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Estimating growth in paua

New Zealand Fisheries Assessment Report 2016/14

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EXECUTIVE SUMMARY

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The results of a literature search detailing research conducted on paua growth and length at maturity are presented along with a summary of the collation of growth and length at maturity data into a database. Regions of potentially different growth within the paua fishery, are suggested based on industry perception, available growth information, geographic location, and the results of tree regression analyses of commercial length frequency distributions.

Tree regression analyses were carried out on the commercial catch length samples from 2008 to 2013 for each of the QMAs (PAU 5A, PAU 5B, PAU 5D, PAU 2, PAU 3, PAU 4, and PAU 7). The analyses stratified the length samples into groups with different mean lengths, with the aim of separating the QMAs into subregions with potentially different growth rates. Explanatory variables included fine scale statistical area, FIN, and month, which were offered as categorical variable, or alternatively as ordered categorical variables. Additional models using only statistical area as the splitting variable were also considered.

The collection of growth information is likely to be most efficiently done by industry. The literature suggests that tags attached through the respiratory pores will provide a simple methodology, unlikely to affect growth, and likely to provide good retention and easy detection.

1. INTRODUCTION

Achieving reliable biomass and reference point estimates from a stock assessment model is highly dependent on quality data and reliable parameter estimates being entered into the model. For the length-based Bayesian model used for assessing the status of the stock in New Zealands paua fishery, these parameters include estimates of growth and length at maturity, which can differ over various spatial scales. Growth is one of the key parameters for the length-based model which determines the productivity of the stock. Improved growth data may also be used to inform a review of the Minimum Legal Size (MLS) and the spatial scale at which it could apply. Growth data for paua have been collected from a number of sites around New Zealand (Naylor et al. 2006). These data are limited and need to be expanded to gain a better understanding of spatial variation in growth.

Current stock assessments for paua in NZ are generally conducted at the QMA level (Fu 2012, 2013, 2014), and the whole population in the QMA is assumed to be homogenous (with the same growth, length at maturity, etc.). The stock assessment may be improved to better inform management decisions if differences in stock productivity are taken into account and incorporated into the model. This requires growth data in each QMA that informs a suitable subdivision of the QMA area that reflects differences in the productivity of the stock.

Paua are currently managed under a single MLS throughout the whole New Zealand, with the exception of Taranaki, although voluntary minimum harvest sizes have been initiated by industry in various QMA sub-regions (Appendix C). Setting an appropriate MLS is important to ensure that paua are able to spawn and contribute to local recruitment and this requires an understanding of how length-at-maturity and growth rates differ between regions.

The Ministry for Primary Industries is currently developing a programme to collect more growth and length-at-maturity data for paua from all QMAs in order to develop a better understanding of potential differences in growth between different regions within QMAs..

The objectives of the project are:

1) To conduct a literature search and summarise the results of research estimating growth and length at maturity in paua.
2) To collate, into a database, all growth and length at maturity data for paua in PAU 3 and PAU 5D.
3) To make recommendations on how best to subdivide each QMA into regions of potentially different growth rates and how sampling would be undertaken in a cost effective manner.

2. LITERATURE REVIEW

Objective 1: Undertake a literature search detailing the results of all research that has been conducted on estimating growth and length at maturity in PAU 1, PAU 2, PAU 3, PAU 4, PAU 5A, PAU 5B, PAU 5D, and PAU 7.

2.1 Methods

The primary sources of information for this review were from research carried out by government agencies and universities. Key contacts from universities were also consulted. Other research was accessed from web-based search engines such as Google Scholar, Scopus, and the ISI Web of Knowledge. Other literature that the authors were aware of was also consulted. Once relevant articles were found, their bibliographies were examined to identify older articles on the subject. The information was then summarised.

2.2 Results

Relevant literature is reported chronologically under subsections relating to growth and maturity.

2.2.1 Growth

Poore (1972b) used a combination of tagging and changes in length frequency to estimate the growth of paua at Kaikoura (PAU 3). He found that in the first year a length of about 21 mm was attained and at the end of the second year paua were about 50 mm long. There was variation in growth within and between sites, and growth accelerated during late spring to summer.

Sainsbury (1977, 1982) used modal progression and tagging to estimate the growth of paua at Peraki Bay on Banks Peninsula (PAU 3). He found that paua reached about 21 mm in their first year, 40 mm in two years and took about five years to reach 80 mm. Growth in the Peraki Bay population was similar in the first year to that found by Poore (1972b) at Kaikoura, but thereafter slower.

Murray & Akroyd (1984) note that growth rates in paua vary within and between regions. They present Von Bertalanffy growth parameters based on shell ring counts for sites in PAU 7, PAU 5D, PAU 5B, and PAU 4.

Murray (1986) presents growth curves for paua from five sites at the Chatham Islands based on the number of protein layers in vertical cross sections of shells. He states that tagging has shown that the layers are laid down about once every year.

Petherick (1987 provides age and growth estimates for four sites on the Wairarapa coast (PAU 2) similarly based on unvalidated growth ring counts.

Wilson (1987) estimated growth in paua at Seacliff (north of Dunedin, PAU 5D) using modal progression of length frequency samples. She estimated that the annual growth rate of juvenile *H. iris* was about 23 mm, which is greater than that recorded by either Poore (1972b) or Sainsbury (1977, 1982).

Schiel & Breen (1991) reported paua growth estimates from D'Urville Island and the Marlborough Sounds (PAU 7) obtained from tag recapture studies. Estimated annual growth at 90 mm and 125 mm in length was in the order of 15 mm and 5 mm respectively.

Pirker (1992) estimated growth in paua at four sites in the Kaikoura region (two sites at Blue Duck Creek, and a site at Laboratory Rocks and at Pukaroro Rock). Annual increments for juvenile paua ranged between about 22 mm and 28 mm. Annual growth for adult paua ranged between about 7 mm and 11 mm.

McShane (1992) presents incremental growth data from paua tagged at D'Urville Island.

McShane et al. (1993) present incremental growth from tag recapture for paua at Breaker Bay on Wellington's south coast.

McShane et al. (1994) present a larger data set of incremental growth from tag recapture for paua at Breaker Bay on Wellington's south coast.

McShane & Naylor (1995) present incremental growth from six sites at the northern end of D'Urville Island. They found that growth was significantly faster off headlands than in bays and that paua on headlands reached a higher maximum size than those in bays.

McShane et al. (1996) present a comparison of incremental growth estimates for paua between 80 mm and 90 mm tagged at D'Urville Island in bays, D'Urville Island on headlands, the Staircase, and from

Breaker Bay in Wellington. Annual growth estimates ranged from about 11 mm at the Staircase (PAU 7) to about 20 mm in Wellington (PAU 2).

Hooker et al. (1997) tagged paua at Okakari Point north of Leigh. Both tagging and modal size class analysis suggested that paua in this area grew to about 30 mm in their first year and to about 52 mm in their second year, reaching 70 mm in about three years. Growth was rapid up to about 70 mm and negligible above 80 mm. Paua in the area rarely reached the minimum legal size (MLS) of 125 mm. They also found that during winter (from June until August) there was a sharp decrease in the rate of growth.

Naylor et al. (1998) present incremental growth for paua between 80 mm and 90 mm tagged and recaptured at Waituna (PAU 5B) and Kahurangi (PAU 6). Annual growth estimates at these sites were about 15 mm and 9 mm respectively.

Naylor & Andrew (2000) present growth estimates from three sites at Taranaki and four sites on Banks Peninsula. Growth rates between the Banks Peninsula sites did not appear to be different, while growth was variable between sites at Taranaki. No paua larger than 100 mm were found at Taranaki, and very few paua larger than 125 mm were found at sites around Banks Peninsula. Mean annual growth at Banks Peninsula for paua 80 mm long and 115 mm long was 7.2 mm and 0.8 mm respectively. At Taranaki, mean annual growth for paua 25 mm long and 75 mm long was about 18 mm and 3 mm respectively.

Andrew et al. (2000) present incremental growth data from the six sites sampled at D'Urville Island (the same data reported by McShane & Naylor 1995).

Breen et al. (2000) present a plot of annual incremental growth against initial length from tag recapture work at Waituna as part of the 2000 stock assessment of paua in PAU 5B.

Clarke (2001) used cohort analysis of size-frequency data to estimate growth in paua at sites to the north of Leigh and found that *H. iris* grew to a mean length of about 30 mm during their first year. Tag-recapture data were variable within and among populations. Growth in paua greater than 80 mm in length was slow and most paua reached a maximum size of between about 111 and 116 mm.

Naylor & Andrew (2002) present incremental growth data from three sites in PAU 2, three sites in PAU 5A, three sites in PAU 5B, and two sites in PAU 5D. Mean annual growth estimates for paua 90 mm in length ranged from about 9 mm at Poison Bay in PAU 5A to about nearly 23 mm at both the Catlins East site (PAU 5D) and the Christmas Village site (PAU 5B). Paua 90 mm in length at all sites in PAU 5B, at Landing Bay (PAU 5A), and at Breaker Bay and Turakirae (PAU 2) grew about 20 mm a year. Paua 125 mm in length grew about 10 mm per year at Catlins West (PAU 5D) and at Landing Bay (PAU 5A), between 5 and 6 mm per year at Turakirae (PAU 2), Breaker Bay (PAU 2), Red Head Point (PAU 5A), Christmas Village (PAU 5B), Ocean Beach (PAU 5B), and Catlins East (PAU 5D). At Poison Bay (PAU 5A), and at Mataikona (PAU 2) paua of this length grew 2.1 mm and 0.1 mm respectively. Large paua do not occur at either of these sites.

Naylor et al. (2003) present incremental growth data from three sites at the Chatham Islands (PAU 4). The mean annual growth of paua 75 mm in length at these sites was between about 16 mm and 21 mm. Paua 125 mm in length grow between about 3 mm and 4 mm per year.

Russell (2004) used tag-recapture methods to determine the growth of paua at several sites around Wellington. She found that on average paua grew between 1 mm and 3 mm per month, attained a length of 12.5 mm in their first year, grew 21 mm in their second year and 30 mm in their third year. She found that growth decreased over winter and increased during spring and summer. Growth was also variable between sites, being lowest at Red Rocks and highest at Palmer Head.

Naylor et al. (2006) present predicted growth estimates for 30 sites around New Zealand which spanned 10^{o} of latitude. They found that growth was generally faster in areas with lower mean monthly sea surface temperatures (SST) and that sites with the slowest growth had the highest mean monthly SST. They discuss possible explanations for growth variation including temperature related physiological processes, the availability and quality of food, and wave action in the context of supplying food.

2.2.2 Maturity

Poore (1973) found that ripe eggs may appear in the female gonad of *H.iris* at a length of about 60 mm, but that a substantial number of eggs were only produced once the paua reached a length of about 100 mm.

Sainsbury (1977, 1982) found that while some *H. iris* as small as 70 mm contained ripe eggs they contained very few of them (between 100 and 1000) and would make very little contribution to egg production within the population. He found that fecundity increased rapidly between about 90 mm and 120 mm, although in larger animals there was considerable variation in fecundity.

Wilson (1987) and Wilson & Schiel (1995) found that paua in Otago began to mature at around 70 mm in length, and at about 90 mm in length produced enough eggs to make a significant contribution to gamete production. This is similar to the estimates of Poore (1972b) at Kaikoura and Sainsbury (1982) at Banks Peninsula.

McShane et al. (1994) and McShane & Naylor (1995) present estimates of length at maturity for bays and headlands at the northern end of D'Urville Island. The lengths at which 50% were mature in bays and off headlands were about 85 mm and about 80 mm respectively.

McShane et al. (1996) present maturity ogives for paua at Wellington (PAU 2), Cook Strait (PAU 7), East Cape (PAU 5B), and Kahurangi (PAU 6). The size at which 50% of paua were mature ranged from 72 mm at Wellington to 95 mm at Kahurangi.

Hooker & Creese (1995) looked at length at maturity in a paua population at Leigh in north-eastern New Zealand. The two smallest paua they found with gametogenic cells were 44 mm and 59 mm. They thought that this was unlikely to be the minimum size at first spawning, and found that the transition from immature to mature occurred between 50 mm and 60 mm. Paua in this area do not grow to a large maximum size.

Naylor & Andrew (2000) present estimates of length at maturity for sites at Taranaki and Banks Peninsula. The lengths at which 50% of paua were mature at Taranaki and Banks Peninsula were 58.9 mm and 75.5 mm respectively.

Naylor et al. (2006) present the lengths at 50% maturity for 10 sites around New Zealand. These range from 54 mm for a stunted population at New Plymouth to about 98 mm at East Cape at Stewart Island.

3. COLLATE GROWTH AND LENGTH AT MATURITY DATA INTO DATABASE

Objective 2: Collate, into a database, all available data relevant to PAU 3 and PAU 5D from objective 1. It is envisaged that, in the future, the database will be populated with all available growth and length at maturity data from all paua QMAs.

3.1 Methods

All available growth and length at maturity was collated and entered into databases. Growth data was entered into the Ministry for Primary Industries' (MPI) *tag* database. Length at maturity data was entered into MPI's *dive* database, which was modified to accommodate the data.

These databases are managed by NIWA and their documentation can be found at the link below.
http://www.fish.govt.nz/en-nz/Research+Services/Research+Database+Documentation

3.2 Results

A total of 2826 tag recapture records from eight QMAs were loaded onto the MPI's *tag* database on the 4th of November 2014. The number of records by site and QMA are shown in Table 1. The location of sites is shown in Figure 1.

A total of 3070 maturity records from eight QMAs were loaded onto the MPI's *dive* database on the 4th of November 2014. A further 413 records were added on the 21st of November 2014. The database already contained 795 maturity records. The number of records by site and QMA are shown in Table 2. The location of sites is shown in Figure 2.

Table 1: Summary of the location and number of tag recapture records loaded onto MPI's *tag* database.

QMA	Area	Latitude	Longitude	Growth records
PAU 2 (402)	Breaker Bay	-41.3389	174.8269	191
	Egmont	-39.27698	173.751131	40
	Mataikona	-40.6869	176.3473	30
	New Plymouth	-39.054209	174.061983	80
	Opunake	-39.456014	173.848053	17
	Turakirae	-41.4314	174.9089	44
PAU 3 (185)	inside Akaroa	-43.8648	172.9464	83
	inside Pigeon Bay	-43.6559	172.9139	17
	outside Pigeon Bay	-43.6238	172.9318	19
	Scenery Nook	-43.8986	172.925	66
PAU 4 (278)	Ascots	-44.01675	-176.383889	20
	Okawa	-44.274389	-176.158278	1
	Sandy Point Pitt Is.	-44.274389	-176.158278	61
	The Horns	-44.1142	-176.633	36
	Tubong	-43.757944	-176.825694	9
	Waitangi West	-43.7817	-176.8374	120
	Wharekauri	-43.7066	-176.5739	31
PAU 5A (299)	Landing Bay	-45.9987	166.504	73
	Poison Bay	-44.667	167.6326	135
	Red Head	-46.0737	166.5662	91
PAU 5B (333)	Christmas Village	-46.7505	167.9832	78
	Ocean Beach	-46.9781	168.1844	71
	Port Adventure	-47.0674	168.1716	52
	Waituna	-46.7887	167.713	132
PAU 5D (274)	Boat Harbour	-46.6541	169.1943	116
	Catlins East	-46.6295	169.3149	61
	Papatowai			24
	Roaring Bay	-46.4473	169.8119	36
	Seal Pt	-45.899	170.6384	37
PAU 6 (150)	Big Bay	-40.8722	172.1279	37
	Otukoroiti	-40.8114	172.1728	113
PAU 7 (905)	Cape Campbell	-41.7248	174.2787	10
	D'Urville site 1	-40.7272	173.948	106
	D'Urville site 2	-40.7267	173.9363	105
	D'Urville site 3	-40.7129	173.957	148
	D'Urville site 4	-40.7139	173.9533	54
	D'Urville site 5	-40.7454	173.9252	46
	D'Urville site 6	-40.7465	173.9352	46
	Glasgow East	-41.2873	174.2415	5
	GlasgowWest	-41.3074	174.2375	58
	Jackson	-41.0003	174.3062	211
	Smokey Bay	-41.125	174.3885	68
	Staircase	-41.3859	174.0661	48
Total				2826

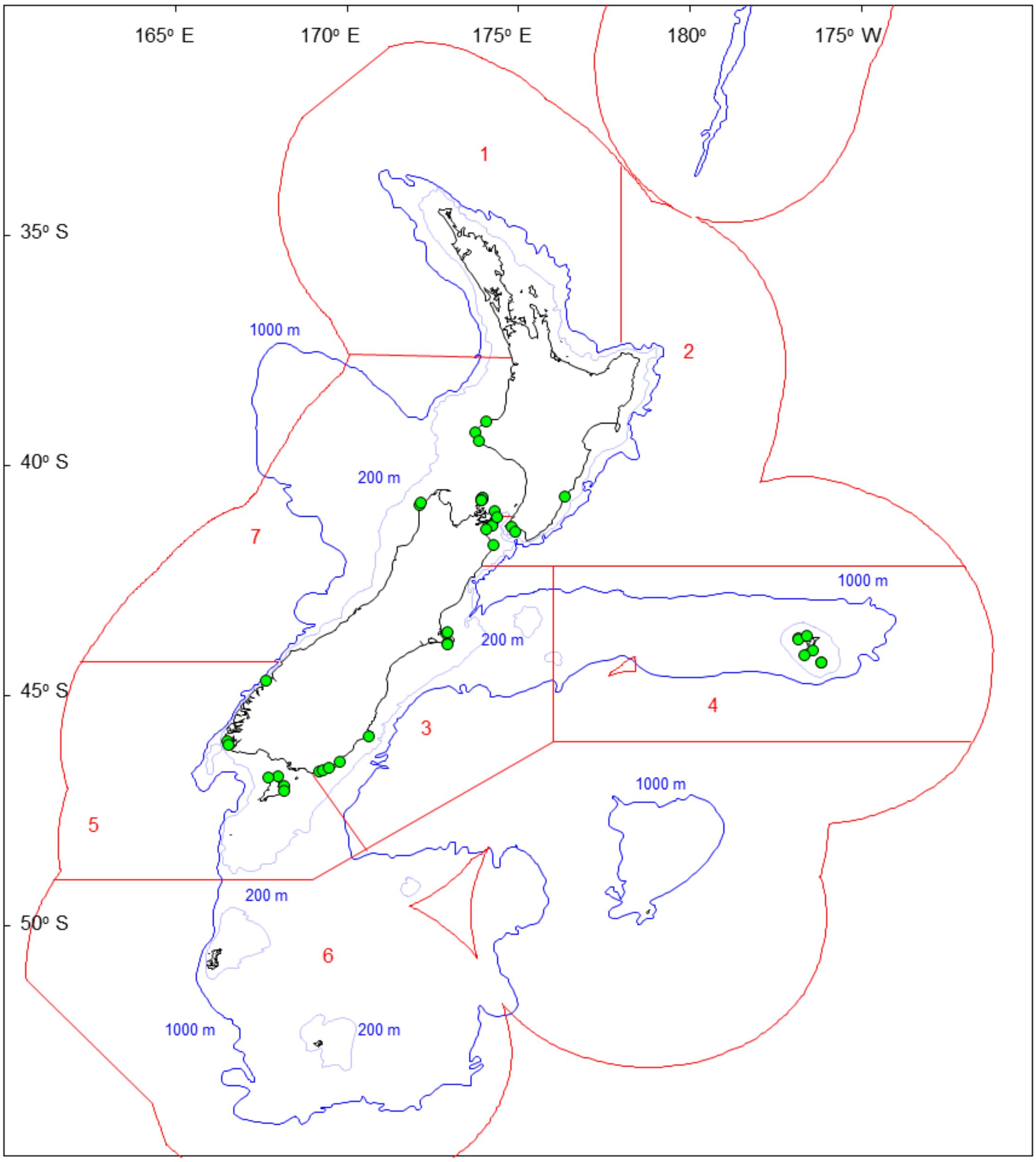

Figure 1: Location of tag recapture sites.

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Table 2: Summary of the location and number of length at maturity records loaded on MPI's *dive* database.

QMA	Area	Latitude	Longitude	Maturity records
PAU 2 (1110)	Breaker Bay	-41.339295	174.825313	118
	Cape Egmont	-39.27698	173.751131	107
	New Plymouth	-39.054209	174.061983	212
	Opunake	-39.456014	173.848053	117
	Pukerua Bay	-41.029564	174.881974	96
	Puketapu	-39.519533	173.91498	109
	Tora	-41.4869	175.5736	115
	Terakirae	-41.4350	174.912	100
	Sponge Bay	-38.7073	178.0489	103
	Blackhead Point			33
PAU 3 (661)	inside akaroa	-43.855814	172.941833	120
	Jorgies Rock	-42.441975	173.587135	106
	Motunau	-43.063645	173.079528	117
	Okiwi Bay	-42.223134	173.857438	114
	Paparoa	-42.235547	173.847514	101
	Scenery Nook	-43.898455	172.925142	103
PAU 4 (96)	Chatham Island	-44.045	-177.243	96
PAU 5A (306)	Milford	-44.577826	167.770837	124
	Poison Bay	-44.66206	167.625357	120
	Green Islets	-46.2250	166.7890	62
PAU 5B (85)	East Cape	-47.013625	168.225439	57
	Waituna	-46.788259	167.713399	28
PAU 5D (194)	Calins west	-46.6717	169.026	79
	Moeraki	-45.3666	170.8655	115
PAU 6 (112)	Kahurangi	-40.811465	172.173017	112
PAU 7 (1714)	Campbell	-41.725874	174.278074	86
	D'Urville	-40.746	173.926	136
	Lookout Bay East	-40.738	173.873	102
	Lookout BayWest	-40.737	173.873	104
	Northern faces	-41.05	173.981	425
	Perano	-41.198451	173.374	230
	Rununder	-41.334765	174.178691	251
	Staircase	-41.377	174.07	42
	Swamp Bay North	-40.747	173.935	106
	Swamp Bay South	-40.745	173.928	105
	Tory Channel	-41.214936	174.309375	127
Total				4,278

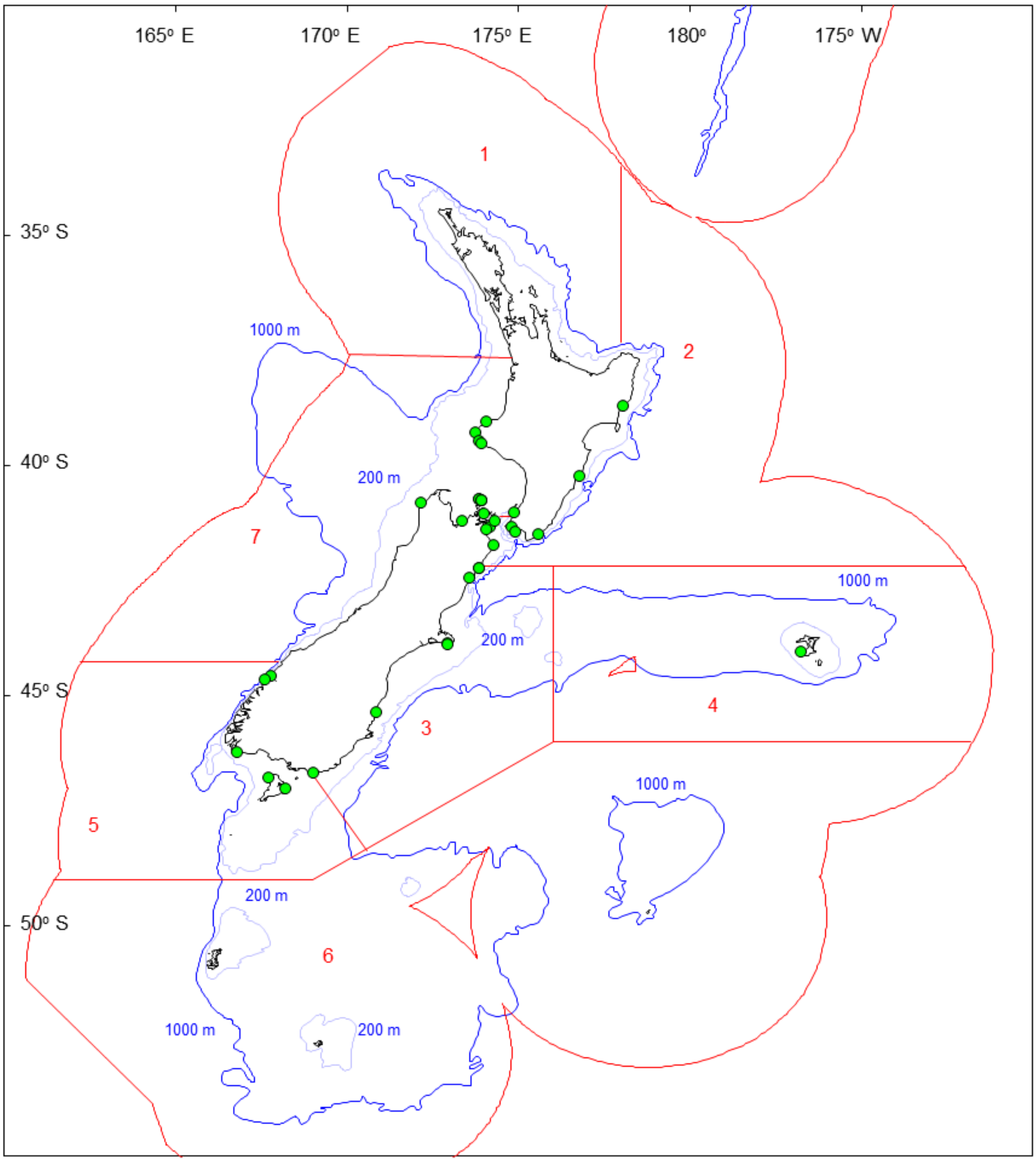

Figure 2: Location of length at maturity data sets.

4. SUBDIVIDE QMAS INTO REGIONS OF POTENTIALLY DIFFERENT GROWTH

Objective 3: Noting that improved growth data is required in each QMA in order to better inform the stock assessment model and management decisions about suitable minimum legal sizes, from the literature search, make recommendations on how best to subdivide each QMA into regions of potentially different growth rates and how sampling would be undertaken in a cost effective manner.

This objective was investigated in collaboration with the Paua Industry Council Ltd. (PICL). In most QMAs the spatial scale of available growth data did not adequately inform QMA subdivision.

4.1 Methods

Two approaches were considered to assist in decisions on the appropriate subdivision of QMAs by area. The first approach involved discussion with commercial paua fishers. The second approach analysed the commercial length frequency data using tree regression techniques to identify area effects or boundaries that separate length distributions based on area. Any differences may be explained by the growth characteristics of the populations.

