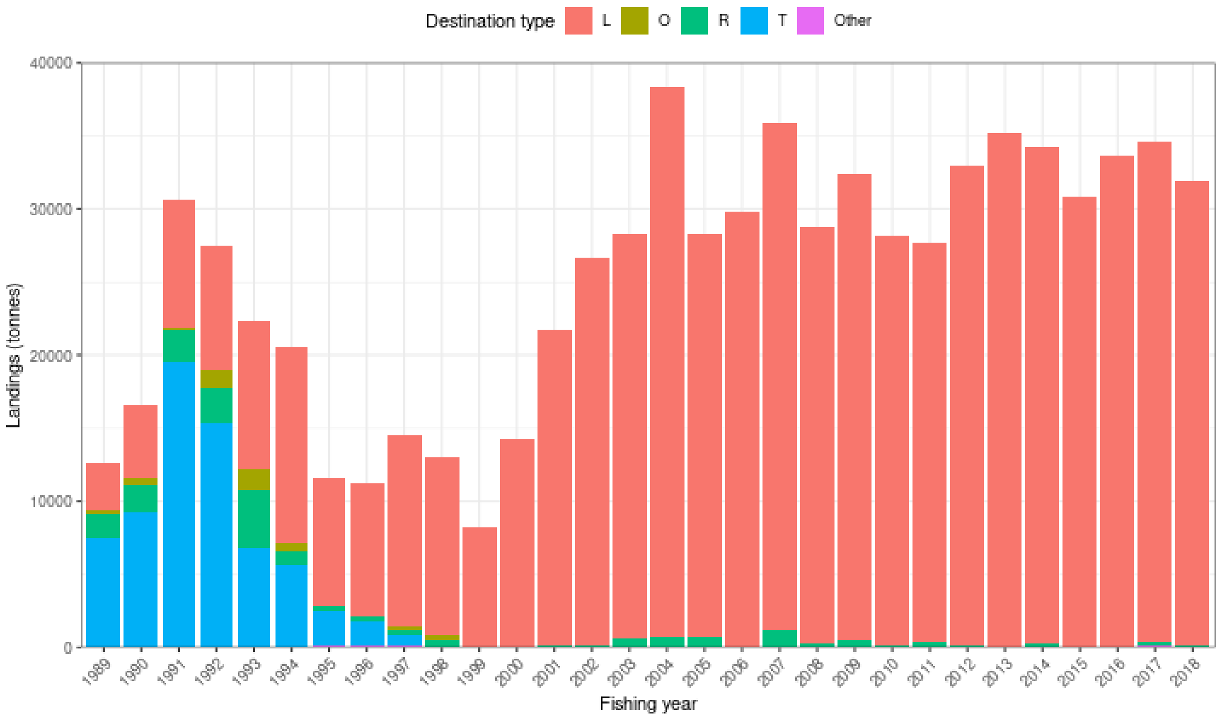

Figure 13: Commercial landings (tonnes) by destination type and fishing year from 1989–90 to 2018–19. The destination code 'L' is landed catch, 'O' is 'Conveyed outside New Zealand', 'R' is 'Retained on board', and 'T' is 'Transferred at sea'. Data plotted in Table 7 as percentages. Note that fishing year has been labelled with the first year of the pair.

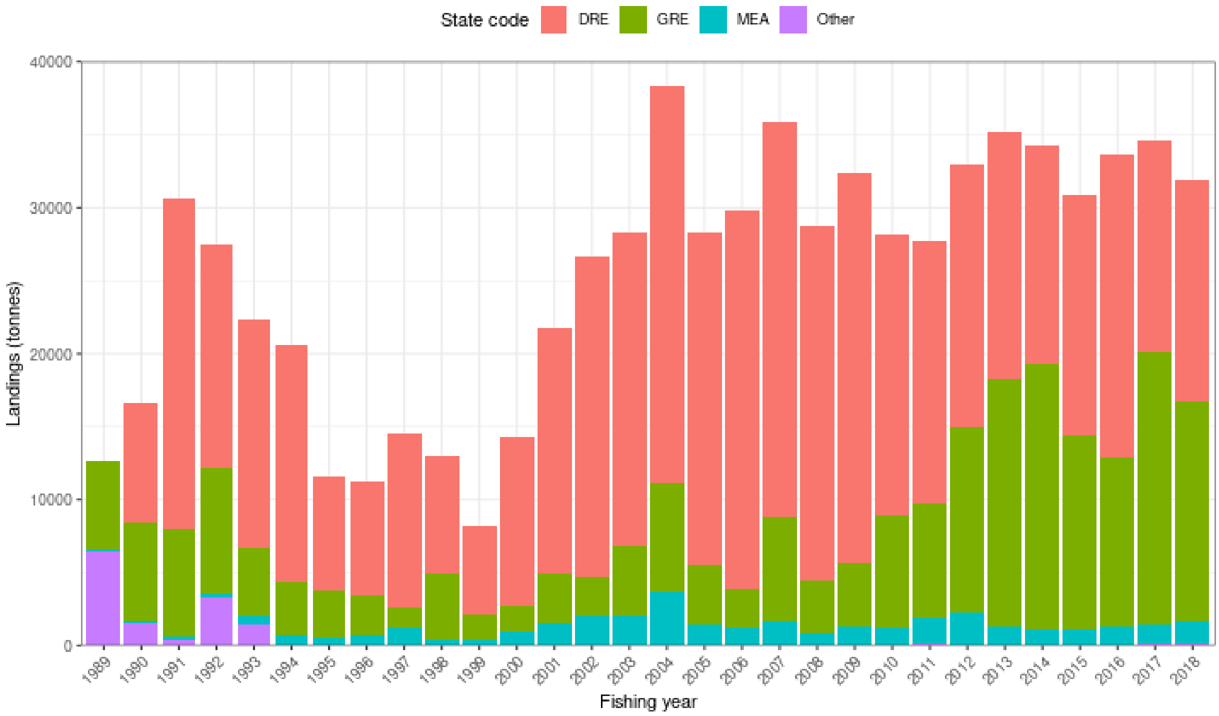

Figure 14: Commercial landings (tonnes) by state and fishing year from 1989–90 to 2018–19. The state code 'DRE' is dressed, 'GRE' is green, and 'MEA' is mealed. Note that fishing year has been labelled with the first year of the pair.

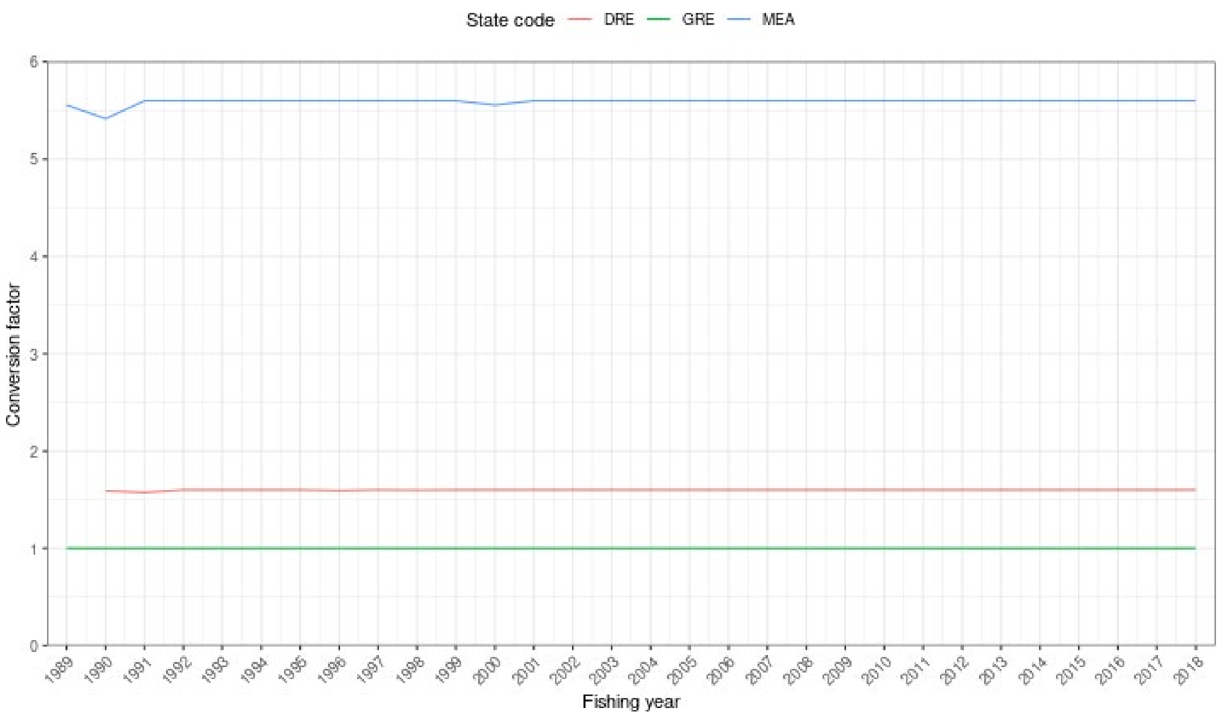

Figure 15: Conversion factor by landed state and fishing year from 1989–90 to 2018–19. The state code 'DRE' is dressed, 'GRE' is green, and 'MEA' is mealed. Note that fishing year has been labelled with the first year of the pair.

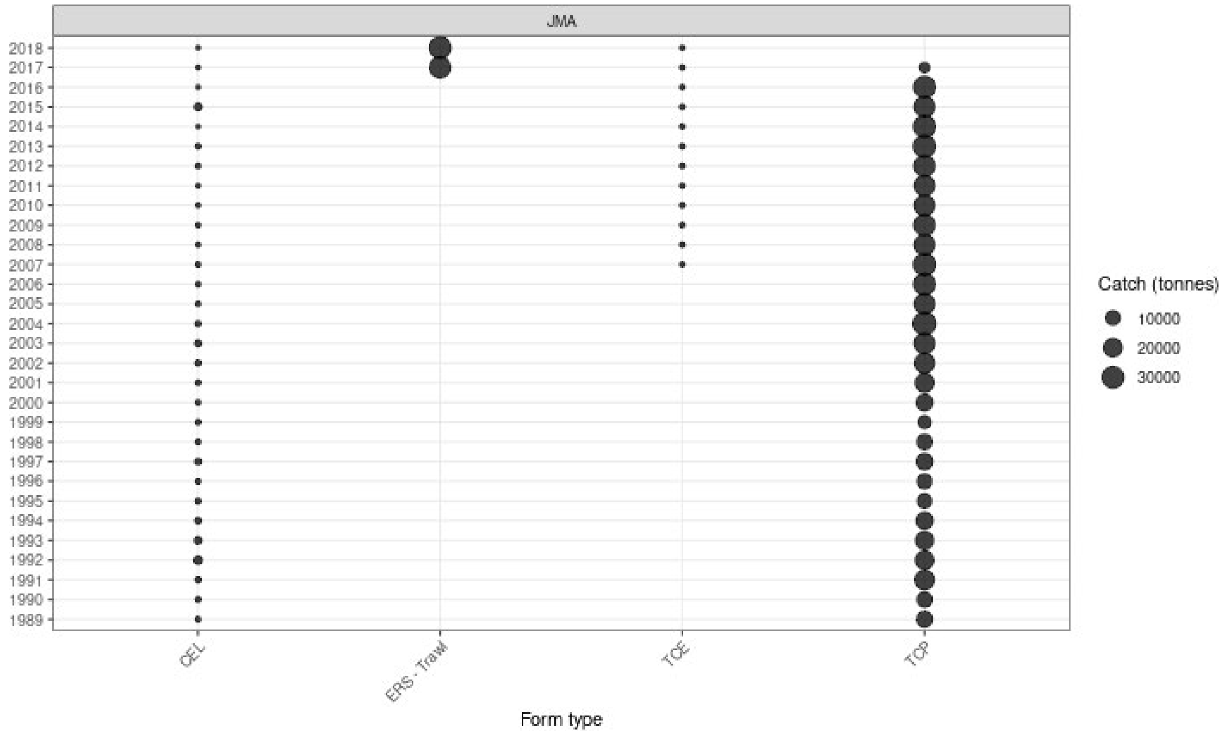

Figure 16: Estimated catch (tonnes) by form type and fishing year from 1989–90 to 2018–19. These data are derived from the EDW database. Data plotted in Table 8 as percentages. Note that fishing year has been labelled with the first year of the pair.

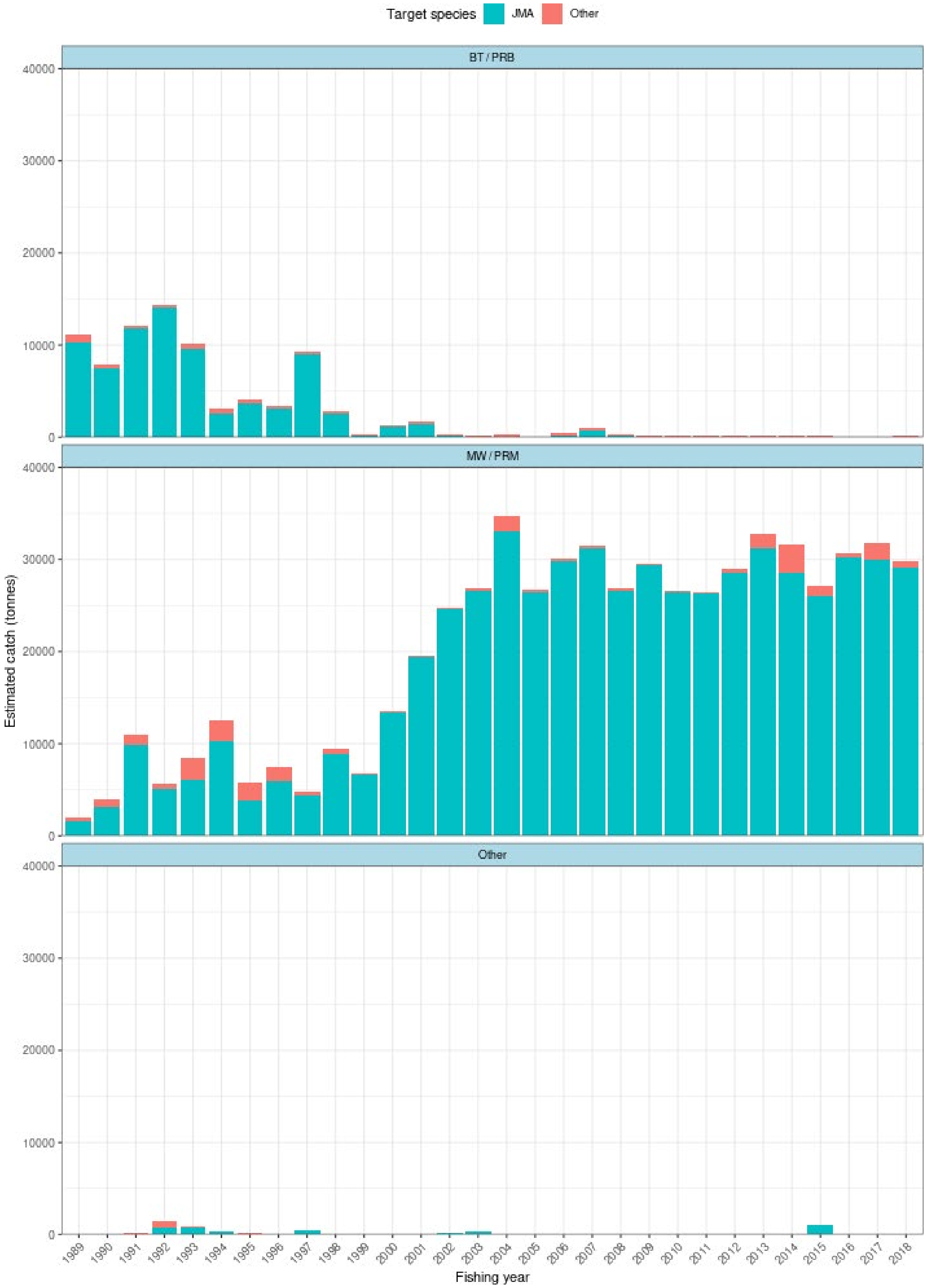

Figure 17: Estimated catch (tonnes) of JMA by fishing method (BT/PRB = bottom trawl and precision bottom trawl, MW/PRM = midwater trawl and precision midwater trawl), target species, and fishing year from 1989–90 to 2018–19. Note that fishing year has been labelled with the first year of the pair.

