Ministry for Primary Industries
Manatū Ahu Matua

Species composition of the jack mackerel (genus *Trachurus*) catch from the JMA 1 purse seine fishery, 2005/06 to 2013/14

New Zealand Fisheries Assessment Report 2016/11

A.D. Langley,
D.A.J. Middleton
O.L. Wilson

ISSN 1179-5352 (online)
ISBN 978-1-77665-180-1 (online)

March 2016

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Langley, A.D.; Middleton, D.A.J.; Wilson, O.L. (2016). Species composition of the jack mackerel (genus *Trachurus*) catch from the JMA 1 purse seine fishery, 2005/06 to 2013/14.

***New Zealand Fisheries Assessment Report 2016/11.* 33 p.**

Commercial catches of jack mackerel (JMA) are comprised of three species: *Trachurus declivis* (JMD), *T. novaezelandiae* (JMN) and *T. murphyi* (JMM), although the commercial fishery reports catches for the aggregated species assemblage only. Most of the JMA 1 catch is taken by the target purse seine fishery. To enable the catches of the individual species to be monitored, species sampling of the catch from the fishery has been conducted since 1994/95, although the sampling strategy and sampling design have varied over time.

This study applies a tree based ANOVA approach to investigate the factors that contribute to the variability of the species composition of the JMA 1 purse seine catches. Annual estimates of species specific catches are derived for the 2005/06–2013/14 fishing years from the time-series of sampled landings. The estimation of annual catches incorporated the stratification of the fishery into two main areas (east Northland and Bay of Plenty) and the uncertainty in the species catch estimates was determined using a bootstrapping approach.

The study concludes that the current sampling design is providing reasonably reliable estimates of catch for the three main jack mackerel species. The high precision of the catch estimates is attributable to the recent dominance of catches of *T. novaezelandiae* from the Bay of Plenty fishing area. The species composition of the jack mackerel catch is considerably more variable from the East Northland fishery area, although limited fishing has occurred in that area during the last decade. Any increase in the catch from the East Northland area should be accommodated in the sampling design by partitioning sampling effort between the two fishery areas (spatial stratification).

Recent trends in the length composition of *T. novaezelandiae* catch from the Bay of Plenty area are also presented. The catch from 2004/05–2013/14 was dominated by 27–35 cm (F.L.) fish. The annual length compositions are very similar for 2006/07–2008/09 (mean lengths 31.7–31.9 cm). For 2009/10–2013/14, the catch was comprised of smaller fish (mean lengths 29.8–30.8 cm) compared to the preceding three years.

1. INTRODUCTION

Commercial catches of jack mackerel (JMA) are comprised of three species: *Trachurus declivis* (JMD), *T. novaezelandiae* (JMN) and *T. murphyi* (JMM), although the commercial fishery reports catches for the aggregated species assemblage only. To enable the catches of the individual species to be monitored, auxiliary sampling programmes have been implemented in the main jack mackerel fisheries (Penney et al. 2011).

The TACC for JMA 1 has been maintained at 10 000 t since 1994/95 and annual catches have approached that level since 2004/05. Most of the JMA 1 catch is taken by the target purse seine fishery. Routine species sampling of the catch from the fishery has been conducted since 1994/95, although the sampling strategy and sampling design have varied over time. The sampling has revealed considerable variation in the species composition of the annual catches from the fishery (Penney et al. 2011).

In recent years, the JMA 1 sampling programme has annually sampled approximately 30 purse seine landings from the fishery (Walsh et al. 2016). The target number of samples are allocated amongst 3 month strata in proportion to the expected seasonal distribution of the total JMA 1 catch. The estimates of species proportions obtained from the sampled landings are applied to determine monthly or seasonal stratified catch estimates for each species. The stratified catch estimates are then combined to derive the estimate of annual catch for each species (Walsh et al. 2016).

In recent years, annual JMA 1 catches have been dominated by *T. novaezelandiae* and the estimated annual catches for this species have been determined with relatively high precision (Walsh et al. 2016). By comparison, annual catch estimates for *T. declivis* and *T. murphyi* are relatively low and considerably less precise.

The current sampling approach distributes sampling effort relative to the anticipated seasonal operation of the fishery. This is a pragmatic approach to ensure that sampling effort is broadly representative of the overall catch from the fishery. Nonetheless, the sampling allocation and seasonal stratification applied to derive annual catch estimates presumes that most of the inter-annual variation in species composition is attributable to season.

The primary objective of this study was to conduct an analysis of the variation in the species composition of the JMA 1 purse seine catches using the time-series of sampling data to identify factors contributing significantly to the variation in species composition. Based on the results of the analysis, annual estimates of species specific catches from the JMA 1 fishery were derived for the period 2005/06–2013/14 (fishing years).

2. PREVIOUS STUDIES

Sampling to estimate the species composition of the JMA 1 commercial catch commenced in 1994/95 and has been conducted almost continuously since then. Jack mackerel catches from the JMA 1 purse seine fishery are usually graded by fish size immediately following unloading of the vessel. Initially, the sampling programmes adopted a stratified design to sample the graded components of the catch. In 2009/10, the sampling protocol was revised to randomly sample the total catch prior to the grading procedure.

Estimates of annual catches (by calendar and fishing years) based on sampled landings have been documented in a series of reports: 1994/95–1996/97 (Taylor 1998), 1997/98 (Taylor 1999), 1998/99 (Taylor 2000), 1999/2000 (Taylor 2002), 2000/01 (Taylor 2004a), 2001/02 and 2002/03 01 (Taylor 2004b) and 2004/05 (Taylor & Julian 2008). The sampling of the purse seine fishery during the 2005/06–2008/09 is documented in Taylor et al. (2012), while more recent sampling has been documented in Walsh et al. (2012, 2016).

The species composition data collected from the JMA 1 purse seine fishery can be broadly categorised into two main phases of data collection:

1. Grade sampling data from 1994/95 to 2005/06. These data were primarily collected by one of the main processors and involved sampling most of the landings of JMA 1 by the purse-seine fleet. These data are available in summary form only; and for each sampled fishing trip, the total catch of fish in each fish size grade was apportioned amongst the three jack mackerel species. These data represent a substantial proportion (50–100%) of the total annual purse seine catch for 1994/95–2004/05 and 35% of the catch for 2005/06. The grade sampling data set is primarily composed of data collected by staff of the Tauranga branch of Sanford Ltd. A description of the sampling procedure is provided in Taylor (1999) and Taylor & Julian (2008).

2. Landing sampling data. In 2005/06, NIWA became responsible for the overall management of the JMA 1 sampling programme and introduced sampling of landings rather than grades. Sampling at Sanford Tauranga continued to be conducted by Sanford staff, although the overall intensity of sampling was reduced. Since 2006/07, the landing sampling data has represented the primary source of species composition data from the purse-seine fishery. Sampling data collected from this phase of the JMA 1 sampling are primarily stored in the MPI *market* database. From 2013/14 sampling has been managed by Trident Systems, and data were sourced from Trident's sampling database. In addition, the data set includes a limited number of landings sampled by NIWA staff during 1993/94–2003/04. The NIWA samples from 1999/2000–2003/04 were exclusively collected from one processor (Pelco Ltd), as Sanford sampled their own landings. Length frequency data have also been collected from the sampled component of the catch since 1998/99.

Penney et al. (2011) provides a comprehensive time series of estimates of catch for the individual jack mackerel species. The estimates of annual species catch composition for 1994/95–2005/06 were based on the species proportions from the grade sampling data, aggregated by fishing year (Taylor et al. 2012).

For 2006/07–2013/14, annual species catch estimates were derived from the landing sampling data (Taylor et al. 2012, Walsh et al. 2012, Walsh et al. 2016). The annual species proportion estimates were based on a sampling design stratified by month and/or season. The sampled catch from each month/season was prorated to represent the total catch in each month/season and then combined across months/seasons to derive annual catch estimates (by calendar year or fishing year).

3. DATA SETS

The current analysis utilised commercial catch and effort data from the JMA 1 fishery and the time-series of jack mackerel species sampling data from the JMA 1 purse seine fishery.

3.1 Catch and effort data

Commercial catch and effort data from the JMA 1 fishery were sourced from the MPI *warehou* database. The data extracted included all fishing event records and landed catch records from fishing trips that landed jack mackerel (JMA, JMN, JMD or JMM) from the JMA 1 Fishstock (Figure 1). The extract included data from October 1989 to October 2014.

Landed catches of jack mackerel were aggregated by fishing trip and the reliability of large landed catches (exceeding 200 t) was evaluated by comparing the landed catch with the other available catch metrics from the trip, i.e. the processed catch (derived from the number of units multiplied by the unit weight and the conversion factor) and the aggregated estimated catches from fishing events. Obvious errors in the landed catch records were corrected by substituting the processed catch values.

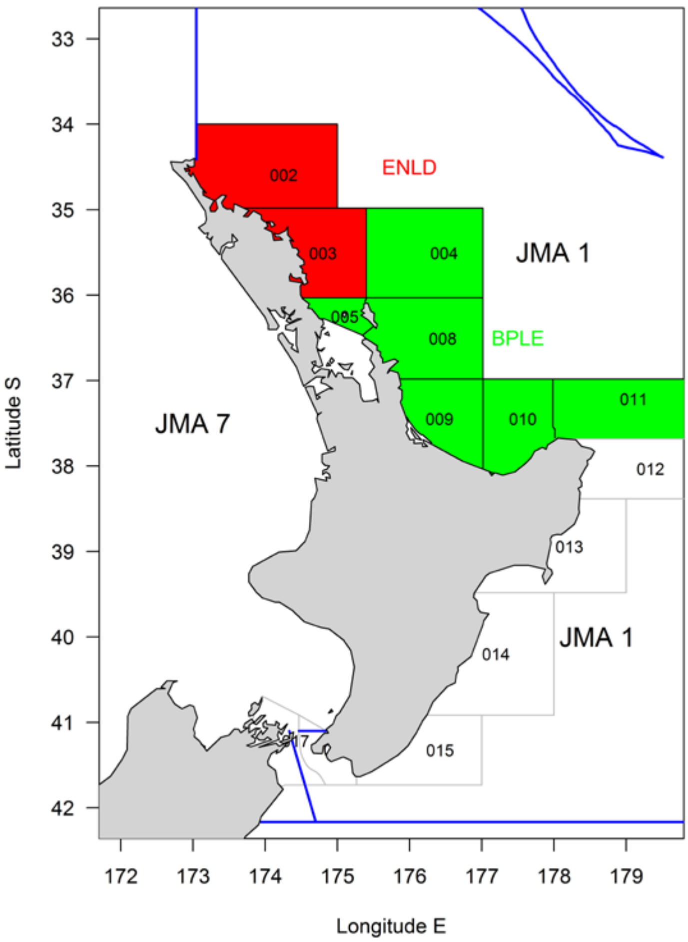

Figure 1: Map of the JMA 1 fishstock area and constituent Statistical Areas.

The annual landed catches from JMA 1 are comparable to the reported annual catches obtained from Quota Management Reports (QMR) and Monthly Harvest Returns (MHR) (MPI 2014) (Figure 2).

Most (95%) of the annual JMA 1 catch is attributable to the purse-seine fishing method (Figure 2). The purse seine catch of jack mackerel is predominantly taken by the target fishery although jack mackerel may also be caught in association with catches of blue mackerel and kahawai.

Most of the jack mackerel catch has been taken from the Bay of Plenty (BPLE) and off the east Northland coast (ENLD). During 1989/90–2003/04, a smaller and variable proportion of the annual JMA 1 purse seine catch was taken from central east coast (CEC) of the North Island (Statistical Areas 013–015). Since 2004/05, purse seine catches from the CEC area have been minor (less than 2% of total).

Since 2002/03, almost all of the JMA 1 purse seine catch (99%) of jack mackerel has been landed in Tauranga.

A composite summary record was configured for each purse seine fishing trip, including vessel name, total landed catch of JMA 1, fishing start date, fishing end date, total number of sets and landing date (*fishing trip record*). Most of the jack mackerel catch from a purse seine fishing trip is taken from within a single statistical area; i.e. 95% of JMA 1 purse seine trips reported at least 90% of the (estimated) catch from a single statistical area. Based on that observation, the total landed catch from individual purse seine fishing trips were assigned to the statistical area that accounted for the highest proportion of the estimated jack mackerel catch from the fishing trip.

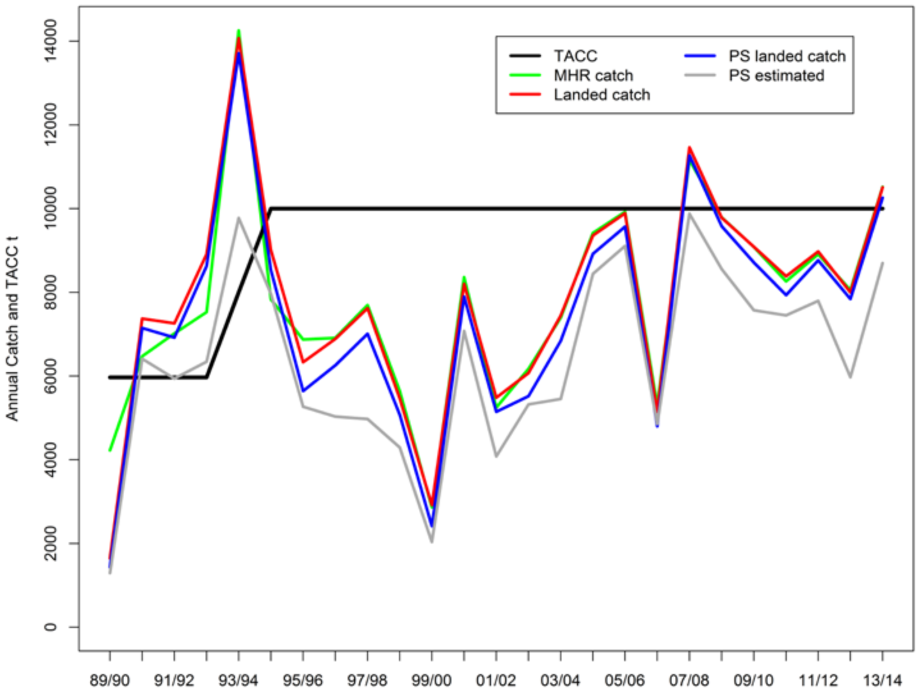

Figure 2: Annual catches of JMA 1 from various sources, including Monthly Harvest Returns (MHR), total Landed catch from Catch and Effort Landing Returns and purse seine (PS) landed and estimated catches.