4.1.1 Discussion with fishers

Commercial fishers are the people likely to be most familiar with the habitat and the nature of paua within the areas that they fish. They become aware of the overall abundance and size range of paua in particular areas, the response of the population to fishing pressure, the meat recovery rates, and the prevailing weather and sea conditions (i.e., how accessible the population is).

The appropriate scale for subdivision into regions within the each QMA was determined through discussion with PICL, who asked fishers to mark areas of perceived differing growth regimes onto a map of the coastline of the QMA. About six industry participants from each of the main QMAs were consulted over the maps. The maps were examined by NIWA and subsequently discussed with industry divers. Boundaries were then drawn based on the industry maps, subsequent discussion, NIWA knowledge of the areas concerned, available biological information, and obvious geographic boundaries. The boundaries were also compared with the results of the tree regression; however, these results were often not informative and sometimes reflected the accessibility of areas rather than growth characteristics.

The most cost-effective sampling method may be the collection of information by fishers in association with PICL; however, this will require a commitment from a number of fishers, within each QMA, that are keen and able to complete the work. PICL have indicated that there are fishers keen to be involved with the collection of this information.

4.1.2 Tree regression analysis

Commercial fishery length frequency data were extracted from the market database. The analyses presented here are restricted to the 2007–08 through to the 2012–13 fishing years. This is the period where there is consistent information at the paua fine-scale statistical area level and on the individual (or FIN number) collecting the sample. The number of samples collected in each QMA are summarised in Table 3. No commercial sample was taken from PAU 1 and only 6 samples were from PAU 6 between 2010 and 2013. PAU 1 and PAU 6 have very low Total Allowable Commercial Catches of 1.9 t and 1.0 t so were therefore not considered in this analysis.

The distribution of sampling, relative to the distribution of commercial catch, for the period between 2008 and 2012 was examined by Haist (2014). She suggested that the sampling has generally improved over the 2008 to 2012 period. The number of samples collected has increased (see Table A1) and the samples tend to be more representative of the fisheries in terms of seasonal timing and location. However, the spatial and temporal distribution of sampling was variable among years. In some QMAs, there are considerable mismatches in the timing of sample collection relative to the catch with no overall pattern (Haist 2014). A summary of number of samples by statistical area and fishing year for each QMA is given in Appendix A.

Stratification of the length samples was carried out using regression tree-based methods described by Breiman et al. (1984). The tree construction method is similar to that used in Smith (2005) and Francis (2002). The regression tree method for obtaining the stratification is iterative and at each stage subdivides one of the existing strata by "splitting" on one of the three stratification variables statistical area, FIN, or month. The choice of variable together with the splitting value is made so that the reduction in the weighted sum of squares is the greatest possible at each stage. The decision to stop the subdivision of the strata is made on the basis of cross-validation of the reduction in the relative error after each iteration. Each subdivision always results in a reduction but there is danger of over-fitting the recursive partition model and producing too many strata that only accommodate for random variation. Cross-validation checks the predictive power of a particular size of tree and therefore avoids over-fitting. Cross-validation is carried out by first splitting the data randomly into 10 data subsets. Trees of the particular size are fitted to the combined data of 9 of the subsets and the reduction in the relative error is calculated for the tenth subset. The process is repeated for each of the 10 subsets and the predicted reduction calculated. The average reduction is then an estimate of the reduction in relative error for each tree size. Estimates of the standard error in the relative error, are also available from the 10-fold cross validation. Breiman et al. (1984) advocated growing a large tree and then pruning the tree back to the smallest size tree that is within 1 standard error of the minimum cross-validated relative error, and this is the approach that we have used. The recursive partitioning program *rpart*, available in the statistical package R (R Core Team 2014) was used for the analysis.

The mean length of paua for each sample in the length data is used as a response variable in the tree regression analysis. Four models were fitted for each QMA. Model 1 included statistical area, FIN, and month as explanatory variables, with each being treated as a categorical variable (each split could result in any combination of levels in each variable); Model 2 included statistical area, FIN, and month as explanatory variables, with each as an ordered categorical variable (the split must be continuous on each variable). Model 3 and 4 included only statistical area as a categorical and an ordered categorical variable, respectively. For each QMA, a linear model was also fitted to the mean length of each sample, and effects of statistical area, FIN, month, fishing year were estimated.

Table 3: Number of catch samples by year and QMA from 2008 to 2013.

	2008	2009	2010	2011	2012	2013
PAU 2	24	28	118	124	141	181
PAU 3	47	65	78	89	97	80
PAU 4	29	61	118	151	239	241
PAU 5A	22	25	63	32	31	52
PAU 5B	37	49	72	79	65	88
PAU 5D	12	34	40	24	31	56
PAU 6			2	1	1	2
PAU 7	72	54	109	172	237	221

4.2 Results

4.2.1 Discussion with fishers

Regions of potentially different growth are proposed by QMA. These are presented on the industry provided maps for respective QMAs which largely formed the basis of regional differentiation. Results from the tree regression are referred to briefly in this section, and reported fully at the end of it.

4.2.2 PAU 5A

PAU 5A was divided into three regions of potentially different growth: Northern, Central, and Southern (Figure 3). Paua in the Northern zone are generally considered to be smaller than those further south. This is supported by the distribution of lengths shown in the tree regression (Figure 4). The Southern zone has a southerly aspect, while the central zone has a north-west aspect.

There is; however, no evidence that growth between these two areas is different and some evidence that growth between the two areas is similar (Naylor & Breen 2008). Naylor and Breen (2008) estimated growth in three paua from each of 10 sites across PAU 5A (Figure 5) using stable oxygen isotope analyses and found that their results did not suggest large differences in growth among sites or strata, but suggested large differences between individuals within sites.

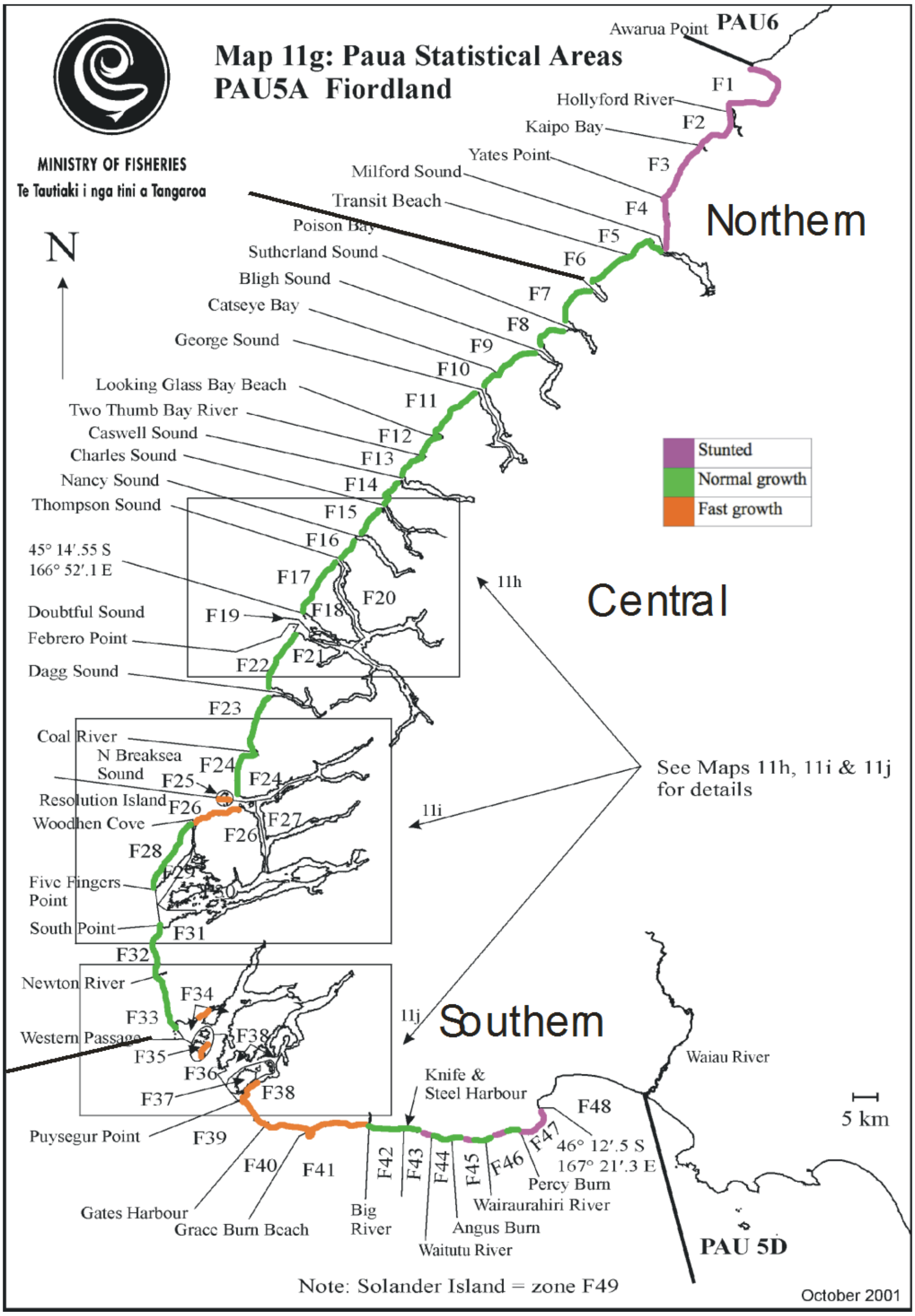

Figure 3: PAU 5A showing areas of areas of perceived stunted, normal, and fast growth, and Southern, Central, and Northern regions of potentially different growth.

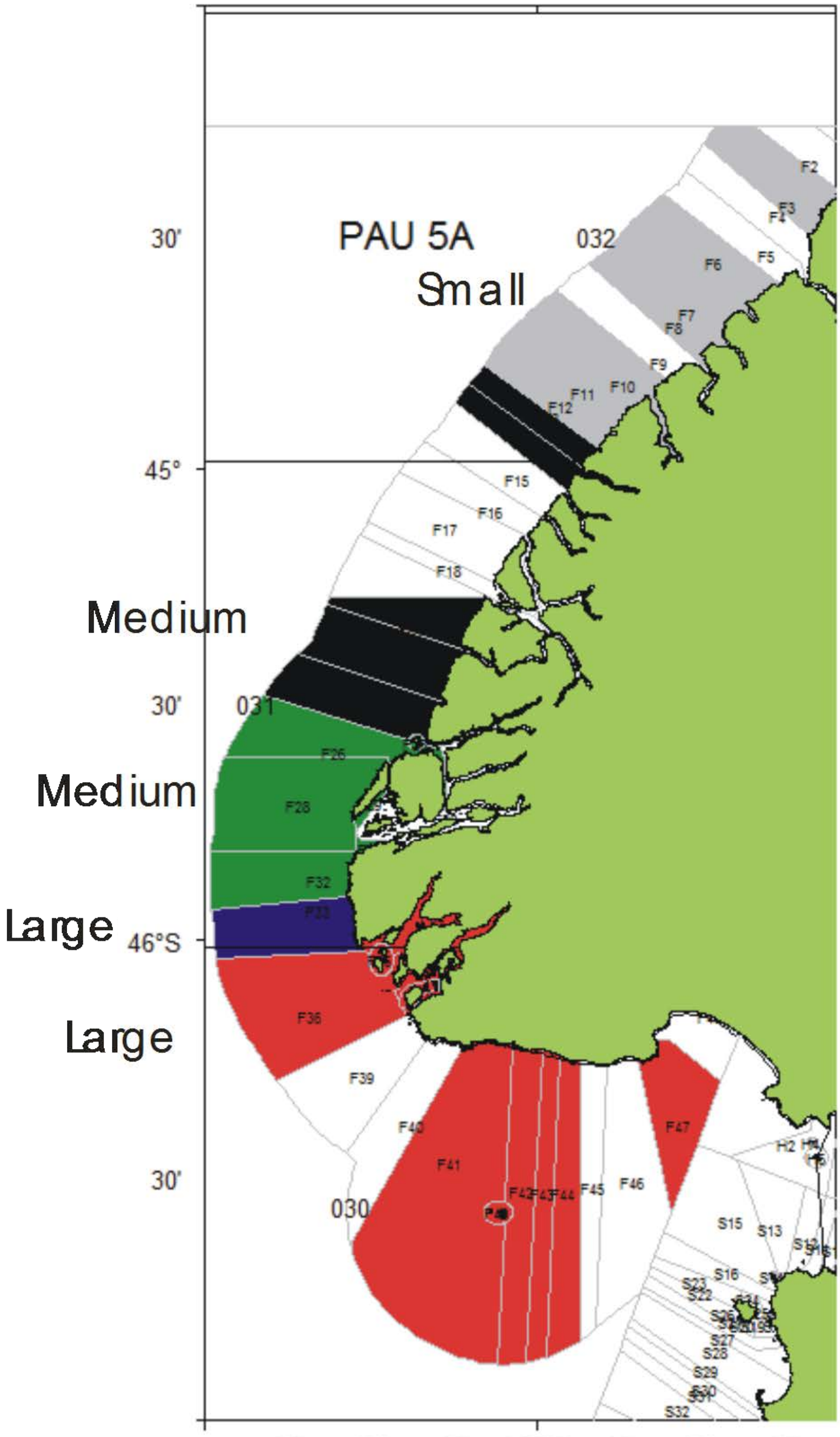

Figure 4: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 5A. Different colours represent stratification by the model, and small, medium and large refer to the size of paua in the group. No catch was recorded from white areas.

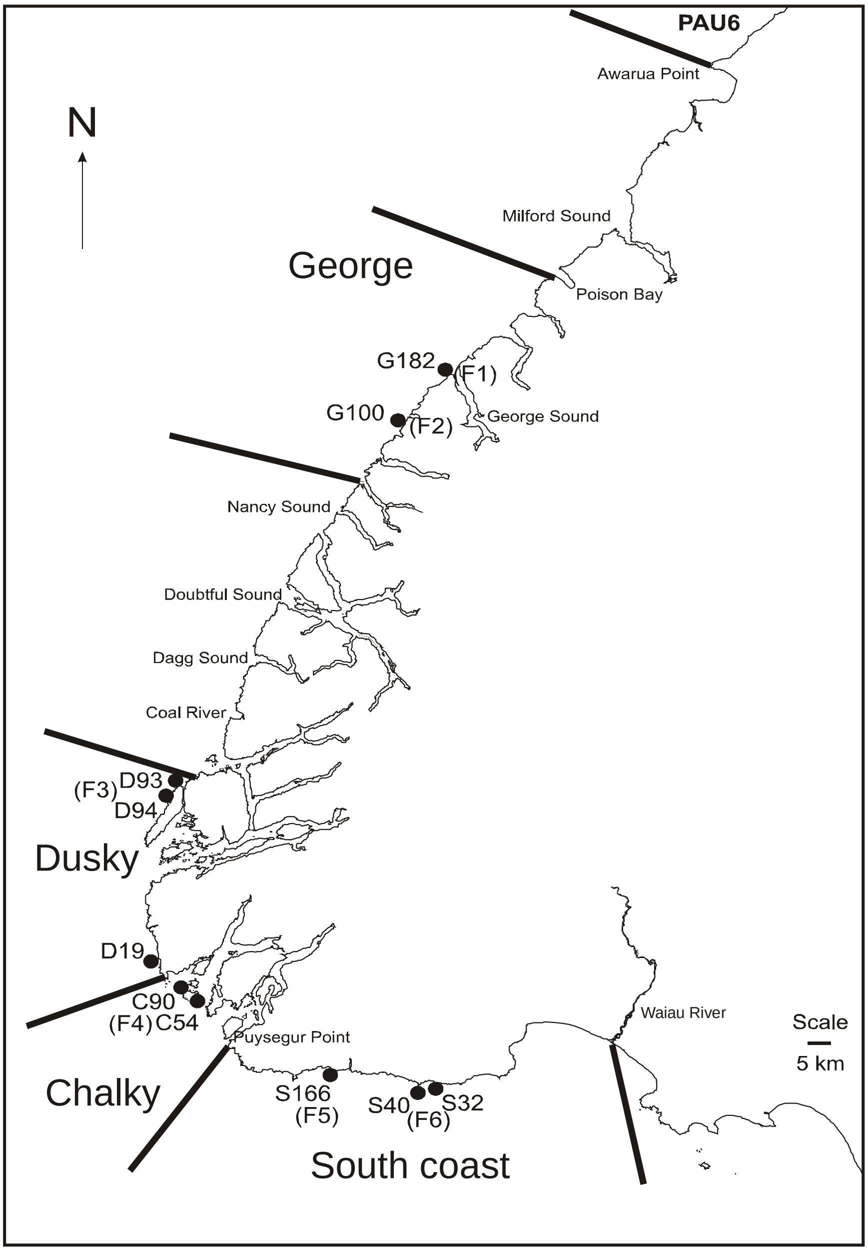

Figure 5: Location of sampling sites for oxygen isotopic growth estimation in PAU 5A.

4.2.3 PAU 5B

PAU 5B was divided into three areas, an Eastern area, a South-west area and a Western area (Figures 6 and 7).

The three zones reflect the aspect of the shoreline and their consequent accessibility to commercial divers. The Western area, from West Ruggedy Beach to just south of Doughboy Bay Beach is perceived by divers to be an area of fast growth, while the southwest and East areas are thought to be areas of largely normal growth, and occasionally fast growth (Figures 6 and 7). Growth information is available from four sites in PAU 5B (Figure 8) and annual incremental growth between sites appears to be similar (Figure 9).

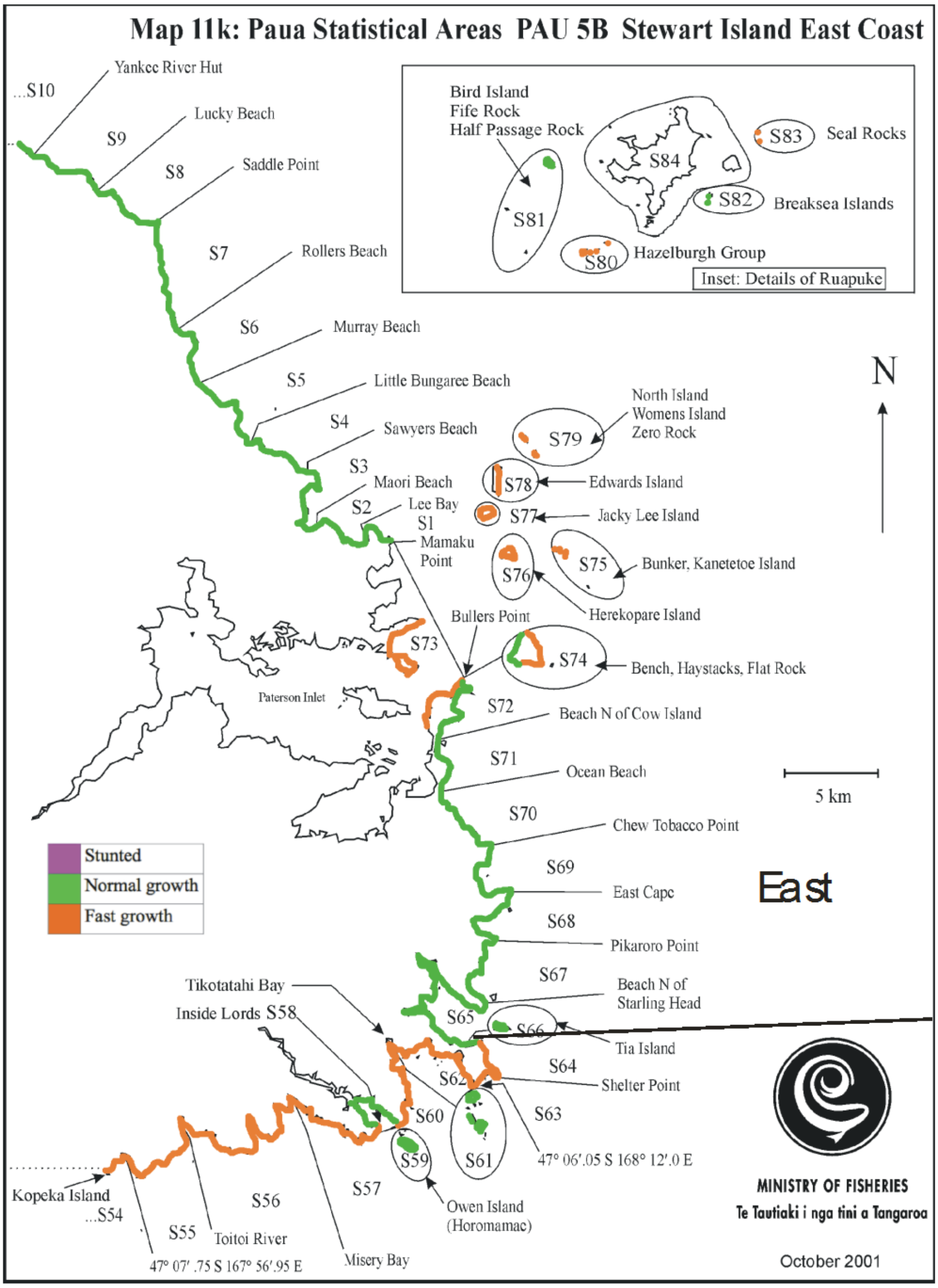

Figure 6: PAU 5B showing areas of areas of perceived stunted, normal, and fast growth, and the Eastern region of potentially different growth.

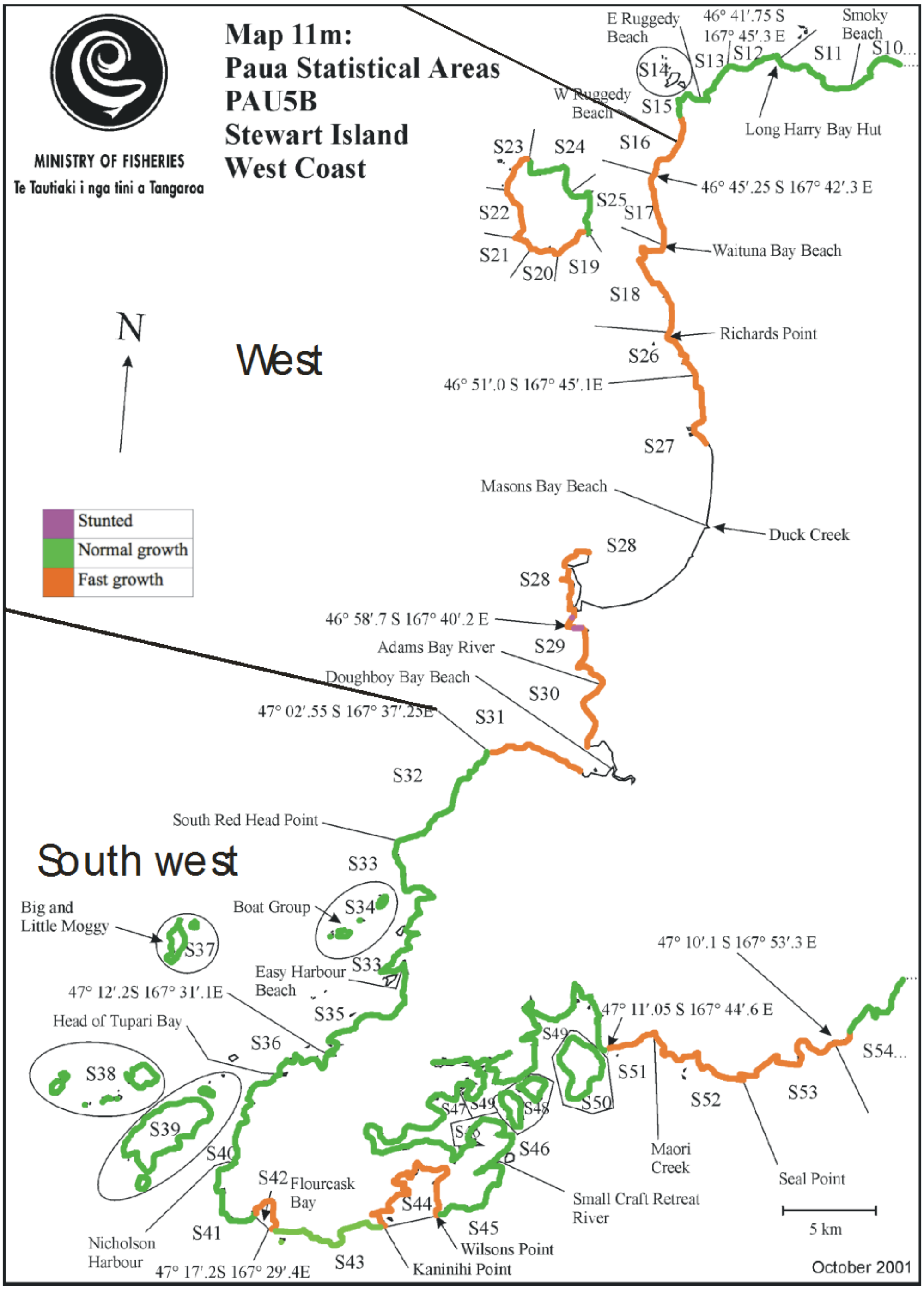

Figure 7: PAU 5B showing areas of areas of perceived stunted, normal, and fast growth, and Western and South-western regions of potentially different growth.

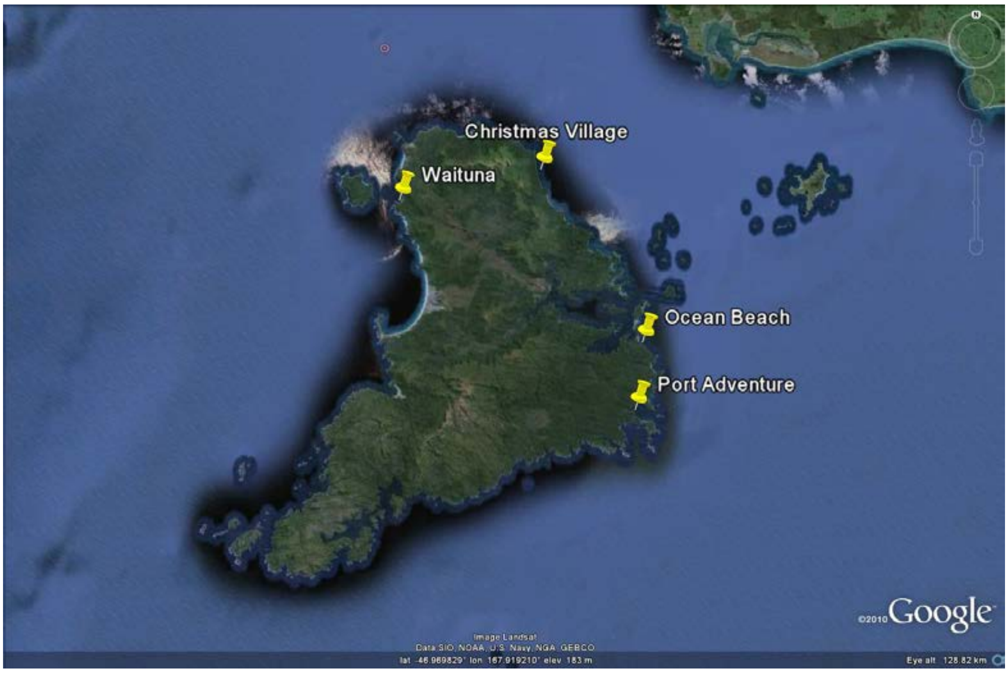

Figure 8: Location of tagging sites at Stewart Island (PAU 5B).