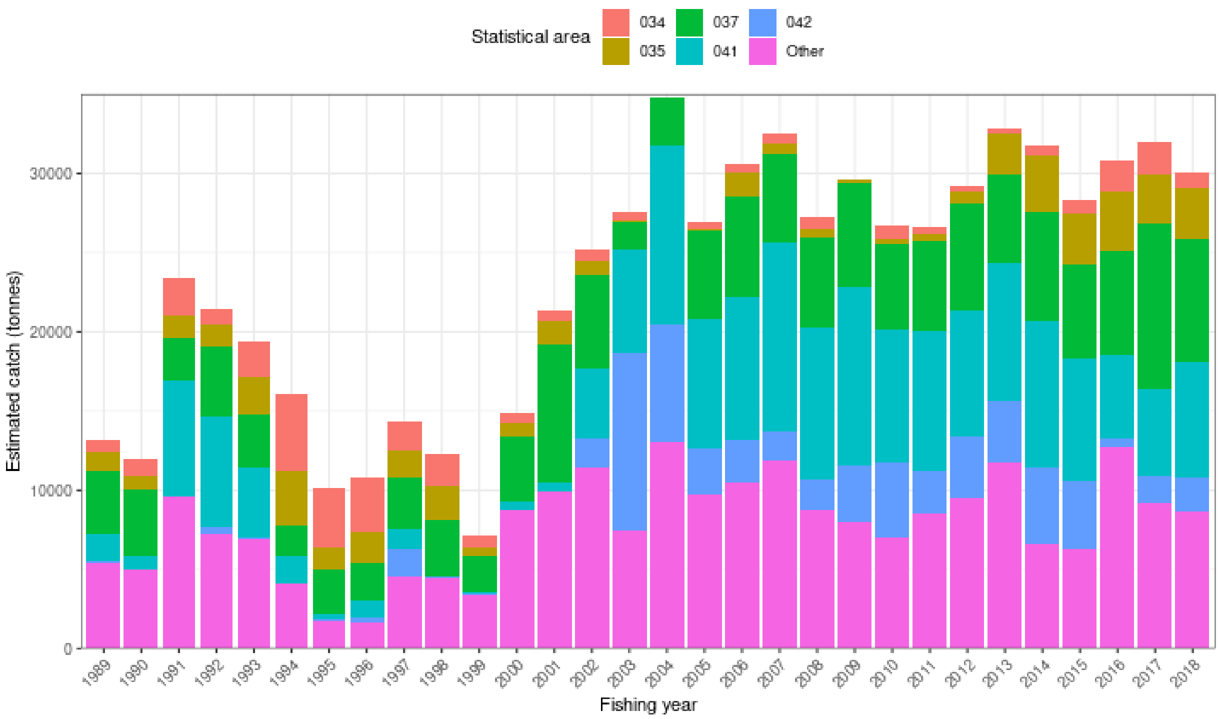

Figure 18: Estimated catch (tonnes) by statistical area and fishing year from 1989–90 to 2018–19. Data are given in Table 11 as percentages. Note that fishing year has been labelled with the first year of the pair.

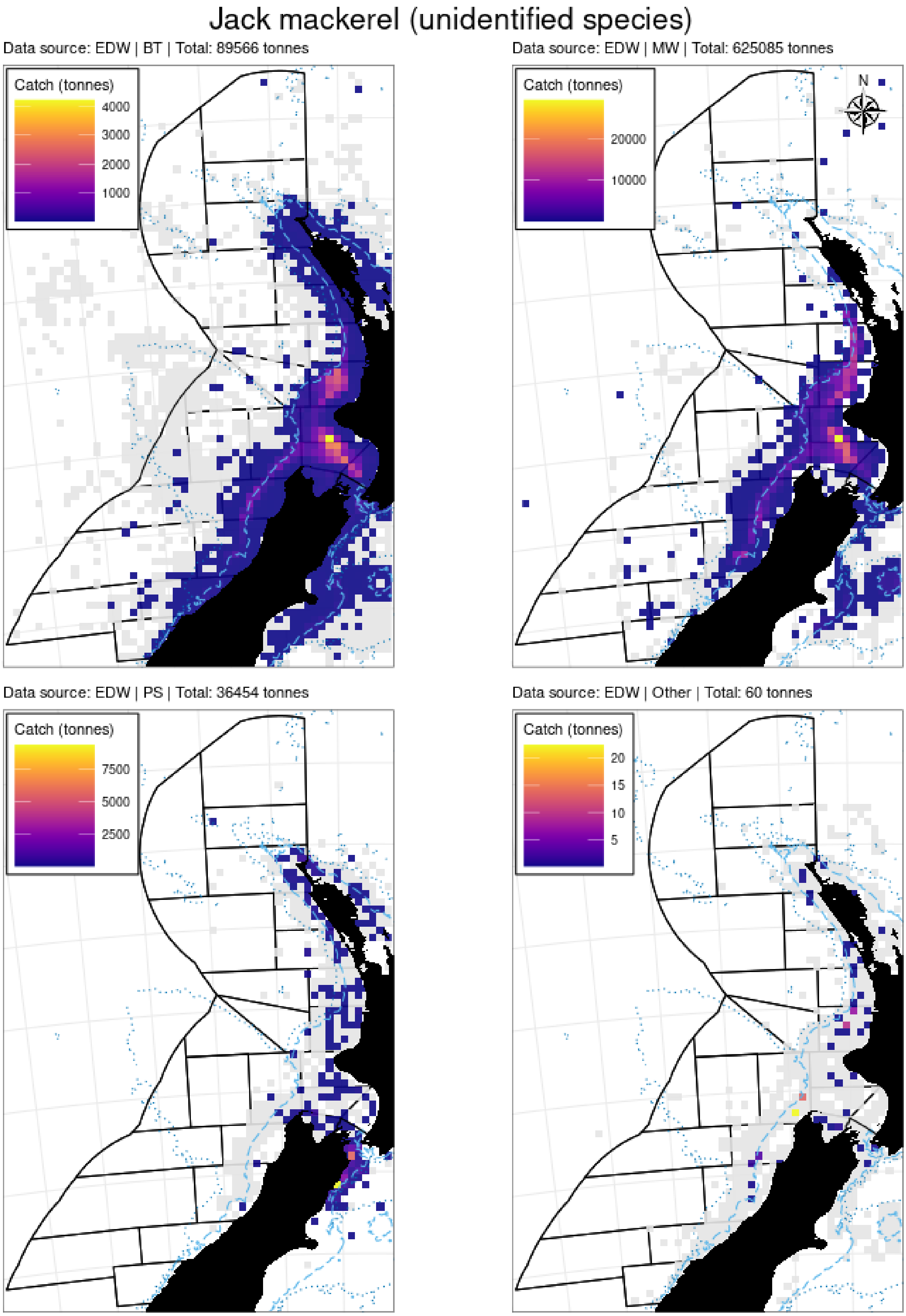

Figure 19: Total catch (tonnes) of all JMA species by fishing gear for all fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there has been effort but no JMD recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from the EDW database.

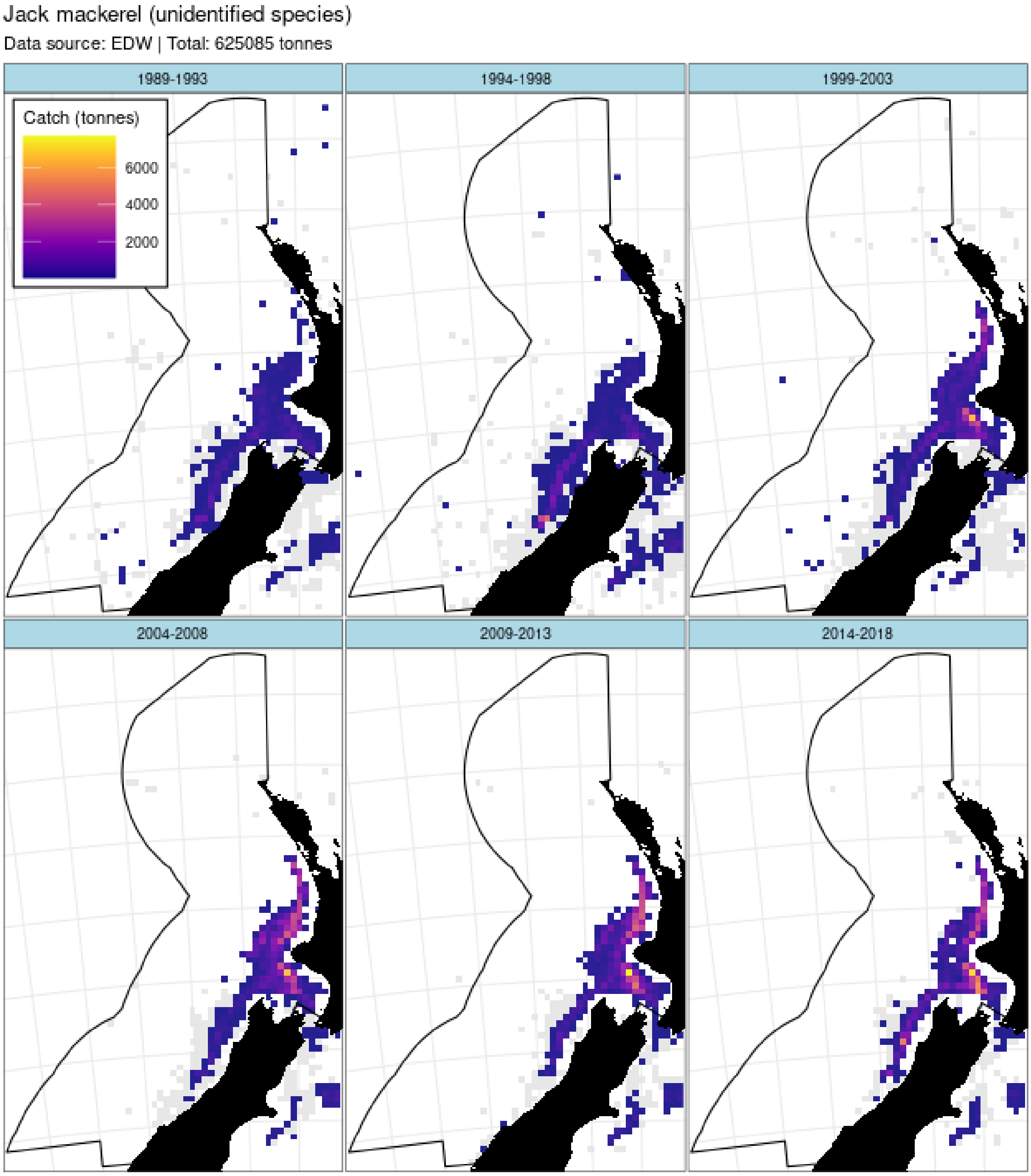

Figure 20: Total catch (tonnes) of all JMA species caught by MW split into five-year blocks of fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there has been effort but no JMA recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from the EDW database.