3.2 Catch sampling data

JMA 1 catch sampling data are available in two data formats corresponding to the two main sampling phases described in Section 2; i.e. the grade sampling data from 1994/95–2005/06 and the landing sampling data from the subsequent period (Figure 3). The landing sampling data represents 30–45% of the total annual catches from the JMA 1 purse seine fishery from 2006/07–2013/14.

Both data sets include the name of the fishing vessel and the date of the landing, and these variables were combined to provide a unique reference for the individual sampling event. The index was used to link the individual sampling records with the associated fishing trip record derived from the catch and effort data.

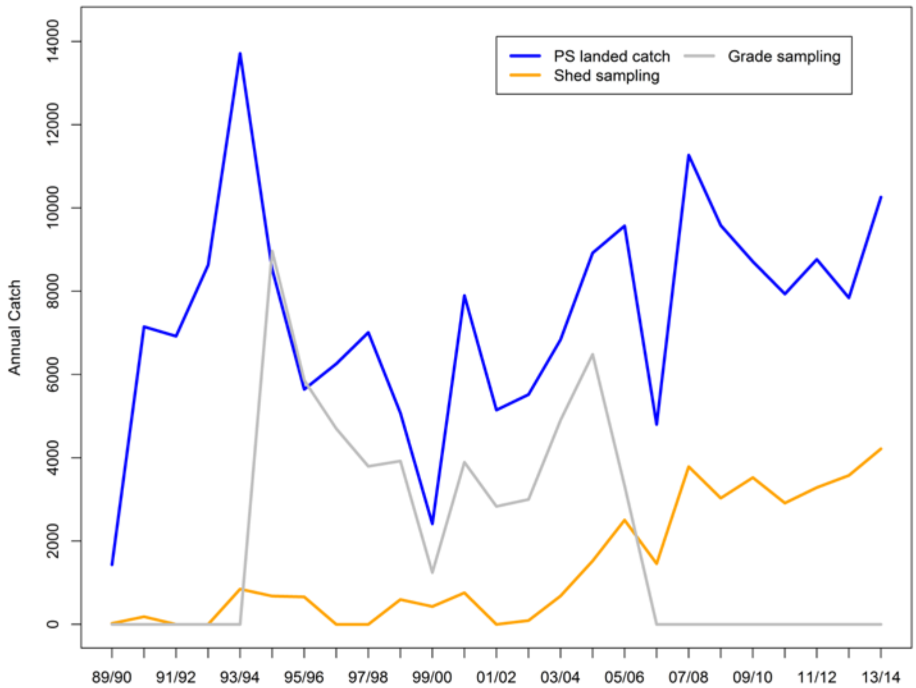

Figure 3: Annual landed JMA 1 purse seine catch and the total landed catch from the two sample components.

4. DATA ANALYSIS

4.1 Analysis of variability in species composition

The main sources of variability in the species composition were investigated using the time series of species composition data collected by the JMA 1 sampling programme. Separate analyses were conducted using the landing sampling and the grade sampling data sets.

4.1.1 Landing sampling data

The analysis was limited to samples collected during the January 2005 – March 2015 period, thereby excluding the small number of samples collected earlier. For each sampled landing, the proportional species composition of the landed catch of jack mackerel was determined according to the stratified sampling design. Prior to 2009/10, sampling was stratified by fish size grade and each sampled grade represented a separate stratum ($S_{1 \ldots N}$, where N represents the number of size grades) of the sampled landing (L). From 2009/10 onwards, samples were selected from the ungraded catch and, consequently, there is a single stratum (S_1) for each landing.

For most sampled landings, the weight of each species included in the sample was not available and sample weights were determined indirectly from the length frequency sampling data and the established length-weight relationship for the individual species. The sampled weight ($Wsamp_{L,S,species}$) of each species (*JMD*, *JMN*, *JMM*) was therefore determined for each landing stratum (S_i), from the sample length frequency distribution (total number of fish measured *nsamp* at each length interval *lgth*) and the species specific length-weight relationship (Table 1).

Table 1: Length weight relationship parameters for the three jack mackerel species.

Species	α	β	Source
T. novaezelandiae	0.000028	2.84	Horn (1991)
T. declivis	0.000023	2.84	Horn (1991)
T. murphyi	0.0000162	2.85	Basten (1981)

A limited number of landings also have the species sample weights measured directly. A comparison between the actual sample weights and the sample weights estimated from the length-weight relationships revealed a reasonable correlation between the two values (Figure 4), although the length-weight relationship tended to overestimate the sample weight of JMN. The length-weight relationships also appeared to slightly under-estimate the weight of JMD and JMM (Figure 4).

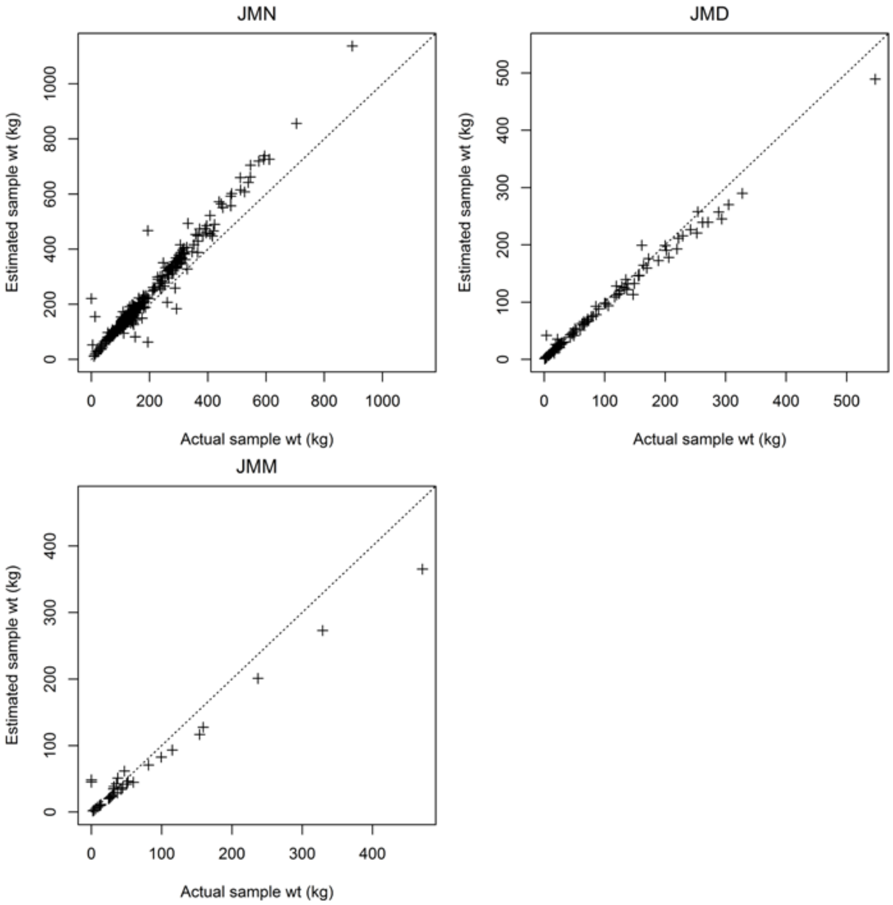

Figure 4: A comparison of the species sampled weights derived from length-weight relationships and actual sample weights for the subset of samples with actual weights recorded.

The total sampled weight ($Tsamp_{L,S}$) for each landing stratum was determined from the sum of the sampled weights of the three species. The proportion of each species ($Prop_{L,S,JMD}$, $Prop_{L,S,JMN}$, $Prop_{L,S,JMM}$) in the stratum was determined from the total sampled weight. The species proportions were multiplied by the total recorded weight of JMA catch in the landing stratum to determine the estimate of the species weight in the landing stratum ($Catch_{L,S,species}$).

The total weight of each species in the individual landing ($Catch_{L,species}$) was determined from the sum of the species weight from the strata that constituted the landing. The proportion of each species in the individual landing ($Prop_{L,JMD}$, $Prop_{L,JMN}$, $Prop_{L,JMM}$) was then determined from the total weight of each species.

A total of 260 sampled landings were included in the data set. The variability in the proportional species composition was examined using a recursive partitioning procedure implemented using the *rpart* package (Therneau et al. 2012) in *R* (R Core Team 2013). Separate ANOVA regression trees were derived for the three species. The dependent variable was the species proportion from each landing ($Prop_{L,JMD}$, $Prop_{L,JMN}$ or $Prop_{L,JMM}$) and the potential explanatory variables were the categorical variables: month, calendar year, fishing vessel, statistical area and processor. The significant variables were determined using a pruning approach based on the complexity parameter *cp* (Venables & Ripley 1999).

An additional regression tree was derived for the proportion of JMN in the combined catch of JMN and JMD (i.e. $Prop_{L,JMN} / (Prop_{L,JMN} + Prop_{L,JMD})$). The proportion of JMM in the catch was excluded from the analysis to better understand the factors that influence the variability in the catch of the two native species (JMN and JMD).

4.1.2 Grade sampling data

The grade sampling data set includes the total weight of the catch of each species in each size grade stratum ($Catch_{L,S,species}$) that constitutes the landing. The total weight of each species in the individual landing ($Catch_{L,species}$) was simply determined from the sum of the species weight from the constituent strata. The proportion of each species in the individual landing ($Prop_{L,JMD}$, $Prop_{L,JMN}$, $Prop_{L,JMM}$) was then determined.

The data set included a total of 455 sampled landings from 1994 to 2005. Only fishing trips that operated within the east Northland and Bay of Plenty areas were included in the data set. The recursive partitioning procedure applied for the analysis of the landing sampling data was also applied to the analysis of the grade sampling data set.

4.2 Species catch estimation

The sampling data were applied to derive estimates of the JMA 1 purse seine catches of the three species of jack mackerel by fishing year for 2005/06 to 2013/14. The analysis of variance of the species composition of the samples revealed that fishing area accounted for most of the variability. Accordingly, the determination of annual catch estimates incorporated two strata that represented the two main fishery areas (Bay of Plenty and east Northland). For comparative purposes, annual catch estimates were also derived without the spatial stratification. Unlike previous studies (e.g. Walsh et al. 2012), there was no seasonal stratification included in the derivation of the annual catch estimates as the recursive partitioning did not identify strong seasonal variation.

The total annual JMA1 purse seine catch was determined from the landed catch data (Section 3.1). The data set excluded purse seine trips that targeted pilchards and/or caught less than one tonne of jack mackerel. Fishery area was assigned to each trip based on the Statistical Area that accounted for most of the jack mackerel catch. The small number of trips from outside of the two principal fishery areas were excluded from the data set. The excluded data accounted for a trivial proportion (0–2%) of the annual jack mackerel purse seine catches from 2005/06–2013/14.

Annual catches were estimated using a bootstrapping procedure similar to the methodology of Walsh et al. (2012). For each iteration, an estimate of the total catch of each species was obtained from the two areas combined, as follows.

i. Randomly select *n* sampled landings (with replacement) from the fishing year and fishery area (BPLE or EN), where *n* represents the total number of samples collected from the fishing year/area.
ii. For each selected landing, randomly select with replacement *x* fish from the length frequency sample collected from each stratum (fish grade) of the landing. The number of fish selected (*x*) is equivalent to the total number of fish sampled from each stratum of the landing.

iii. For each landing stratum, determine the weight of each species in the selected sample (ii) based on the species specific length-weight relationship. Determine the proportion of each species in the total sample weight for the landing stratum.
iv. Determine the total weight of each species in the landing stratum and combine the strata to determine the weight of each species in the landing.
v. Combine the species catch weights from the individual landings and determine the species composition of the combined catch.
vi. Apply the combined species composition (from step v) to the total catch from the corresponding fishing year/fishery area to determine the annual species catch for the fishing year/fishery area.
vii. Combine the annual species catches from the two fishery areas to determine the estimate of the total species catch.

For each year, the procedure was repeated 1000 times and the final estimate of each species catch was determined from the average of the bootstrapped species catches. The coefficient of variation of the annual species estimates was also determined.

The procedure was modified somewhat to enable the estimation of catches from years where limited catches were taken from one area (less than 10% of the total catches) and insufficient samples were available from the area (less than three samples). In these cases, the catch from the minor area was attributed to the primary area and the estimates of species composition were based solely on the samples from the primary area.

The area stratified catch estimates were not determined for fishing years when insufficient samples (less than three sampled landings) were available from a fishery area that accounted for more than 10% of the total annual catch.

For comparative purposes, the bootstrapping procedure was repeated without the area stratification. In this analysis, all sampled landings were considered representative of a single area fishery and the combined species compositions were applied to the total annual catch (both fishery areas combined) to determine the total species catch.

Annual species catch estimates were also derived by calendar year following the same procedures.