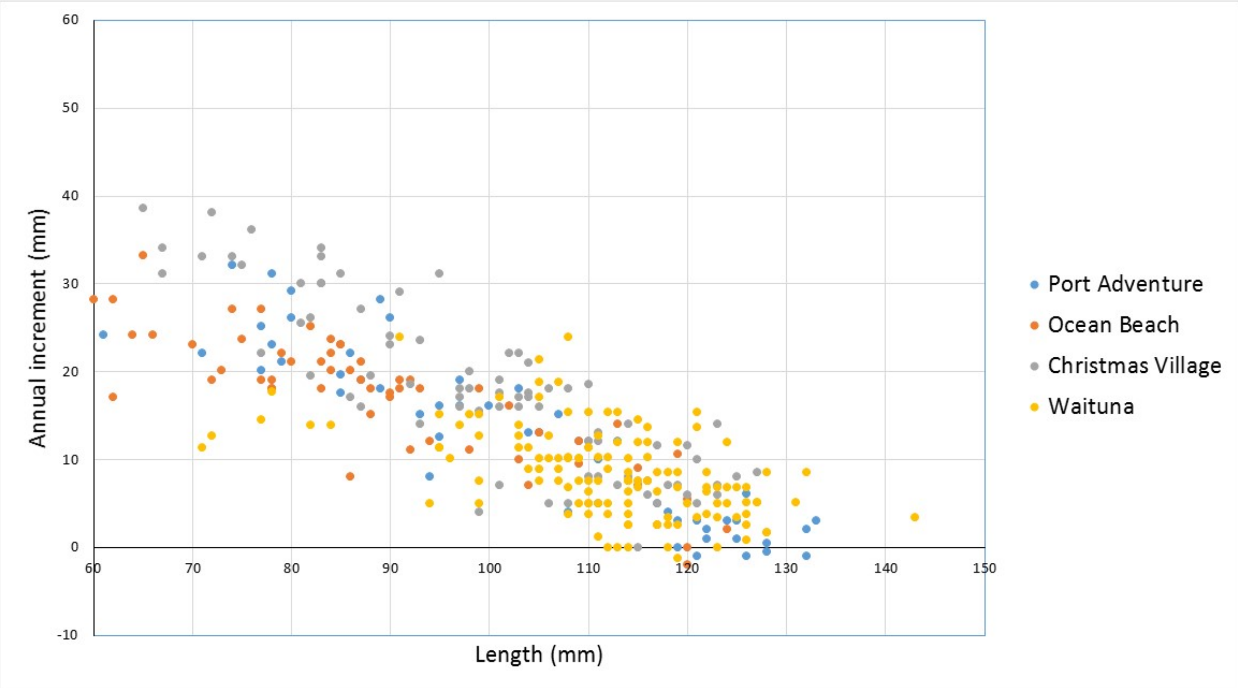

Figure 9: Annual incremental growth from four sites at Stewart Island (PAU 5B).

Tree regression analyses (Figure 10) suggest that paua on the north-eastern side of the island are smaller than in other areas of the island; however, this could be due to this area being more protected from the predominant southerly swells than other areas so that it is more heavily fished.

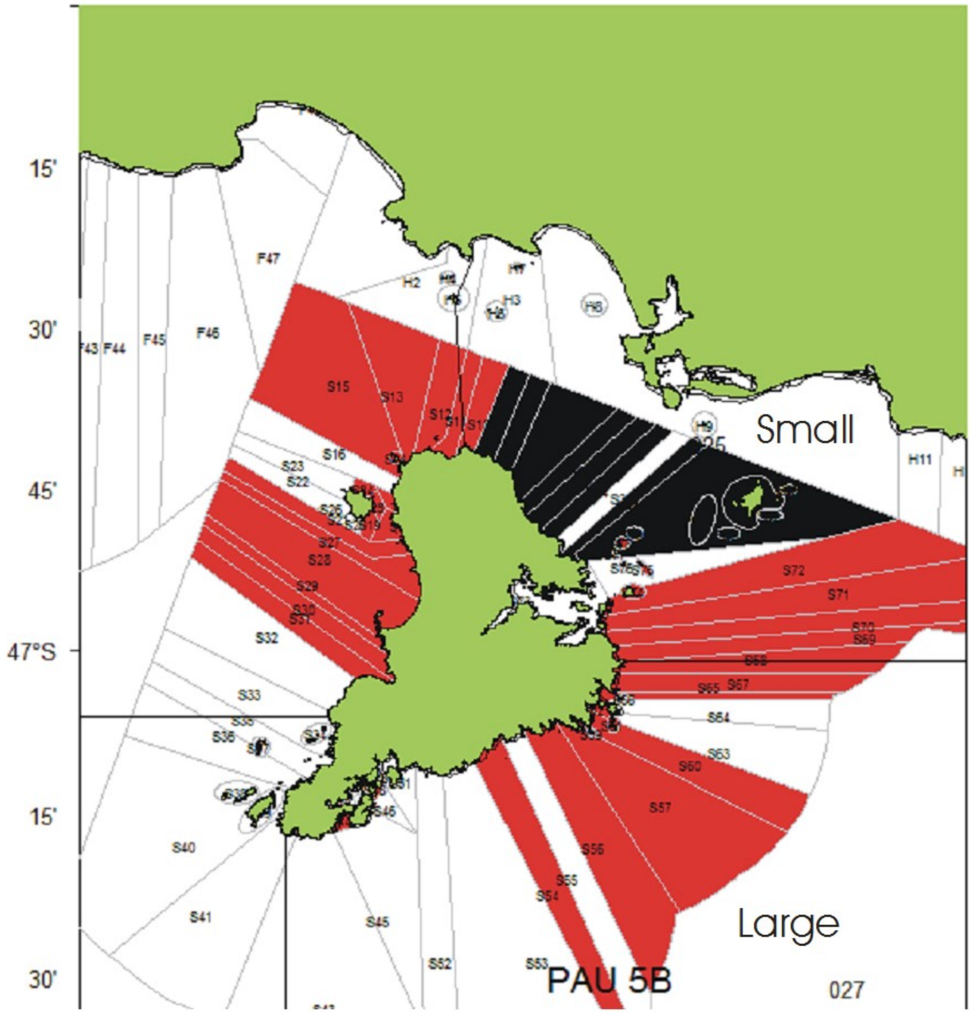

Figure 10: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 5B. Different colours represent stratification by the model, and small, and large refer to the size of paua in the group. No catch was recorded from white areas.

4.2.4 PAU 5D

Diver perceptions of paua growth in PAU 5D are shown for northern and southern parts of the QMA in Figures 11 and 12 respectively. To the north of Dunedin, with the exception of Moeraki, almost all of the coast is perceived by divers as supporting stunted paua (Figure 11). The northern part of the QMA has therefore been divided into three regions of potentially different growth, North Dunedin, Moeraki, and North. The southern part of the QMA has been divided into two geographically separate regions of potentially different growth, the Catlins and Colac Bay (Figure 12). Both areas are perceived by industry divers to support normal growth. The area to the west of Colac Bay contains only small paua and is only very lightly fished.

The tree regression analyses of the commercial catch length frequencies indicates that in the commercially fished part of the QMA most paua are large (Figure 13).

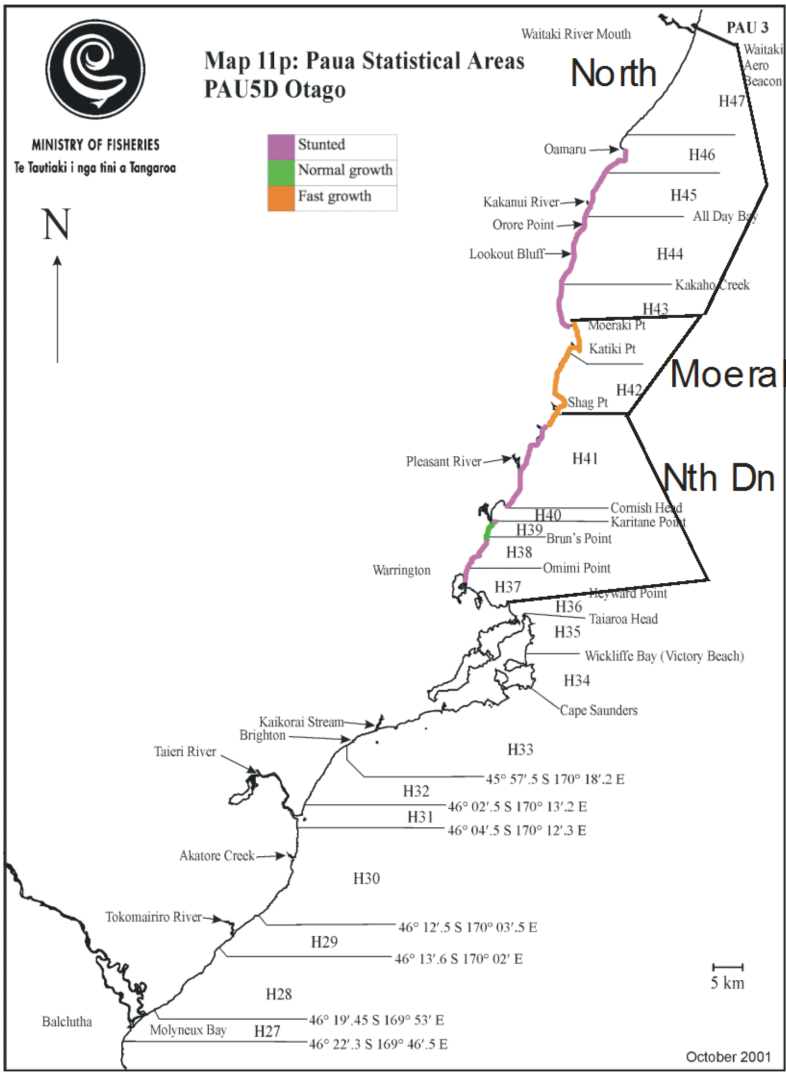

Figure 11: The northern part of PAU 5D showing areas of areas of perceived stunted, normal, and fast growth, and North Dunedin, Moeraki, and Northern regions of potentially different growth.

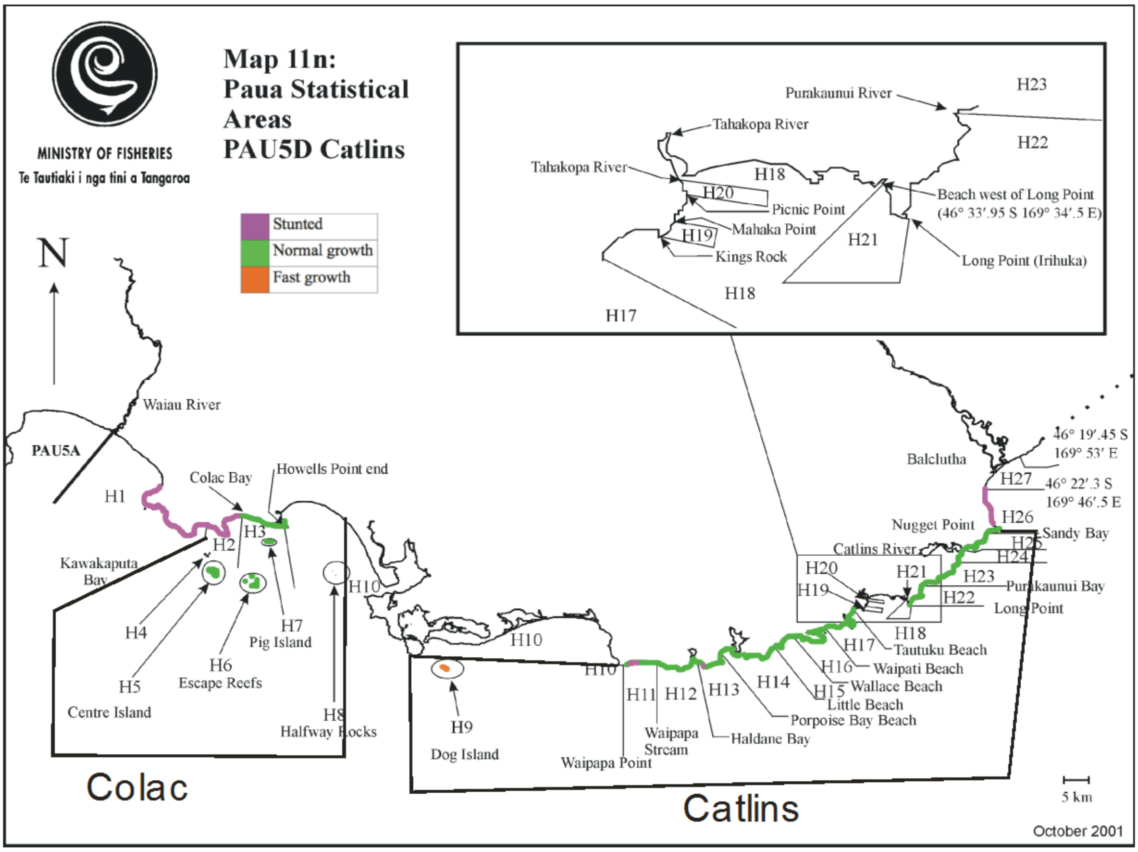

Figure 12: The southern part of PAU 5D showing areas of areas of perceived stunted, normal, and fast growth, and the Catlins and Colac Bay regions of potentially different growth.

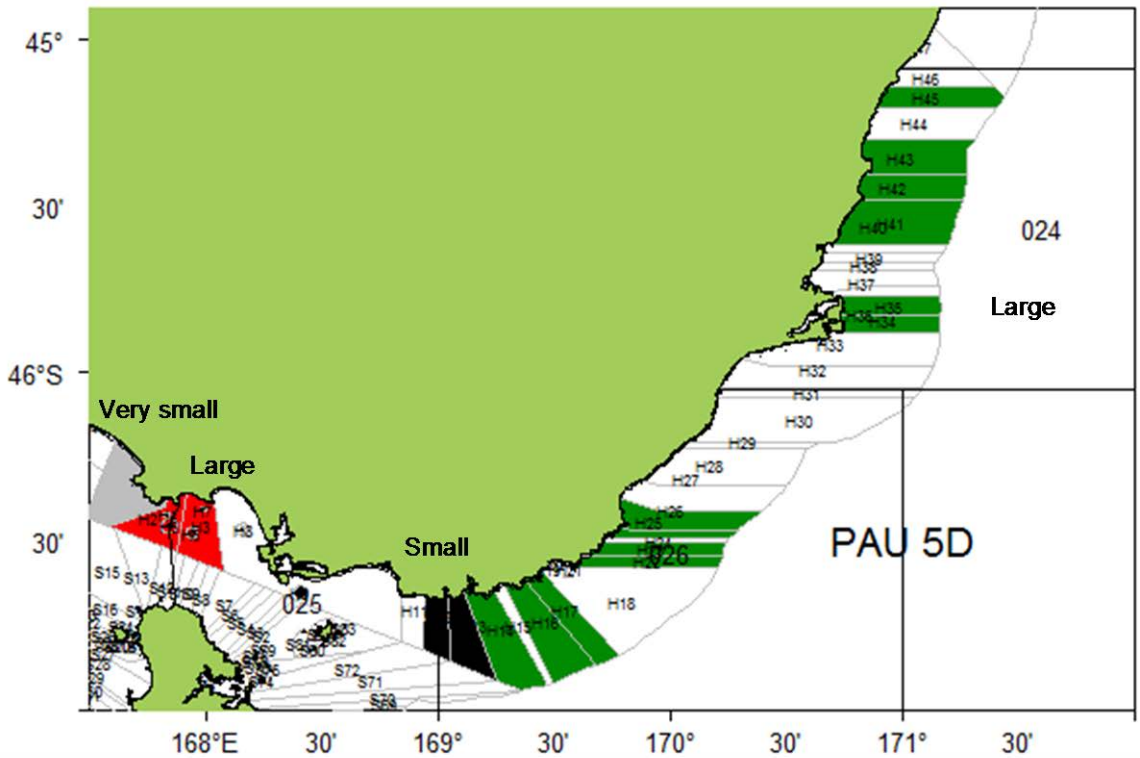

Figure 13: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 5D. Different colours represent stratification by the model, and very small, small, medium and large refer to the size of paua in the group. No catch was recorded from white areas.

4.2.5 PAU 2

PAU 2 is a large QMA extending from Cape Runaway in the east to Tirua Point on the eastern coast of the North Island. The commercial fishery; however is largely confined to the area between Turakirae Head and Castle Point. In the southern Wairarapa area as far north as Flat Point, divers identified a mixture of fast and normal growth with some localised stunted areas (Figure 14). The substrate also changes from rock to papa at about this point, and the algal composition is more dominated by Carpophyllum species (Keith Michael, NIWA, pers. comm.). The tree regression analyses of the commercial catch length frequencies also indicates that paua are generally smaller north of Flat Point (Figure 15), and this is supported by the comments of Petherick (1987). We therefore propose that the areas north and south of Flat Point be considered regions of potentially different growth (Figures 14 and 16). The area between Flat Point and the Mataikona River, which we propose be separated as the Castle Point region, supports a mixture of normal and stunted growth, but north of the Mataikona River large paua are rare. There are exceptions; however, one of which is Blackhead Point. We propose that the area to the north of the Mataikona River (the North eastern region, Figure 16) be considered an area of potentially different growth to other regions on the east coast of the QMA.

On the west coast of PAU 2, which is effectively closed to the commercial fishery, we propose that there be two zones of potentially different growth, one from Wellington to Pukerua Bay, where large paua are relatively common, and one extending north from Pukerua Bay to the north eastern extent of the QMA, where large paua are relatively rare.

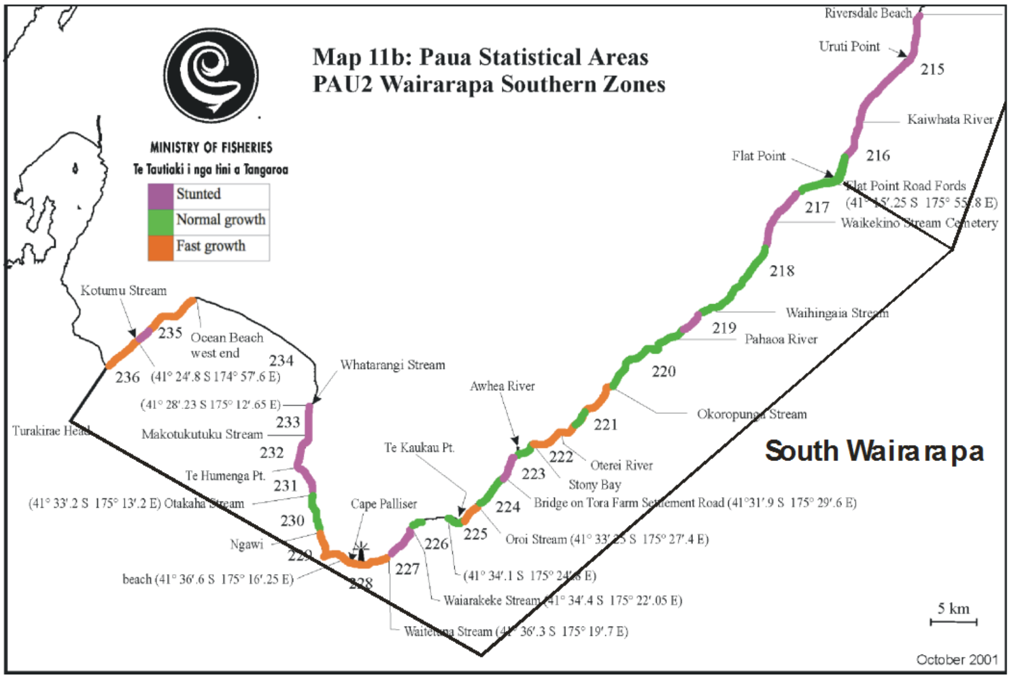

Figure 14: The southern part of PAU 2 showing areas of areas of perceived stunted, normal, and fast growth, and the South Wairarapa region of potentially different growth.

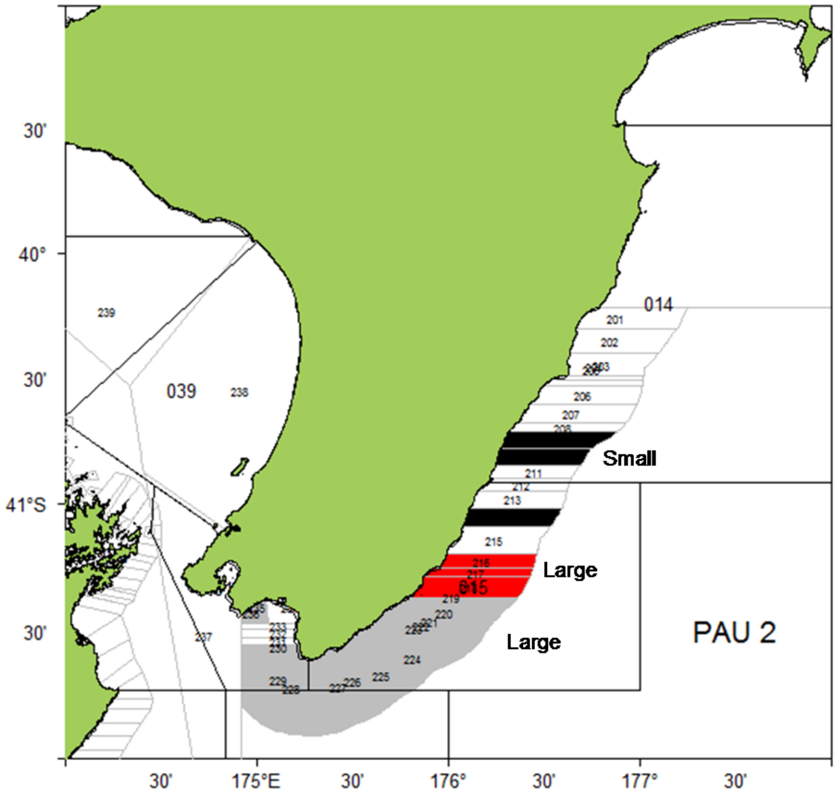

Figure 15: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 2. Different colours represent stratification by the model, and small, and large refer to the size of paua in the group. No catch was recorded from white areas.

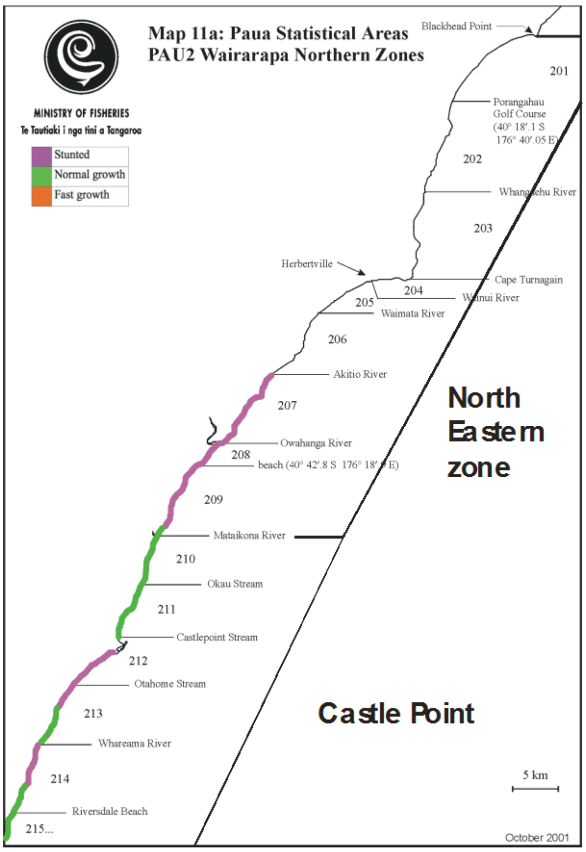

Figure 16: The northern part of PAU 2 showing areas of areas of perceived stunted, normal, and fast growth, and the Castle Point and North-eastern regions of potentially different growth.

4.2.6 PAU 3

PAU 3 is already divided into four regions of perceived biological differences (Figures 17 and 18) and it appears sensible to retain these. Diver perceptions indicate that the northern area (A) has more areas of faster growth than area B, which is a mixture of fast and normal growth, and that area D has a mixture of fast growth and stunted paua (Figure 17). Area E (Banks Peninsula) has three areas of potentially different growth, E1, E2, and E3, which are perceived to have stunted, normal, and fast growth respectively (Figure 18).

The tree regression analyses of the commercial catch length frequencies indicate that the largest paua come from the northern part of the QMA and the smallest paua are harvested in the southern part (Figure 19).