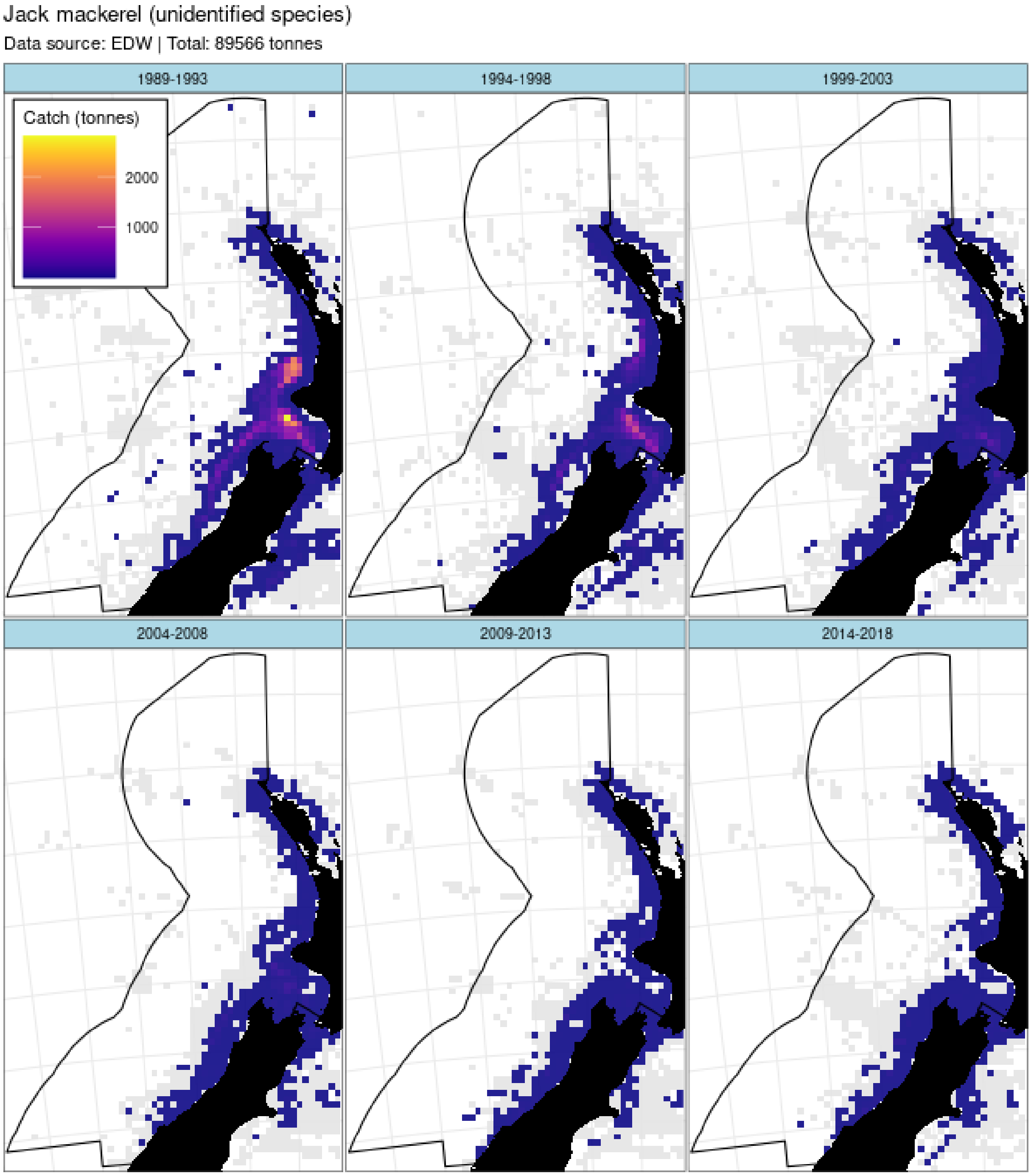

Figure 21: Total catch (tonnes) of all JMA species caught by BT split into five-year blocks of fishing years (1989–90 to 2018–19) in the waters surrounding New Zealand, including beyond the New Zealand EEZ and outside JMA 7. Grey cells represent areas where there has been effort but no JMA recorded. The defined JMA 7 (Figure 1B) boundary is shown in black. These data are derived from the EDW database.

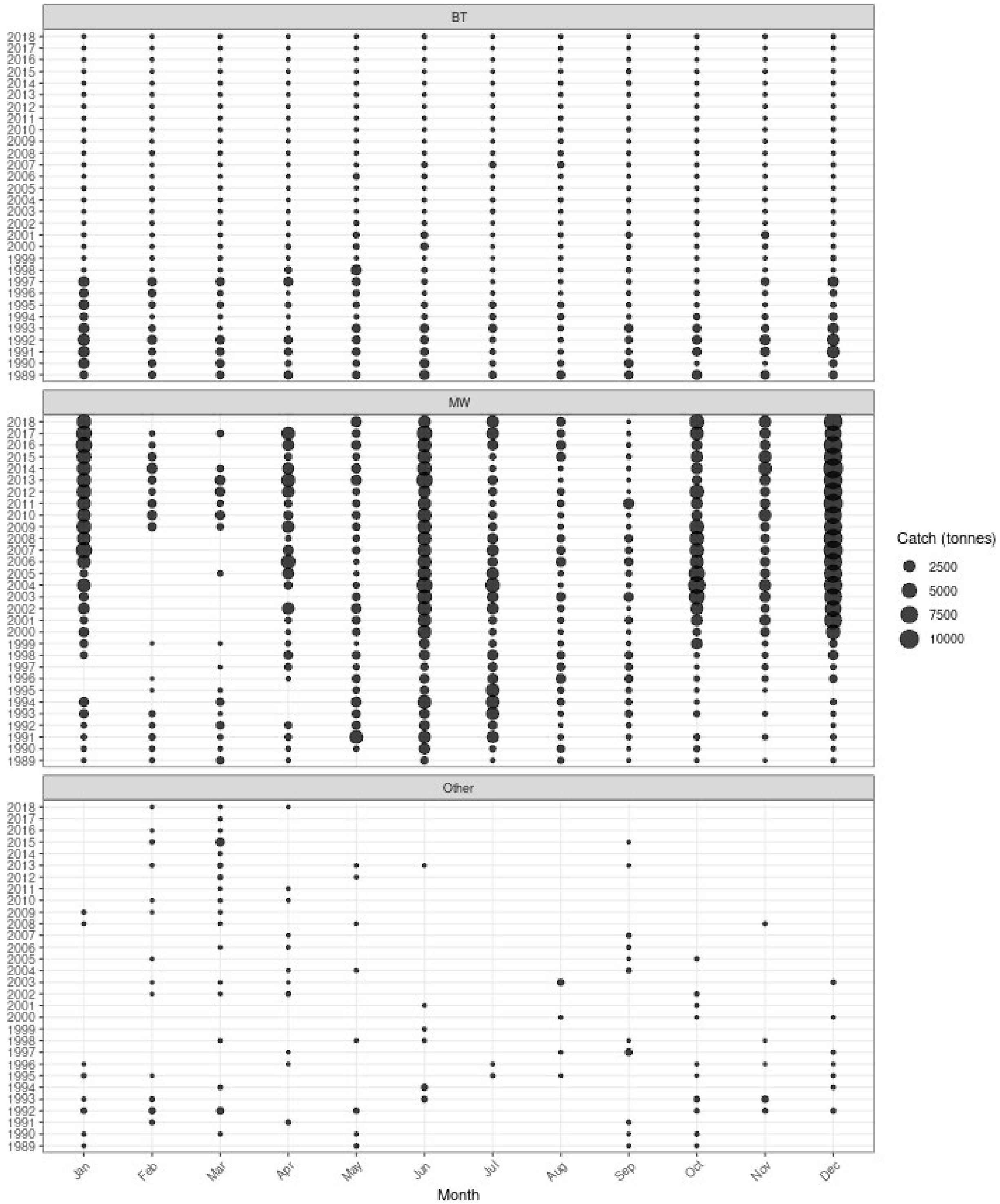

Figure 22: Estimated catch (tonnes) by fishing method (BT = bottom trawl, MW = midwater trawl), month, and fishing year from 1989–90 to 2018–19. These data are derived from the EDW database. Note that fishing year has been labelled with the first year of the pair.

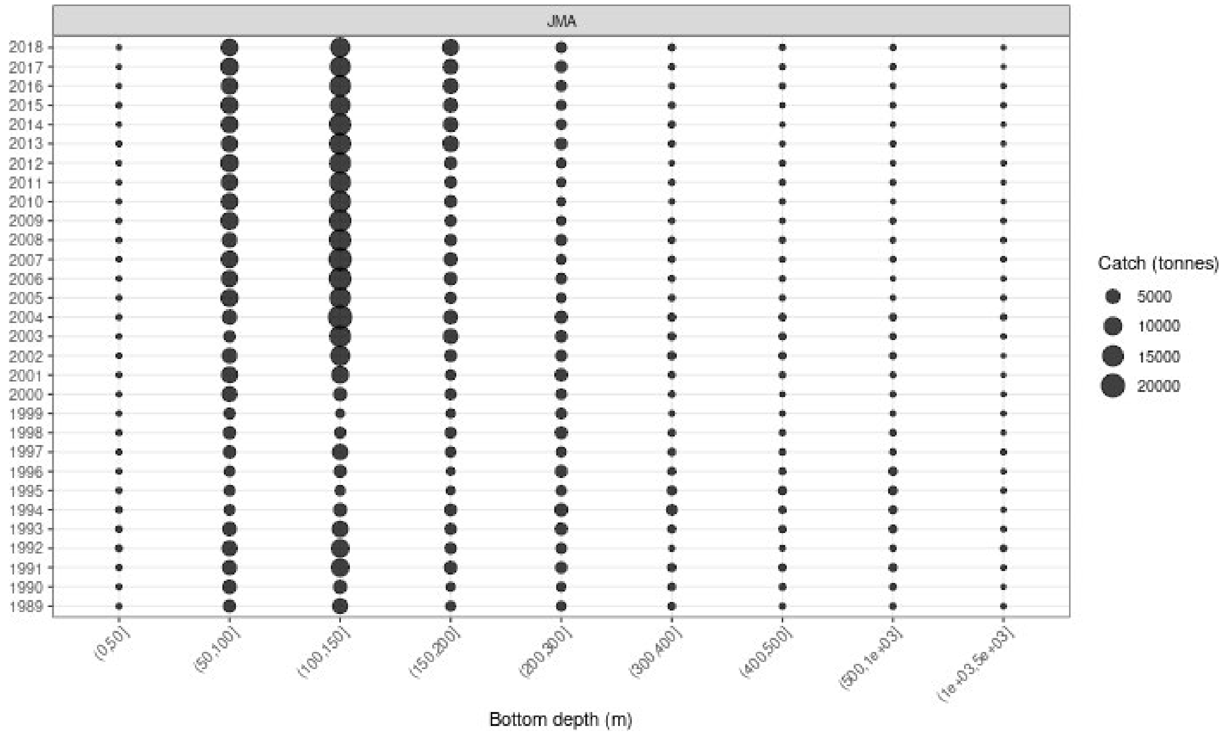

Figure 23: Estimated catch (tonnes) by bottom depth and fishing year from 1989–90 to 2018–19. These data are derived from the EDW database. Note that fishing year has been labelled with the first year of the pair.

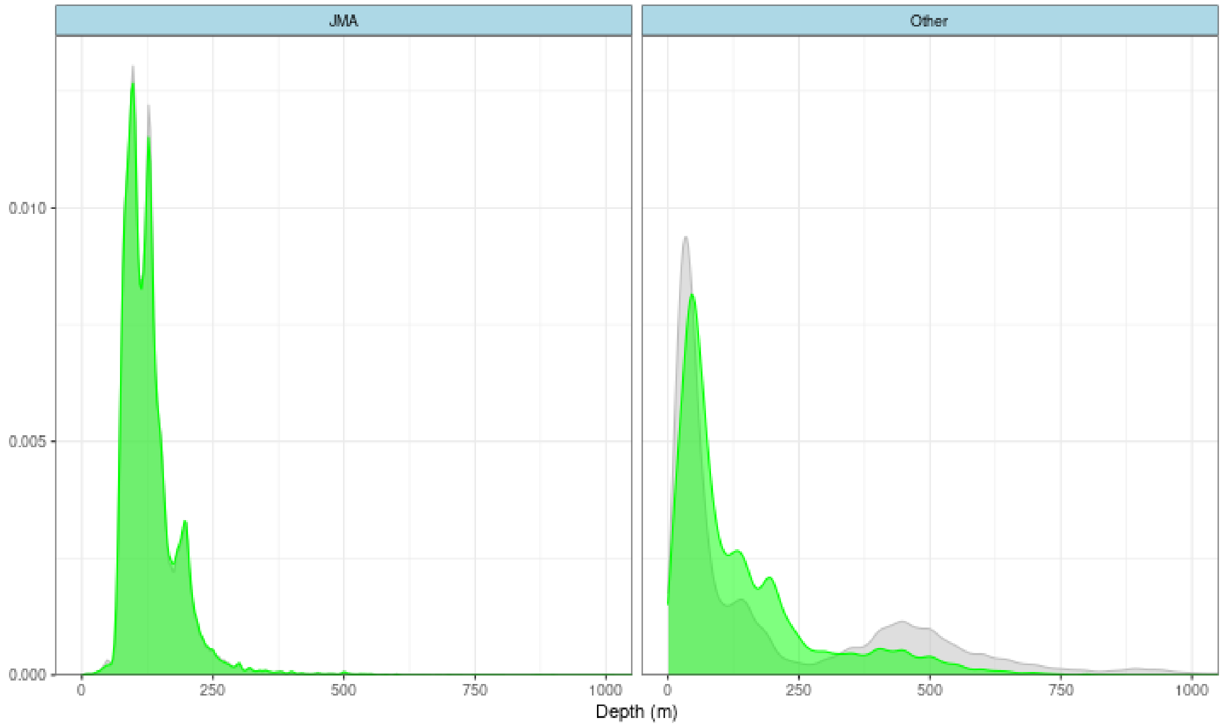

Figure 24: The distribution of bottom depth (m) for all tows targeting either JMA or other species (grey) and the distribution of tows that caught JMA or targeted JMA (green). These data are derived from the EDW database.

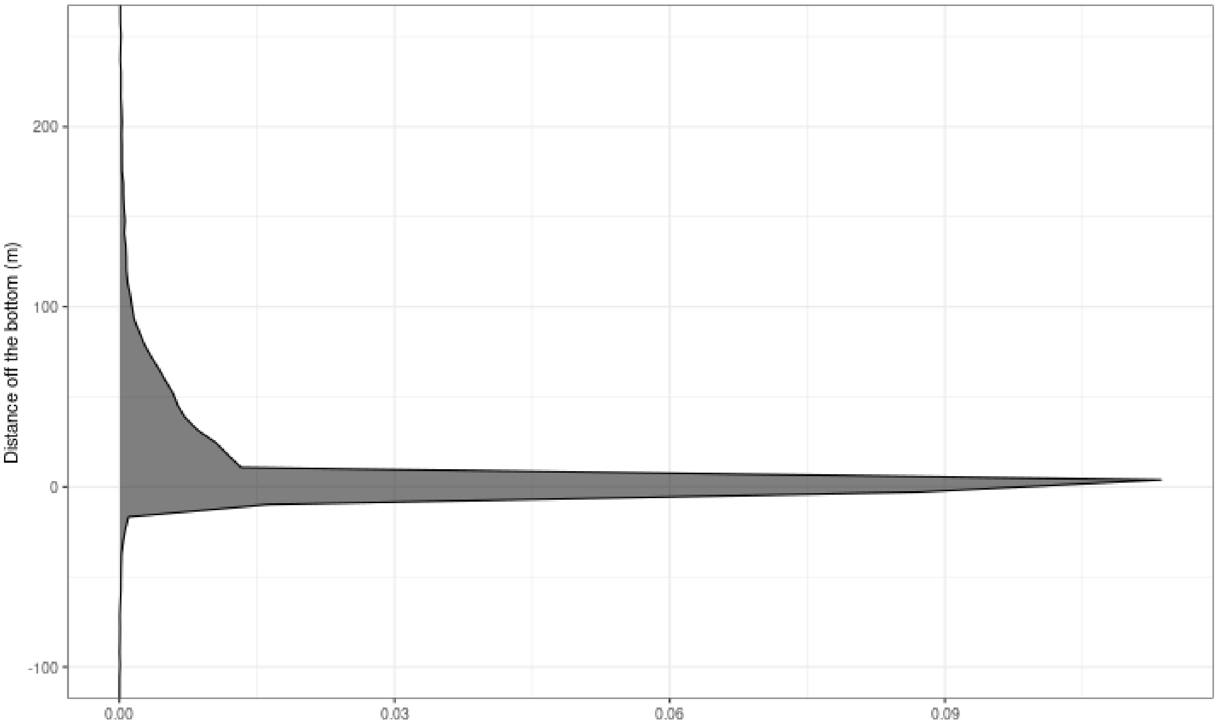

Figure 25: The distribution of the distance off the bottom (D_i) for fishing events that caught JMA for MW and PRM (D_i = effort depth – bottom depth). These data are derived from the EDW database.