4.3 Length composition

The landing sampling programmes have collected length frequency data from the sampled component of the catch. The fish are measured to the nearest centimetre below the fork length. Sampled fish are usually not sexed.

Annual length compositions were derived from the sampled catches of *T. novaezelandiae* from the Bay of Plenty fishery area which has represented the dominant component of the catch over the last decade. The length compositions were derived by scaling the individual stratum (size grade) length samples to the estimated species weight in the stratum ($Catch_{L,S,JMN}$). The scaled length compositions were aggregated by landing and fishing year to estimate the total length composition of the *T. novaezelandiae* catch (male and female fish combined) from the Bay of Plenty area.

5. RESULTS

5.1 Species composition

The tree based ANOVAs identified Statistical Area as the variable that accounted for most of the observed variation in the proportion of each of the three jack mackerel species. Similarly, Statistical Area was selected for the model that excluded the JMM component from the catch (i.e. $Prop_{L,JMN}$ /($Prop_{L,JMN}$ + $Prop_{L,JMD}$)) (Appendix 1). In all cases, records from Statistical Areas 002 and 003 were partitioned from the other records (predominantly from Statistical Areas 008 and 009). Samples from

Statistical Areas 002 and 003 typically had a lower proportion of JMN in the catch and, correspondingly, higher proportions of JMD and JMM.

There was no strong seasonal (month) variation in the species composition of the sampled catches. Of the four analyses, the month variable was included at the second branch of the $Prop_{L,JMD}$ model (Appendix 1, Figure A2). The partitioning indicated that JMD represented a lower proportion of the catch from Statistical Areas 002 and 003 during April, October and November compared to August, September and December.

Year was only included as a significant variable in the $Prop_{L,JMM}$ model at the second node (Appendix 1, Figure A3). The model indicates that JMM generally represented a lower proportion of the catch from Statistical Areas 002 and 003 from 2011–2015 compared to 2005–2010.

Fishing vessel and processor were not significant variables in any of the four analyses of the landing sampling data (Appendix 1).

The results from the tree based analysis of the grade sampling data were broadly similar (Appendix 2). For both the $Prop_{L,JMN}$ model and $Prop_{L,JMD}$ model, the primary source of variance in the species proportion was attributed to Statistical Area. Higher proportions of JMN were obtained from sampled catches from Statistical Areas 008–010, while higher proportions of JMD were taken from Statistical Areas 002 and 003.

Fishing area did not appear to strongly influence the proportion of JMM in the catch (Appendix 2). The proportion of JMM in the catch was primarily partitioned by calendar year; there was a higher proportion of JMM in the catches from 1994–1998 compared to 1999–2005 (Figure A7). Within the earlier period, JMM represented a higher proportion of the catch during October–January compared to February–July.

The proportion of JMD in catches in both Statistical Areas groups (002–003 and 008–010) tended to be lower during 1994–2001 than 2001–2004 (Figure A6). This is likely to be directly related to the higher proportion of JMM in the catches during the earlier years (especially 1994–1998). This was evident when the JMM component of the catch was removed from the tree based analysis (Appendix 2 Figure A8).

For JMN, month was included as a significant variable within both statistical area partitions (Figure A5), with lower proportions of JMN in the catches during August–October. This result may be partly influenced by the overall proportion of JMM in the catches which tended to be higher during October–January compared to February–July. However, excluding the JMM component from the analysis did not fundamentally change the monthly partitioning of the data set (Figure A8).

In summary, the results of the partitioning analysis reveal that most of the variation in the proportion of JMN and JMD in the catches is attributable to fishing area. JMN tends to represent a higher proportion of the catch from the Bay of Plenty (008–010), while JMD tends to represent a higher proportion of the catch from the east Northland area (Statistical Areas 002 and 003).

There was a strong temporal pattern in the catches of JMM; with the proportion of JMM highest in 1994–1998 and very low in the subsequent years. During the early period, there was a strong seasonal pattern in the JMM catches with the species representing a higher proportion of the catch during October–January. JMM catches do not appear to be strongly influenced by fishing area.

Overall, the relative proportion of JMN and JMD in the catch was not strongly influenced by fishing season, especially during the more recent period (2005–2015). However, there was some indication that fishing season may have influenced JMN catches during the earlier data period (1994–2005), with somewhat lower proportions of JMN in the catches during August–October.

Based on these results, individual samples collected from the landing sampling programme were partitioned into two main fishing areas: Bay of Plenty (008–010) and east Northland (002 and 003). JMM represented a small proportion of the catch sampled from both areas from 2009 (Figure 5). Typically, the proportion of JMN from the catches from the Bay of Plenty has been high (over 80%), although during 2010–2015 there were a number of samples from the Bay of Plenty fishery that included a substantial proportion of JMD in the catch.

The species composition of catches sampled from the east Northland fishery was more variable, although limited sampling from the east Northland fishery has occurred since 2009 (Figure 5).

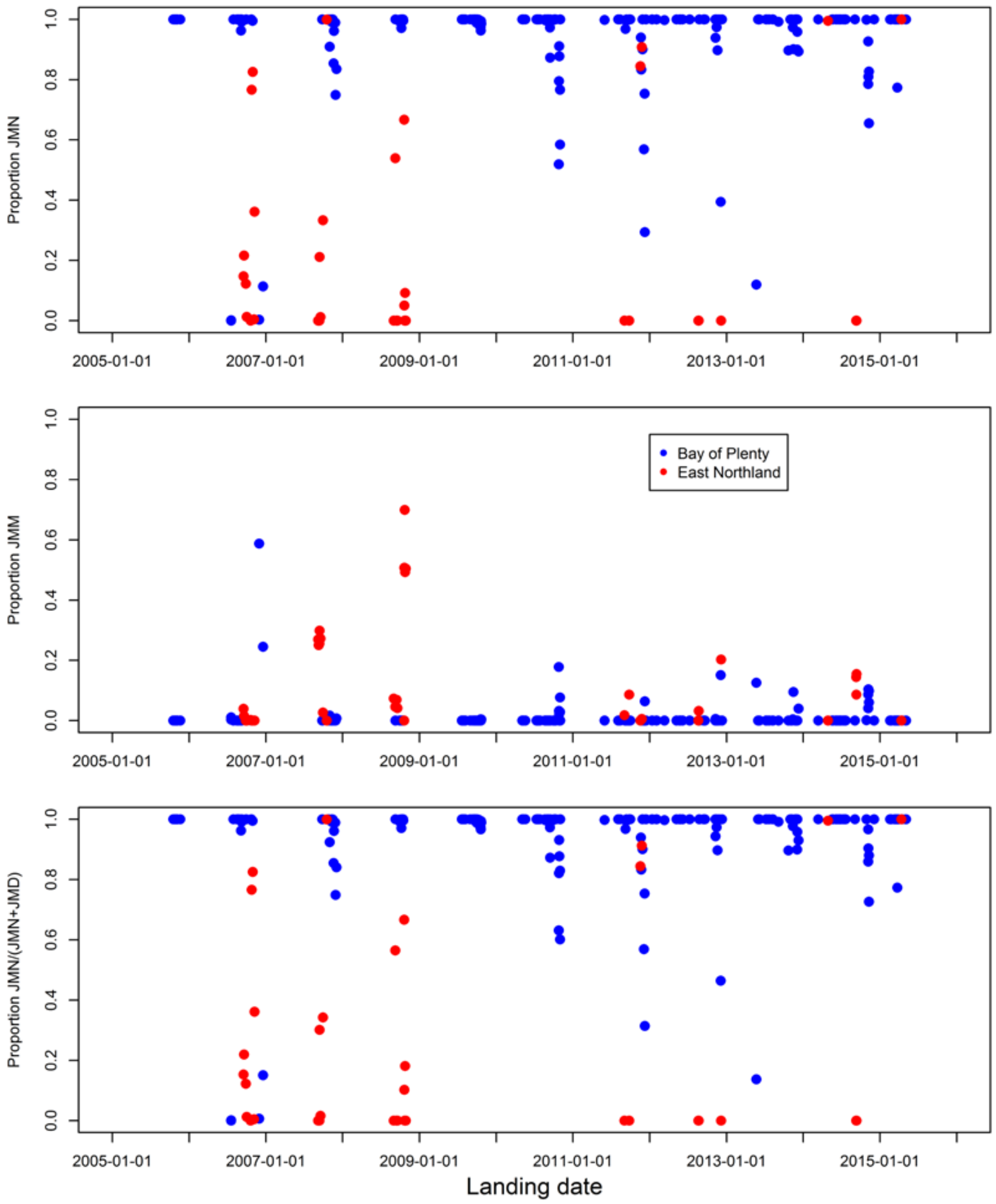

Figure 5: The proportion of JMN (top panel) and JMM (middle panel) in the total catch, and proportion of JMN in the combined JMN and JMD catch (bottom panel) for sampled landings (landing sampling data only) from the Bay of Plenty and east Northland fishery areas by sampling date.

5.2 Species catch estimation

5.2.1 Sampling coverage

Annual catches from the JMA 1 purse seine fishery are generally dominated by catches from the Bay of Plenty area, although the East Northland fishery area accounted for most of the catch in 1993/94 and 1994/95 (Table 2 and Figure 6).

During the 2005/06–2013/14 sampling period, the annual JMA 1 landings were dominated by catches from the Bay of Plenty area; with the east Northland area accounting for 2–28% of the annual JMA 1 purse seine catch (Table 2 and Figure 6).

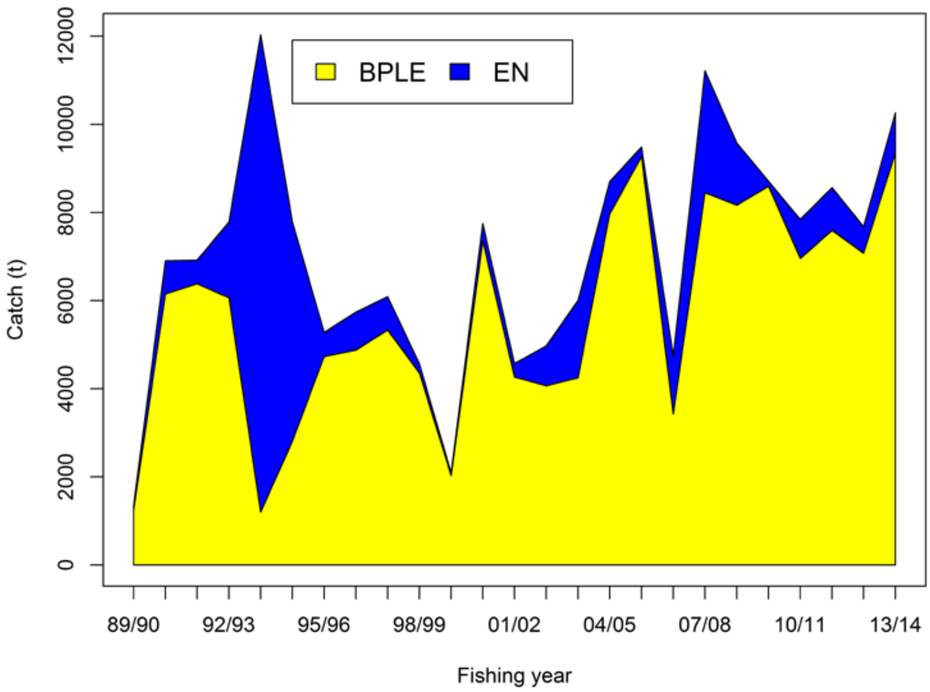

Figure 6: Annual catches from the JMA 1 purse seine fishery by fishing area.

In general, the spatial distribution of sampling effort was comparable to the distribution of the catch from the fishery (Table 3 and Figure 7), with the exception of the 2006/07 fishing year which had a disproportionately high level of sampling from the east Northland fishery catch.

Overall, the landing sampling programme sampled 25–45% of the total annual catches from the Bay of Plenty fishery and a higher proportion (40–70%) of the smaller annual catches from east Northland (Table 4). No sampling of the catch from the East Northland fishery occurred in 2009/10, although the total annual catch from the area was minimal.

The derivation of area stratified catch estimates required a minimum of three samples to be available from each area that accounted for at least 10% of the total JMA 1 purse seine catch. For 2010/11, the east Northland area accounted for 11% of the total catch (Figure 7) although only two samples were collected from the area (Table 3). Consequently, area stratified species catch estimates were not determined for 2010/11.

Sampling from the East Northland area was negligible in the 2009/10 and 2012/13 fishing years (Table 3), when total catch from the area was below the 10% threshold (Table 2). For these years, the area stratified catch estimates assumed that the species composition in the East Northland fishery was equivalent to the Bay of Plenty fishery area.

Table 2: Summary of JMA 1 purse seine landed catch (t) and number of purse seine fishing trips assigned to fishery area (BPLE, Bay of Plenty; EN, east Northland). Catch from the Central East Coast (CEC) area of JMA 1 is not included, and the dataset has been restricted to trips that caught at least 1 t of JMA.