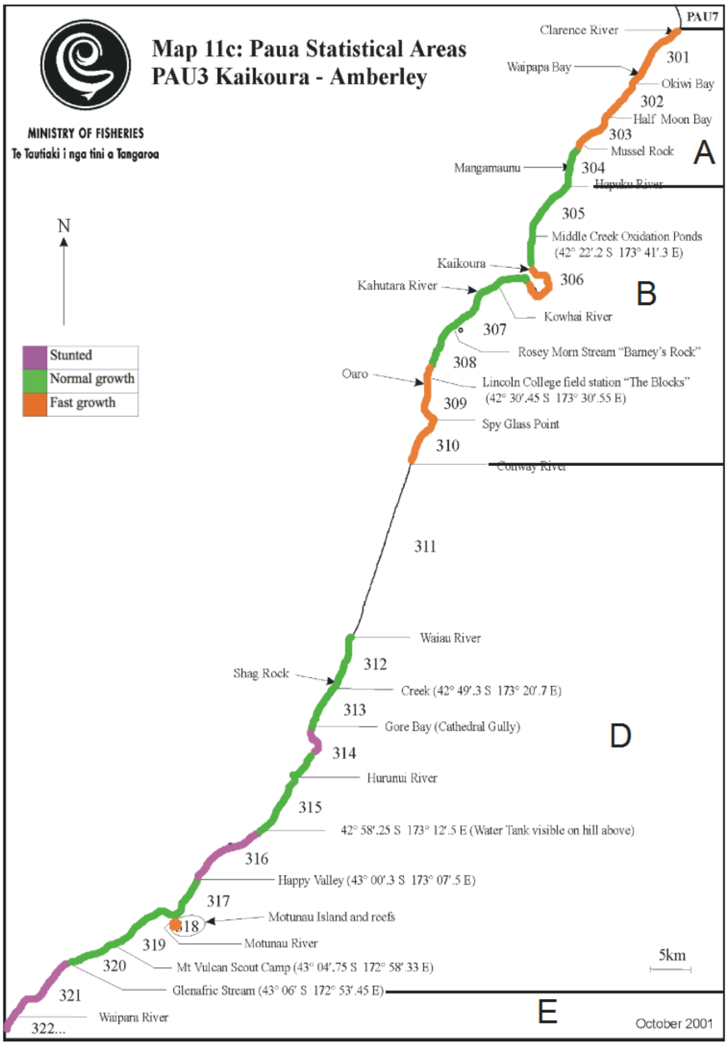

Figure 17: The northern part of PAU 3 showing areas of areas of perceived stunted, normal, and fast growth, and regions A, B, and D of potentially different growth.

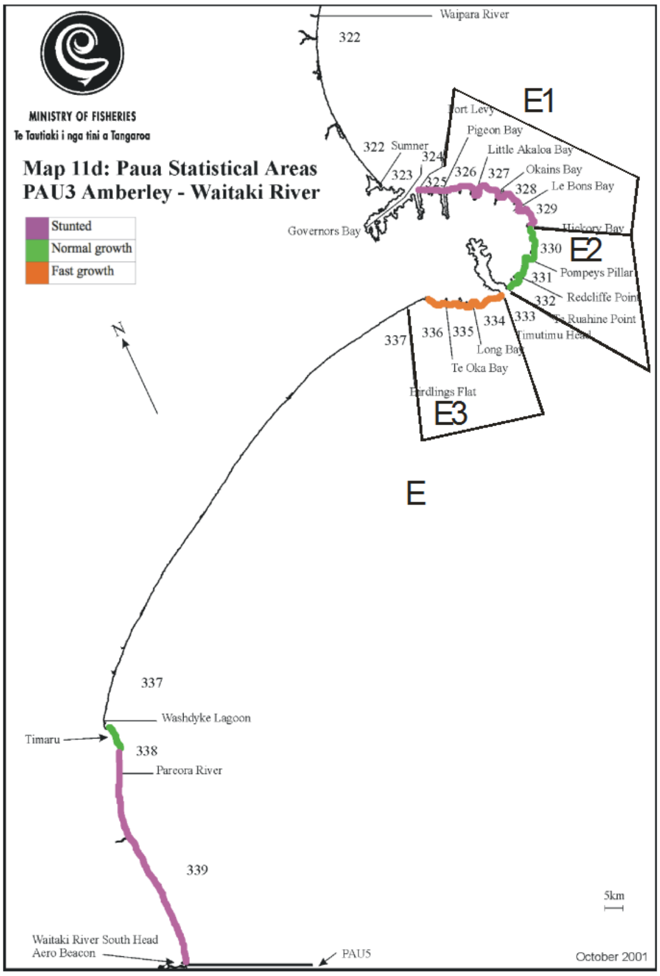

Figure 18: The southern part of PAU 3 showing areas of areas of perceived stunted, normal, and fast growth, and regions E, E1, E2, and E3 of potentially different growth.

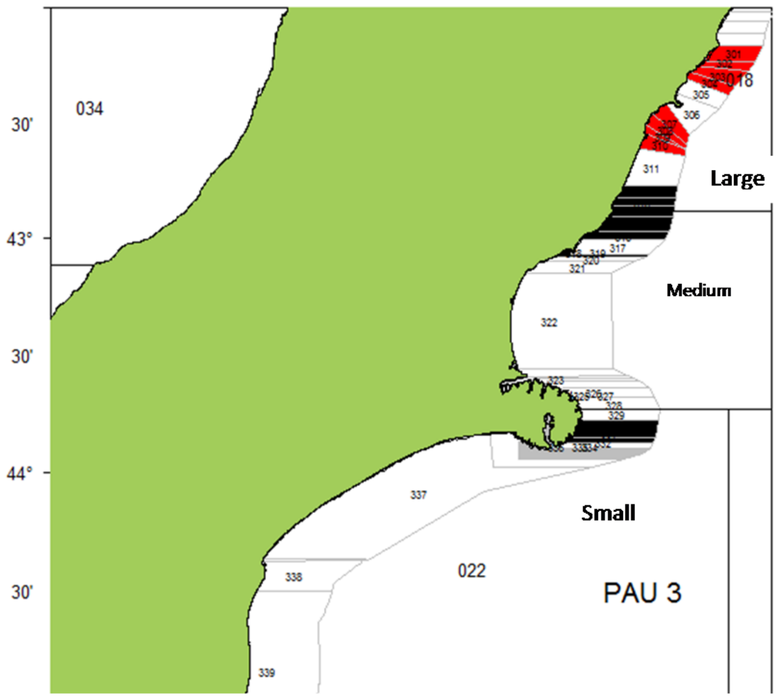

Figure 19: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 3. Different colours represent stratification by the model, and small, medium and large refer to the size of paua in the group. No catch was recorded from white areas.

4.2.7 PAU 4

We propose that PAU 4 be divided into five regions of potentially different growth (Figure 20). Growth information is available from six sites in PAU 4 (Figure 21). Growth appears to be similar for all sites except Sandy Point on the north eastern end of Pitt Island (Figure 21). Because this area is also geographically isolated from the main island we propose that it be considered an area of potentially different growth. The other proposed regions are Southern, Central western, Western, North eastern and South eastern (Figure 20). Both the South eastern and North eastern regions are areas containing stunted or low recovery paua, but are considered to be potentially different because they are at opposite ends of the eastern coast of the island (Figure 20). The southern area contains predominantly fast recovery stocks so should be treated as a separate region. The Central western area is predominantly low recovery or is not fished and the Western region supports predominantly fast recovery stock (Figure 20). The tree regression analyses of the commercial catch length frequencies generally support the diver perceptions of growth regimes between regions (Figure 22).

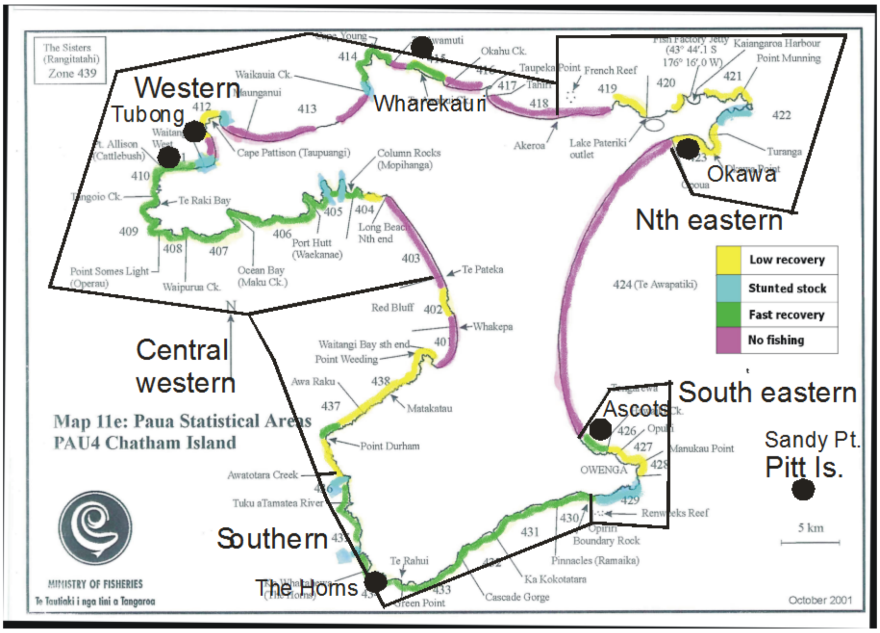

Figure 20: PAU 4 showing areas of perceived stunted, normal, and fast growth, and Western, Central western, North eastern, and South eastern regions of potentially different growth.

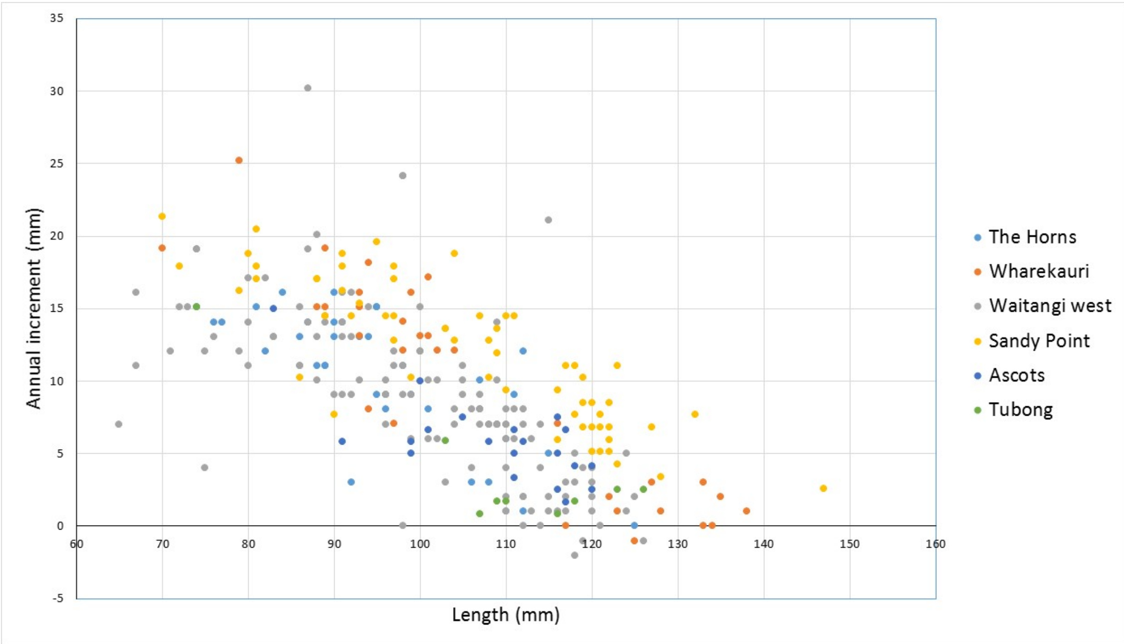

Figure 21: Annual incremental growth of paua at six sites in PAU 4.

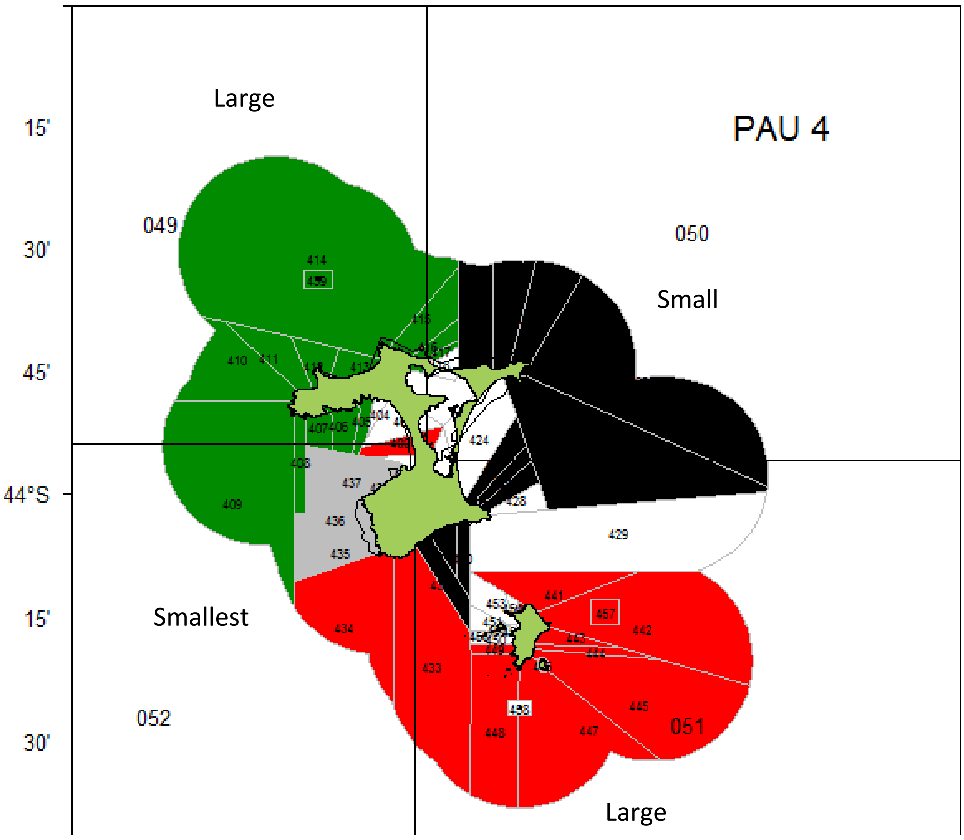

Figure 22: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 4. Different colours represent stratification by the model, and small, medium and large refer to the size of paua in the group. No catch was recorded from white areas.

4.2.8 PAU 7

Both the West coast region of PAU 7 and the Cape Campbell area are perceived as having large and fast growing paua (Figure 23) and the tree regression analyses of the commercial catch length frequency distributions indicate that both areas support large paua (Figure 24). Both regions are geographically isolated from the rest of PAU 7 and are only lightly fished because sea conditions are seldom suitable for diving. These two areas should be treated as separate regions of potentially different growth.

The area between the Staircase and Cape Koamaru (Figure 25) is generally considered to be an area of fast growth and apart from the area inside Tory Channel, has a similar aspect. The tree regression analyses of the commercial catch length frequencies indicates that this area supports large paua (Figure 24), and we suggest that this area be considered an area of potentially different growth.

The Northern Faces area is perceived to support a mixture of growth regimes, contains many stunted populations and is a different aspect to the Straits region (Figure 26). The tree regression analyses of the commercial catch length frequencies indicates that this area supports medium sized paua (Figure 24), and we suggest that this area be considered an area of potentially different growth.

D'Urville Island (Figure 27), is geographically isolated, and supports some areas of normal growth, but most of the island contains stunted paua. The tree regression analyses of the commercial catch length frequency distributions indicate that this area supports medium sized paua (Figure 24) in those areas where paua are harvested, and we suggest that this area be considered an area of potentially different growth.

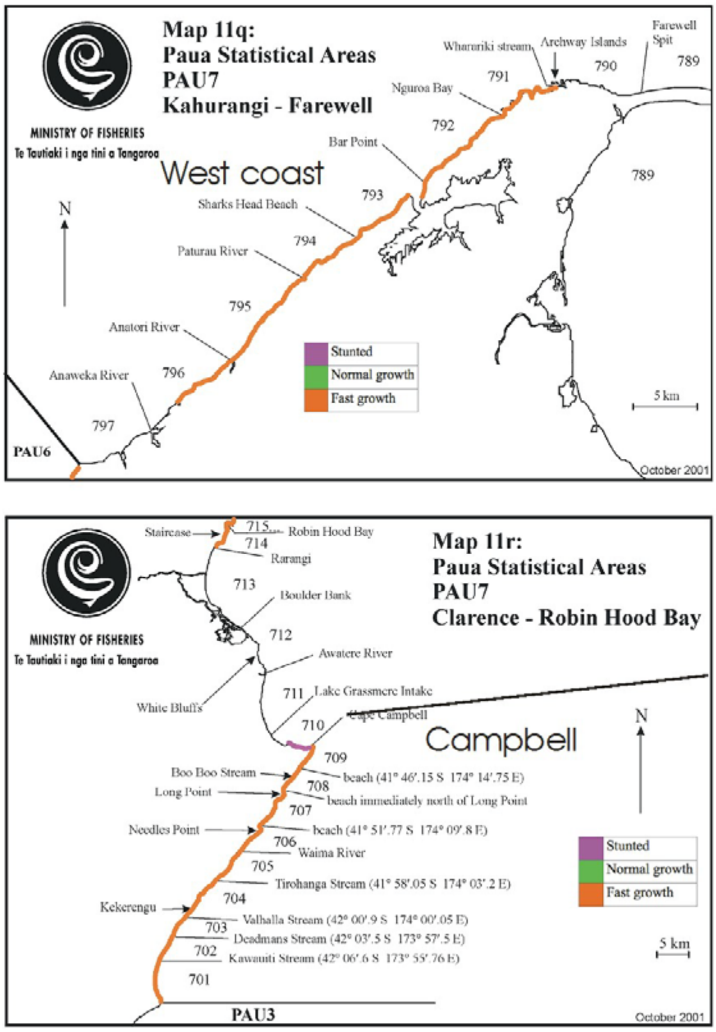

Figure 23: PAU 7 showing areas of perceived stunted, normal, and fast growth, and West Coast (upper) and Campbell (lower) regions of potentially different growth.

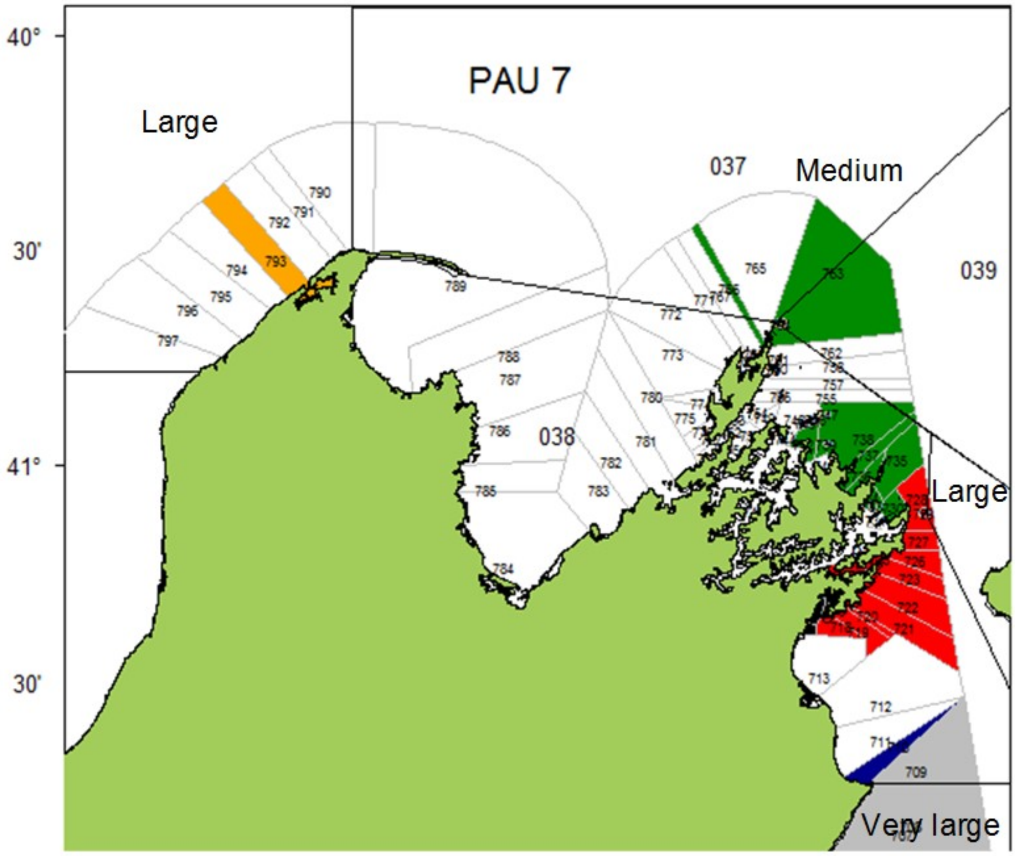

Figure 24: Stratification of commercial catch length samples from model 4 of the tree regression for PAU 7. Different colours represent stratification by the model, and medium, large, and very large refer to the size of paua in the group. No catch was recorded from white areas.

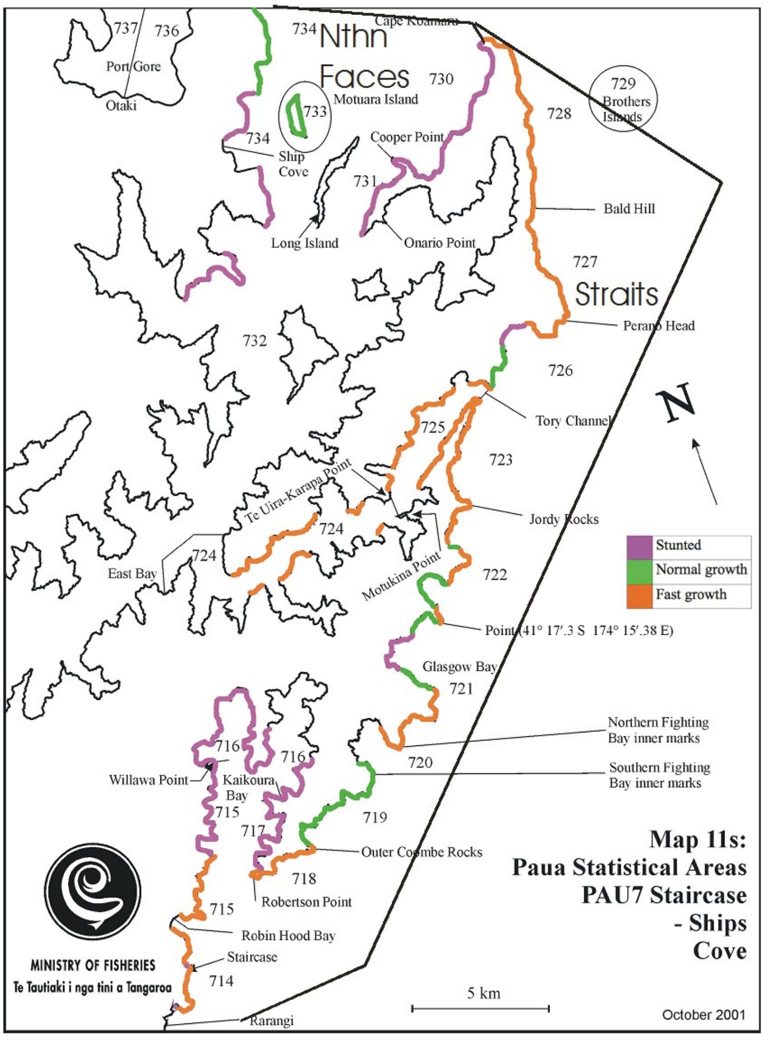

Figure 25: PAU 7 showing areas of perceived stunted, normal, and fast growth, and the Straits and beginning of Northern faces regions of potentially different growth.

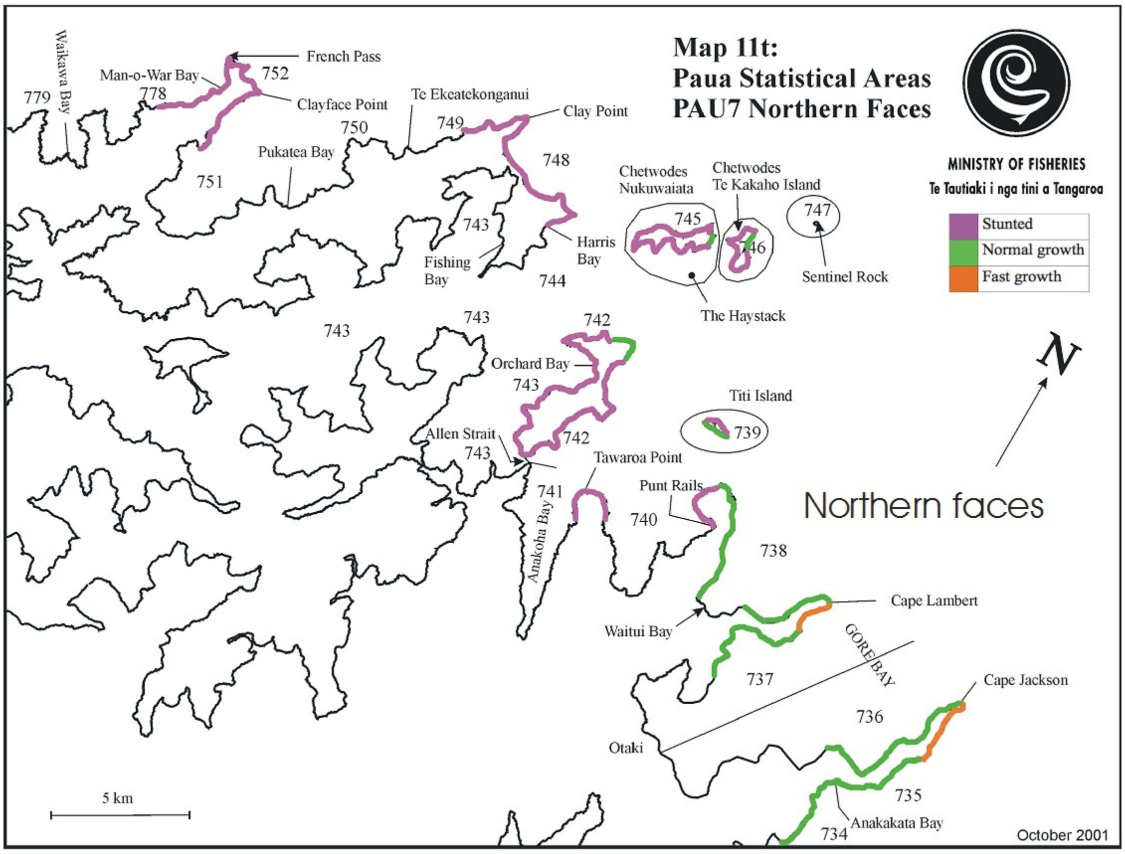

Figure 26: PAU 7 showing areas of perceived stunted, normal, and fast growth, and West Coast (upper) and Campbell (lower) regions of potentially different growth.