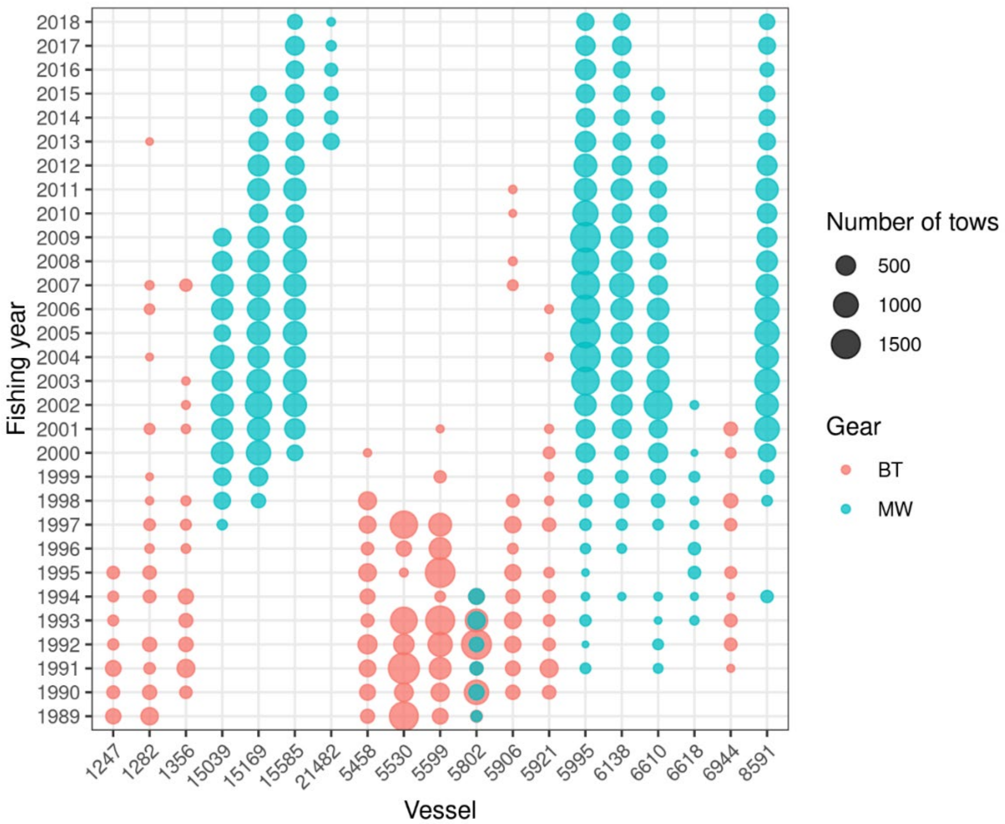

Figure 26: Number of tows in the EDW dataset by vessel, fishing gear (BT or MW), and fishing year from 1989–90 to 2018–19 for core vessels and core statistical areas only. Note that fishing year has been labelled with the first year of the pair.

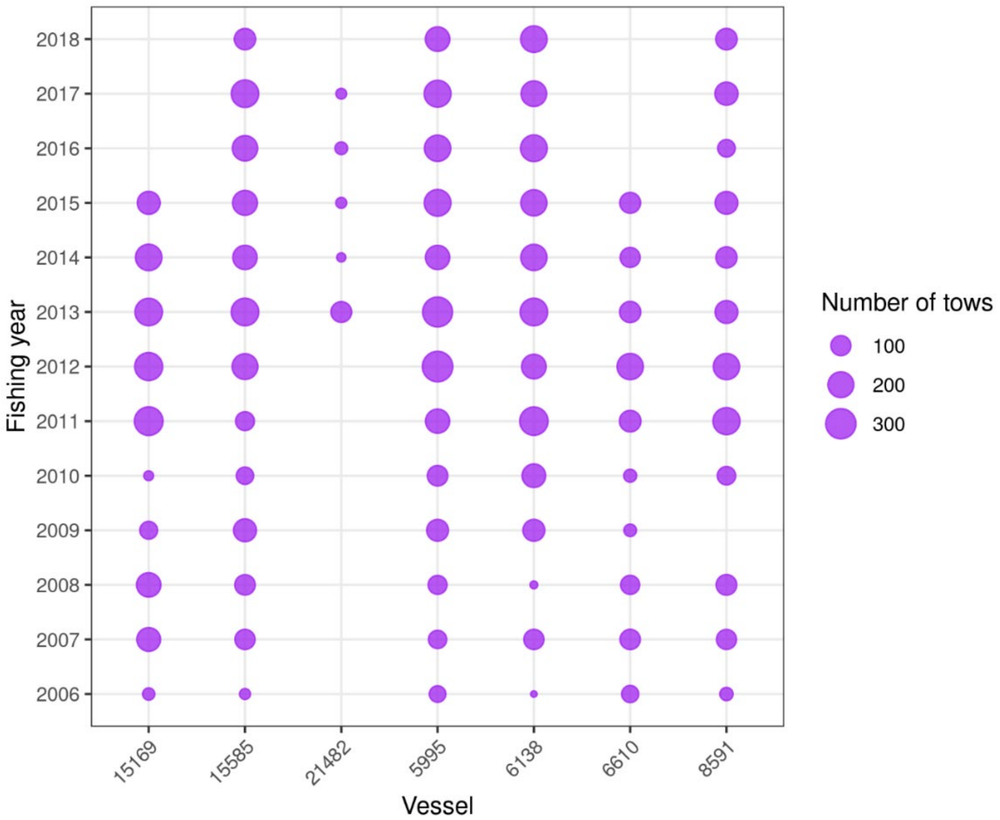

Figure 27: Number of tows in the COD dataset by vessel, MW fishing gear, and fishing year from 2006–07 to 2018–19 for core vessels and core statistical areas only. Note that fishing year has been labelled with the first year of the pair.

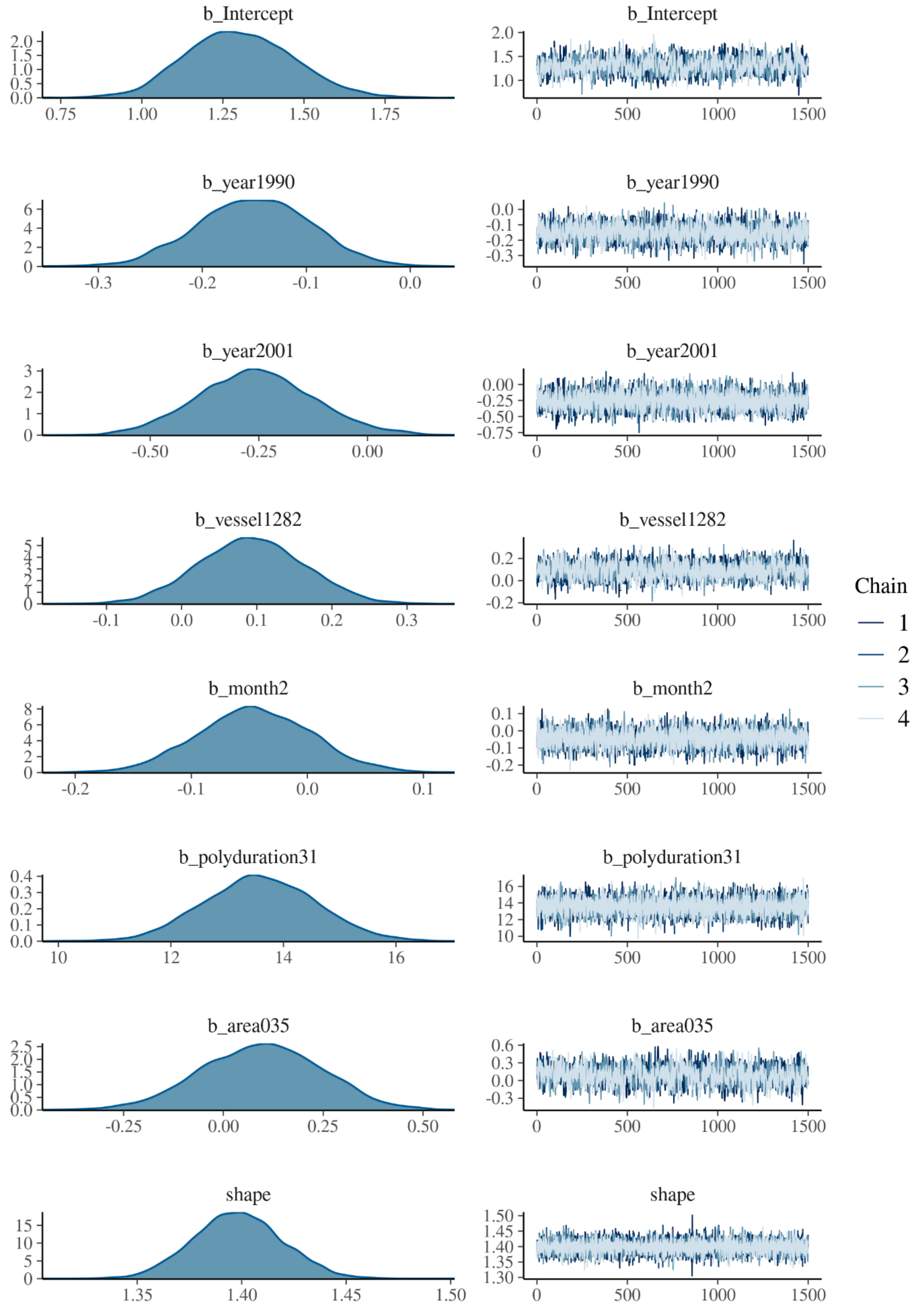

Figure 28: MCMC trace plots for a selection of variables including the intercept, two of the twelve year coefficients, one of the nine vessel coefficients, one of the eleven month coefficients, one of the three fishing duration third order polynomial coefficients, two of the eight statistical area coefficients, and the gamma distribution shape parameter for the EDW, BT, 1989–2001, gamma model.

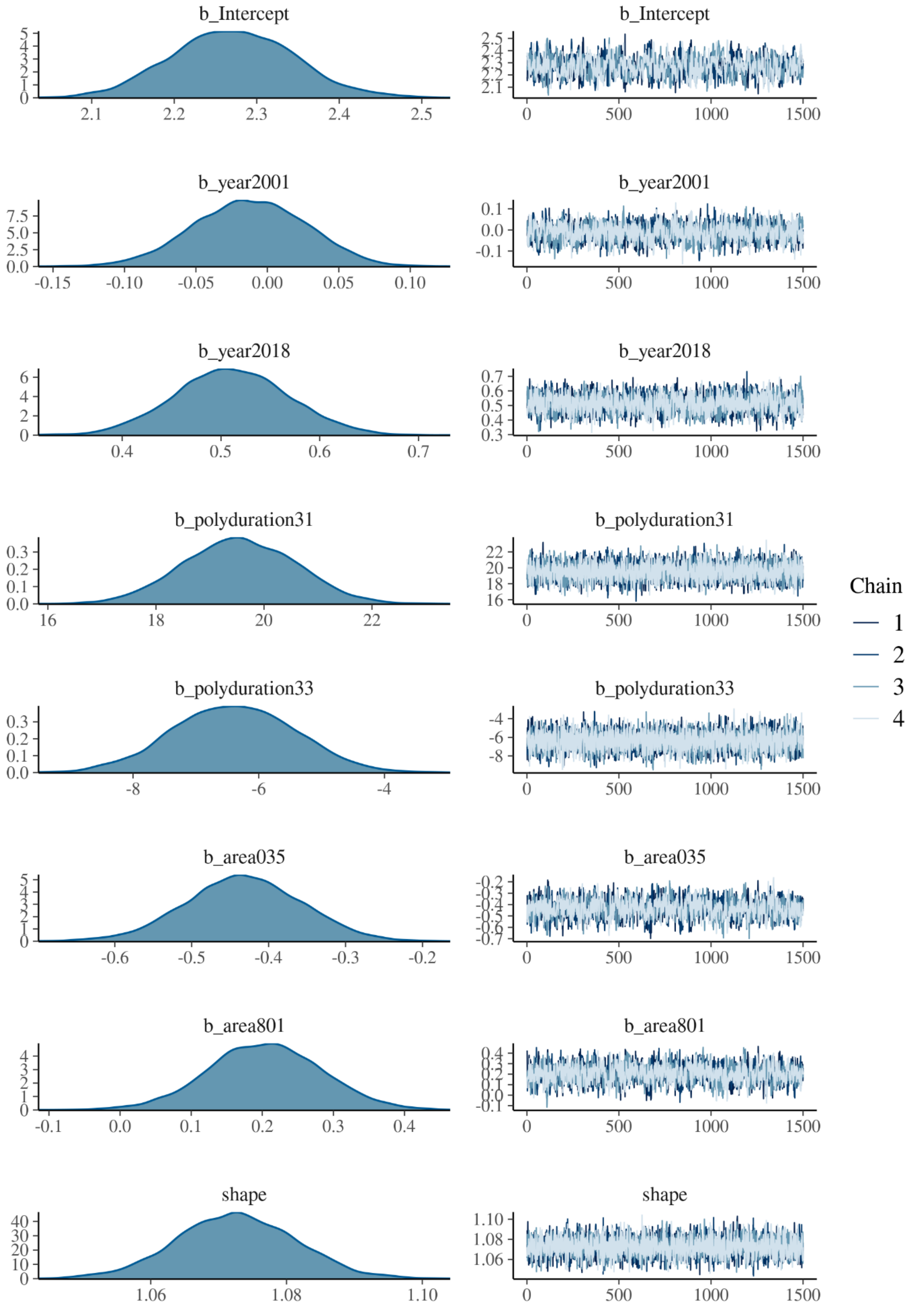

Figure 29: MCMC trace plots for a selection of variables including the intercept, two of the eighteen year coefficients, two of the three fishing duration third order polynomial coefficients, two of the nine statistical area coefficients, and the gamma distribution shape parameter for the EDW, MW, 2001–2018, gamma model.