Fishing Year	Landed catch (t)			Number of trips		
	BPLE	EN	Total	BPLE	EN	Total
1989/90	1 246.3	101.2	1 347.5	22	1	23
1990/91	6 149.5	752.6	6 902.1	82	16	98
1991/92	6 381.2	538.2	6 919.5	82	16	98
1992/93	6 063.2	1 720.4	7 783.6	70	26	96
1993/94	1 200.2	10 832.9	12 033.1	27	83	110
1994/95	2 805.5	4 984.6	7 790.1	44	42	86
1995/96	4 730.1	547.1	5 277.3	47	14	61
1996/97	4 875.9	862.4	5 738.3	57	22	79
1997/98	5 330.6	759.0	6 089.6	51	20	71
1998/99	4 355.3	210.2	4 565.5	52	12	64
1999/2000	2 027.2	61.3	2 088.5	34	7	41
2000/01	7 353.2	395.9	7 749.1	94	14	108
2001/02	4 266.3	306.4	4 572.7	54	15	69
2002/03	4 064.1	909.2	4 973.2	55	26	81
2003/04	4 248.3	1 755.9	6 004.2	57	20	77
2004/05	7 966.1	735.0	8 701.0	80	24	104
2005/06	9 265.8	221.2	9 487.0	109	14	123
2006/07	3 425.0	1 323.5	4 748.6	40	28	68
2007/08	8 446.4	2 771.6	11 218.0	82	27	109
2008/09	8 164.9	1 410.4	9 575.3	75	14	89
2009/10	8 592.5	114.3	8 706.8	92	4	96
2010/11	6 954.6	884.3	7 838.9	79	13	92
2011/12	7 592.4	973.1	8 565.5	83	14	97
2012/13	7 076.6	602.2	7 678.8	65	19	84
2013/14	9 345.4	914.3	10 259.7	87	20	107

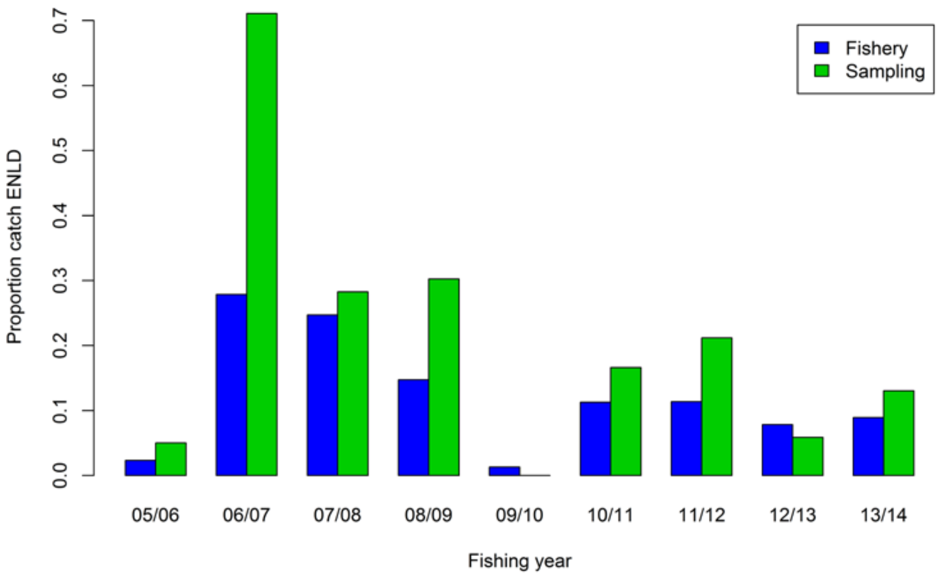

Figure 7: Proportion of the total JMA 1 purse seine fishery catch and sampled catch from the East Northland fishery area by fishing year.

Table 3: Summary of JMA1 PS catch sampling data and number of purse seine fishing trips assigned to fishery area (BPLE, Bay of Plenty; EN, east Northland).

Fishing Year	Sampled catch (t)			Number of samples		
	BPLE	EN	Total	BPLE	EN	Total
2005/06	2 379.6	125.4	2 505.0	18	3	21
2006/07	405.8	998.1	1 404.0	5	12	17
2007/08	2 716.3	1 069.6	3 785.9	17	6	23
2008/09	2 115.3	916.9	3 032.2	21	5	26
2009/10	3 523.8	0.0	3 523.8	33	0	33
2010/11	2 429.1	483.7	2 912.7	23	2	25
2011/12	2 442.2	655.9	3 098.1	23	4	27
2012/13	3 221.8	201.1	3 423.0	23	1	24
2013/14	3 667.5	549.9	4 217.4	26	4	30

Table 4: The proportion of the total JMA 1 purse seine catch sampled and proportion of trips sampled by fishery area and fishing year.

Fishing Year	Proportion of catch			Proportion of trips		
	BPLE	EN	Total	BPLE	EN	Total
2005/06	0.26	0.57	0.26	0.17	0.21	0.17
2006/07	0.12	0.75	0.30	0.13	0.43	0.25
2007/08	0.32	0.39	0.34	0.21	0.22	0.21
2008/09	0.26	0.65	0.32	0.28	0.36	0.29
2009/10	0.41	0.00	0.40	0.36	0.00	0.34
2010/11	0.35	0.55	0.37	0.29	0.15	0.27
2011/12	0.32	0.67	0.36	0.28	0.29	0.28
2012/13	0.46	0.33	0.45	0.35	0.05	0.29
2013/14	0.39	0.60	0.41	0.30	0.20	0.28

5.2.2 Species catch estimates

For each of the three species, catch estimates were generally comparable regardless of whether or not the estimation procedure was stratified by fishery area, although the spatially stratified catch estimates were usually more precise than the unstratified catch estimates (Figure 8, Figure 9 and Figure 10). Spatially stratified catch estimates were not computed for 2010/11 due to the limited number of samples collected from the East Northland area. The similarity between the spatially stratified and unstratified catch estimates reflects the high proportion of the total catch that was taken from one area (Bay of Plenty) in most years.

The overall level of precision of the species catch estimates is high for the individual species that dominates the total catch. *T. novaezelandiae* (JMN) accounted for at least 75% of the total catch in all years (except for 2006/07) and the corresponding CVs for those years are less than 8% (Appendix 3).

For the other two species (*T. declivis* and *T. murphyi*), the CVs of the catch estimates are generally considerably higher (20–100%); however, the magnitude of the variation in absolute catch is relatively low for years when the species catch is very low, especially 2008/09 and 2009/10 (Figure 9 and Figure 10). During 2010/11–2013/14, *T. declivis* generally represented less than 10% of the total catch, although the precision of the catch estimates was relatively low and correspondingly there was considerable uncertainty in the absolute annual catch estimates for some years (Figure 9).

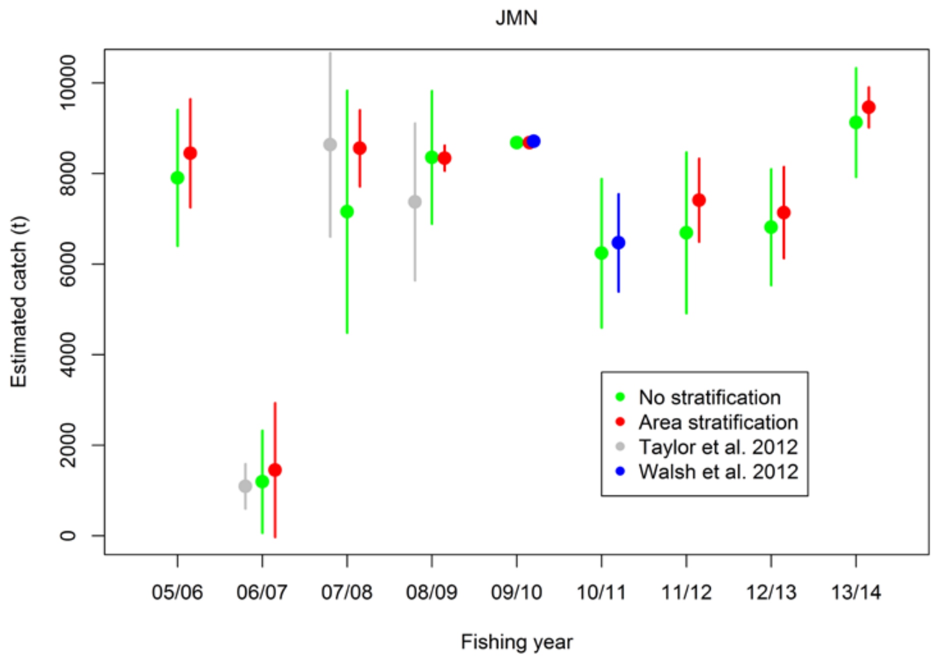

Figure 8: Estimates of annual catch (t) of *T. novaezelandiae* (JMN) with and without stratification by fishery area and the associated 95% confidence intervals. Comparative catch estimates from other studies are also presented.

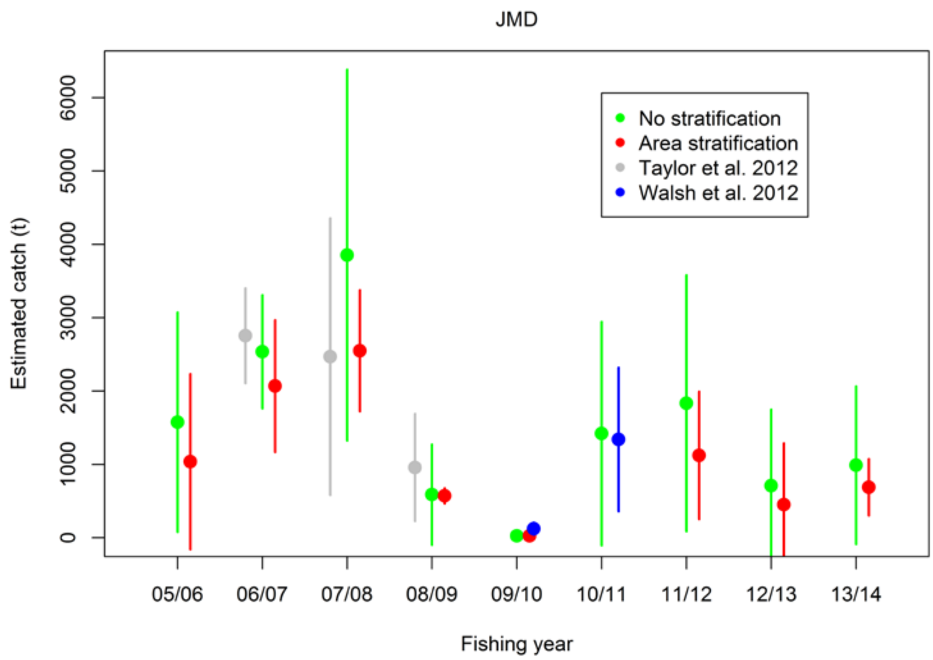

Figure 9: Estimates of annual catch (t) of *T. declivis* (JMD) with and without stratification by fishery area and the associated 95% confidence intervals. Comparative catch estimates from other studies are also presented.

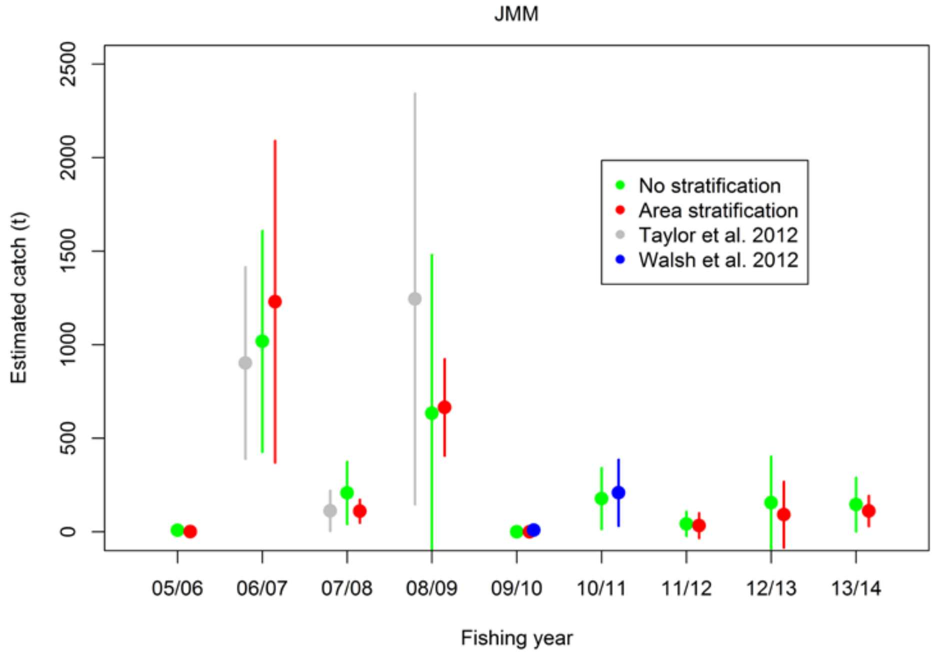

Figure 10: Estimates of annual catch (t) of *T. murphyi* (JMM) with and without stratification by fishery area and the associated 95% confidence intervals. Comparative catch estimates from other studies are also presented.

5.3 Length composition of *T. novaezelandiae*

Limited length frequency sampling of the *T. novaezelandiae* catch from the Bay of Plenty fishery was conducted prior to 2004/05 (Table 5). In contrast, large numbers of fish were sampled from the fishery during 2007/08–2013/14.

Table 5: The number of landings sampled and *T. novaezelandiae* measured from the Bay of Plenty purse seine fishing by fishing year.

Fishing year	Samples	Number of fish	Fishing year	Samples	Number of fish
1998/99	8	3 263	2006/07	3	1 069
1999/00	4	1 039	2007/08	16	22 852
2000/01	7	1 516	2008/09	21	18 355
2001/02	0	0	2009/10	33	21 575
2002/03	1	290	2010/11	19	16 564
2003/04	2	546	2011/12	20	23 424
2004/05	12	4 802	2012/13	21	27 005
2005/06	15	17 440	2013/14	26	33 297

The annual length compositions of the Bay of Plenty *T. novaezelandiae* catches vary considerably during 1998/99–2003/04 (Figure 11). Sample sizes are low for these years and the resulting length compositions are not considered to be reliable estimates of the length composition of the total catch.