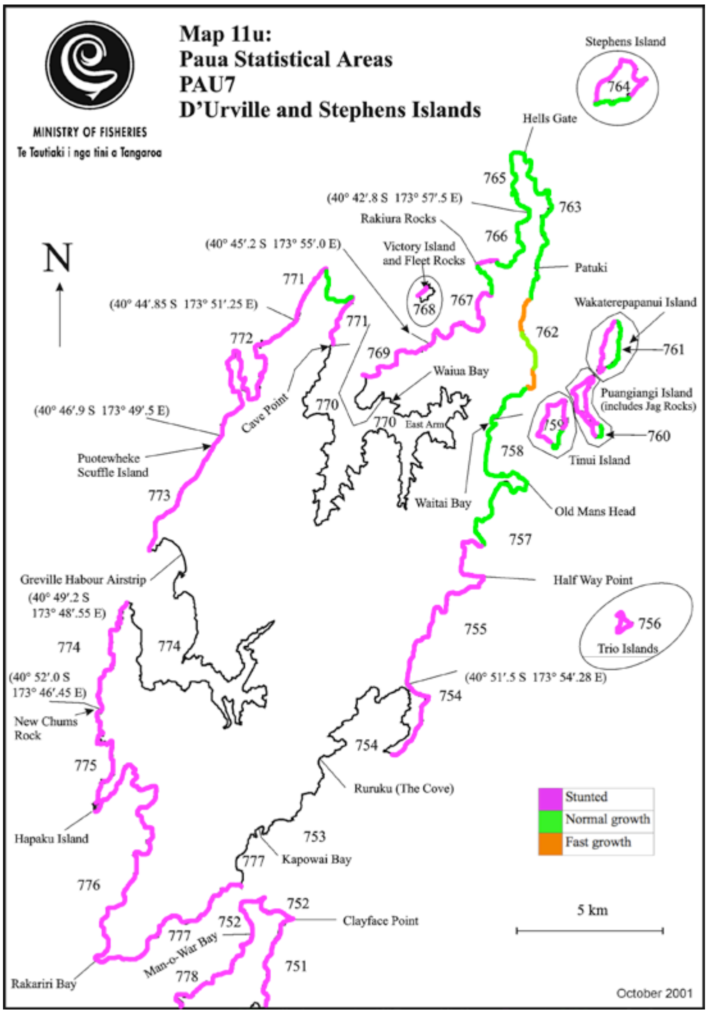

Figure 27: PAU 7 showing areas of perceived stunted, normal, and fast growth, and West Coast (upper) and Campbell (lower) regions of potentially different growth.

4.2.9 PAU 1

Commercial fishing in PAU 1 occurs only in the Far North region (Figure 28) and occasionally at the Three Kings Islands (about 56 km North-east of Cape Reinga, Keith Michael, NIWA, pers. comm.). Paua to the south of the Far North region of PAU 1 are generally believed to be smaller with only isolated pockets of legal sized paua. More work is required in PAU 1 before any determination on variation in growth by area can be made.

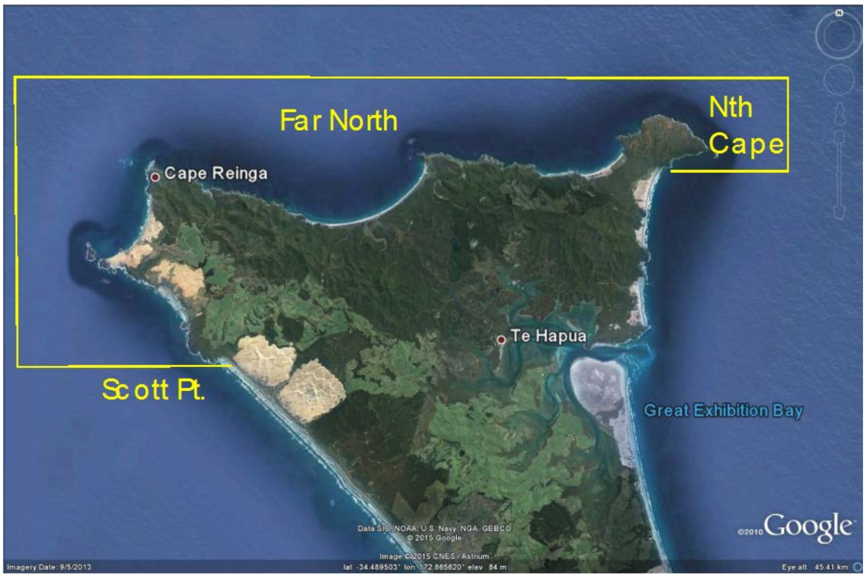

Figure 28: PAU 1 showing the area where commercial fishing for the 1 t TACC takes place.

4.2.10 PAU 6

PAU 6 has a nominal TACC of only 1 t. It is on the North-west coast of the South Island and extends from Awarua Point in the south to Kahurangi Point in the north. We suggest that the whole of PAU 6 be treated as one region with respect to potentially different growth.

4.3 Tree regression

The main results from linear models and tree regressions are presented in Figures 29–49. For each QMA, three figures are presented: (1) the estimated effects for statistical area, FIN, month, and fishing year from the linear model; (2) mean length of length samples by stratified group from each of the tree regression models; (3) a map showing stratified statistical areas from models 3 and 4. Plots of the cross-validated relative error against tree size from the fitting process, and dendrograms of the resultant trees from selected models for each QMA are given in Appendix B. Detailed descriptions of the stratifications for model 1 and model 2 for each QMA are given in Tables 4–10.

In general, the estimated effects of statistical area from the linear models exhibited most variations in mean length among samples. Statistical area was the most important explanatory variable in all QMAs. It was selected as the splitting variable at the first level of the regression tree (where the greatest reduction in relative error occurred) in almost all the models (except for PAU 5D–2). For PAU 5B and PAU 3, it was the only splitting variable used in all models (noting that it was the only candidate explanatory variable offered in model 3 and 4). FIN appeared to be the second most important variable in explaining the variations in mean length, and was selected in models for most QMAs. Month was only used in model PAU 5A–1.

Because statistical area was usually included in most models and month was seldom selected, models with three candidate variables generally resulted in similar subdivision of regions to models with statistical area being the only splitting variable (e.g. PAU 5A–1 and PAU 5A–3 in 30, and PAU 4–1 and PAU 4–3 in45). Treating variables as categorical allowed the model to combine areas with similar mean lengths into the same group, in spite of them being geographically isolated (e.g. PAU 5B–1 and PAU 5B–3 in
Figure 33, and PAU 4–1 and PAU 4–3 in Figure 45). In some instances, similar sub-divisions were obtained regardless of whether statistical area was treated as categorical or continuous (e.g. PAU 7–2 and PAU 7–4 in Figure 48).

4.3.1 PAU 5A

Table 4: Description of the stratifications of the PAU 5A catch length samples 2008–2013 for models 5A–1 and 5A–2

Model	stratum	Description
(5A–1) area + month + fin	1	area: 03 06 07 08 10 11 12 14 22 38 64
(categorical variables)	2	area: 13 23 24 25 26 28 31 32 34 35 43 44 47
	3	area: 29 33 36 41 42 49 31; month 12 1 5 7 8
	4	area: 29 33 36 41 42 49 31; month 11 6
(5A–2) area + month + fin	1	area: 03 06 07 08 10 11 12 13 14 22 23 24
(ordered categorical variables)	2	area:25 26 28 29 31 32 33 34 35 36 38 41 42 43 44 47 49; fin: 1–13
	3	area: 25 26 28 29 31; fin: 14 15 19
	4	area: 32 33 34 35 36 38 41 42 43 44 47 49; fin: 14 15 19

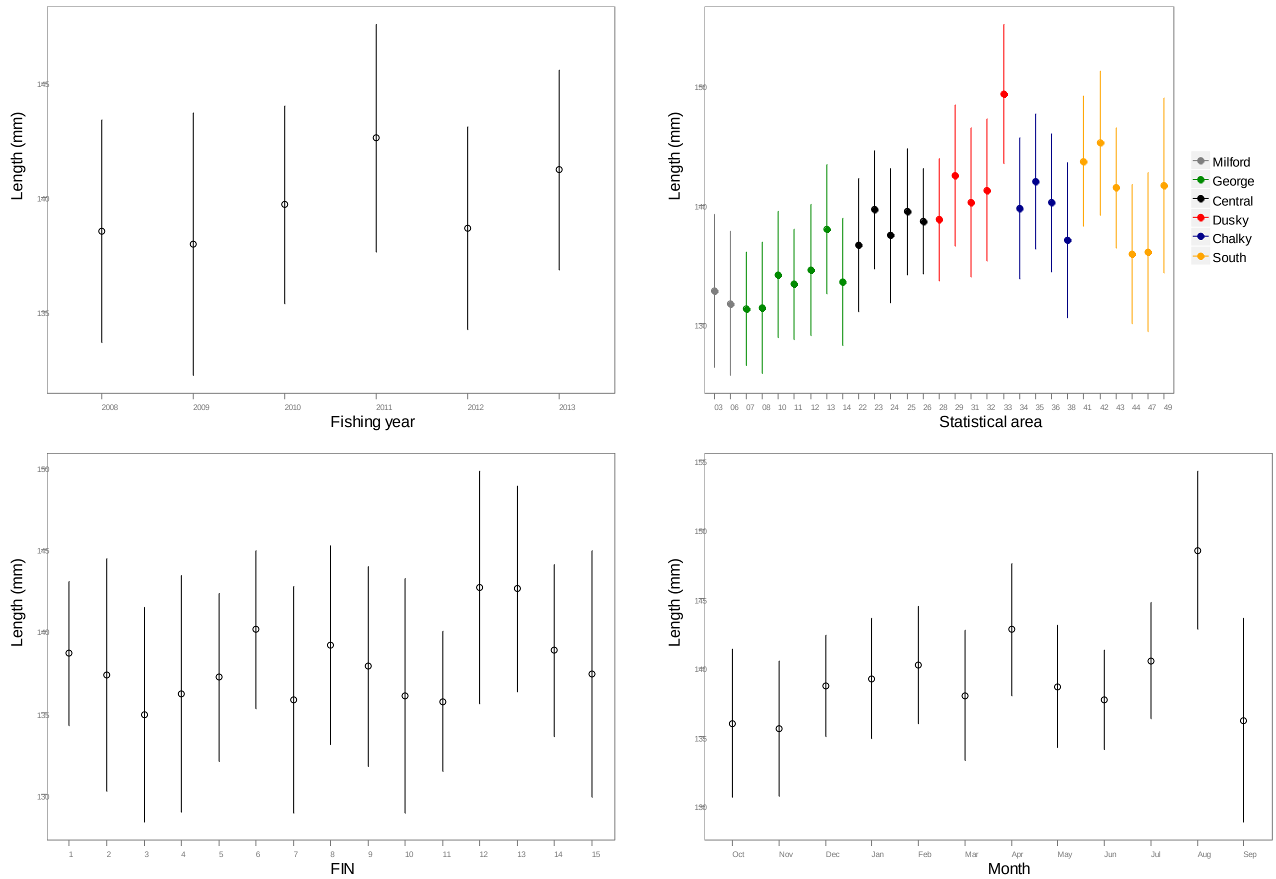

Figure 29: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 5A catch sampling length data 2008–2013.

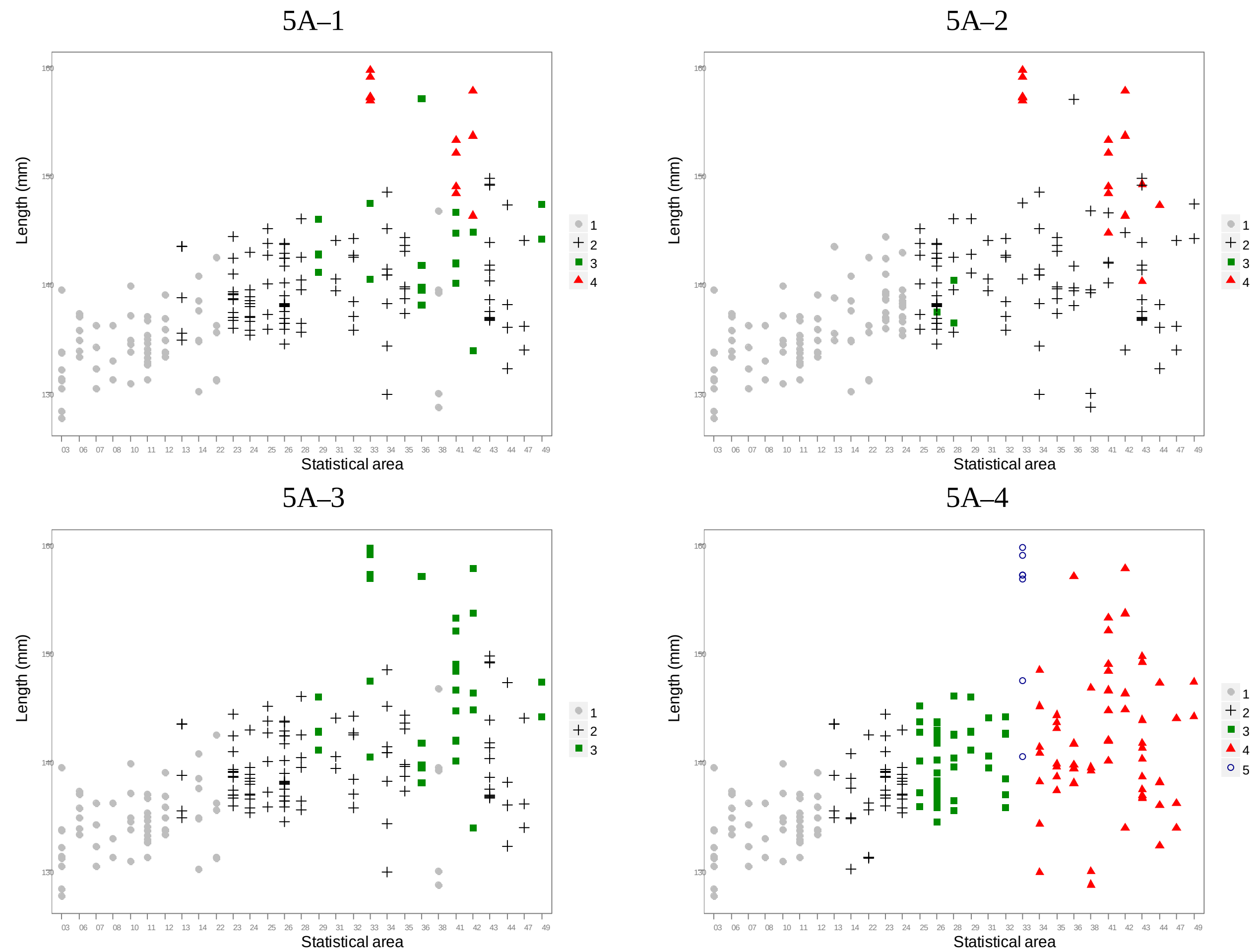

Figure 30: Stratifying the PAU 5A catch length samples from fishing years 2008–2013 from models 5A–1, 2, 3, and 4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 5A–1 and 5A–2 are summarised in Table 4.

5A–3 5A–4

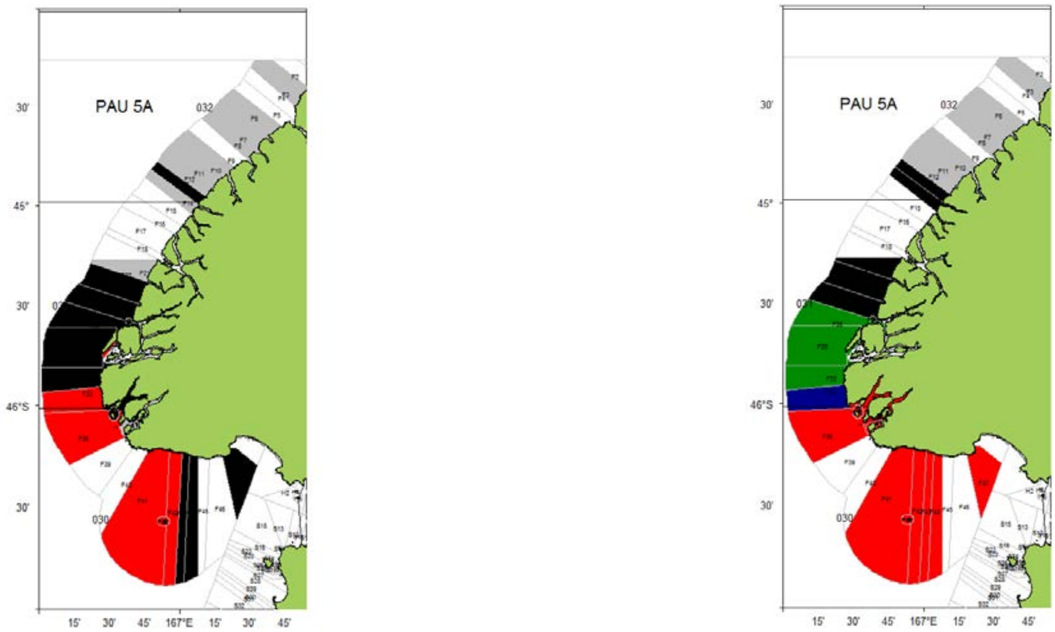

Figure 31: A map showing the stratification of the PAU 5A catch length samples (2008–2013) from models 5A–3 and 4.

4.3.2 PAU 5B

Table 5: Description of the stratifications of the PAU 5B catch length samples 2008–2013 for models 5B–1 and 5B–2. For model 5B–1, data from Statistical Areas 01–11 were not included in the model, but were simply treated as a separate group.

Model	Stratum	Description
(5B–1) area + month + fin	0	area: 01–11
(categorical variables)	1	area: 19 24 25 26 29 56 57 58 61 65 68 69 70 71 72 78
	2	area: 12 13 15 17 18 27 28 30 31 44 48 54 60 62 67 74 75 80
(5B–2) area + month + fin	1	area: 01–09
(ordered categorical variables)	2	area:10–80

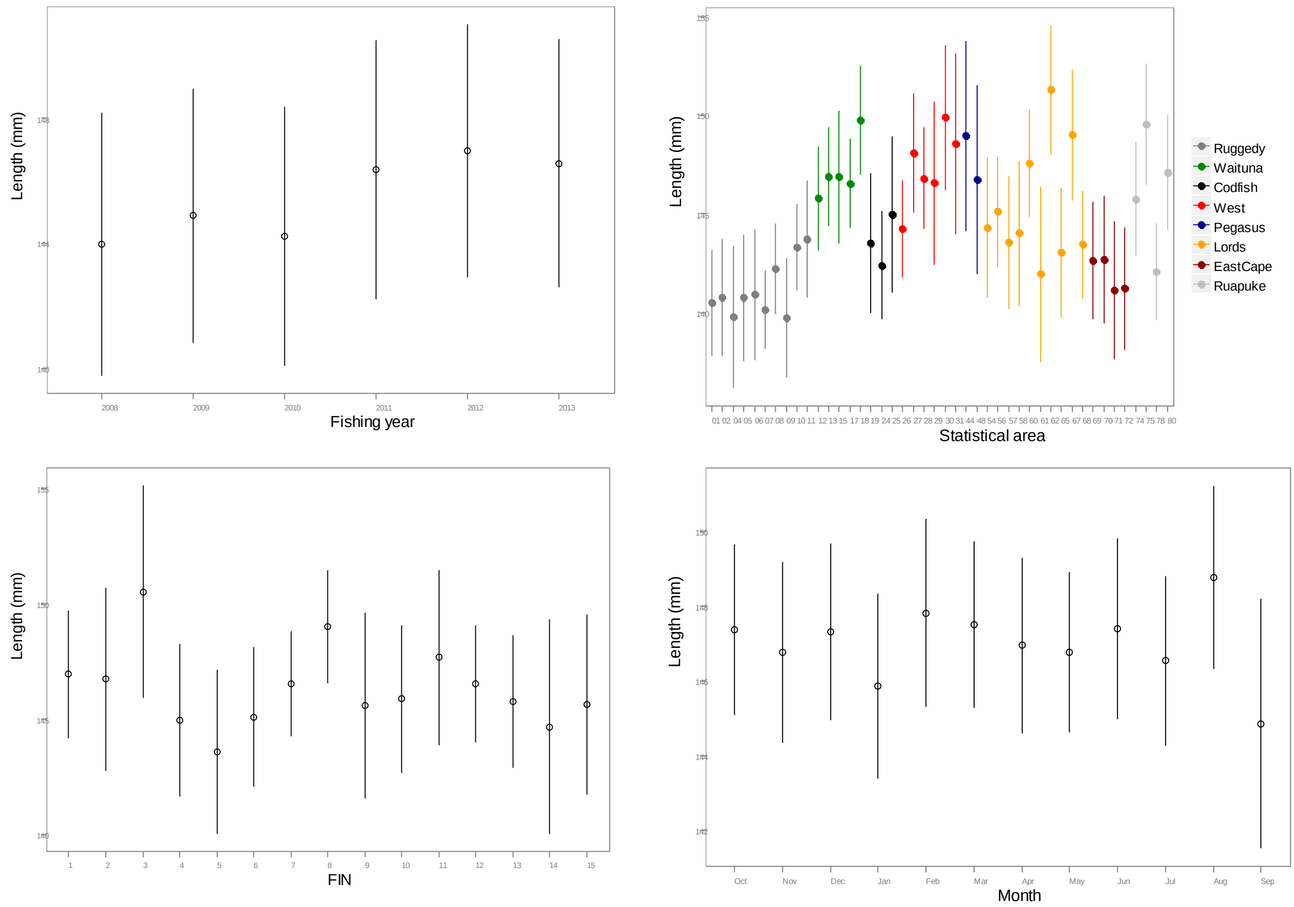

Figure 32: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 5B catch sampling length data 2008–2013.

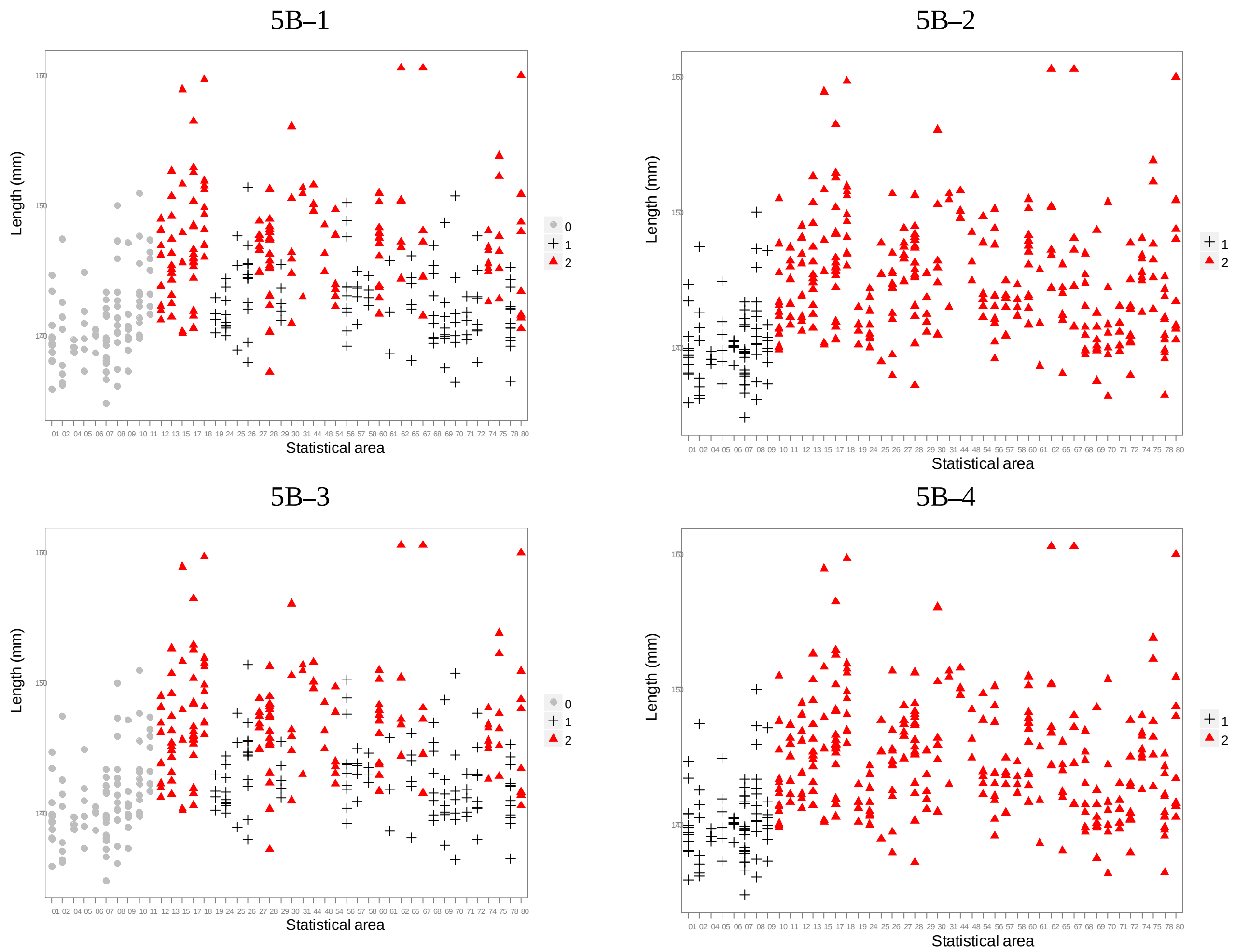

Figure 33: Stratifying the PAU 5B catch length samples from fishing years 2008–2013 from models 5B–1, 2, 3, and 4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 5B–1 and 5B–2 are summarised in Table 5.

5B–3 5B–4

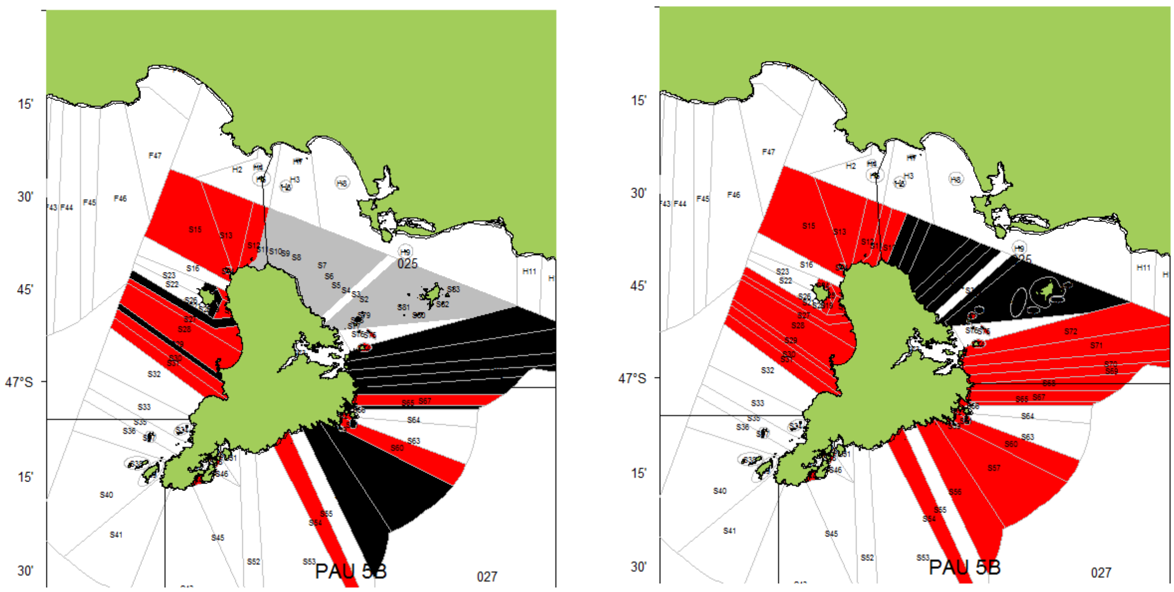

Figure 34: A map showing the stratification of the PAU 5B catch length samples (2008–2013) from models 5B–3 and 4.