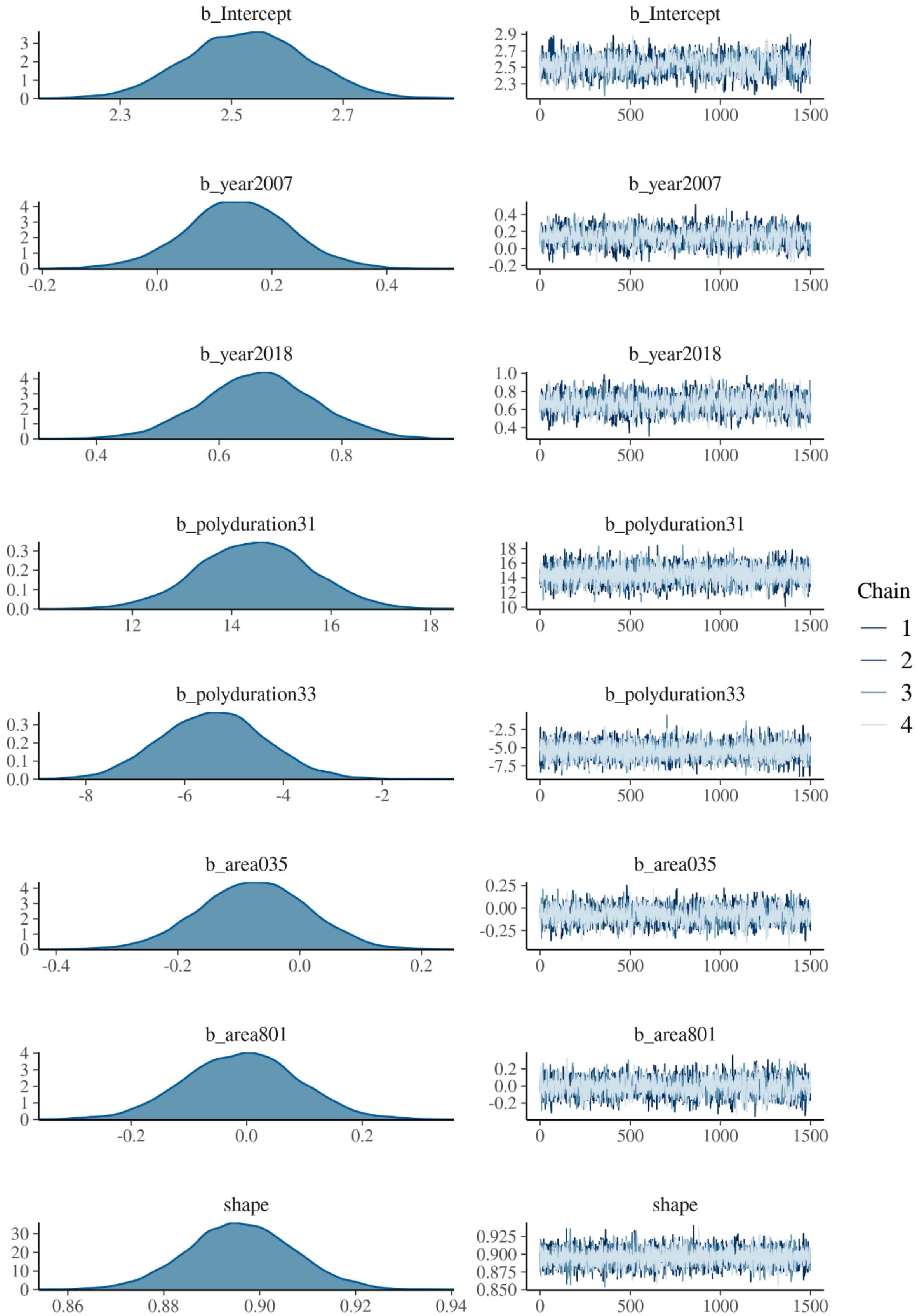

Figure 30: MCMC trace plots for a selection of variables including the intercept, two of the twelve year coefficients, two of the three fishing duration third order polynomial coefficients, two of the nine statistical area coefficients, and the gamma distribution shape parameter for the COD, MW, 2006–2018, gamma model.

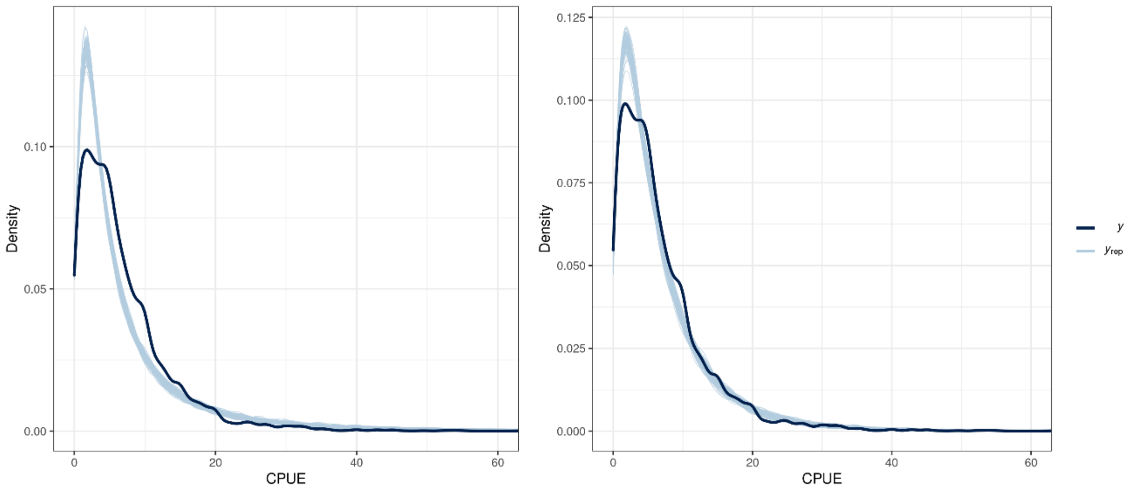

Figure 31: Comparison of the empirical distribution of the data (y) to the distributions of simulated/replicated data (y_{rep}) from the posterior predictive distribution. EDW, BT 1989–2001 model, for lognormal (left) and gamma (right) distributions.

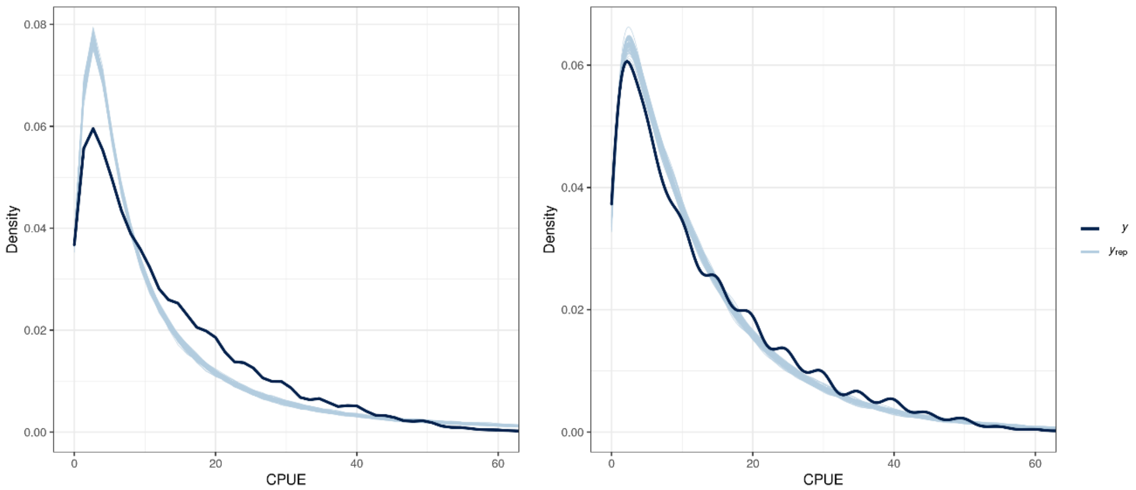

Figure 32: Comparison of the empirical distribution of the data (y) to the distributions of simulated/replicated data (y_{rep}) from the posterior predictive distribution. EDW, MW 2000–2018 model: for lognormal (left) and gamma (right) distributions.

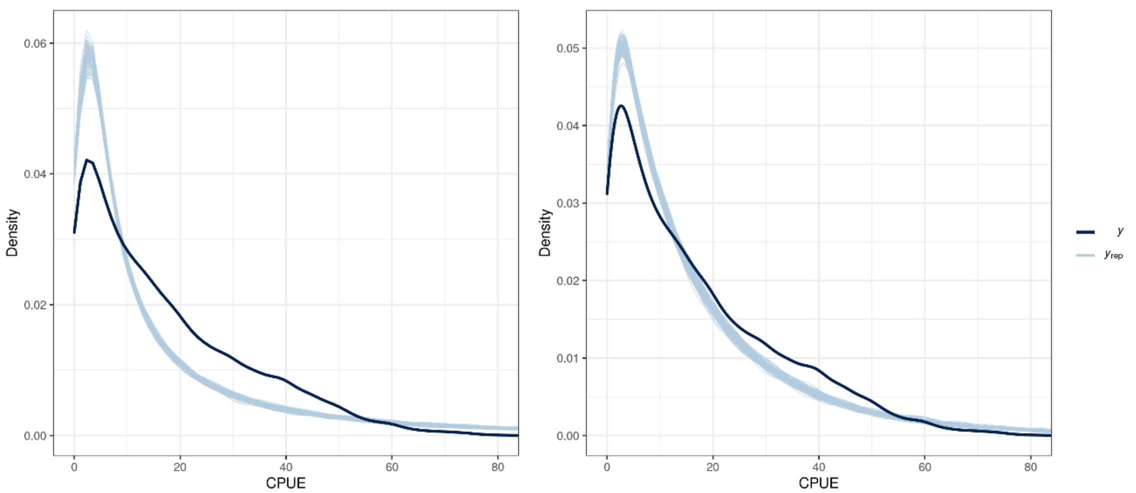

Figure 33: Comparison of the empirical distribution of the data (y) to the distributions of simulated/replicated data (y_{rep}) from the posterior predictive distribution. COD, MW 2006–2018 model: for lognormal (left) and gamma (right) distributions.

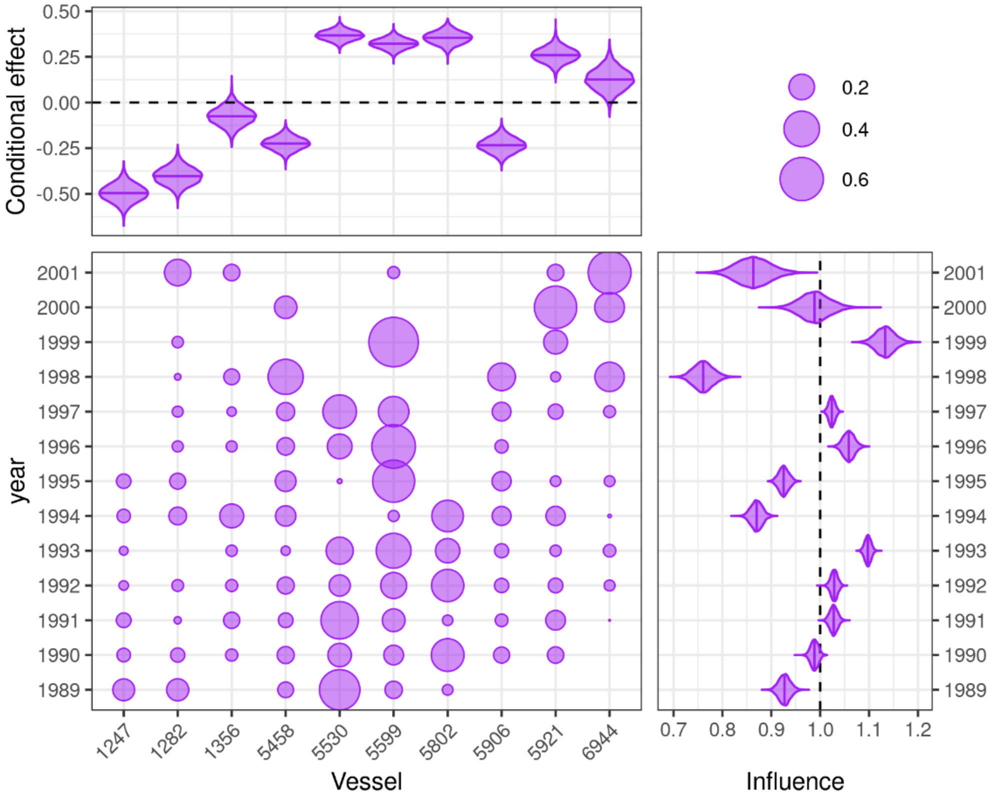

Figure 34: CDI plot for vessel for the EDW, BT, 1989–2001, gamma model. Note that fishing year has been labelled with the first year of the pair.