The Bay of Plenty *T. novaezelandiae* sampled catch from 2004/05–2013/14 was dominated by 27–35 cm (F.L.) fish (Figure 11). The annual length compositions are very similar for 2006/07–2008/09 (mean lengths 31.7–31.9 cm) (Figure 11). For 2009/10–2013/14, the catch was comprised of smaller fish (mean lengths 29.8–30.8 cm) compared to the preceding three years.

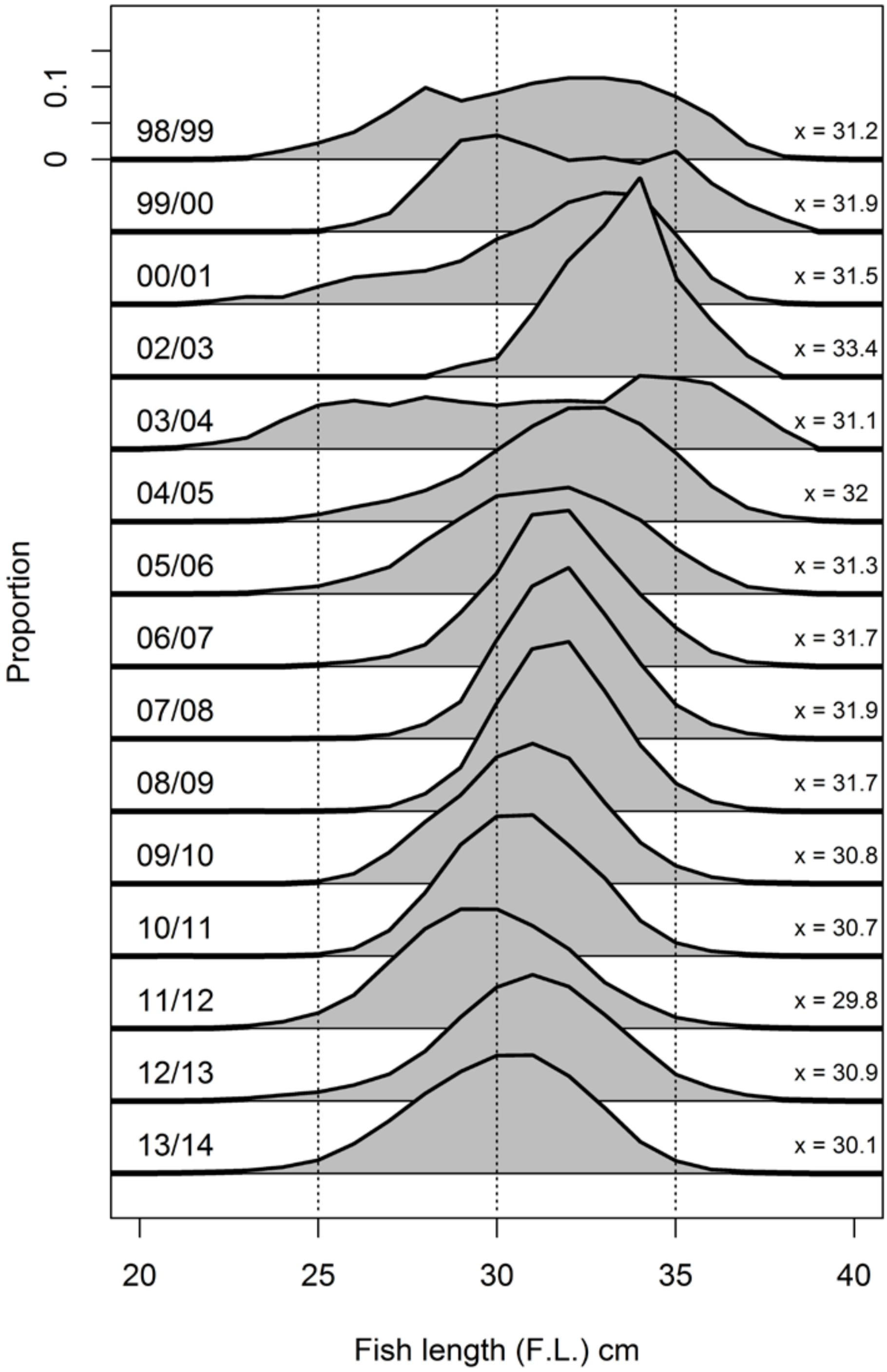

Figure 11: Annual length compositions of *T. novaezelandiae* from the Bay of Plenty fishery, x is the average fish length (cm).

6. DISCUSSION

The fishing year species catch estimates for 2009/10 and 2010/11 were comparable to the seasonally stratified estimates derived by Walsh et al. (2012) (Figure 8, Figure 9 and Figure 10). Similarly, the species catch estimates from 2006/07–2008/09 are comparable to those derived from Taylor et al. (2012 table C2). The only substantive difference is the higher and considerably more uncertain estimate of *T. murphyi* catch for 2008/09 from Taylor et al. (2012). The similarity in the catch estimates from the three sources is likely to be due to the dominance of catches and sampling from the Bay of Plenty area and the lack of any substantial seasonal variation in species catch composition in that area.

The calendar year species catch estimates were more sensitive to the area stratification of the sampling data, especially for 2007 and 2008 (Appendix 4). This appears to be related to sampling effort being skewed towards the East Northland fishery in those two years. On that basis, it is considered that the area stratified catch estimates are more reliable than the unstratified catch estimates.

The current sampling strategy requires a relatively intensive level of sampling, representing approximately 40% of the total landed catch from the fishery. The sampling programme achieves a high level of precision for the catches of the main species *T. novaezelandiae*. This is largely due to the dominance of the species in catches during the recent period (2005/06 to 2013/14). However, there has been sufficient variability in the species composition of individual landings to necessitate a relatively high level of sampling to determine reliable estimates of the total species catch.

For *T. novaezelandiae*, most of the total annual catches have been estimated with coefficients of variation (CVs) of less than 8%. This is substantially lower than the target CV of 30% that has been previously specified by MPI (Walsh et al. 2012). However, the primary objective of the sampling programme is to obtain reliable catch estimates for each species for stock monitoring and, potentially, species based stock assessments. Therefore, it is important to derive precise estimates of the catches, expressed in absolute terms. For example, a coefficient of variation of 5% associated with a catch estimate of 8000 t corresponds to a 95% confidence interval of about 1500 t. This level of precision may be suitable for monitoring overall trends in species catch. However, the precision of the estimates of absolute catch may introduce an additional source of uncertainty in the quantitative analysis of these data, such as the inclusion in stock assessment modelling.

Additional sources of data are available from the fishery that could augment the current sampling programme. Grading of the jack mackerel catch by fish size is conducted by the two processors. The smaller size grades are typically comprised almost exclusively of *T. novaezelandiae*, while the larger size grades may be comprised of a combination of species. In recent years, a substantial proportion of fishing trips have landed catches of fish that are dominated by the smaller size grades. These landings could be assumed to represent catches of *T. novaezelandiae* and be incorporated directly into the overall estimation of the total species catch from the fishery. Additionally, sampling could be focussed on the graded catches to determine the species proportion in the larger size grades. Utilising the grading data could achieve a higher level of sampling coverage and improve the overall precision of the species catch estimates. However, the approach is considerably more complicated than the current sampling strategy of randomly sampling the ungraded catches and may be difficult to implement.

The current estimates of species catch composition were used to update the available time series of species catch estimates from the JMA 1 purse seine fishery (Figure 12 and Appendix 5). The species catch estimates for the years prior to 2005/06 were obtained from Penney et al. (2011) and Taylor et al. (2012). The catch proportions from 1994/95–2004/05 were based on the grade sampling data described in Section 2 of this report. These data have not been reanalysed to account for the spatial variation in species composition of the catches. However, the sampled component of the catch represented a substantial proportion of the total annual catches (Figure 3) and, therefore, the current estimates of species catch are likely to be indicative of the species composition of the entire fishery catch.

The time series of species catch estimates reveal that JMA 1 purse seine catches of *T. novaezelandiae* increased from about 2000–5000 t during the 1990s to about 8300 t in 2007/08–2013/14 (Figure 12), increasingly dominating the total JMA 1 purse seine catch. Correspondingly, annual catches of *T. declivis* and *T. murphyi* have been low in the latter period (7% and 2%, respectively).

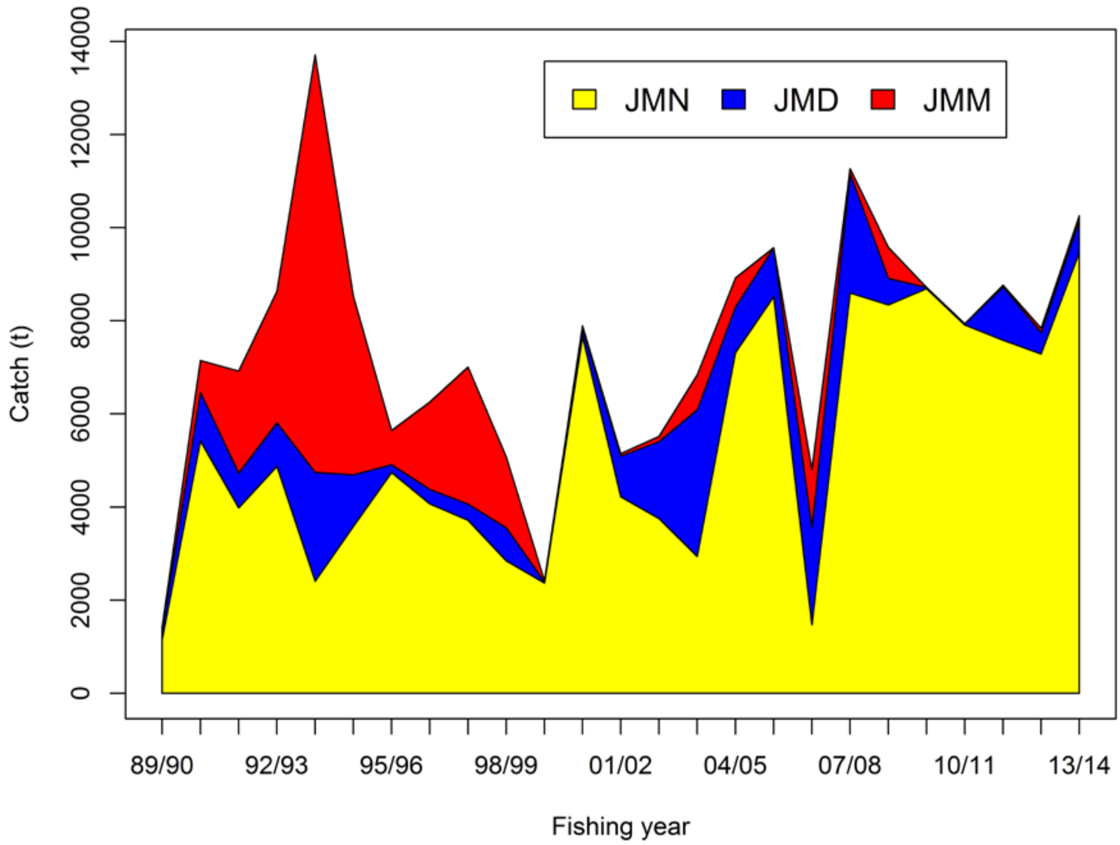

Figure 12: The time series of annual species catch estimates from the JMA 1 purse seine fishery.

The increase in *T. novaezelandiae* catch has predominantly occurred within the Bay of Plenty fishery area. There has been a small decrease in the length of fish caught from the fishery since 2006/07–2008/09, although it is unknown whether the decline in fish size is attributable to an increase in fishing mortality rates, changes in fishing operation or variation in annual recruitment. Age composition data are available for the *T. novaezelandiae* catch from 2006/07–2008/09 (Taylor et al. 2012), although age based sampling was discontinued due to the relatively high inter-annual variability in the age compositions. It may be appropriate to reinstate age based monitoring of the *T. novaezelandiae* catch. There have been at least five years of relatively high catches from the fishery during the interim period (2009/10–2013/14). If there has been a substantial increase in fishing mortality rates over the last 10 years then it may be evident in a change in the population age structure (from 2006/07–2008/09).

7. RECOMMENDATIONS FOR FUTURE MONITORING

The current sampling design is providing reasonably reliable estimates of catch of the three main jack mackerel species. This is due to the relatively high level of sampling coverage and the current dominance of catches of *T. novaezelandiae* from the Bay of Plenty area.

The species composition of jack mackerel catches is considerably more variable from the East Northland fishery area, although limited fishing has occurred in this area during the last decade. Any increase in the catch from the East Northland area should be accommodated in the sampling design by partitioning sampling effort between the two fishery areas (spatial stratification).

The current sampling design partitions sampling effort amongst 3 month periods within each fishing year. The current study did not reveal a strong seasonal pattern in the species composition of the jack mackerel catches. Nonetheless, the allocation of sampling effort by season is a pragmatic approach to ensure that sampling effort is reasonably well distributed throughout the fishing year. However, there is no strong justification for maintaining the seasonal stratification in the determination of the annual species catch estimates.

Ongoing sampling of the JMA 1 purse seine fishery is required to continue to monitor the species catch composition. The level of precision required for the individual species catches should be reviewed to ensure that the resulting data are sufficiently reliable for ongoing catch monitoring and more rigorous applications of the time series of species catch estimates (e.g. stock assessment).

The Northern Inshore Working Group (17 September 2015) accepted the results of the current study and made the following recommendations:

- The bootstrap method with spatial stratification should be used for all future analyses deriving catch composition of JMA1.
- JMA1 specific length weight relationships should be produced for JMD and JMN. To this end length and weight measurements should be taken throughout the year to account for changes in condition.
- Future sample designs for JMA1 catch composition projects should be based on a target CV of 10% for the JMN estimate of total catch (i.e. not the proportion). CVs for catches of the remaining two species would not be included in the design.
- There is potential for grade based sampling to improve precision, but this needs to be balanced with the complexity of the sampling design.