4.3.3 PAU 5D

Table 6: Description of the stratifications of the PAU 5D catch length samples 2008–2013 for models 5D–1 and 5D–2.

Model	Stratum	Description
(5D–1) area + month + fin	1	area: 01 09 12 13 26 42 45
(categorical variables)	2	area: 02 03 05 07 14 16 17 22 23 25 34 35 41 43
(5D–2) area + month + fin	1	fin: 1–5
(ordered categorical variables)	2	fin: 6–15

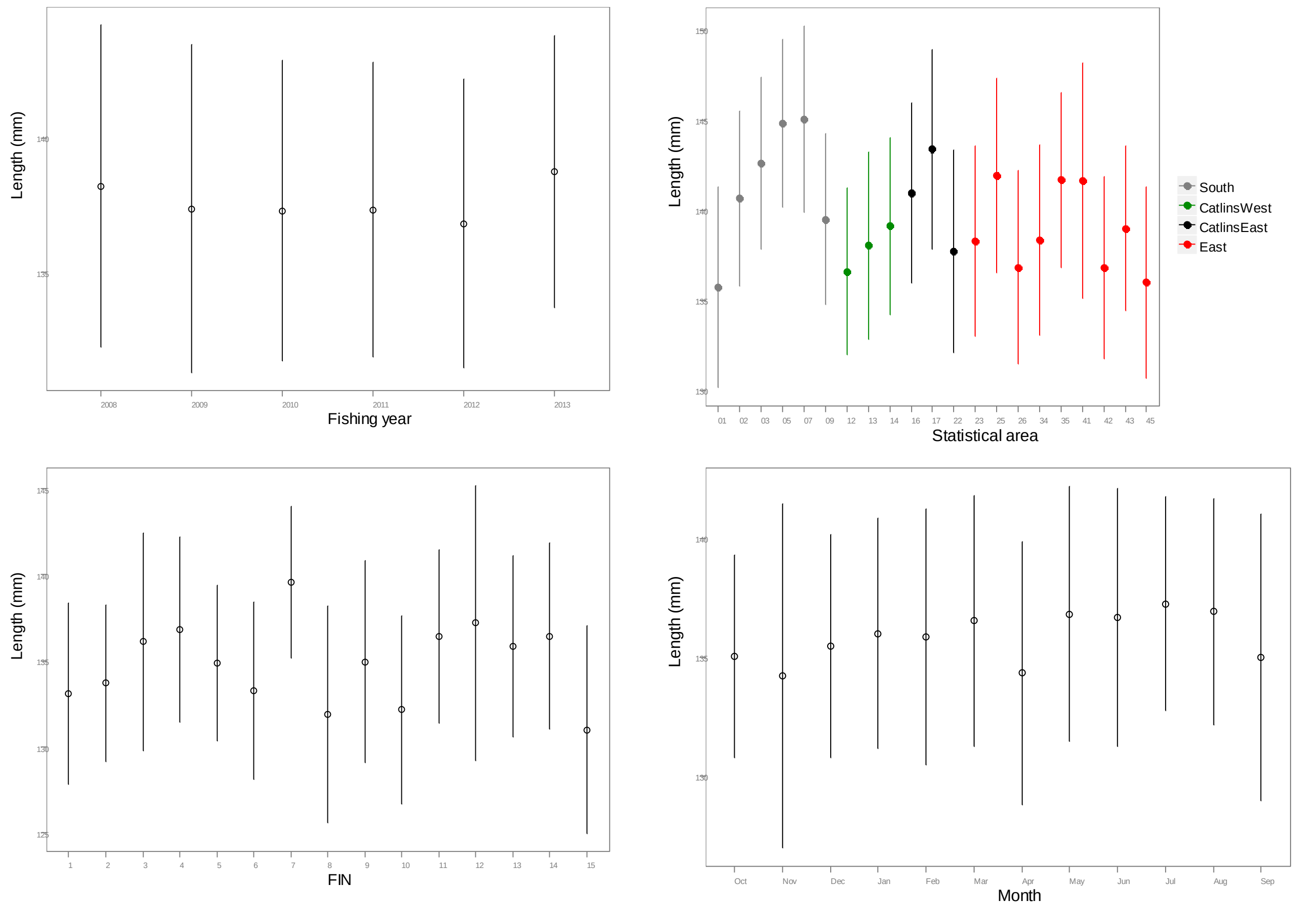

Figure 35: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 5D catch sampling length data 2008–2013.

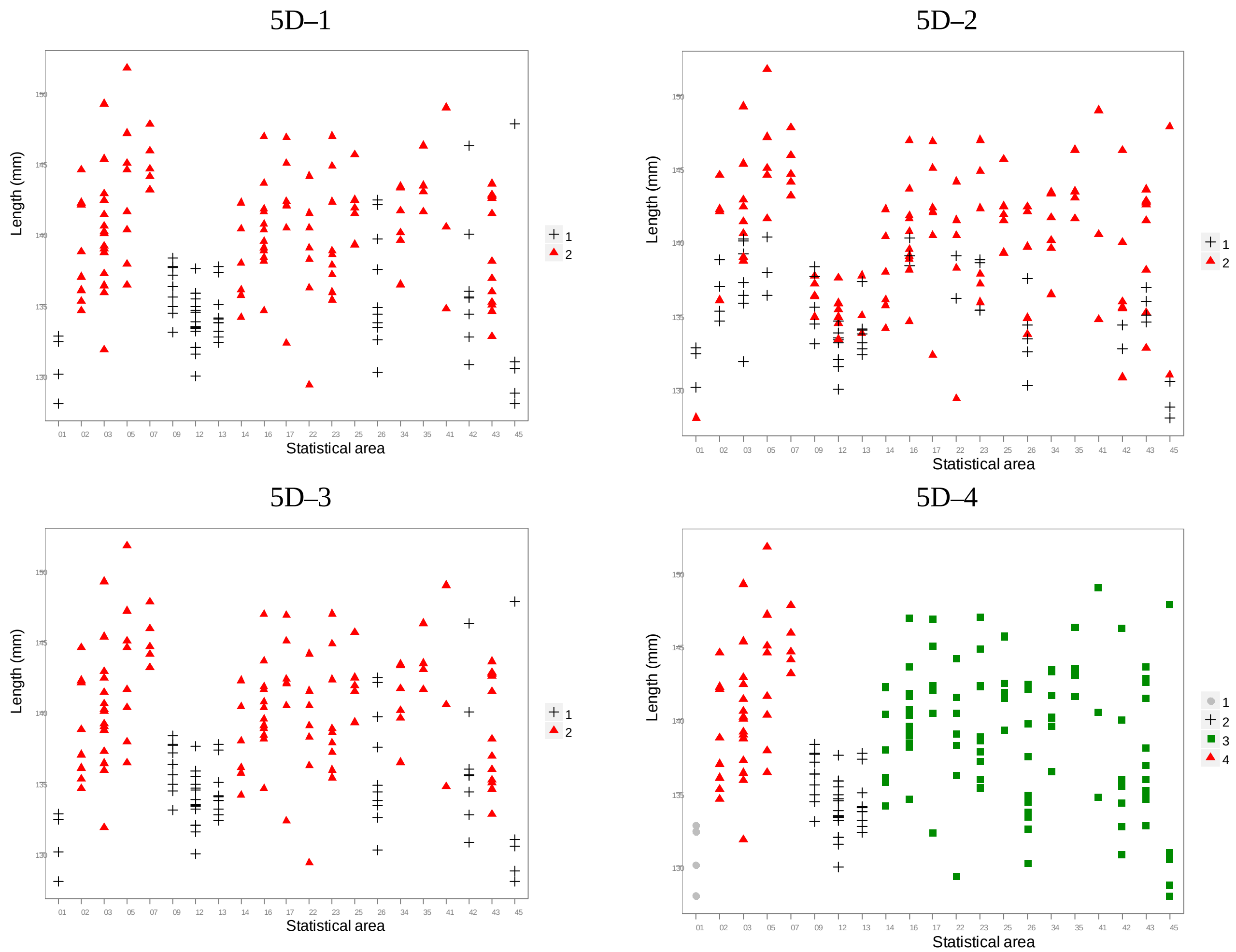

Figure 36: Stratifying the PAU 5D catch length samples from fishing years 2008–2013 from models 5D–1, 2, 3, and 4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 5D–1 and 5D–2 are summarised in Table 6.

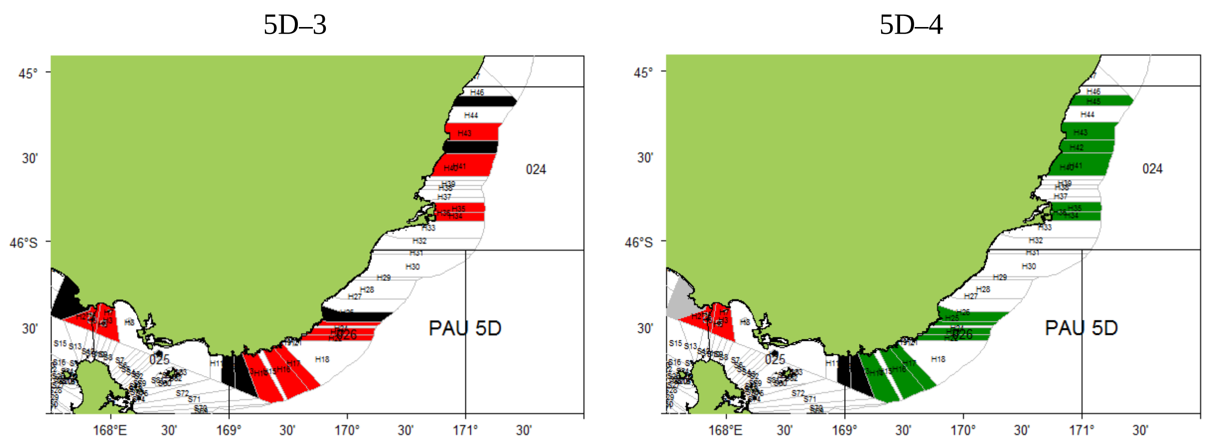

Figure 37: A map showing the stratification of the PAU 5D catch length samples (2008–2013) from models 5D–3 and 4.

4.3.4 PAU 2

Table 7: Description of the stratifications of the PAU 2 catch length samples 2008–2013 for models 2–1 and 2–2. For model 2–1, data from Statistical Areas 01–11 were not included in the model, but were simply treated as a separate group.

Model	Stratum	Description
(2–1) area + month + fin	1	area: 09 10 14 17 19 20 21 22 23 24 25 26 27 28 29 30 35 36
(categorical variables)		fin:1 2 3 4 5 6 7 9 10 12
	2	area: 09 10 14 17 19 20 21 22 23 24 25 26 27 28 29 30 35 36
		fin:8 11 13 14 15 16
	3	area:16 18
(2–2) area + month + fin	1	fin:1–7
(ordered categorical variables)		area:19 20 21 22 23 24 25 26 27 28 29 30 35 36
	2	fin:1–7
		area:09 10 14 16 17 18
	3	fin:8–16

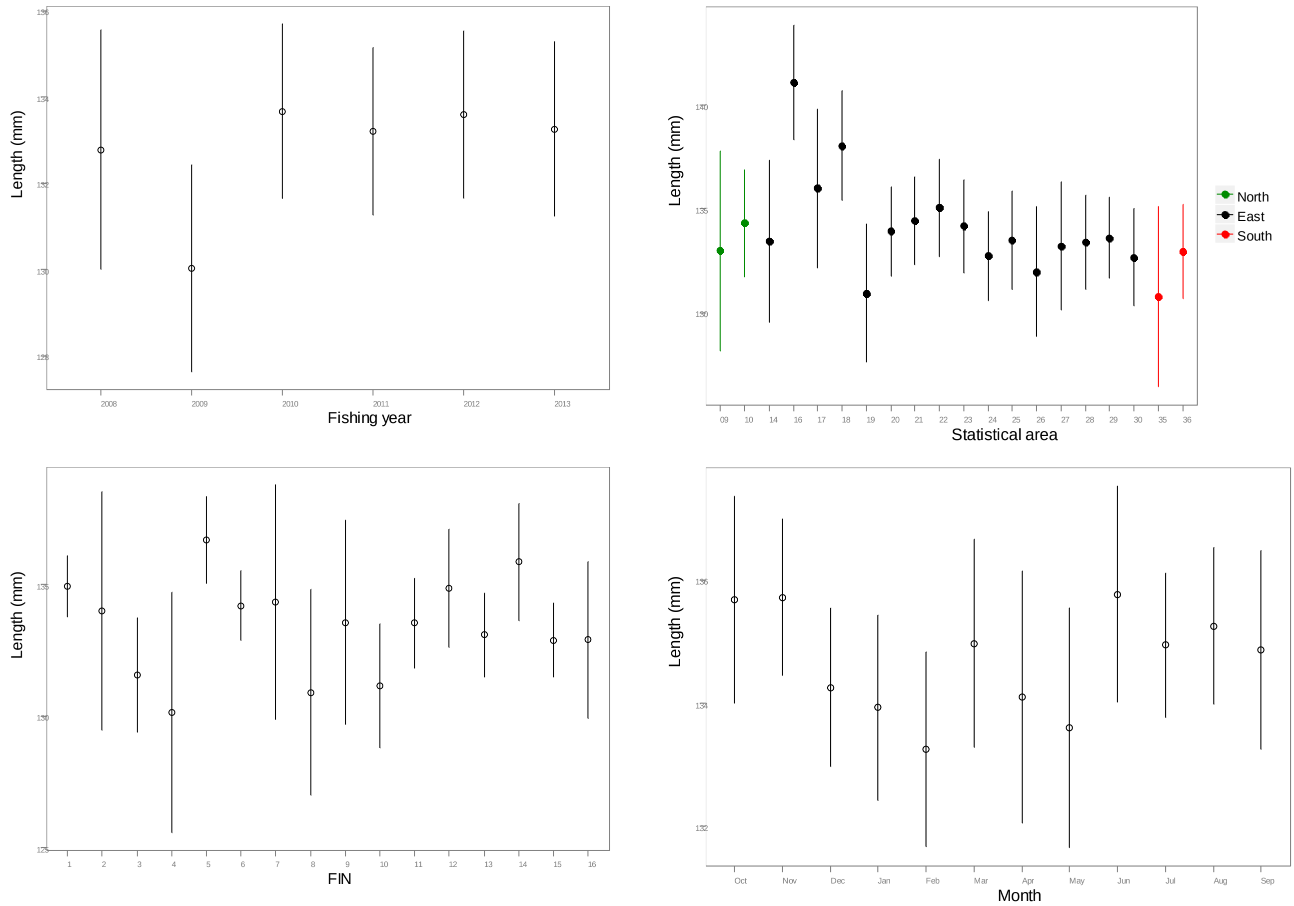

Figure 38: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 2 catch sampling length data 2008–2013.

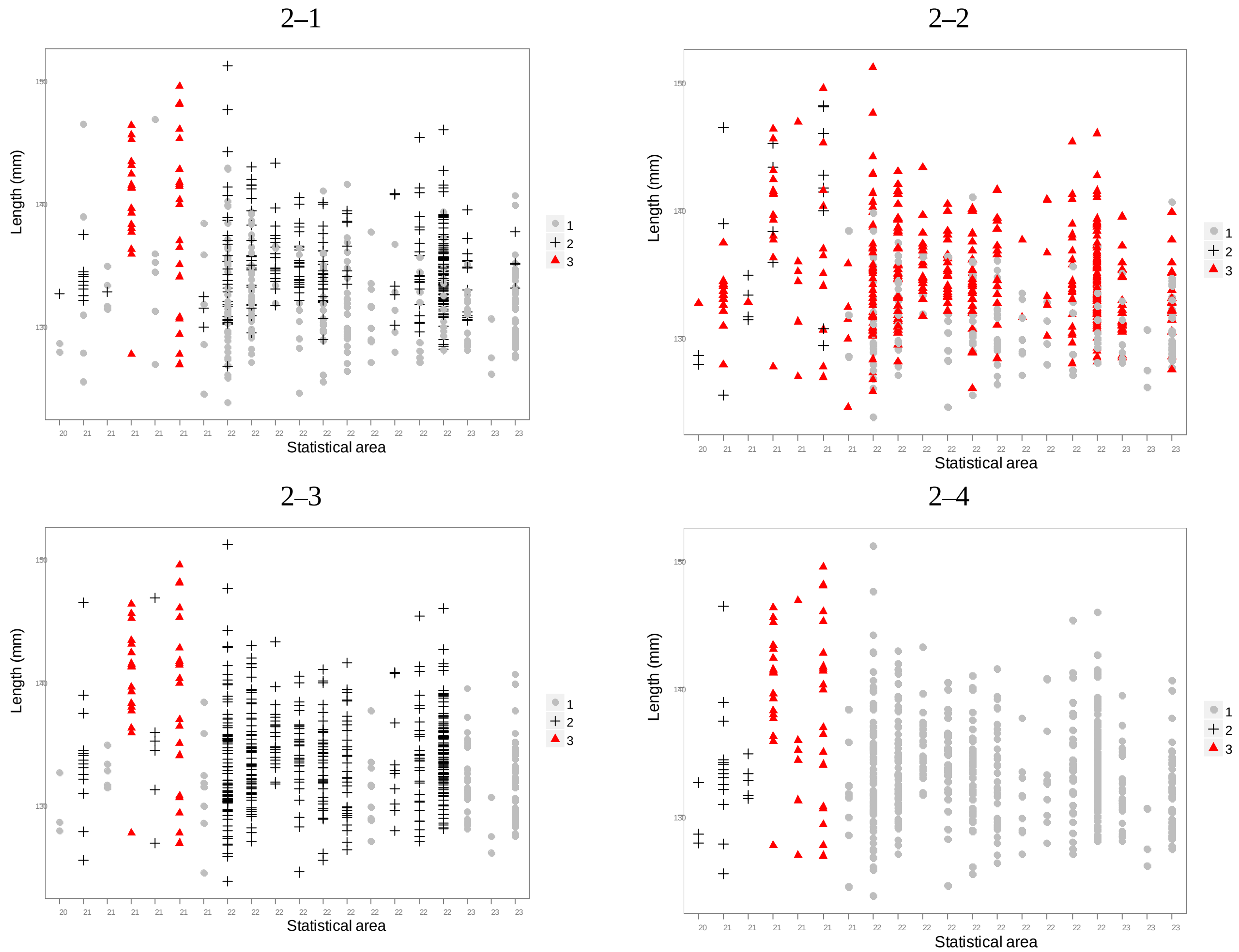

Figure 39: Stratifying the PAU 2 catch length samples from fishing years 2008–2013 from models 2–1, 2–2, 2–3, and 2–4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 2–1 and 2–2 are summarised in Table 7.

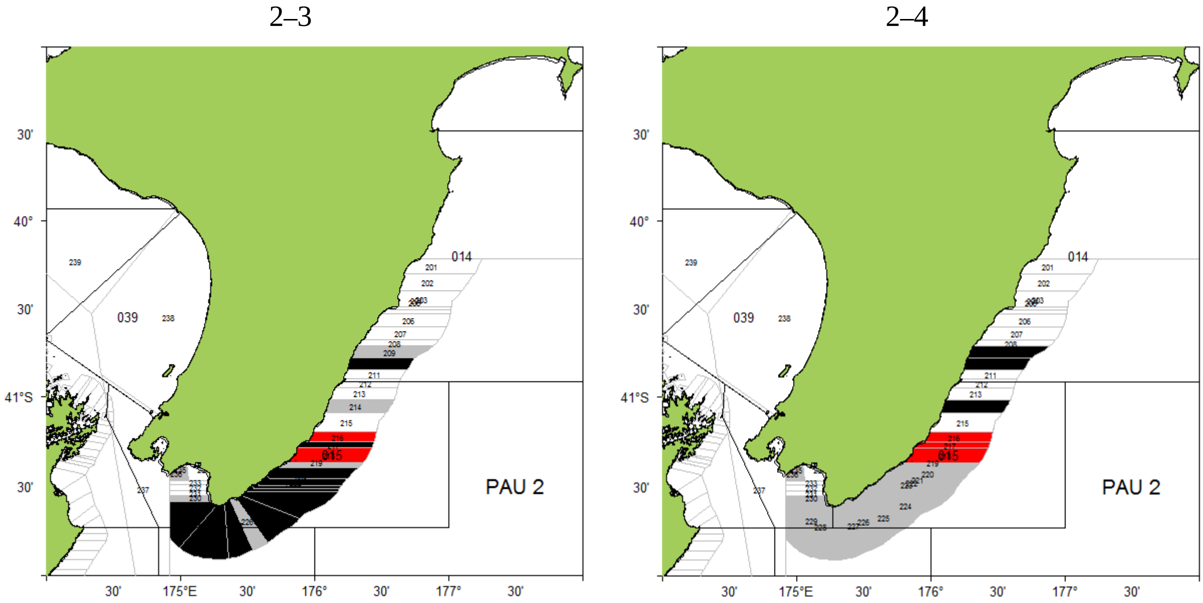

Figure 40: A map showing the stratification of the PAU 2 catch length samples (2008–2013) from models 2–3 and 2–4.

4.3.5 PAU 3

Table 8: Description of the stratifications of the PAU 3 catch length samples 2008–2013 for models 3–1 and 3–2.

Model	Stratum	Description
(3–1) area + month + fin	1	area: 33 34 35
(categorical variables)	2	area: 04 12 13 14 15 16 18 19 30 31
	3	area: 01 02 03 07 08 09 10
(3–2) area + month + fin	1	area: 33 34 35
(ordered categorical variables)	2	area: 12 13 14 15 16 18 19 30 31
	3	area: 01 02 03 04 07 08 09 10

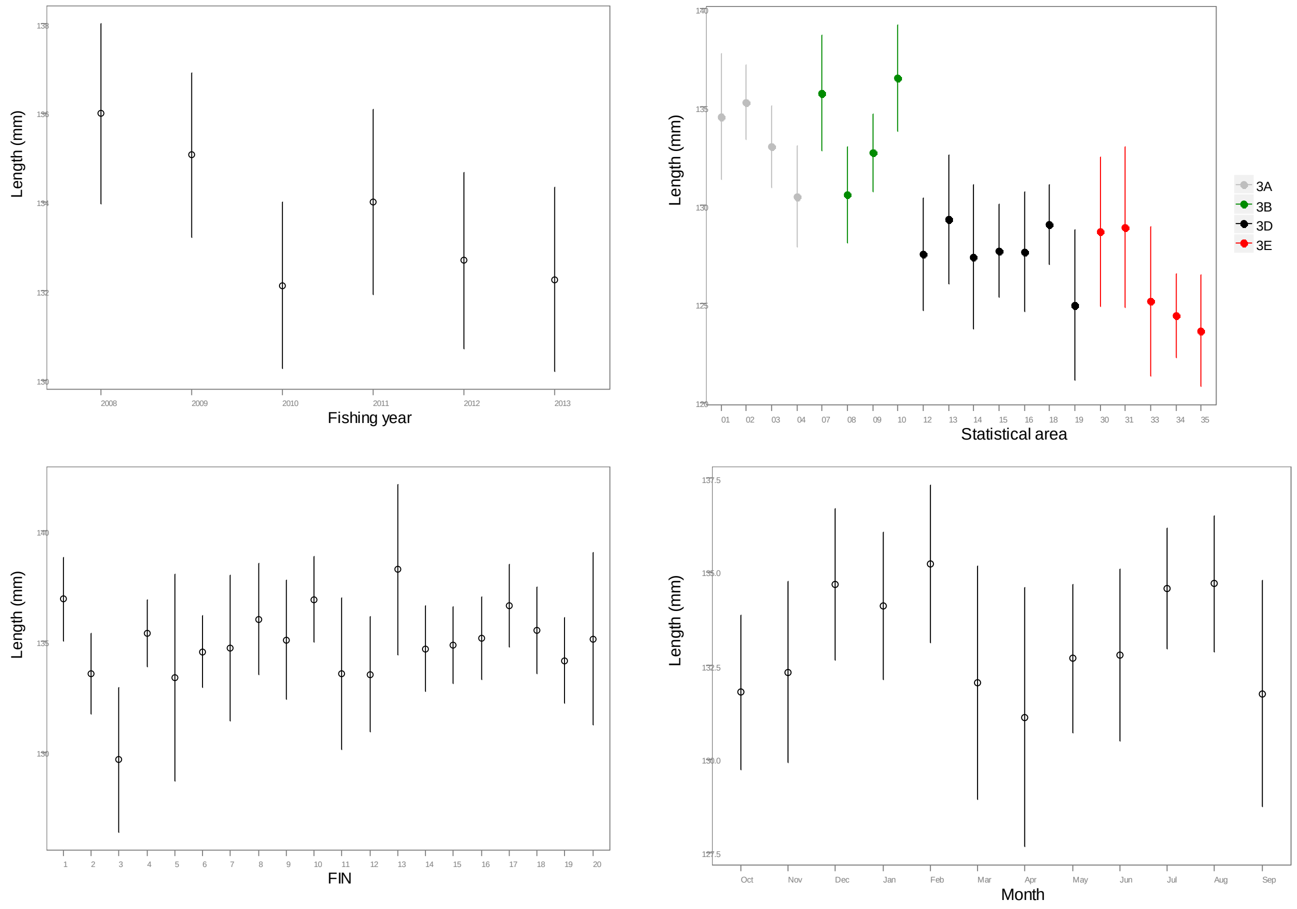

Figure 41: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 3 catch sampling length data 2008–2013.