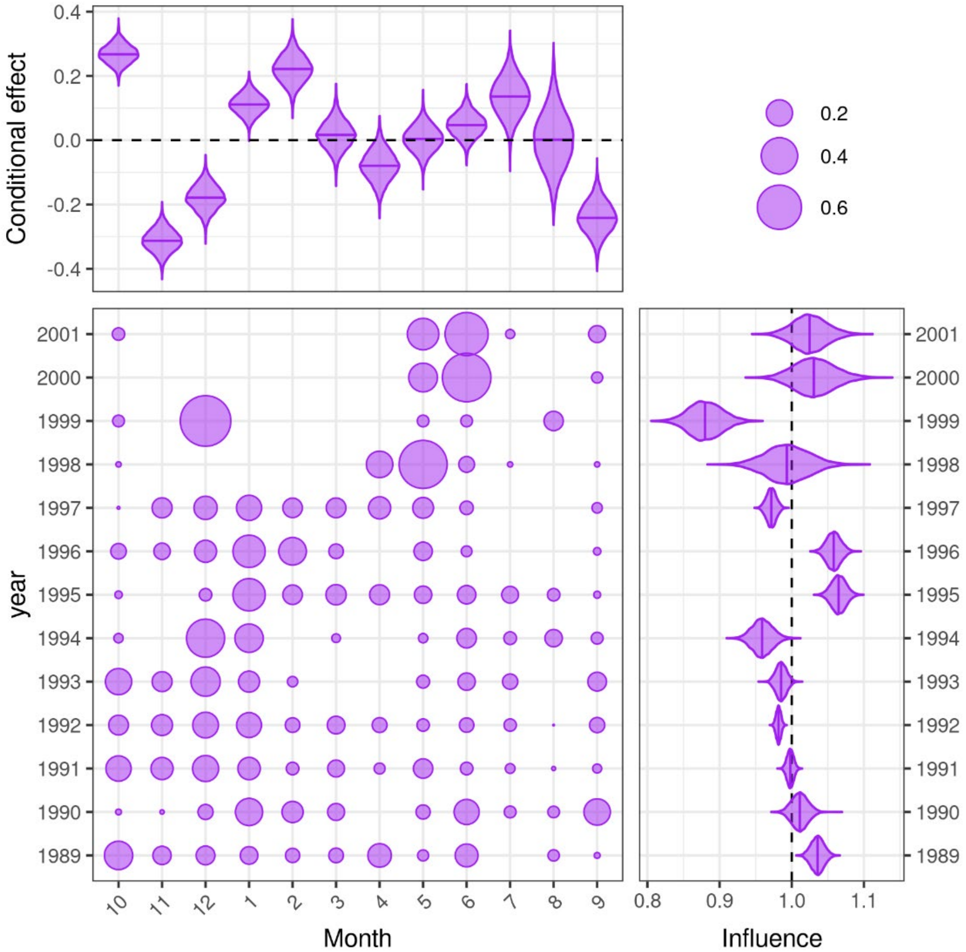

Figure 35: CDI plot for month (1 = Jan, 2 = Feb, 3 = Mar, 4 = Apr, 5 = May, 6 = Jun, 7 = Jul, 8 = Aug, 9 = Sep, 10 = Oct, 11 = Nov, 12 = Dec) for the EDW, BT, 1989–2001, gamma model. Note that fishing year has been labelled with the first year of the pair.

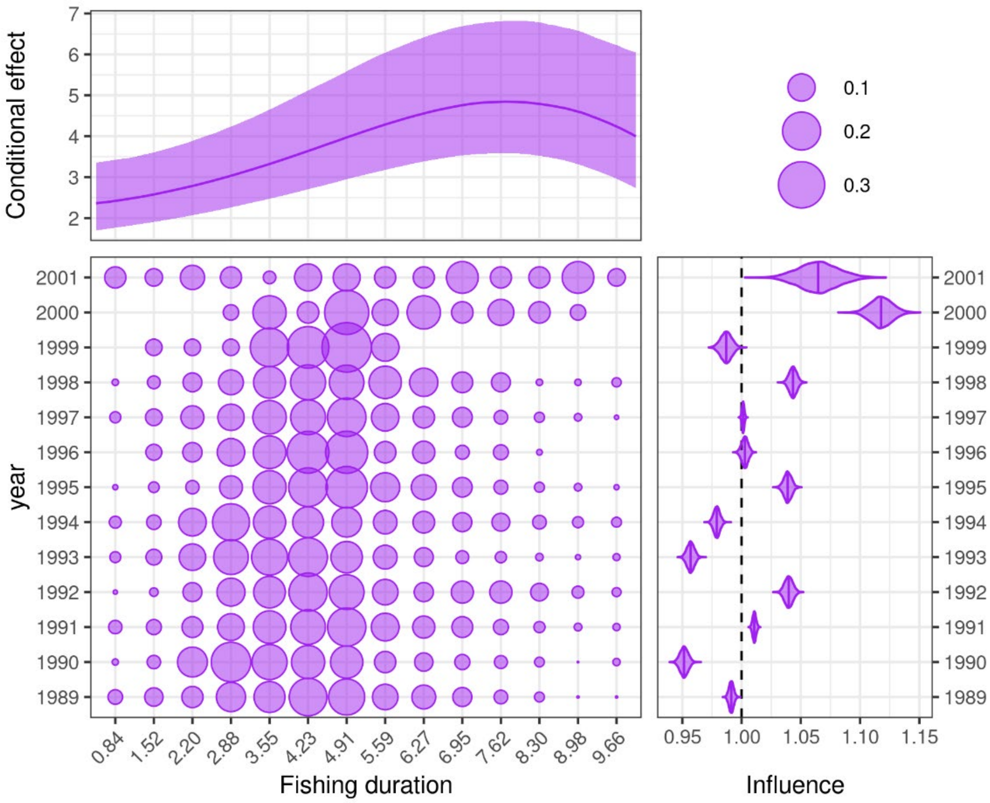

Figure 36: CDI plot for fishing duration as a third order polynomial for the EDW, BT, 1989–2001, gamma model. Note that fishing year has been labelled with the first year of the pair.

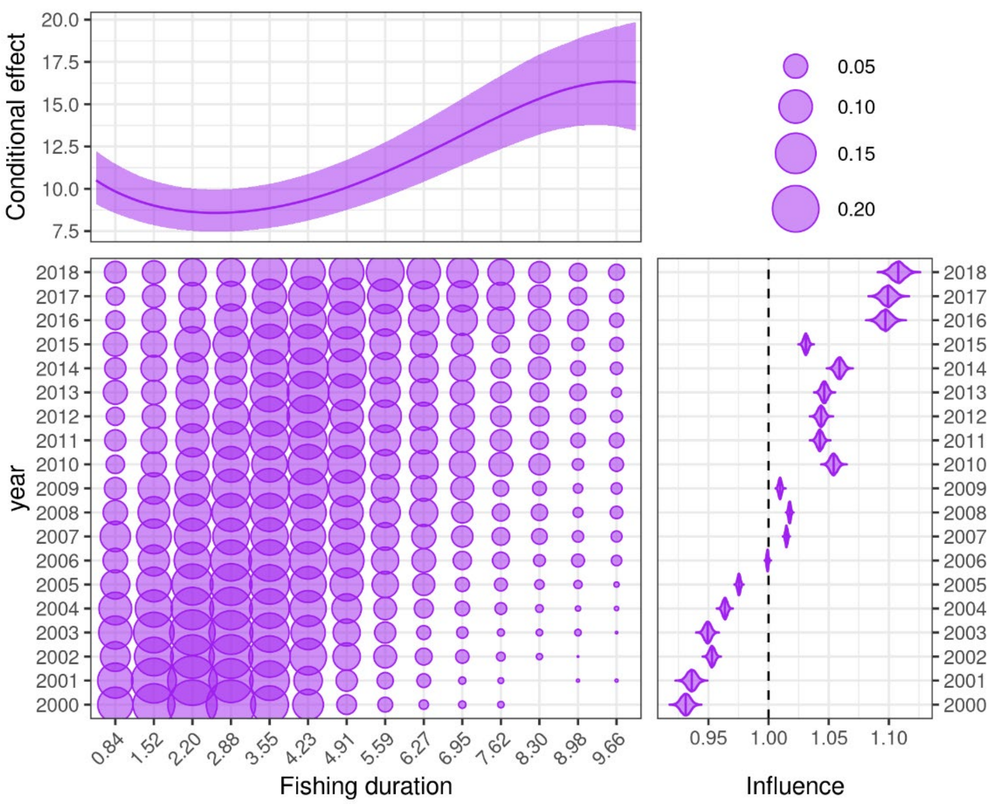

Figure 37: CDI plot for fishing duration as a third order polynomial for the EDW, MW, 2000–2018, gamma model. Note that fishing year has been labelled with the first year of the pair.

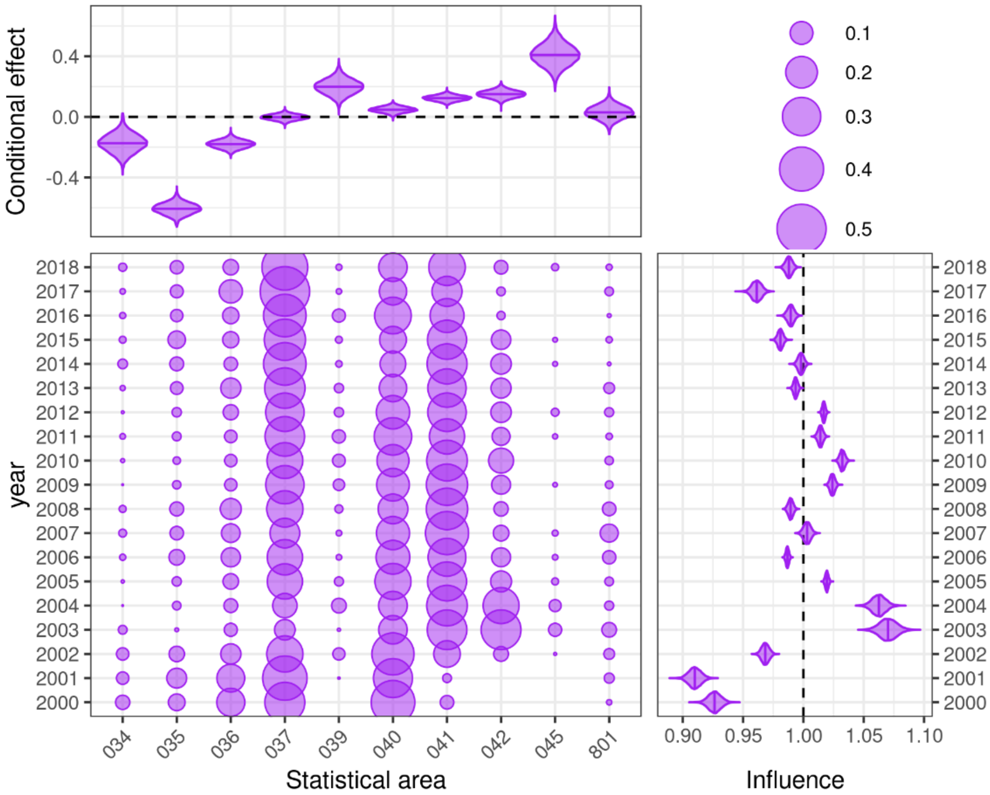

Figure 38: CDI plot for statistical area for the EDW, MW, 2000–2018, gamma model. Note that fishing year has been labelled with the first year of the pair.

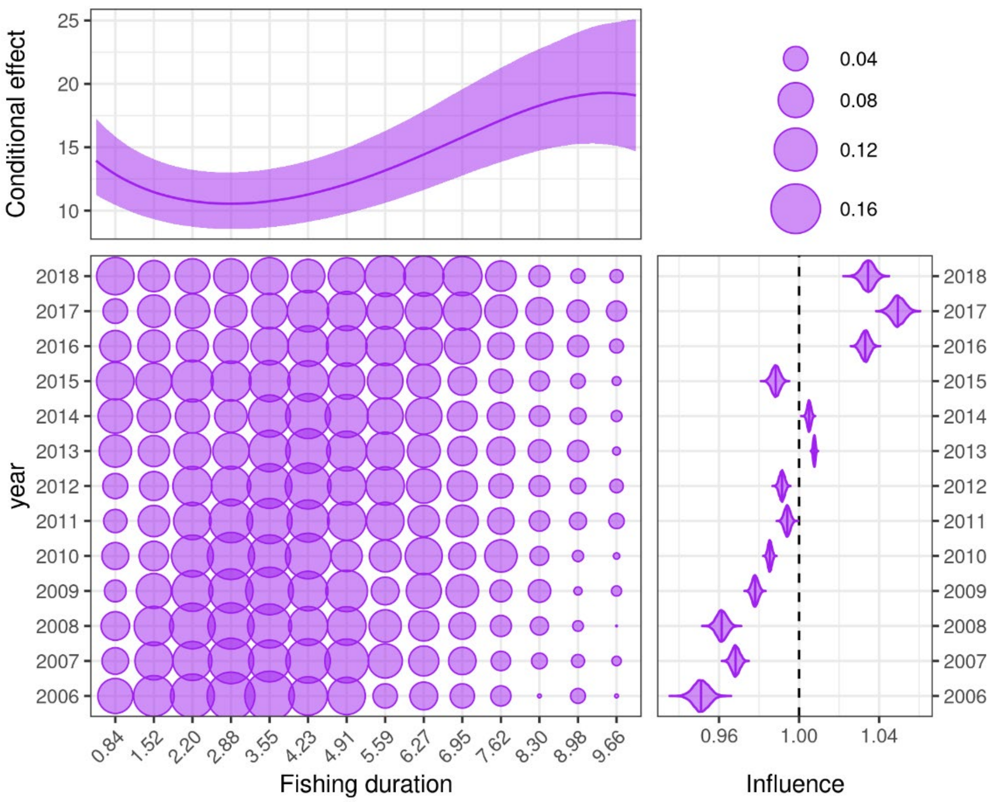

Figure 39: CDI plot for fishing duration as a third order polynomial for the COD, MW, 2006–2018, gamma model. Note that fishing year has been labelled with the first year of the pair.

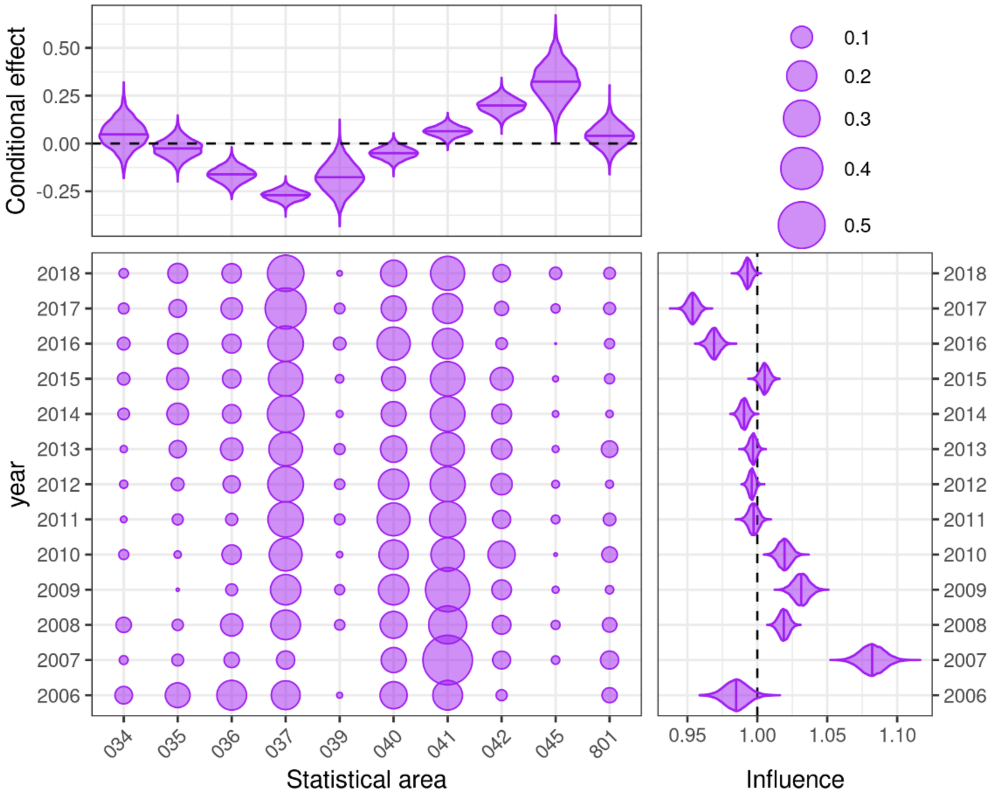

Figure 40: CDI plot for statistical area for the COD, MW, 2006–2018, gamma model. Note that fishing year has been labelled with the first year of the pair.