8. ACKNOWLEDGMENTS

This report is based on a large quantity of sampling data collected by dedicated sampling staff, primarily from Sanford Limited, NIWA and Trident Systems. David Fisher (NIWA) provided the JMA 1 catch sampling data sets held by Ministry for Primary Industries. This study was contracted by Fisheries Inshore New Zealand and funded by JMA 1 quota owners.

9. REFERENCES

Basten, J.C. (1981). The fishery for jack mackerel (*Trachurus murphyi*) off Northern Chile. Theses, Dissertations and Student Research Papers (College of Earth, Ocean and Atmospheric Sciences), School of Oceanography, Oregon State University, June 1981. 65 p.

Horn, P.L. (1991). Assessment of jack mackerel stocks off the central west coast, New Zealand, for the 1990–91 fishing year. New Zealand Fisheries Assessment Research Document 1991/6. 14 p. (Unpublished report held in NIWA library, Wellington.)

Ministry for Primary Industries (2014). Fisheries Assessment Plenary, May 2014: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 1381 p.

Penney, A.J.; Loveridge, C.J.; Moriarty, J.A.; George, K. (2011). Estimation of New Zealand monthly purse-seine and midwater trawl catches of *Trachurus declivis*, *T. murphyi*, *T. novaezelandiae* by fisheries management area from October 1985 to December 2010. *New Zealand Fisheries Assessment Report 2011/41*.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Taylor, P.R. (1998). Estimates of biological parameters, total mortality, and maximum constant yield for jack mackerel, *Trachurus declivis* and *T. novaezelandiae*, in JMA 1. New Zealand Fisheries Assessment Research Document 98/11. 38 p. (Unpublished report held in NIWA library, Wellington.).

Taylor, P.R. (1999). Species composition and seasonal variability of jack mackerel, *Trachurus declivis*, *T. murphyi*, *T. novaezelandiae* in JMA 1, 3, and 7. New Zealand Fisheries Assessment Research Document 99/49. 21 p. (Unpublished report held in NIWA library, Wellington.).

Taylor, P.R. (2000). Species composition and seasonal variability in commercial catches and aerial sightings of jack mackerel, *Trachurus declivis*, *T. murphyi*, and *T. novaezelandiae* in JMA 1, JMA 3, and JMA 7. *New Zealand Fisheries Assessment Report 2000/45*. 25 p.

Taylor, P.R. (2002). Species composition and seasonality of jack mackerel (*Trachurus declivis*, *T. murphyi*, *T. novaezelandiae*) in commercial catches from JMA 1, 3, and 7 during 1998–99 and 1999–2000, with a summary of biological information from 1990–91 to 1999–2000. *New Zealand Fisheries Assessment Report 2002/51*. 72 p.

Taylor, P.R. (2004a). Species composition and seasonal variability in commercial catches of jack mackerel (*Trachurus declivis*, *T. murphyi*, *T. novaezelandiae*) in JMA 1, 3, and 7 during 2000–01. *New Zealand Fisheries Assessment Report 2004/28*. 22 p.

Taylor, P.R. (2004b). Species composition and seasonal variability in commercial catches of jack mackerel (*Trachurus declivis*, *T. symmetricus murphyi*, and *T. novaezelandiae*) in JMA 1, JMA 3, and JMA 7 during 2001–02 and 2002–03. Final Research Report for MFish Project JMA2001/01. 20 p. (Unpublished report held by Ministry for Primary Industries,Wellington).

Taylor, P.R.; Horn, P.L.; Ó Maolagáin, C. (2012). Commercial catch sampling for species proportion, sex, length, and age of jack mackerels in JMA 1 in the 2006–07, 2007–08 and 2008–09 fishing years. *New Zealand Fisheries Assessment Report 2012/48*. 36 p.

Taylor, P.R.; Julian, K.A. (2008). Species composition and seasonal variability in commercial catches of jack mackerel (*Trachurus declivis*, *T. murphyi*, *T. novaezelandiae*) in JMA 1, 3, and 7 during 2004–05. *New Zealand Fisheries Assessment Report 2008/25*. 24 p.

Therneau, T.; Atkinson, B.; Ripley, B. (2012). rpart: Recursive Partitioning. R package version 4.1-0.

Venables, W.N.; Ripley, B. (1999). Modern applied statistics with S-PLUS.

Walsh, C.; Bian, R.; McKenzie, J.M.; Miller, A.; Spong, K., Armiger, H. (2012). Species composition and seasonal variability in commercial purse-seine catches of jack mackerel (*Trachurus declivis, T. murphyi,* and *T. novaezelandiae*) in JMA 1 between January 2009 and September 2011. *New Zealand Fisheries Assessment Report 2012/46*. 41 p.

Walsh, C.; Bian, R.; McKenzie, J.; Spong, K., Armiger, H. (2016). Species composition and seasonal variability in commercial purse-seine catches of jack mackerel (*Trachurus declivis, T. murphyi,* and *T. novaezelandiae*) in JMA 1 between January 2011 and September 2013. *New Zealand Fisheries Assessment Report 2016/10*. 44 p

APPENDIX 1. DETAILED RESULTS OF TREE BASED ANALYSIS OF LANDING SAMPLING DATA

Proportion JMN

```
rpart(formula = propJMN ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) +
    as.factor(vesselname) + as.factor(shed), data = summ3, method = "anova")
  n= 260

          CP nsplit rel error    xerror       xstd
1 0.59532961      0 1.0000000 1.0041619 0.12632045
2 0.05430200      1 0.4046704 0.4116670 0.08295654
3 0.02319853      2 0.3503684 0.4092508 0.08116535
4 0.01370378      3 0.3271699 0.4139738 0.07944256
5 0.01000000      4 0.3134661 0.4078997 0.07824323

Variable importance
  as.factor(StatArea)        as.factor(mon)         as.factor(yr) as.factor(vesselname)
                   83                     9                     7                     1

node), split, n, deviance, yval
      * denotes terminal node

 1) root 260 27.0901200 0.8415853
   2) as.factor(StatArea)=2,3 38  4.7294840 0.2396051
     4) as.factor(mon)=8,9,12 22  0.4159219 0.0718135 *
     5) as.factor(mon)=4,10,11 16  2.8425140 0.4703186 *
   3) as.factor(StatArea)=10,13,14,5,8,9 222  6.2330850 0.9446270
     6) as.factor(yr)=2006 16  2.8103270 0.7537152 *
     7) as.factor(yr)=2005,2007,2008,2009,2010,2011,2012,2013,2014,2015 206  2.7943070 0.9594551
      14) as.factor(mon)=12 13  0.6840054 0.7958868 *
      15) as.factor(mon)=1,2,3,4,5,6,7,8,9,10,11 193  1.7390650 0.9704726 *
```

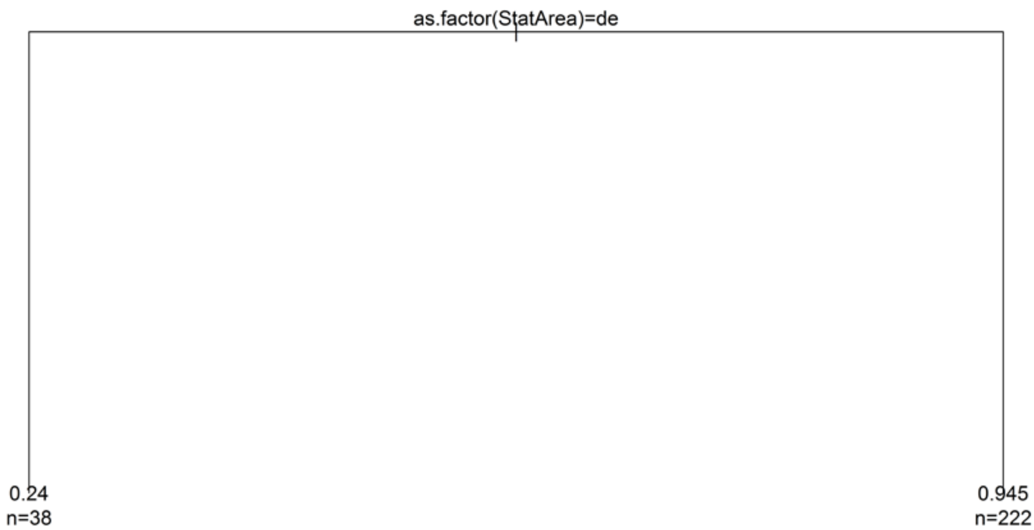

Figure A1: Pruned regression tree of the variation in the proportion of JMN in the sampled JMA catches. The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMD

```
rpart(formula = propJMD ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) +
    as.factor(vesselname) + as.factor(shed), data = summ3, method = "anova")
  n= 260

          CP nsplit rel error    xerror       xstd
1 0.57721033      0 1.0000000 1.0031375 0.14171716
2 0.08525029      1 0.4227897 0.4397518 0.08739481
3 0.01913382      2 0.3375394 0.3981957 0.08903554
4 0.01462299      3 0.3184056 0.4046969 0.08769037
5 0.01000000      4 0.3037826 0.4059890 0.08788271

Variable importance
  as.factor(StatArea)        as.factor(mon)         as.factor(yr) as.factor(vesselname)        as.factor(shed)
                   79                    12                     7                     1                     1

node), split, n, deviance, yval
      * denotes terminal node
1) root 260 19.7851200 0.13192580
  2) as.factor(StatArea)=10,13,14,5,8,9 222  4.3239870 0.04521668
    4) as.factor(yr)=2005,2007,2008,2009,2010,2011,2012,2013,2014,2015 206  1.9920360 0.03370814
      8) as.factor(mon)=1,2,3,4,5,6,7,8,9,10,11 193  1.1772960 0.02398186 *
      9) as.factor(mon)=12 13  0.5254225 0.17810600 *
    5) as.factor(yr)=2006 16  1.9533860 0.19338910 *
  3) as.factor(StatArea)=2,3 38  4.0409560 0.63848990
    6) as.factor(mon)=4,10,11 16  1.8519420 0.39144450 *
    7) as.factor(mon)=8,9,12 22  0.5023278 0.81815930 *
```

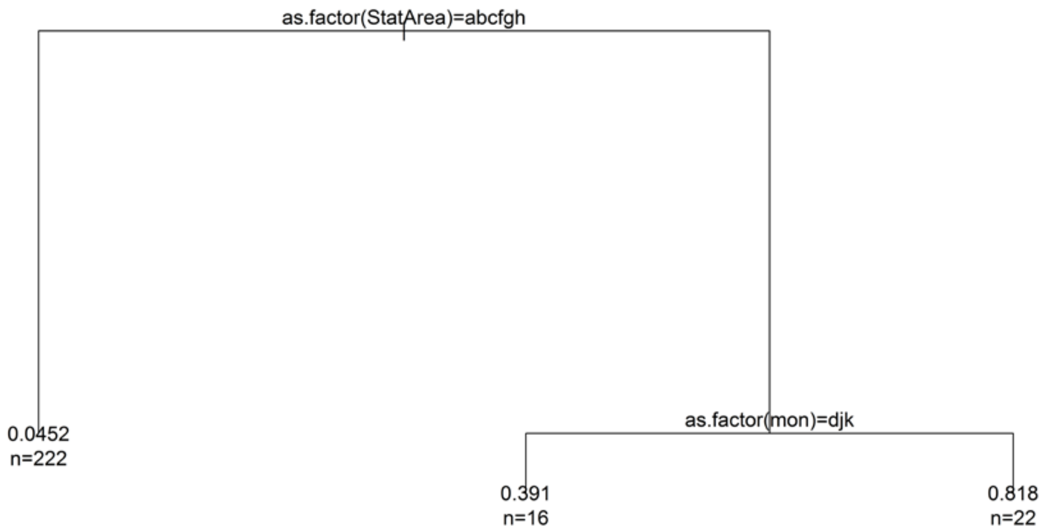

Figure A2: Pruned regression tree of the variation in the proportion of JMD in the sampled JMA catches. The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMM

```
rpart(formula = propJMM ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) +
    as.factor(vesselname) + as.factor(shed), data = summ3, method = "anova")
  n= 260

          CP nsplit rel error    xerror      xstd
1 0.19724474      0 1.0000000 1.0077679 0.3275182
2 0.16031117      1 0.8027553 1.0560440 0.3233671
3 0.03637364      2 0.6424441 0.7113998 0.2215851
4 0.01419384      4 0.5696968 0.7187629 0.2205204
5 0.01000000      5 0.5555030 0.7194034 0.2204855

Variable importance
        as.factor(yr)   as.factor(StatArea)       as.factor(mon) as.factor(vesselname)
                   40                    40                   13                     7
node), split, n, deviance, yval
      * denotes terminal node

 1) root 260 2.090441000 0.026488840
   2) as.factor(StatArea)=10,14,5,8,9 220 0.511765200 0.009508212
     4) as.factor(mon)=1,2,3,4,5,6,7,8,9,10 164 0.048093480 0.002321310 *
     5) as.factor(mon)=11,12 56 0.430393300 0.030555570
      10) as.factor(yr)=2005,2007,2010,2011,2012,2013 47 0.039384620 0.010400770 *
      11) as.factor(yr)=2006,2014 9 0.272213200 0.135808400 *
   3) as.factor(StatArea)=13,2,3 40 1.166347000 0.119882300
     6) as.factor(yr)=2006,2011,2012,2014,2015 23 0.077881580 0.041190120
      12) as.factor(mon)=4,8,10,11 13 0.007293924 0.009688472 *
      13) as.factor(mon)=9,12 10 0.040916280 0.082142260 *
     7) as.factor(yr)=2007,2008 17 0.753344600 0.226348100 *
```