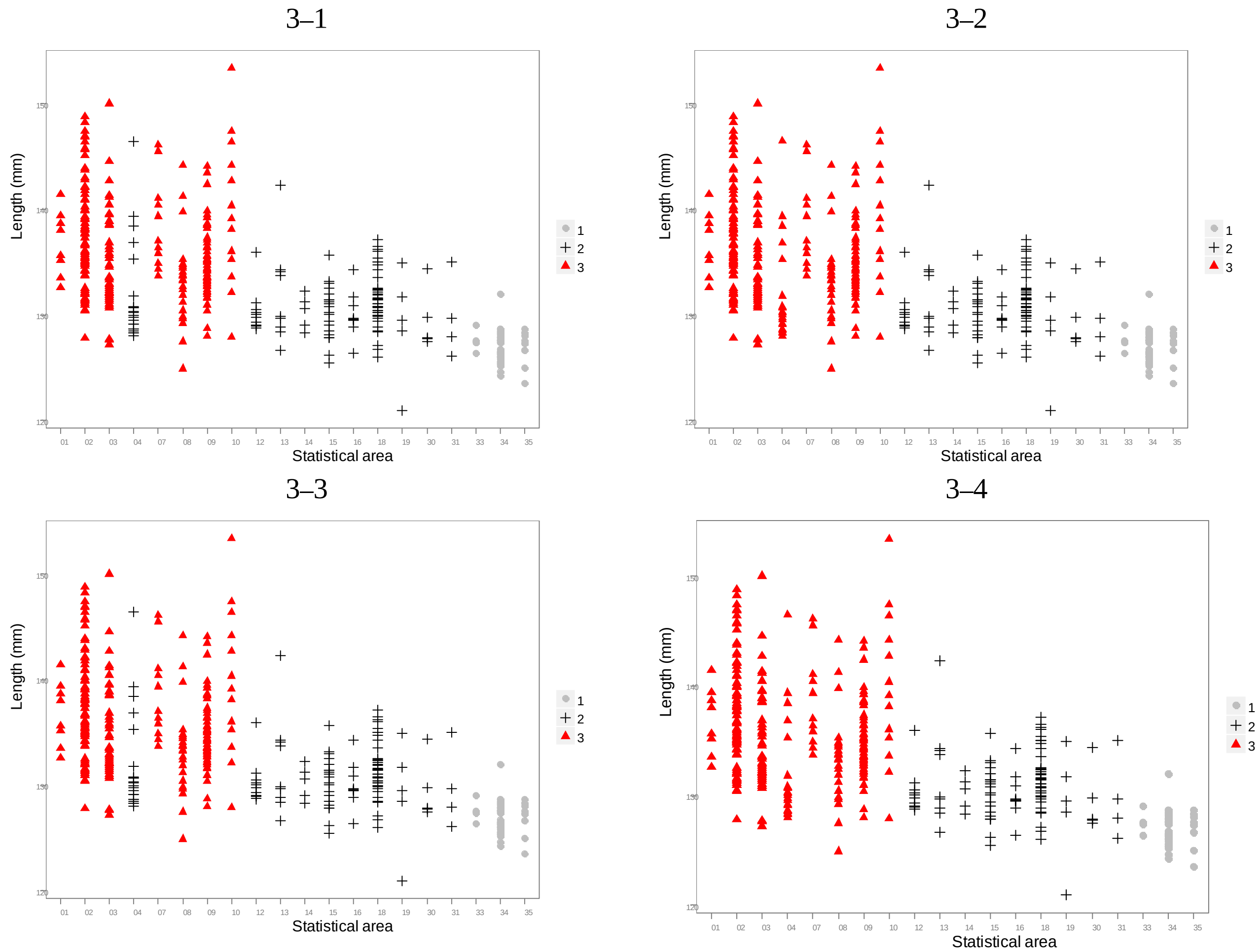

Figure 42: Stratifying the PAU 3 catch length samples from fishing years 2008–2013 from models 3–1, 3–2, 3–3, and 3–4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 3–1 and 3–2 are summarised in Table 8.

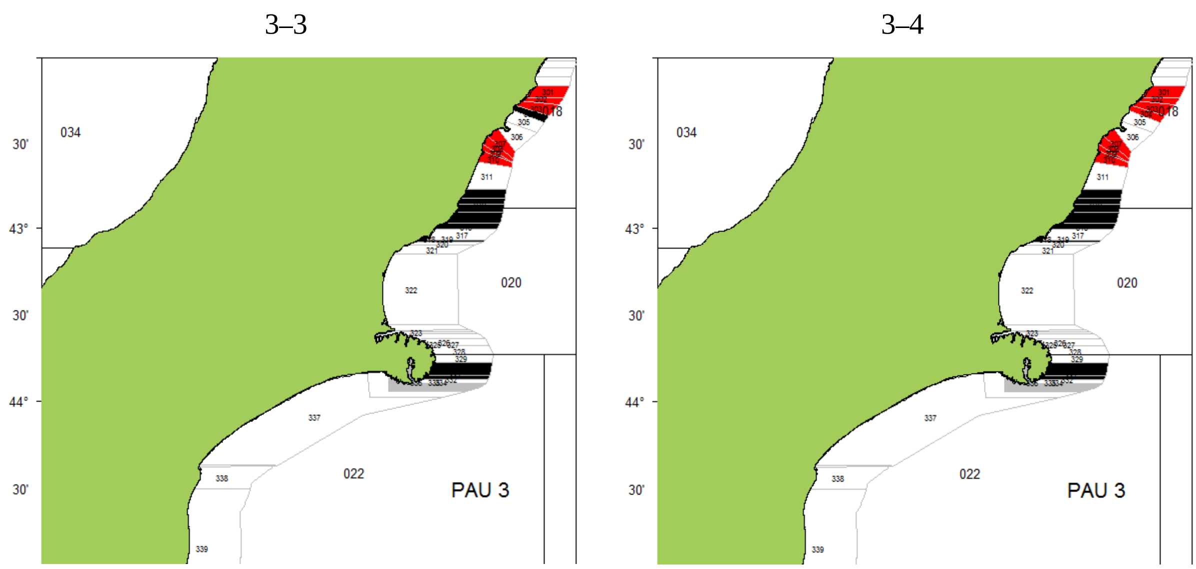

Figure 43: A map showing the stratification of the PAU 3 catch length samples (2008–2013) from models 3–3 and 3–4.

4.3.6 PAU 4

Table 9: Description of the stratifications of the PAU 4 catch length samples 2008–2013 for models 4–1 and 4–2.

Model	Stratum	Description
(4–1) area + month + fin (categorical variables)	1	area: 05 11–14 19 20 21 22 23 25 26 27 30 32 44 48 49 02 34 –38 fin:1 2 3 4 5 6 7 8 9 10 11 12 13 14 17 21
	2	area: 05 11–14 19 20 21 22 23 25 26 27 30 32 44 48 49 02 34–38 fin:15 16 18 19 20 22 23 24 25 26 27 28 29 30 31 33
	3	area: 06 –10 15 16 17 31 40 41 42 43 45 46 47 57 33 fin:1 3 6 8 9 10 12 13 14 17 18 19 20 22 23
	4	area: area: 06 –10 15 16 17 31 40 41 42 43 45 46 47 57 33 fin:21 24 25 26 27 28 29 30 31 32 33
(4–2) area + month + fin (ordered categorical variables)	1	fin:1–13
	2	fin: 14–19
	3	fin: 20–24
	4	fin: 25–33

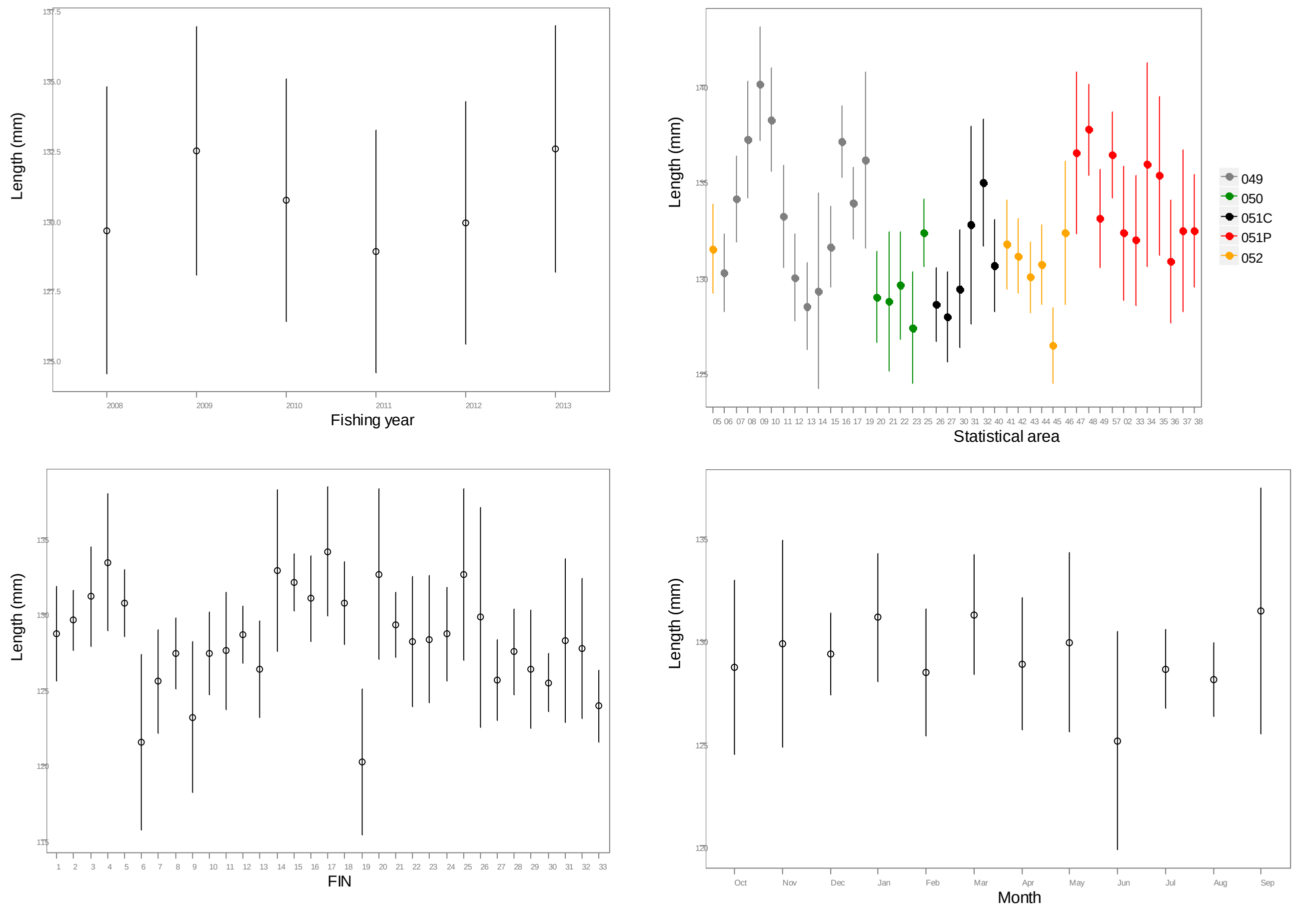

Figure 44: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 4 catch sampling length data 2008–2013.

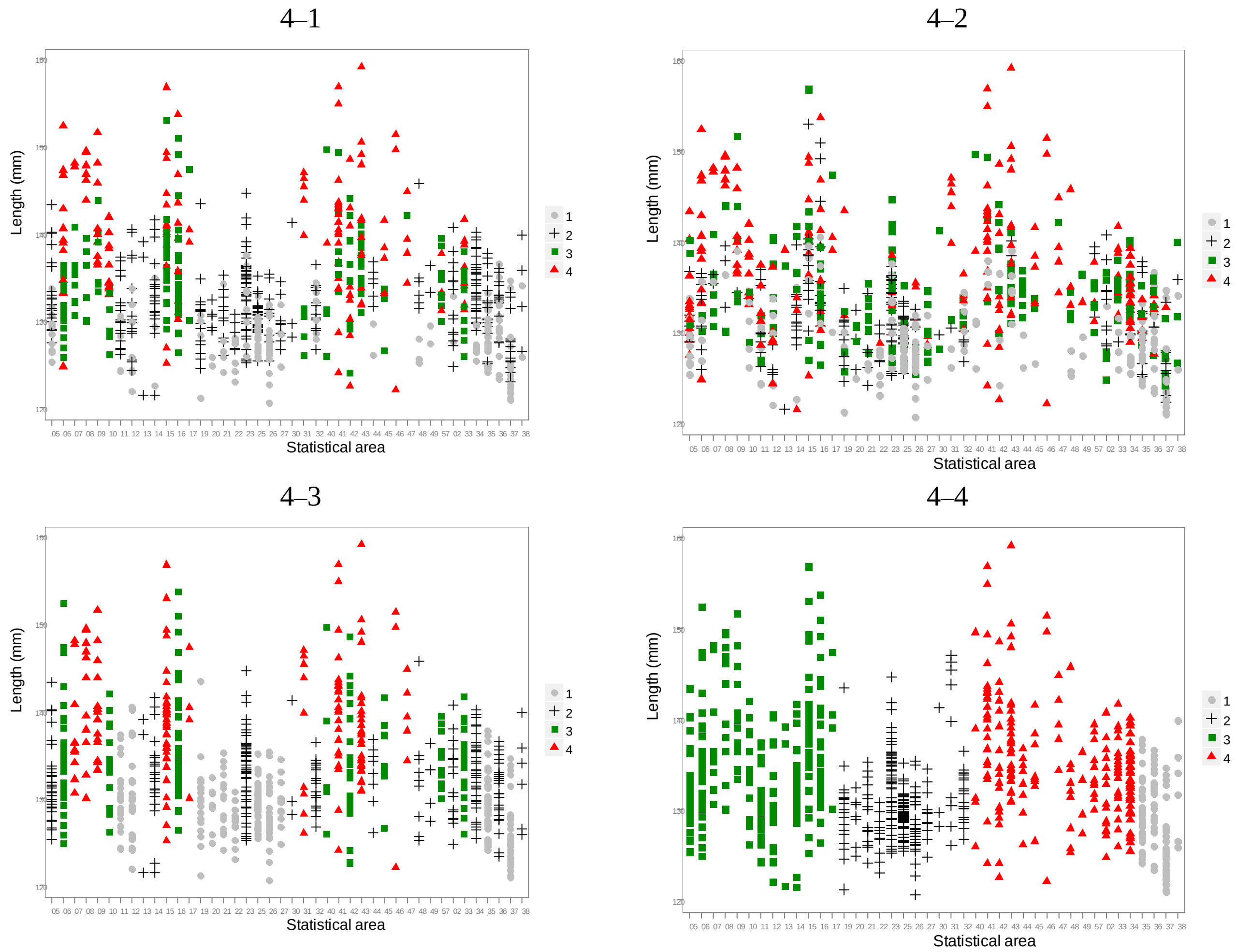

Figure 45: Stratifying the PAU 4 catch length samples from fishing years 2008–2013 from models 4–1, 4–2, 4–3, and 4–4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 4–1 and 4–2 are summarised in Table 9.

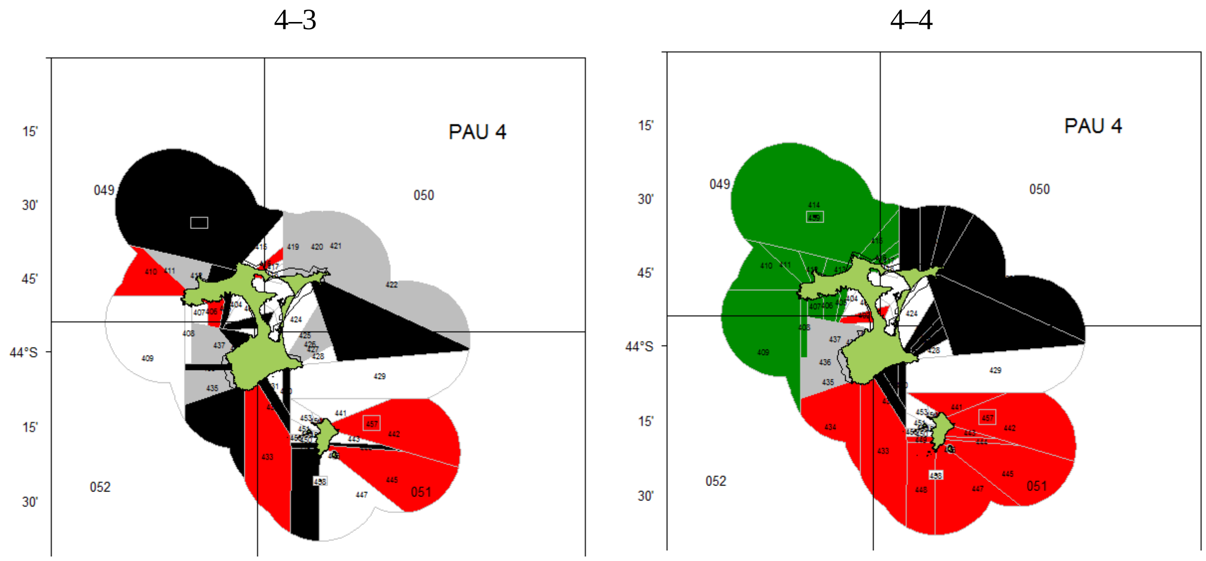

Figure 46: A map showing the stratification of the PAU 4 catch length samples (2008–2013) from models 4–3 and 4–4.

4.3.7 PAU 7

Table 10: Description of the stratifications of the PAU 7 catch length samples 2008–2013 for models 7–1 and 7–2. For both models, data from Statistical Areas 04–09 were not included in the model, but were simply treated as a separate group.

Model	Stratum	Description
(7–1) area + month + fin	0	area: 04 05 06 07 08 09
(categorical variables)	1	area: 14 15 16 17 18 27 30 33 34 36 37 38 39 42 63 64 66
	2	area: 19 20 21 22 23 24 25 26 28 35 fin:1 2 3 4 6 7 8 9 11 12 14
	3	area: 19 20 21 22 23 24 25 26 28 35 fin:10 13 15 16
	4	area: 10 93
(7–2) area + month + fin	0	area: 04 05 06 07 08 09
(ordered categorical variables)	1	area: 14 15 16 17
	2	area: 30 33 34 35 36 37 38 39 42 63 64 66
	3	area: 18 19 20 21 22 23 24 25 26 27 28
	4	area: 10
	5	area:93

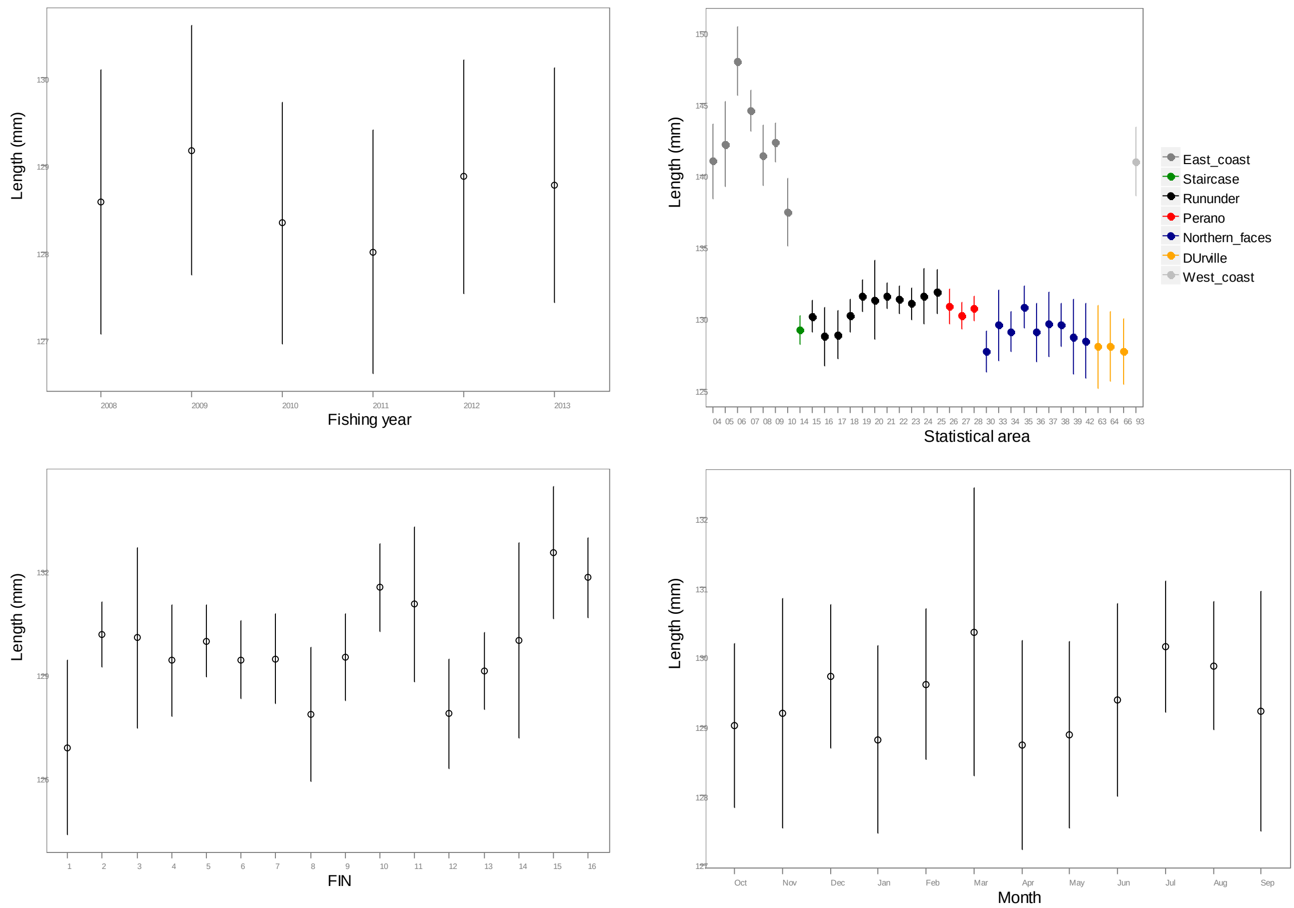

Figure 47: Estimated effects for fishing year, statistical area, FIN, and month from the linear model fitted to the PAU 7 catch sampling length data 2008–2013.

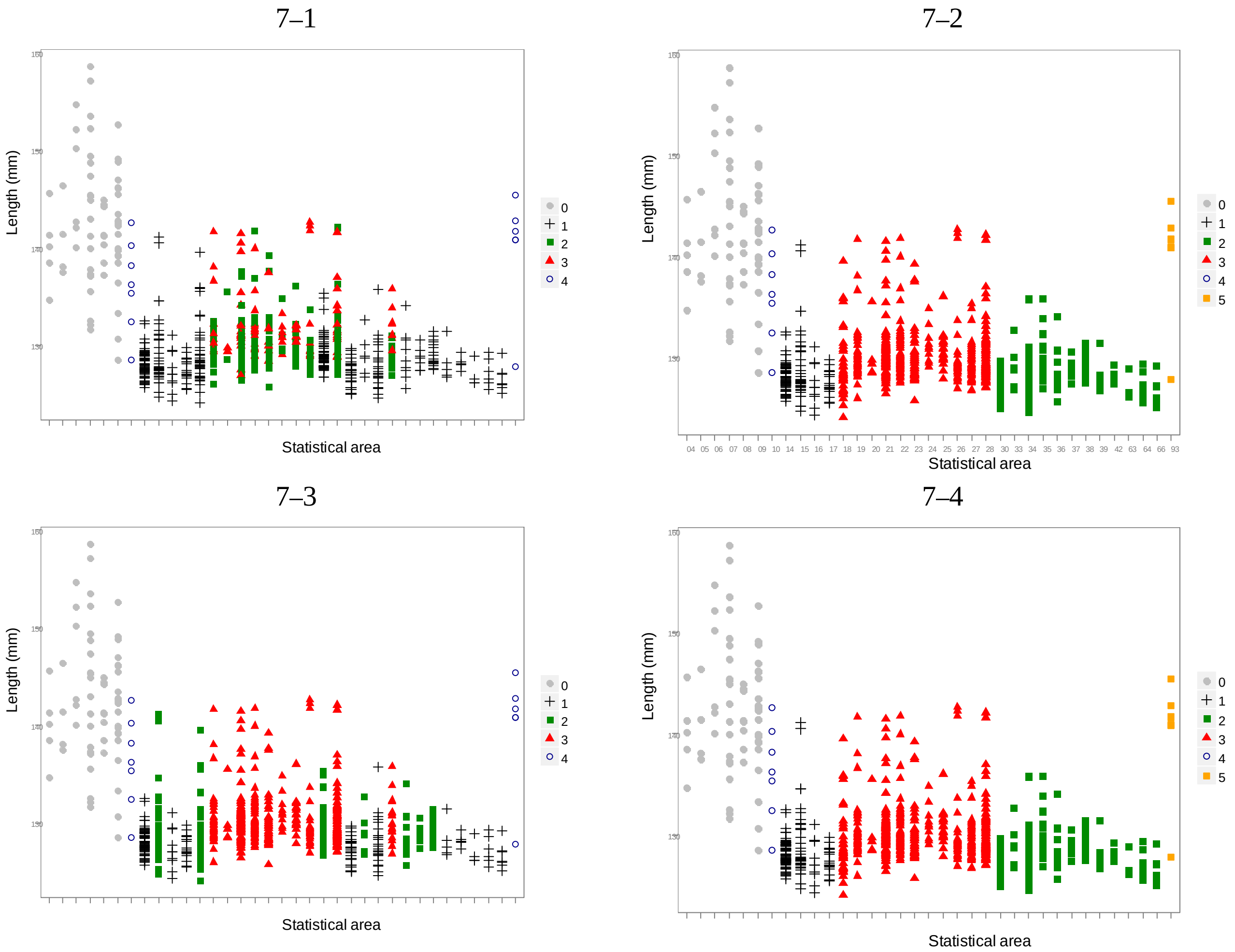

Figure 48: Stratifying the PAU 7 catch length samples from fishing years 2008–2013 from models 7–1, 7–2, 7–3, and 7–4. Each plot shows the mean length of each sample by statistical area, with colours indicating strata determined from respective tree-regression models. The stratification for models 7–1 and 7–2 are summarised in Table 10.