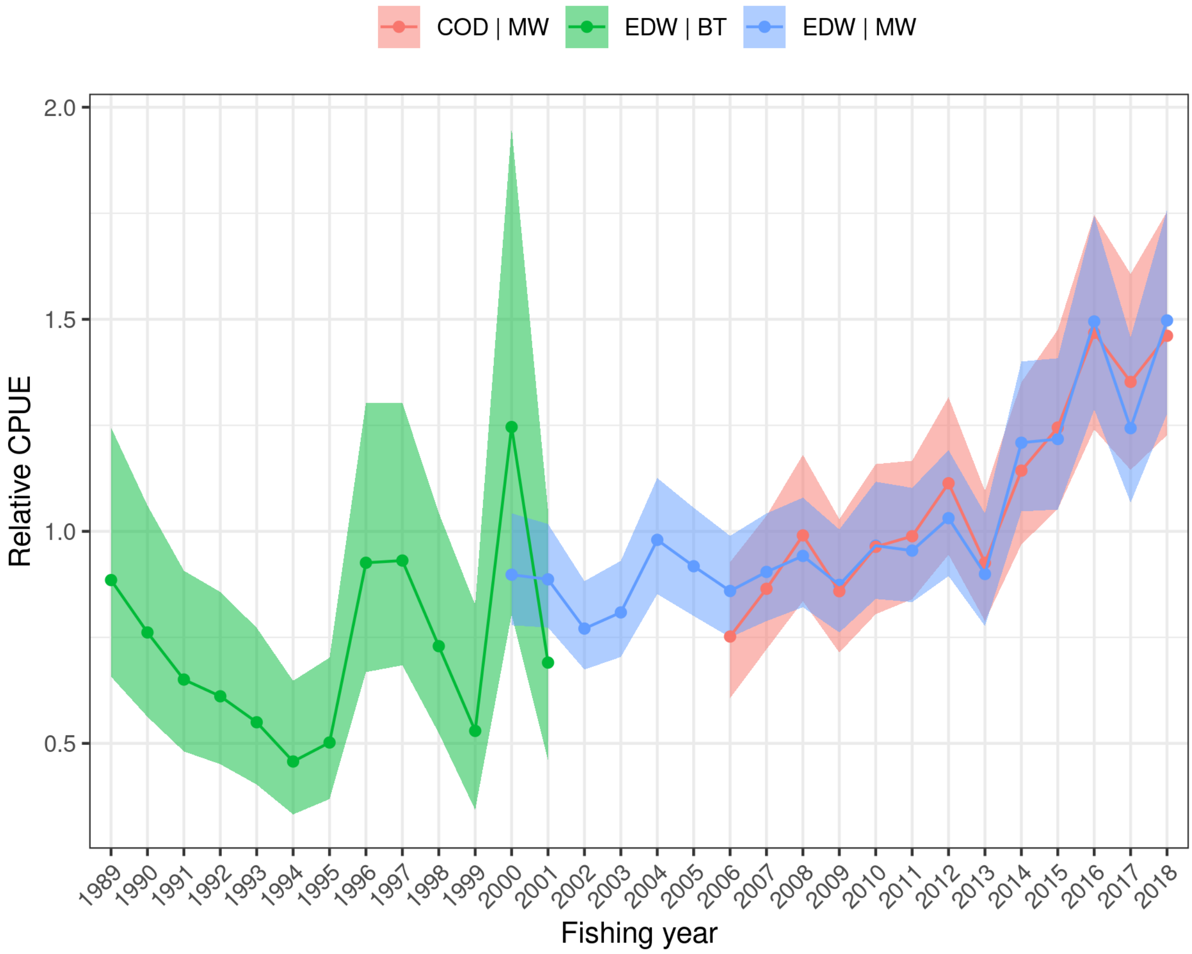

Figure 41: Standardised catch per unit effort (CPUE) indices of all three JMA species combined (i.e., JMD, JMM, and JMN) in JMA 7 by fishing year from 1989–90 to 2018–19. Three series are presented: a bottom trawl (BT) series from 1989–2001 based on data held in the Electronic Data Warehouse (EDW); a midwater (MW) series from 2000–2018 also based on EDW data; and a MW series from 2006–2018 based on data held in the Centralised Observer Database (COD). Points represent the median, and shaded region represents the 95% credible interval. The MW EDW series is scaled to have a geometric mean of 1, and the MW COD and BT EDW series are scaled to have the same geometric mean as the MW EDW series for the overlapping years. Note that fishing year has been labelled with the first year of the pair.

APPENDIX I: DEFINITIONS OF CODES USED THROUGHOUT THIS REPORT

Code	Definition	Code	Description
BLL	Bottom longlining	BAR	Barracouta
BPT	Bottom trawl (pair)	EMA	Blue mackerel
BT	Bottom trawl (single)	HOK	Hoki
MPT	Midwater trawl (pair)	JDO	John dory
MW	Midwater trawl (single)	JMA	Jack mackerel
PSH	Precision Seafood Harvesting	KAH	Kahawai
PRB	Bottom trawl using PSH	RBT	Redbait
PRM	Midwater trawl using PSH	SWA	Silver warehou
		TAR	Tarakihi
		TRE	Trevally
		WAR	Blue warehou

APPENDIX II: INSTRUCTIONS TO OBSERVERS

The JMA sampling instructions provided to observers (valid as of 5 March 2019), which have been in existence for several years, are given below (from Fisheries New Zealand Observer Services).

JMA:

The JMA sampling regime has changed, so please adhere to the following sampling protocol.

** You are no longer required to stage males.*
** Please carry out one length frequency test every day.*
** Each sample must consist of 100kg. (If your 100kg sample is more than 150 fish then only sample 150 fish.)*
** For catches containing up to 100kg JMA – all fish are to be sampled.*
** For catches greater than 100kg but less than 1 tonne – take two random sub samples (totalling at least 150 fish) throughout the catch. (i.e. 2 tests of 75 fish).*
** Catches greater than 1 tonne but less than 10 tonne – take three random sub samples (totalling at least 150 fish) throughout the catch (i.e 3 tests of 50 fish).*
** Catches greater than 10 tonne – take four random sub samples (totalling at least 150 fish) throughout the catch (i.e 4 tests of 37-38 fish).*

All fish from these samples must first be sorted into the three sub-species (JMM/JMD/JMN).

Each group of sub-species must then be:

** Weighed*
** Measured*
** Sexed*
** Gonads staged (females only).*

In addition, a sub-sample of otoliths must be collected as follows:

JMN & JMD:

Over the trip you should collect at least three otoliths in each 1 cm size class from 27cm to 65cm where possible. If there are any fish outside this range, their otoliths should also be collected and noted on the otolith collection tally sheet.

The tally sheets included with this request are to assist in keeping track of the number of otoliths you have collected as well as providing a clear summary of what has been collected at the end of the trip. It should be amended with any additional size classes outside the suggested range (where necessary), clearly labelled with your name, trip date, trip number and collection area.

Each pair of otoliths from specimens in the sub-sample to be removed, cleaned and stored in the otolith envelopes.

JMM & EMA:

Please take five sets of otoliths (randomly) from each sample.

All the usual information (trip number, tow number, date, area, species, sex etc) to be recorded on an otolith envelope.

If you encounter any difficulties with this sampling, please make contact with shore staff as soon as *possible. We appreciate that this sampling programme is not necessarily always achievable, so please just do your best.*

Ensure that you take regular breaks and exercises when cutting fish.

Please note that JMM sampling is higher priority than EMA.

Otolith packets – The sex and stage should be recorded on all otolith packets. NEVER write 'JMA' on an otolith packet. ALWAYS write the sub-species otherwise the otoliths are of no use.

Please be aware that you need to achieve what you can within your 12 hour shift and then start again the next day.

Do JMA species proportion work and then focus on JMA/EMA otoliths (only do one species on one day – don't try and do both on the same day unless there is obviously enough time).

APPENDIX III: REPRESENTATIVENESS OF THE CENTRALISED OBSERVER DATABASE (COD)

The following plots compare the cumulative proportion of JMA catch by day of year, depth, latitude, and longitude, from the observer COD database with the equivalent cumulative proportions for the defined JMA 7 (Figure 1B) commercial fishery. These plots are presented for all years from 1989–90 to 2018–19 (Figure 42), and individually for a selection of years including 1989–90 (Figure 43), 1998–99 (Figure 44), 2000–01 (Figure 45), 2006–07 (Figure 46), 2007–08 (Figure 47), and 2018–19 (Figure 48).

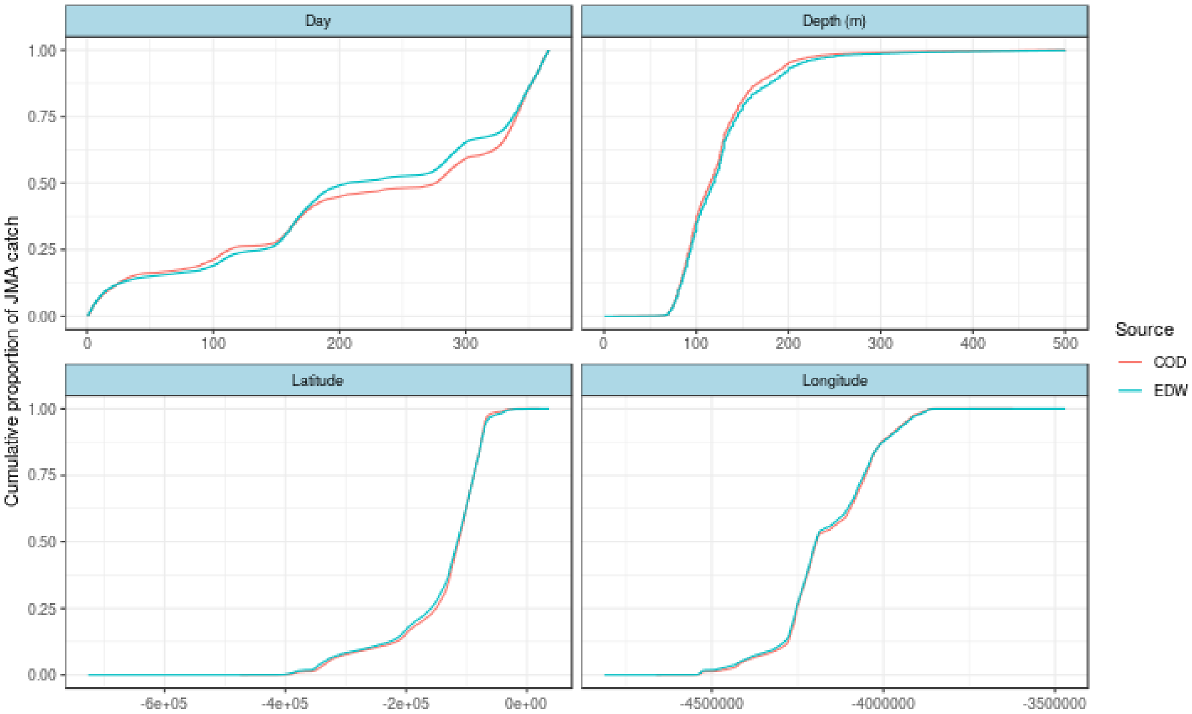

Figure 42: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for all years from 1990–91 to 2018–19 for the observer data (COD) and the commercial catch effort data (EDW).

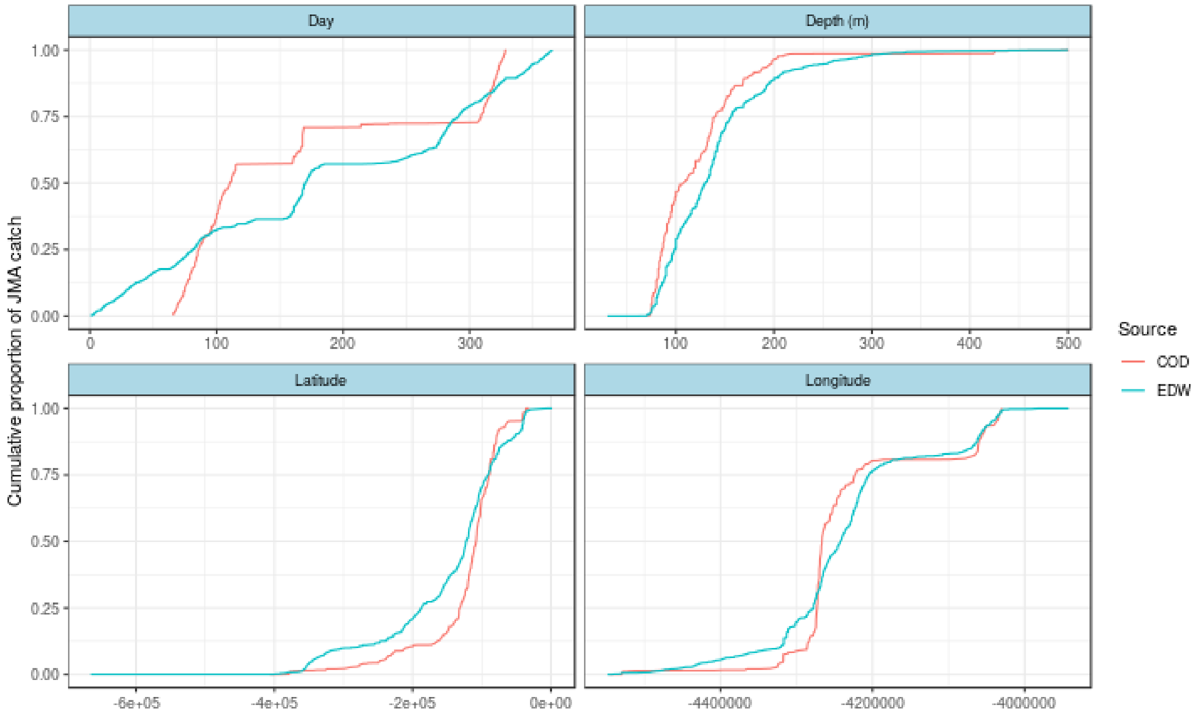

Figure 43: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 1989–90 fishing year for the observer data (COD) and the commercial catch effort data (EDW).