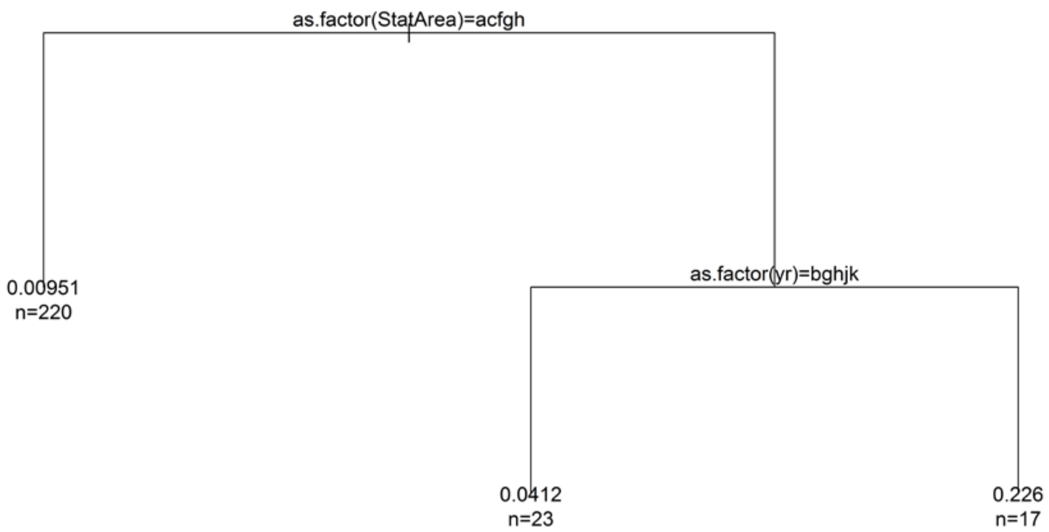

Figure A3: Pruned regression tree of the variation in the proportion of JMM in the sampled JMA catches. The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMN/(JMN+JMD)

```
rpart(formula = propJMN/(propJMN + propJMD) ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) +
as.factor(vesselname) + as.factor(shed), data = summ3, method = "anova")
  n= 260

          CP nsplit rel error    xerror       xstd
1 0.60384988      0 1.0000000 1.0093703 0.12971464
2 0.05633252      1 0.3961501 0.4014394 0.08296530
3 0.02423642      2 0.3398176 0.3615249 0.07629780
4 0.01230877      3 0.3155812 0.3832275 0.07824240
5 0.01000000      4 0.3032724 0.3598786 0.06811062

Variable importance
 as.factor(StatArea)       as.factor(mon)        as.factor(yr) as.factor(vesselname)
                  83                    9                    7                     1

node), split, n, deviance, yval
      * denotes terminal node
 1) root 260 26.4883600 0.84658120
   2) as.factor(StatArea)=2,3 38  4.7162690 0.24708000
     4) as.factor(mon)=8,9,12 22  0.4789319 0.07808887 *
     5) as.factor(mon)=4,10,11 16  2.7451810 0.47944290 *
   3) as.factor(StatArea)=10,13,14,5,8,9 222  5.7770980 0.94919860
     6) as.factor(yr)=2006 16  2.7589880 0.75624230 *
     7) as.factor(yr)=2005,2007,2008,2009,2010,2011,2012,2013,2014,2015 206  2.3761270 0.96418550
      14) as.factor(mon)=12 13  0.6171849 0.81089740 *
      15) as.factor(mon)=1,2,3,4,5,6,7,8,9,10,11 193  1.4329030 0.97451060 *
```

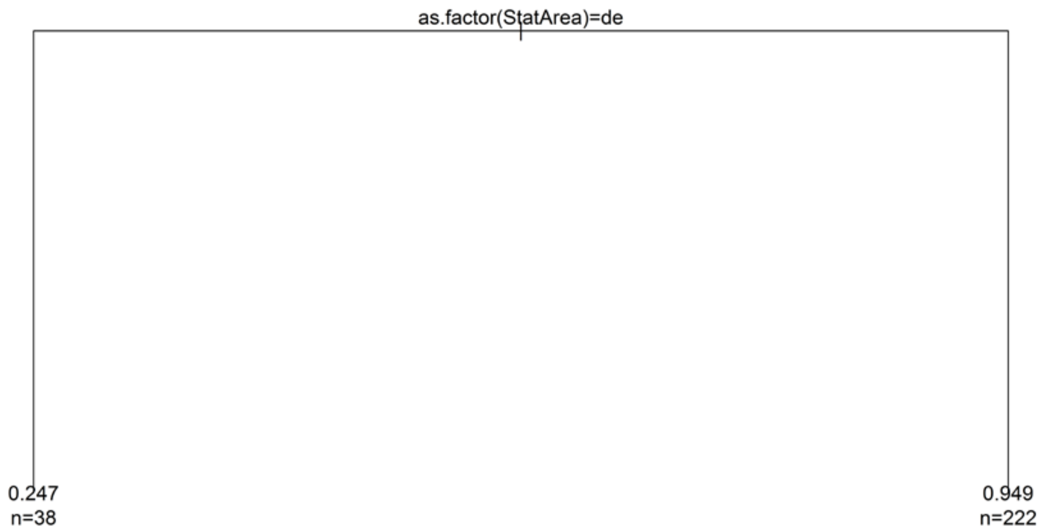

Figure A4: Pruned regression tree of the variation in the proportion of JMN in the combined catch of JMN and JMD from the sampled JMA catches. The values represent the average proportion for the node, n represents the number of records in each node..

APPENDIX 2. DETAILED RESULTS OF TREE BASED ANALYSIS OF GRADE SAMPLING DATA

Proportion JMN

rpart(formula = JMNprop ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) + as.factor(vessel_name2), data = summ, method = "anova")

n= 455

```
node), split, n, deviance, yval
      * denotes terminal node
 1) root 455 70.5114400 0.74288200
   2) as.factor(StatArea)=2,3 130 22.2766200 0.44512610
     4) as.factor(mon)=8,9,10 47  5.5066210 0.21366680
       8) as.factor(yr)=1994,1995,1997,1999,2004 28  1.0881050 0.07218783 *
       9) as.factor(yr)=1996,2001,2002,2003 19  3.0321230 0.42216220 *
     5) as.factor(mon)=1,2,3,4,5,11,12 83 12.8262300 0.57619340
      10) as.factor(yr)=1994 11  0.4394890 0.09426770 *
      11) as.factor(yr)=1995,1996,1997,1998,1999,2000,2001,2002,2003,2004,2005 72  9.4416480 0.64982090
        22) as.factor(mon)=1,2,11 44  5.8789360 0.55658190 *
        23) as.factor(mon)=3,4,5,12 28  2.5791040 0.79633940 *
   3) as.factor(StatArea)=8,9,10 325 32.0989600 0.86198430
     6) as.factor(yr)=1994,1998,2004 66 12.4249500 0.56079730
      12) as.factor(mon)=8,9,10,11 49  8.3006670 0.41570780
        24) as.factor(mon)=11 14  1.0807060 0.22584450 *
        25) as.factor(mon)=8,9,10 35  6.5134190 0.49165310 *
      13) as.factor(mon)=3,4,5,6,7 17  0.1196488 0.97899650 *
     7) as.factor(yr)=1995,1996,1997,1999,2000,2001,2002,2003,2005 259 12.1612400 0.93873470
      14) as.factor(yr)=1995,1997 56  7.7285390 0.79785160
        28) as.factor(mon)=1,10,12 9  1.2928210 0.45938010 *
        29) as.factor(mon)=2,3,6,7,8,9,11 47  5.2072130 0.86266530 *
      15) as.factor(yr)=1996,1999,2000,2001,2002,2003,2005 203  3.0145930 0.97759900
        30) as.factor(mon)=11,12 11  1.6343340 0.71849210 *
        31) as.factor(mon)=1,2,4,5,6,7,8,9,10 192  0.5994497 0.99244360 *
```

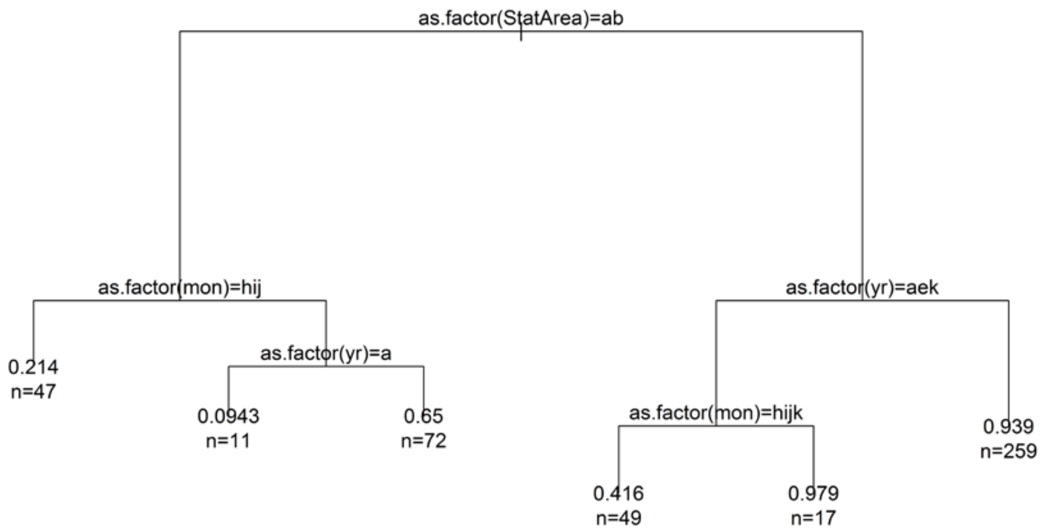

Figure A5: Pruned regression tree of the variation in the proportion of JMN in the sampled graded JMA catches (1994/95 to 2005/06). The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMD

rpart(formula = JMDprop ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) + as.factor(vessel_name2), data = summ, method = "anova")

n= 455

node), split, n, deviance, yval
      * denotes terminal node

```
 1) root 455 28.5788400 0.12157250
   2) as.factor(StatArea)=8,9,10 325  6.1035770 0.04370234
     4) as.factor(yr)=1994,1995,1996,1997,1998,1999,2000,2001,2002,2003,2005 292  1.2583500 0.01935251 *
     5) as.factor(yr)=2004 33  3.1401490 0.25916150
      10) as.factor(mon)=3,4,5,6,10 17  0.1778102 0.04939790 *
      11) as.factor(mon)=9,11 16  1.4195620 0.48203530 *
   3) as.factor(StatArea)=2,3 130 15.5777400 0.31624780
     6) as.factor(yr)=1994,1995,1996,1997,1998,1999,2000,2005 80  4.4706310 0.17705510
      12) as.factor(yr)=1995,1996,1998,2005 46  1.4301060 0.11056440 *
      13) as.factor(yr)=1994,1997,1999,2000 34  2.5620160 0.26701310 *
     7) as.factor(yr)=2001,2002,2003,2004 50  7.0771920 0.53895610
      14) as.factor(mon)=11,12 22  2.5860360 0.37069000
        28) as.factor(vessel_name2)=Vessel1, Vessel2, Vessel3, Vessel4 7  0.2275451 0.14001030 *
        29) as.factor(vessel_name2)= Vessel5, Vessel6 15  1.8121690 0.47834050 *
      15) as.factor(mon)=8,9,10 28  3.3788410 0.67116510
        30) as.factor(StatArea)=3 15  2.3397010 0.52079000 *
        31) as.factor(StatArea)=2 13  0.3085766 0.84467490 *
```

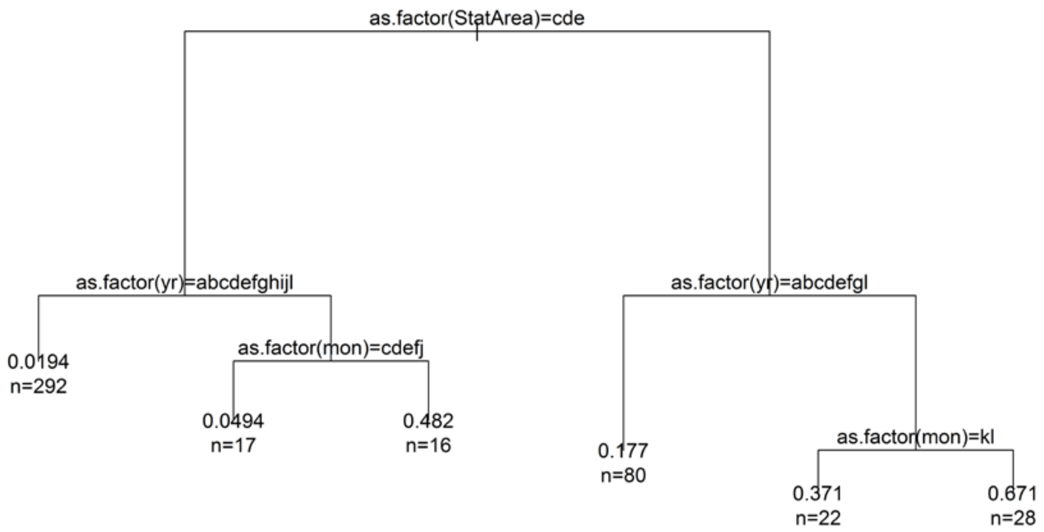

Figure A6: Pruned regression tree of the variation in the proportion of JMD in the sampled graded JMA catches (1994/95 to 2005/06). The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMM

```
rpart(formula = JMMprop ~ as.factor(mon) + as.factor(yr) + as.factor(StatArea) + as.factor(vessel_name2), data = summ,
method = "anova")
  n= 455

node), split, n, deviance, yval
      * denotes terminal node
 1) root 455 34.3214500 0.13554560
   2) as.factor(yr)=1996,1999,2000,2001,2002,2003,2004,2005 313  7.2334440 0.04862993
     4) as.factor(yr)=1999,2000,2001,2002,2003,2005 213  1.2755890 0.01376039 *
     5) as.factor(yr)=1996,2004 100  5.1472370 0.12290200
      10) as.factor(mon)=3,4,5,6,7,8,12 41  0.6012554 0.02584439 *
      11) as.factor(mon)=9,10,11 59  3.8913580 0.19034890 *
   3) as.factor(yr)=1994,1995,1997,1998 142 19.5116000 0.32712720
     6) as.factor(mon)=2,3,4,5,6,7,9 56  4.3302680 0.12864760
      12) as.factor(StatArea)=3,9 45  1.3792460 0.04154241 *
      13) as.factor(StatArea)=2,8 11  1.2128350 0.48498730 *
     7) as.factor(mon)=1,8,10,11,12 86 11.5387500 0.45636970
      14) as.factor(yr)=1995,1997,1998 71  9.1718780 0.39945690
        28) as.factor(yr)=1997 27  3.7631200 0.28252000
          56) as.factor(vessel_name2)=Vessel1, Vessel5 14  0.7907592 0.15961410 *
          57) as.factor(vessel_name2)=Vessel7,Vessel2,Vessel6 13  2.5331290 0.41488020 *
        29) as.factor(yr)=1995,1998 44  4.8129960 0.47121370
          58) as.factor(mon)=10,11,12 25  2.5474440 0.36703080
           116) as.factor(StatArea)=2,3 11  0.7222651 0.19639290 *
           117) as.factor(StatArea)=8,9 14  1.2532310 0.50110350 *
          59) as.factor(mon)=1,8 19  1.6371580 0.60829650 *
      15) as.factor(yr)=1994 15  1.0483570 0.72575690 *
```

Figure A7: Pruned regression tree of the variation in the proportion of JMD in the sampled graded JMA catches (1994/95 to 2005/06). The values represent the average proportion for the node, n represents the number of records in each node.

Proportion JMN/(JMN+JMD)

```
rpart(formula = JMNprop/(JMNprop + JMDprop) ~ as.factor(mon) +
    as.factor(yr) + as.factor(StatArea) + as.factor(vessel_name2),
    data = summ, method = "anova")
  n= 455
          CP nsplit rel error    xerror       xstd
1  0.20041242      0 1.0000000 1.0032120 0.06675359
2  0.09321563      1 0.7995876 0.8496702 0.06374278
3  0.09208917      2 0.7063720 0.8572075 0.06734208
4  0.04653718      3 0.6142828 0.7782760 0.06628823
5  0.04185129      4 0.5677456 0.7478219 0.06523185
6  0.02308019      5 0.5258943 0.6998379 0.06515989
7  0.01786154      6 0.5028141 0.6906308 0.06547073
8  0.01459131      8 0.4670911 0.7050498 0.06635715
9  0.01365309     10 0.4379084 0.7029705 0.06699247
10 0.01197359     11 0.4242553 0.7132488 0.06776922
11 0.01000000     12 0.4122817 0.7096402 0.06701883
Variable importance
        as.factor(mon)          as.factor(yr)     as.factor(StatArea) as.factor(vessel_name2)
                    38                     30                      29                       3
node), split, n, deviance, yval
      * denotes terminal node
 1) root 455 61.7592000 0.78248160
   2) as.factor(StatArea)=2,3 130 23.2148300 0.52169970
     4) as.factor(mon)=8,9,10 47  5.9369990 0.24205050
       8) as.factor(yr)=1994,1995,1997,2004 27  1.2147800 0.09216668 *
       9) as.factor(yr)=1996,1999,2001,2002,2003 20  3.2968050 0.44439360 *
     5) as.factor(mon)=1,2,3,4,5,11,12 83 11.5209100 0.68005530
      10) as.factor(yr)=1994 11  0.8307646 0.22857780 *
      11) as.factor(yr)=1995,1996,1997,1998,1999,2000,2001,2002,2003,2004,2005 72  8.1054400 0.74903100
        22) as.factor(yr)=1997,1998,2000,2001,2002,2003,2004 41  5.5448770 0.65493120 *
        23) as.factor(yr)=1995,1996,1999,2005 31  1.7173590 0.87348570 *
   3) as.factor(StatArea)=8,9,10 325 26.1670600 0.88679440
     6) as.factor(yr)=1994,1998,2004 66 11.1874300 0.62474010
      12) as.factor(mon)=8,9,10,11 49  8.1936650 0.50182490
        24) as.factor(yr)=1994,2004 26  3.8831010 0.39740330
          48) as.factor(mon)=9,11 19  1.4591660 0.24672510 *
          49) as.factor(mon)=10 7  0.8216864 0.80638700 *
        25) as.factor(yr)=1998 23  3.7065840 0.61986680
          50) as.factor(mon)=10,11 12  1.6879070 0.44819270 *
          51) as.factor(mon)=8,9 11  1.2791980 0.80714770 *
      13) as.factor(mon)=3,4,5,6,7 17  0.1196688 0.97902480 *
     7) as.factor(yr)=1995,1996,1997,1999,2000,2001,2002,2003,2005 259  9.2922750 0.95357270
      14) as.factor(yr)=1995,1997,2000 82  7.9712650 0.87048080
        28) as.factor(mon)=1,11 7  1.4477460 0.51376430 *
        29) as.factor(mon)=2,3,6,7,8,9,10,12 75  5.5496570 0.90377440 *
      15) as.factor(yr)=1996,1999,2001,2002,2003,2005 177  0.4925765 0.99206730 *
```

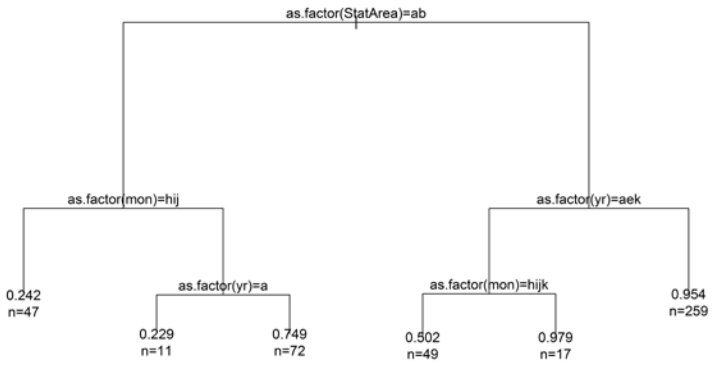

Figure A8: Pruned regression tree of the variation in the proportion of JMN in the combined JMN and JMD catches from sampled graded JMA catches (1994/95 to 2005/06). The values represent the average proportion for the node, n represents the number of records in each node.

APPENDIX 3. SPECIES CATCH ESTIMATES BY FISHING YEAR

Table A1: Catch estimates and coefficient of variation (CV) for *T. novaezelandiae* from the JMA 1 purse seine fishery by fishing year with and without fishing area stratification. NA, not available.

Fishing year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2005/06	8 448.1	0.072	7 903.2	0.097
2006/07	1 451.3	0.520	1 194.8	0.482
2007/08	8 557.7	0.050	7 156.3	0.190
2008/09	8 339.4	0.017	8 354.3	0.090
2009/10	8 682.0	0.003	8 680.8	0.003
2010/11	NA	-	6 240.5	0.134
2011/12	7 409.0	0.063	6 690.2	0.136
2012/13	7 136.4	0.072	6 813.8	0.096
2013/14	9 460.5	0.024	9 125.4	0.067

Table A2: Catch estimates and coefficient of variation (CV) for *T. declivis* from the JMA 1 purse seine fishery by fishing year with and without fishing area stratification. NA, not available.

Fishing year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2005/06	1 037.7	0.588	1 575.2	0.485
2006/07	2 067.5	0.222	2 535.7	0.155
2007/08	2 550.1	0.165	3 853.8	0.335
2008/09	571.1	0.094	587.5	0.596
2009/10	24.8	1.084	26.1	0.973
2010/11	NA	-	1 420.9	0.547
2011/12	1 122.9	0.395	1 832.7	0.486
2012/13	450.7	0.948	708.7	0.749
2013/14	688.1	0.286	988.3	0.555

Table A3: Catch estimates and coefficient of variation (CV) for *T. murphyi* from the JMA 1 purse seine fishery by fishing year with and without fishing area stratification. NA, not available.

Fishing year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2005/06	1.1	0.833	8.5	1.020
2006/07	1 229.8	0.357	1 018.0	0.296
2007/08	110.2	0.286	207.9	0.410
2008/09	664.9	0.198	633.5	0.682
2009/10	0.0	0.000	0.0	0.000
2010/11	NA	-	177.4	0.469
2011/12	33.5	1.015	42.5	0.780
2012/13	91.7	0.981	156.3	0.806
2013/14	111.0	0.375	145.9	0.505

APPENDIX 4. SPECIES CATCH ESTIMATES BY CALENDAR YEAR

Table A4: Catch estimates and coefficient of variation (CV) for *T. novaezelandiae* from the JMA 1 purse seine fishery by calendar year with and without fishing area stratification.

Calendar year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2006	4 704.5	0.181	4 831.2	0.144
2007	6 446.5	0.068	1 972.7	0.414
2008	10 553.4	0.017	8 768.2	0.209
2009	7 232.3	0.002	6 452.7	0.087
2010	8 898.9	0.026	9 445.4	0.003
2011	3 845.5	0.083	3 895.2	0.135
2012	7 090.7	0.046	6 795.2	0.130
2013	9 628.3	0.054	9 243.1	0.094
2014	7 245.2	0.034	7 222.4	0.071

Table A5: Catch estimates and coefficient of variation (CV) for *T. declivis* from the JMA 1 purse seine fishery by calendar year with and without fishing area stratification.

Calendar year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2006	1 844.9	0.369	2 201.9	0.314
2007	1 458.1	0.234	4 472.7	0.136
2008	1 789.5	0.195	4 444.5	0.392
2009	21.0	0.764	401.5	0.660
2010	475.0	0.392	27.3	0.887
2011	1 121.1	0.264	1 008.7	0.477
2012	1 421.4	0.182	1 838.5	0.472
2013	554.4	0.780	848.4	0.834
2014	703.5	0.274	789.7	0.580

Table A6: Catch estimates and coefficient of variation (CV) for *T. murphyi* from the JMA 1 purse seine fishery by calendar year with and without fishing area stratification.

Calendar year	Area stratification		No stratification	
	Catch (t)	CV	Catch (t)	CV
2006	499.2	0.707	15.5	0.812
2007	372.0	0.352	1 831.2	0.225
2008	1 105.0	0.299	235.2	0.442
2009	2.9	0.842	402.0	0.808
2010	98.7	0.626	0.0	-
2011	55.9	0.510	118.6	0.494
2012	162.8	0.605	41.2	0.843
2013	94.8	0.985	186.2	0.894
2014	178.3	0.351	114.8	0.520

APPENDIX 5. SPECIES CATCH PROPORTIONS

Table A7 Time series of estimates of the annual jack mackerel species proportions for the JMA 1 purse seine fishery and annual total JMA 1 purse seine catches. The source of the species proportion estimates is also presented.

Fishing year	Catch (t)	Species proportion			Source
		JMD	JMM	JMN	
1989/90	1 432.9	0.152	0.040	0.808	Penney et al. 2011, table 7
1990/91	7 146.5	0.146	0.096	0.758	Penney et al. 2011, table 7
1991/92	6 920.8	0.108	0.317	0.575	Penney et al. 2011, table 7
1992/93	8 629.1	0.108	0.327	0.565	Penney et al. 2011, table 7
1993/94	13 709.9	0.171	0.654	0.176	Penney et al. 2011, table 7
1994/95	8 530.0	0.130	0.450	0.420	Taylor et al. 2012, table C2
1995/96	5 642.8	0.030	0.130	0.840	Taylor et al. 2012, table C2
1996/97	6 256.2	0.050	0.300	0.650	Taylor et al. 2012, table C2
1997/98	7 009.0	0.050	0.420	0.530	Taylor et al. 2012, table C2
1998/99	5 076.5	0.140	0.300	0.560	Taylor et al. 2012, table C2
1999/00	2 415.6	0.010	0.010	0.980	Taylor et al. 2012, table C2
2000/01	7 896.0	0.020	0.010	0.970	Taylor et al. 2012, table C2
2001/02	5 145.8	0.170	0.010	0.820	Taylor et al. 2012, table C2
2002/03	5 517.7	0.300	0.020	0.680	Taylor et al. 2012, table C2
2003/04	6 838.3	0.460	0.110	0.430	Taylor et al. 2012, table C2
2004/05	8 919.2	0.110	0.070	0.820	Taylor et al. 2012, table C2
2005/06	9 567.6	0.109	0.000	0.890	Current study, area stratified
2006/07	4 802.7	0.435	0.259	0.306	Current study, area stratified
2007/08	11 270.2	0.227	0.010	0.763	Current study, area stratified
2008/09	9 579.0	0.060	0.069	0.871	Current study, area stratified
2009/10	8 713.5	0.003	0.000	0.997	Current study, area stratified
2010/11	7 935.9	0.003	0.000	0.997	Current study, no area stratification
2011/12	8 765.0	0.131	0.004	0.865	Current study, area stratified
2012/13	7 841.2	0.059	0.012	0.929	Current study, area stratified
2013/14	10 259.8	0.067	0.011	0.922	Current study, area stratified