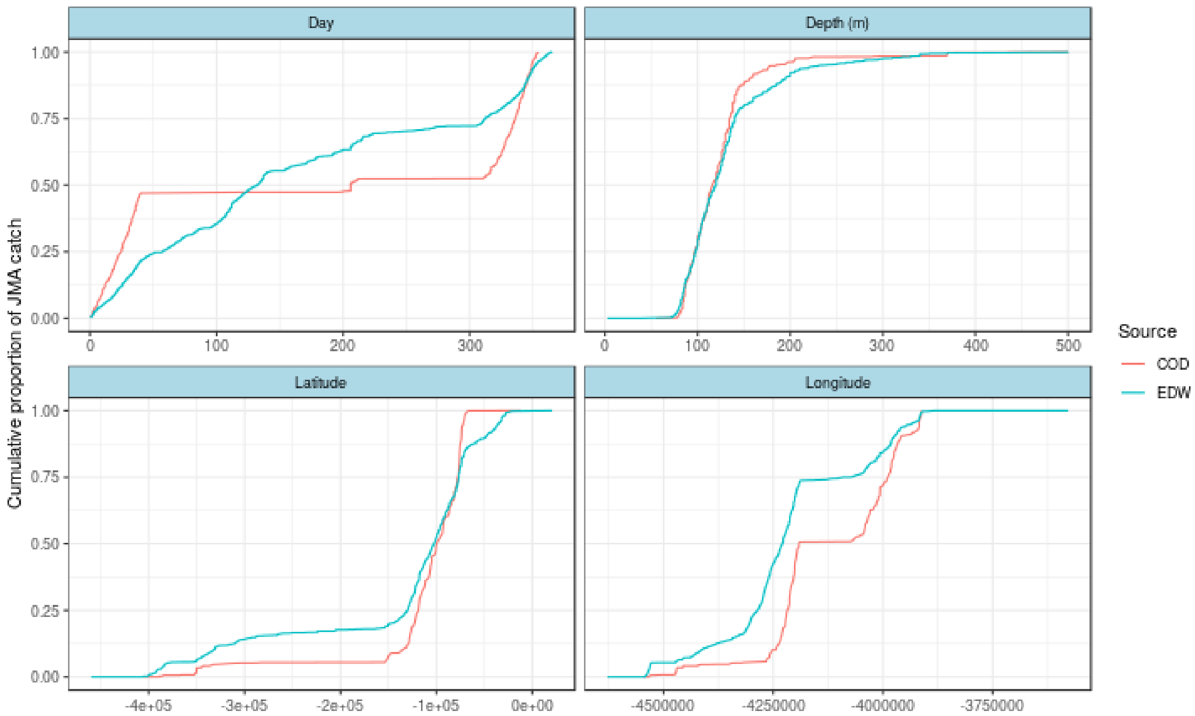

Figure 44: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 1998–99 fishing year for the observer data (COD) and the commercial catch effort data (EDW).

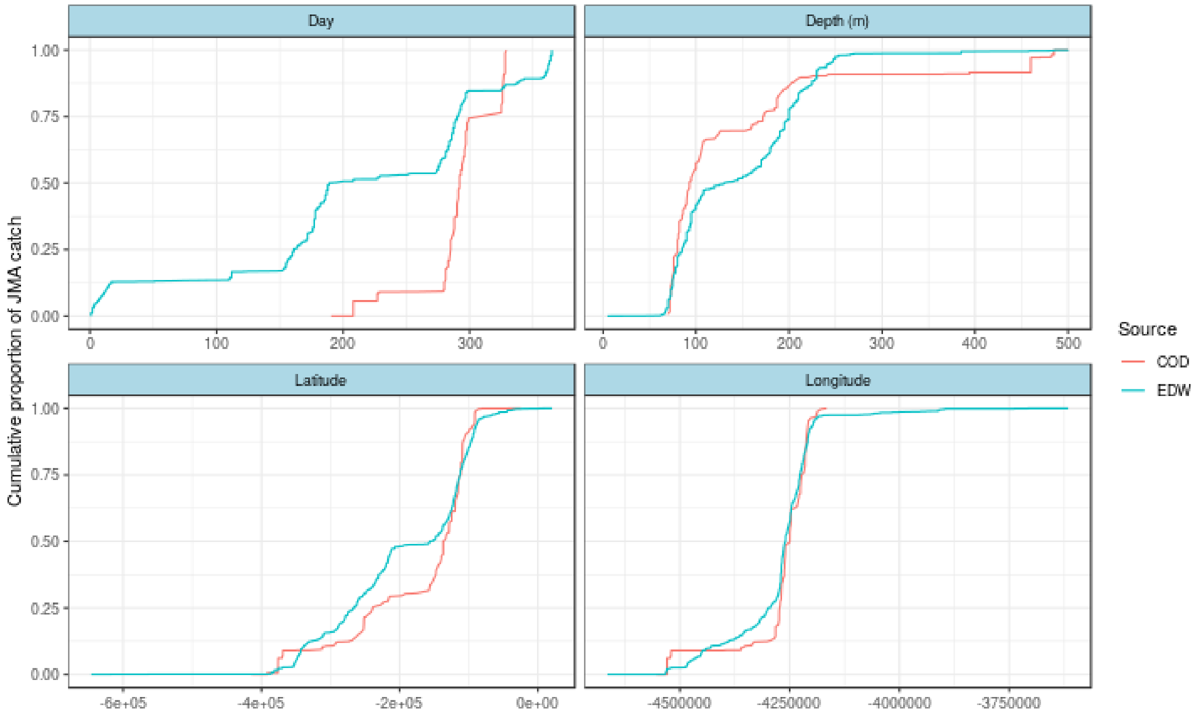

Figure 45: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 2000–01 fishing year for the observer data (COD) and the commercial catch effort data (EDW).

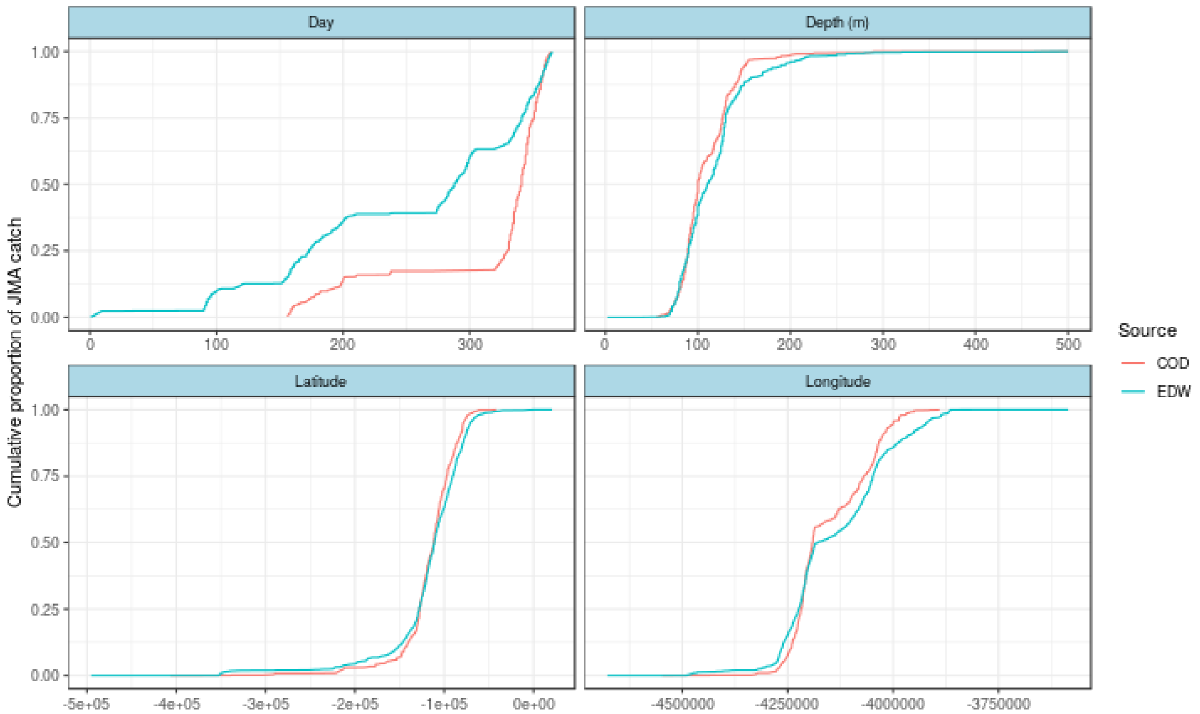

Figure 46: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 2006–07 fishing year for the observer data (COD) and the commercial catch effort data (EDW).

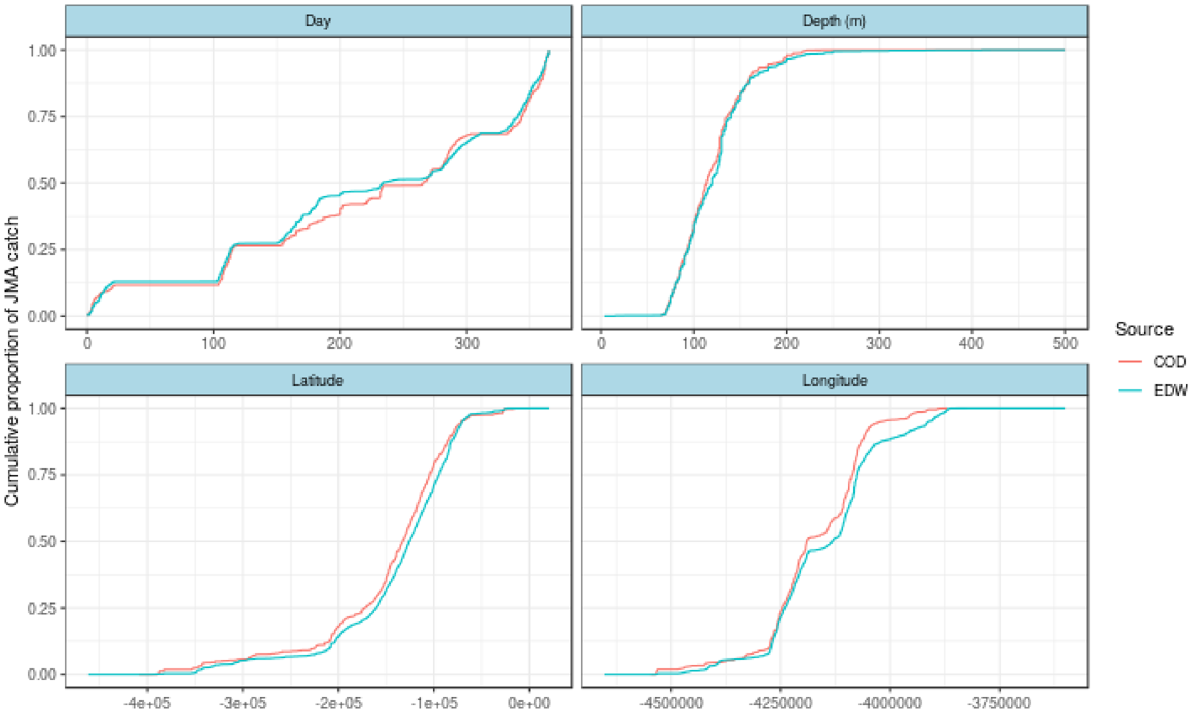

Figure 47: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 2007–08 fishing year for the observer data (COD) and the commercial catch effort data (EDW).

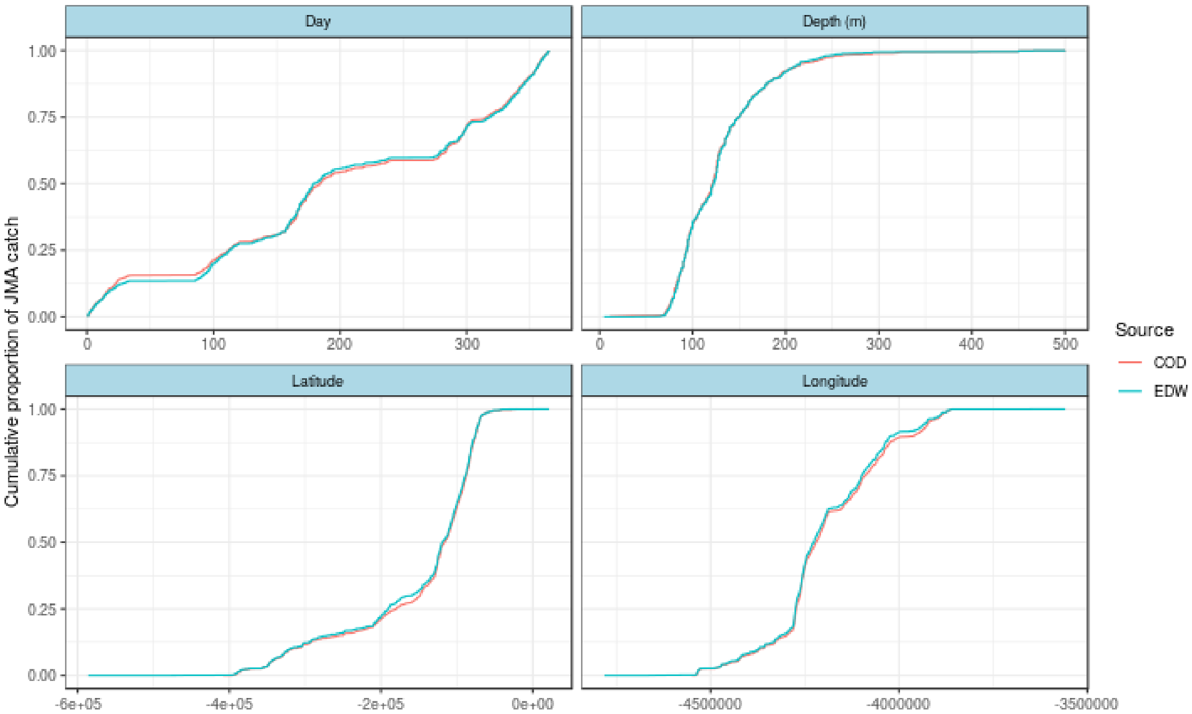

Figure 48: Cumulative proportion of JMA catch by of the year, depth (m), latitude, and longitude for the 2018–19 fishing year for the observer data (COD) and the commercial catch effort data (EDW).