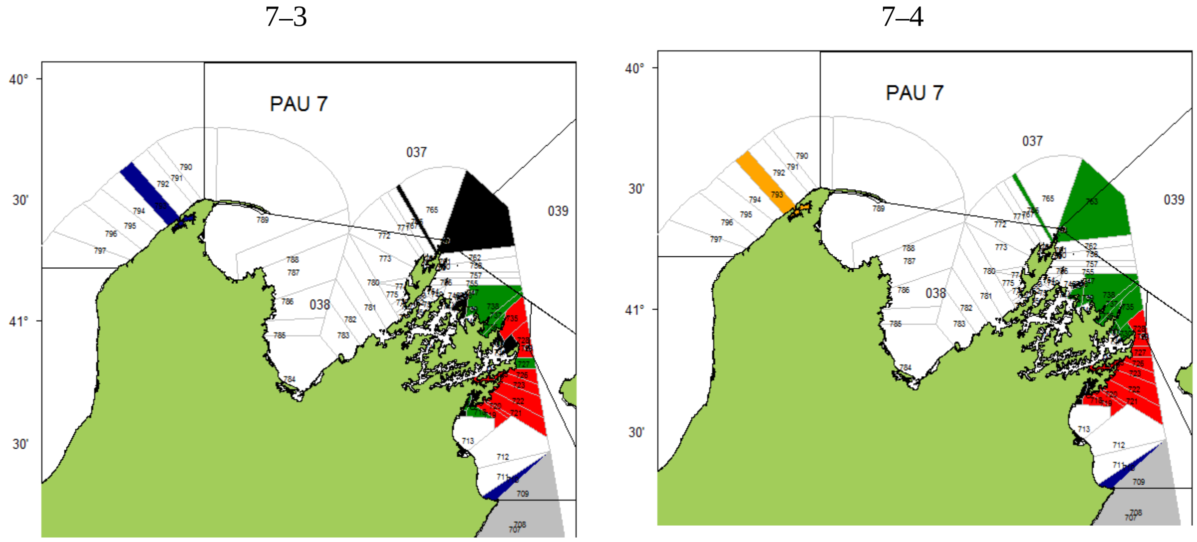

Figure 49: A map showing the stratification of the PAU 7 catch length samples (2008–2013) from models 7–3 and 7–4.

5. MAKE RECOMMENDATIONS ON HOW GROWTH SHOULD BE ESTIMATED IN A COST EFFECTIVE MANNER

5.1 Introduction

Growth in abalone has most commonly been estimated by analysis of length frequencies and by mark-recapture methods. Modal analysis of length-frequency data has been used by numerous authors to estimate growth and age (e.g. Poore 1972b, Sainsbury 1982, Newman 1968, Shepherd et al. 1995). The main problem with this approach arises from the well documented growth variability in abalone (e.g. Shepherd 1988, Sainsbury 1982, Poore 1972b, McShane & Naylor 1995, Naylor et al. 2006) which means that cohorts merge as they become older. Growth in abalone is therefore most commonly estimated using mark-recapture methods.

5.2 Tag types

The two most common methods of tagging involve the use of external tags glued to the shell and tags secured to the shell through the respiratory pores. The use of glues usually requires removal of the animals from the water, which may itself cause disturbance to the animals (McShane et al. 1988).

Evidence in the literature regarding the relative benefits of externally glued tags and tags attached via respiratory pores is conflicting, and may depend on species or even habitat. McShane et al. (1988) used two tag types at each of two locations to estimate growth in *Haliotis rubra*. They used tags attached through a respiratory pore and tags attached with epoxy glue. At one site they found that growth in abalone tagged through the respiratory pore was slower than in externally tagged abalone. At the other site, they found no difference in growth estimated using the two methods. They thought that at one site, the wire attached tags may have interfered with the animals’ behaviour, but note that Poore (1972a) found no evidence of this in paua using similarly attached tags. Poore (1972a) attached 17 mm × 8 mm oval plastic tags through two respiratory pores close to the outer edge of the shell using soft 23-gauge (0.61 mm) stainless wire. Poore (1972a) found that the tags were suitable for paua over a wide range of sizes and found no evidence of either tissue irritation or interference with the animals’ usual behaviour. He also suggested that the method was much more suitable for paua than glued on tags because shell infestation with polychaete worms, barnacles, and coralline algae on the outer shell make it fragile and porous and not suitable for secure tag attachment using adhesives. Outer shell condition appears to vary regionally and in some areas shells are relatively free of encrusting organisms. Poore’s study was carried out at Kaikoura.

Peng et al. (1984) estimated growth in *Haliotis diversicolor* by tagging and length frequency analysis methods. Tags were attached to the shells by threading nylon line through the fourth and fifth anterior respiratory pores. They found that growth was seasonal and rapid between March and July and that growth rates were similar estimated by either method. Prince (1991) inserted nylon rivets with an attached number into a posterior respiratory pore to estimate growth and found no difference in growth attributable to the tagging method.

Protocols have been developed for in situ abalone tagging in Western Australia using resin cast tags and epoxy putty to secure the tags (Anthony Hart, Western Australian Fisheries and Marine Research Laboratories, pers. Comm.); however, the method is reasonably complicated and appears more suited to tagging relatively small numbers of abalone.

Based on the experience of Poore (1972a) and others, we believe that the use of plastic cable ties is simple, unlikely to affect growth, and likely to provide good retention and easy detection. Externally glued tags frequently become overgrown with coralline algae which makes their detection difficult or impossible. Because the locking mechanism on cable ties sits proud of the shell, the tag should still be obvious even if it has been colonised by coralline algae. Cable ties will effectively act in the same way as wire attached tags but will be easier and faster to attach. Some examples are shown in Figure 50, but other options with respect to length and width are available (David Hall, Hallprint, pers. comm.).

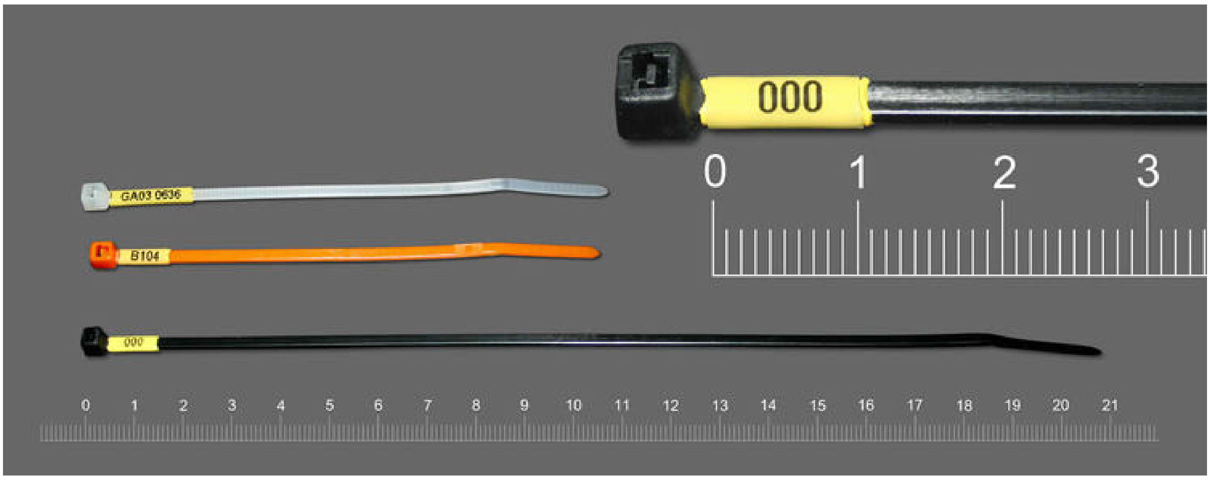

Figure 50: Numbered cable ties (reproduced with permission from Hallprint Fish Tags).

5.3 Tagging procedure

Tagging sites should be representative of the fishery. Relatively good diving conditions are required to ensure that divers are able to collect a good size range (i.e. from about 60 mm to the largest size present). Tag recapture rates are usually in the order of 10%, so tagging 800 paua at a site usually results in the recapture of about 80 paua. Recapture rates, however, may be higher using cable tie tags which are unlikely to fall off and likely to be more obvious than glued on tags if overgrown.

Application of the tags and length measurement in situ is likely to minimise disturbance to the animals and is recommended if it is logistically viable. Waterproof data logging calipers may be used if the tag number can be logged and associated with measurements, or standard calipers may be used and the lengths and tag numbers may be recorded onto either a slate or waterproof paper. If too few paua are able to be tagged in situ, tagging on board a vessel is recommended.

If tags are applied on board the vessel, care must be taken to minimise exposure to both air and sunlight. NIWA's experience suggests that it is most efficient to collect all paua at the beginning of the day. Counting paua as they are collected will ensure that the entire collection can be carried out in one dive. At least 8 catch bags or hand nets are required for the collection so most paua can remain suspended in the water in bags while one of the bags is being tagged. Tagging is best done on a raised table (about 1.5 m by 1 m) on the deck of the vessel. The table should be covered with a wet towel to stop paua adhering too strongly. Once all paua on the table have been tagged, they are measured to the nearest millimetre and the tag number and longest basal shell length are recorded. The bag is then hung back over the side of the vessel. When all bags have been processed they should be returned to the same area they were collected from. Care must be taken to ensure that paua remain the right way up, as they are otherwise vulnerable to predation. The release area should be no more than about 10m by 10 m, and should be marked on a map, photographed, and the GPS coordinates recorded. Notes and drawings will also help to re-locate the site. If the release area is isolated e.g. on a discrete reef surrounded by sand, migration from the site can be minimised. Commercial paua divers who fish in the vicinity of the tagging site should be advised of its approximate location and asked not to harvest any tagged paua in the area for a year from the date of tagging. Processors should be asked to keep an eye out for tagged shells and asked to retain any they notice and record the date and location of the landing. Tagged paua should be collected about a year after they were tagged to ensure that all seasonal components of growth are captured.

Two areas within PAU 5D identified earlier in this objective as regions of potentially different growth are Moeraki and Colac Bay. These areas could be considered as initial tagging sites within the QMA. Growth estimates already exist for the Catlins. In PAU 3 which has already been subdivided into four areas, areas A, and B, could be considered as initial tagging sites. Growth information already exists from four sites in the relatively lightly fished area E (Banks Peninsula).

Tagging by industry is likely to be the most cost effective way to obtain growth information, especially if the work can be done in conjunction with fishing, or during a period when divers are located near to the tagging sites.

6. DISCUSSION

The results of objective three, to identify zones of potentially different growth, were presented to the Shellfish Working Group (SWG) on the 8^{th} of April 2015. Objectives 1 and 2 were presented to the SWG in 2014.

The SWG agreed that the proposed regions of potentially different growth were sensible, but was not convinced that the results of the tree regression were able to consistently guide the differentiation of regions based on growth, or be informative about where additional growth information was required from. While the results of the tree regression frequently reflected either diver perception or actual differences in growth, other factors may influence the length distribution of the catch. These include variations in recruitment, fishing pressure, sampling error, and voluntary minimum harvest sizes.

Spatial variation in growth rates of paua is unlikely to be geographically continuous and variation over both small and large scales is well documented. In the tree regression, it is therefore probably more appropriate to treat statistical area as a categorical variable, allowing greater flexibility in stratifying catch samples based on mean length. However, while treating statistical area as an ordered categorical variable constrains the model, it does allow the subdivision of QMAs into regional blocks.

Tagging by industry is likely to be the most cost effective way to obtain growth information, especially if the work can be done in conjunction with fishing, or at times when the divers are already close to the tagging location. The literature suggests that tags attached through the respiratory pores will provide a simple methodology, unlikely to affect growth, and likely to provide good retention and easy detection.

7. ACKNOWLEDGEMENTS

This project was funded through the Ministry for Primary Industries' project PAU 2013-01. Thanks to Jeremy Cooper, Storm Stanley and industry participants for their substantial input into the determination of regions of potentially different growth. Thanks also to Andy McKenzie for reviewing this report.

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APPENDIX 1: Summary of commercial catch length samples in each QMA.

Table A1: Number of commercial catch length samples by statistical area in PAU 5A 2008–2013. Only areas with at least one sample are shown.

		2008	2009	2010	2011	2012	2013	Total
Milford	P5AF01	0	0	0	1	0	1	2
	P5AF03	0	0	7	0	1	1	9
	P5AF05	0	0	0	0	1	1	2
	P5AF06	0	0	0	4	0	2	6
George	P5AF07	1	0	0	0	1	2	4
	P5AF08	0	0	0	0	1	2	3
	P5AF09	0	0	0	0	0	2	2
	P5AF10	0	0	0	1	2	3	6
	P5AF11	3	0	5	1	0	3	12
	P5AF12	2	1	0	1	1	2	7
	P5AF13	0	0	4	0	0	2	6
	P5AF14	1	0	1	0	3	2	7
Central	P5AF15	0	0	0	2	0	0	2
	P5AF16	0	0	0	2	0	0	2
	P5AF17	1	0	0	0	0	0	1
	P5AF19	1	0	0	0	0	0	1
	P5AF22	5	0	1	0	0	0	6
	P5AF23	1	4	5	1	1	1	13
	P5AF24	0	10	1	0	0	0	11
	P5AF25	0	0	3	1	1	1	6
	P5AF26	1	0	13	2	2	1	19
Dusky	P5AF28	0	0	1	1	2	2	6
	P5AF29	0	0	1	1	1	0	3
	P5AF31	1	0	0	1	0	1	3
	P5AF32	1	0	3	1	1	0	6
	P5AF33	1	0	0	5	0	1	7
Chalky	P5AF34	0	0	4	2	1	2	9
	P5AF35	0	0	3	0	1	3	7
	P5AF36	0	1	2	0	1	3	7
	P5AF37	0	0	2	0	0	0	2
	P5AF38	0	0	2	2	1	0	5
South	P5AF39	0	2	0	0	0	0	2
	P5AF41	0	3	1	0	0	5	9
	P5AF42	1	3	0	0	1	1	6
	P5AF43	2	1	4	0	4	2	13
	P5AF44	0	0	0	2	2	0	4
	P5AF46	0	0	0	0	1	1	2
	P5AF47	0	0	0	1	1	1	3
	P5AF48	0	0	0	0	0	1	1
	P5AF49	0	0	0	0	0	3	3
	Total	22	25	63	32	31	52	225

Table A2: Number of commercial catch length samples by statistical area in PAU 5B 2008–2013. Only areas with at least one sample are shown.

		2008	2009	2010	2011	2012	2013	Total
Ruggedy	P5BS01	1	3	2	2	1	3	12
	P5BS02	0	0	3	0	1	5	9
	P5BS03	0	0	0	0	0	2	2
	P5BS04	1	0	0	0	0	4	5
	P5BS05	1	1	0	0	1	3	6
	P5BS06	1	0	2	1	0	2	6
	P5BS07	3	0	6	3	5	2	19
	P5BS08	1	0	3	5	2	3	14
	P5BS09	0	0	1	2	1	4	8
	P5BS10	0	0	1	5	2	5	13
	P5BS11	1	0	0	2	1	3	7
Waituna	P5BS12	2	1	0	3	2	2	10
	P5BS13	2	3	2	3	1	1	12
	P5BS14	0	0	0	0	1	0	1
	P5BS15	0	0	0	0	2	4	6
	P5BS16	1	0	0	0	0	0	1
	P5BS17	2	4	2	2	5	3	18
	P5BS18	1	1	0	6	3	0	11
Codfish	P5BS19	1	0	1	1	1	0	4
	P5BS22	0	0	0	0	0	2	2
	P5BS23	0	0	0	0	0	2	2
	P5BS24	0	2	3	1	1	2	9
	P5BS25	1	0	1	0	1	0	3
West	P5BS26	1	2	2	3	1	3	12
	P5BS27	0	2	2	1	0	2	7
	P5BS28	0	7	3	2	3	2	17
	P5BS29	0	3	3	0	0	1	7
	P5BS30	0	1	3	0	0	2	6
	P5BS31	0	0	0	1	0	2	3
	P5BS33	0	1	0	0	0	0	1
	P5BS34	0	0	1	0	0	0	1
	P5BS39	0	0	0	0	0	1	1
	P5BS42	0	0	0	0	1	1	2
Pegasus	P5BS44	0	0	0	0	0	3	3
	P5BS45	0	0	0	0	1	1	2
	P5BS46	0	0	0	2	0	0	2
	P5BS48	0	0	1	0	0	2	3
	P5BS49	0	0	0	1	0	0	1
	P5BS50	0	0	0	0	1	1	2
	P5BS52	0	0	0	0	2	0	2
Lords	P5BS53	0	0	0	0	1	0	1
	P5BS54	0	2	1	2	0	1	6
	P5BS55	0	0	1	0	0	0	1
	P5BS56	1	3	2	1	3	0	10
	P5BS57	2	1	0	2	1	0	6
	P5BS58	0	0	2	0	2	0	4
	P5BS60	1	3	3	1	2	1	11
	P5BS61	0	1	2	0	0	0	3
	P5BS62	1	0	1	1	2	1	6
	P5BS63	0	0	0	1	0	0	1

	P5BS64	0	0	1	1	0	0	2
	P5BS65	0	0	2	2	1	2	7
	P5BS67	0	0	1	1	3	1	6
	P5BS68	2	1	2	3	1	0	9
East Cape	P5BS69	1	1	4	1	0	1	8
	P5BS70	0	1	1	3	1	1	7
	P5BS71	0	1	1	0	1	2	5
	P5BS72	2	0	0	4	0	2	8
Ruapuke	P5BS74	0	0	2	2	3	1	8
Ialands	P5BS75	2	1	0	2	1	0	6
	P5BS78	3	1	3	1	3	2	13
	P5BS80	1	2	0	5	0	0	8
	P5BS81	1	0	0	0	0	0	1
	P5BS83	0	0	1	0	0	0	1
	Total	37	49	72	79	65	88	390

Table A3: Number of commercial catch length samples by statistical area in PAU 5D 2008–2013. Only areas with at least one sample are shown.

		2008	2009	2010	2011	2012	2013	Total
South	P5DH01	0	3	0	0	3	0	6
	P5DH02	0	2	2	2	1	2	9
	P5DH03	0	2	5	3	2	6	18
	P5DH05	0	1	1	1	1	6	10
	P5DH07	0	0	0	2	3	2	7
	P5DH09	2	1	6	0	1	1	11
	P5DH10	0	0	0	0	0	2	2
Catlins	P5DH12	1	1	7	4	2	1	16
west	P5DH13	0	5	2	0	0	4	11
	P5DH14	0	2	3	0	1	0	6
	P5DH15	0	1	0	0	0	1	2
Catlins	P5DH16	1	1	4	1	2	5	14
east	P5DH17	0	0	1	2	1	3	7
	P5DH18	0	0	0	0	1	0	1
	P5DH21	1	0	0	0	0	0	1
	P5DH22	2	1	0	1	1	2	7
East	P5DH23	1	6	0	0	0	3	10
	P5DH25	0	0	3	0	0	2	5
	P5DH26	1	0	3	1	1	4	10
	P5DH34	2	2	0	1	1	0	6
	P5DH35	0	1	1	2	0	0	4
	P5DH37	0	0	0	0	0	1	1
	P5DH41	0	0	0	2	0	1	3
	P5DH42	0	0	1	2	3	3	9
	P5DH43	0	5	1	0	3	5	14
	P5DH44	1	0	0	0	0	1	2
	P5DH45	0	0	0	0	4	1	5
	Total	12	34	40	24	31	56	197

Table A4: Number of commercial catch length samples by statistical area in PAU 7 2008–2013.

		2008	2009	2010	2011	2012	2013	Total
East coast	P701	1	0	0	0	0	0	1
	P703	0	0	0	1	0	0	1
	P704	0	0	1	2	1	1	5
	P705	0	0	1	3	0	0	4
	P706	0	0	1	2	2	1	6
	P707	0	1	2	10	4	3	20
	P708	0	1	0	1	6	0	8
	P709	0	1	1	3	10	8	23
	P710	0	2	0	1	2	2	7
Staircase	P712	0	0	0	1	0	0	1
	P714	3	3	0	16	22	20	64
Rununder	P715	3	2	7	4	16	9	41
	P716	0	0	4	0	3	3	10
	P717	2	0	7	9	0	1	19
	P718	2	1	1	14	10	11	39
	P719	1	1	5	5	14	16	42
	P720	0	0	0	3	2	0	5
	P721	8	4	10	12	25	30	89
	P722	8	6	9	8	19	23	73
	P723	7	3	2	7	11	9	39
	P724	3	0	1	3	2	3	12
	P725	1	0	3	5	6	4	19
Perano	P726	4	2	5	6	9	6	32
	P727	4	6	11	11	19	16	67
	P728	3	11	12	13	21	20	80
	P729	0	0	0	1	0	0	1
Northern faces	P730	3	0	4	4	6	6	23
	P731	0	0	0	0	1	0	1
	P733	0	0	1	2	2	1	6
	P734	2	2	4	4	5	6	23
	P735	4	0	4	5	3	5	21
	P736	2	0	2	2	0	3	9
	P737	1	1	2	0	1	2	7
	P738	2	3	3	3	3	2	16
	P739	1	1	0	0	1	2	5
	P742	1	0	0	0	3	1	5
	P745	0	0	0	0	0	1	1
	P746	1	0	0	0	1	0	2
DUrville	P762	1	0	0	1	0	0	2
	P763	1	1	0	1	1	0	4
	P764	1	0	0	1	1	3	6
	P765	1	0	0	0	0	0	1
	P766	0	1	1	3	2	0	7
	P767	0	0	1	1	0	0	2
	P773	1	1	0	0	0	0	2
	P782	0	0	1	0	0	0	1
West coast	P793	0	0	1	3	2	0	6
	P794	0	0	0	1	0	1	2
	P795	0	0	1	0	0	0	1
	P796	0	0	1	0	0	0	1
	P797	0	0	0	0	1	0	1
	Total	72	54	109	172	237	219	863

Table A5: Number of commercial catch length samples by statistical area in PAU 2 2008–2013. Only areas with at least one sample are shown.

		2008	2009	2010	2011	2012	2013	Total
North	P209	0	2	1	0	0	0	3
	P210	0	2	1	2	5	4	14
	P211	0	0	1	0	1	0	2
East	P214	0	0	2	1	0	2	5
	P215	0	0	0	1	0	1	2
	P216	0	2	0	0	1	14	17
	P217	3	0	0	1	0	2	6
	P218	1	1	6	1	3	9	21
	P219	1	0	1	3	0	3	8
	P220	6	8	13	10	14	31	82
	P221	0	1	10	10	18	27	66
	P222	0	0	4	4	7	6	21
	P223	0	2	2	12	5	12	33
	P224	1	1	16	10	9	8	45
	P225	1	1	4	4	7	14	31
	P226	0	0	3	2	1	3	9
	P227	0	0	2	0	2	6	10
	P228	1	1	9	7	7	6	31
	P229	3	4	29	37	34	16	123
	P230	2	0	8	7	6	7	30
	P231	0	0	0	0	1	0	1
South	P235	1	1	0	0	0	2	4
	P236	4	2	6	12	19	7	50
	Total	24	28	118	124	140	180	614

Table A6: Number of commercial catch length samples by statistical area in PAU 3 2008–2013. Only areas with at least one sample are shown.

		2008	2009	2010	2011	2012	2013	Total
3A	P301	1	4	0	0	2	2	9
	P302	3	20	19	18	16	13	89
	P303	7	8	10	7	6	8	46
	P304	0	1	0	9	1	11	22
3B	P305	0	0	1	0	0	1	2
	P306	0	0	1	0	0	0	1
	P307	3	2	4	0	3	0	12
	P308	3	3	7	6	2	3	24
	P309	7	13	15	5	15	9	64
	P310	3	2	0	5	2	2	14
3D	P311	0	0	0	1	0	0	1
	P312	1	1	0	1	4	3	10
	P313	0	1	3	3	1	1	9
	P314	0	0	0	5	1	0	6
	P315	0	1	0	6	7	7	21
	P316	0	0	4	0	5	0	9
	P317	1	0	0	0	0	0	1
	P318	7	3	1	9	15	9	44
	P319	3	0	1	1	0	0	5
3E	P327	0	0	0	0	1	0	1
	P330	0	0	3	1	2	1	7
	P331	0	1	1	0	0	2	4
	P332	0	0	0	0	1	0	1
	P333	0	0	2	1	1	1	5
	P334	5	2	3	8	9	8	35
	P335	2	2	3	3	3	1	14
	P336	0	1	0	0	0	0	1
	Total	46	65	78	89	97	82	457

Table A7: Number of commercial catch length samples by statistical area in PAU 4 2008–2013.

		2008	2009	2010	2011	2012	2013	Total
049	P403	0	0	0	1	0	0	1
	P404	0	0	0	0	2	0	2
	P405	3	0	2	4	14	11	34
	P406	4	1	2	3	13	6	29
	P407	0	0	0	5	6	0	11
	P408	0	1	0	3	7	1	12
	P409	1	3	3	3	3	2	15
	P410	1	4	2	2	5	2	16
	P411	0	0	5	7	12	1	25
	P412	0	0	4	6	6	6	22
	P413	0	0	0	0	1	2	3
	P414	0	1	2	3	10	6	22
	P415	2	9	3	7	11	6	38
	P416	3	5	5	5	9	15	42
	P417	1	0	0	0	1	2	4
050	P419	1	4	4	4	2	3	18
	P420	0	0	4	2	0	1	7
	P421	1	0	7	3	2	2	15
	P422	0	2	3	2	1	3	11
	P423	1	10	12	7	5	17	52
	P424	0	0	0	0	0	1	1
051C	P425	3	3	16	11	11	16	60
	P426	0	1	4	2	4	19	30
	P427	0	1	1	1	4	7	14
	P428	0	0	0	0	0	2	2
	P430	0	0	0	1	2	0	3
	P431	0	1	0	0	1	7	9
	P432	0	1	0	3	7	8	19
051P	P440	0	0	0	1	1	3	5
	P441	0	2	5	5	3	14	29
	P442	1	4	1	4	4	4	18
	P443	0	1	4	7	5	17	34
	P444	0	1	0	3	0	4	8
	P445	0	0	1	2	2	3	8
	P446	0	0	0	0	1	2	3
	P447	0	0	0	1	1	3	5
	P448	0	0	0	1	4	4	9
	P449	0	0	1	2	1	1	5
	P450	0	1	1	0	0	0	2
	P451	0	0	0	0	1	0	1
	P452	0	1	0	0	0	0	1
	P453	1	0	0	0	0	0	1
	P455	0	0	0	1	0	0	1
	P457	1	1	4	3	2	0	11
052	P402	0	2	2	4	7	1	16
	P433	0	0	1	0	9	11	21
	P434	1	0	4	5	14	15	39
	P435	1	1	4	9	18	5	38
	P436	0	0	6	5	11	5	27
	P437	3	0	5	10	14	1	33
	P438	0	0	0	2	2	2	6
	Total	29	61	118	150	239	241	838

APPENDIX 2: Tree- regression models on commercial catch samples for each QMA

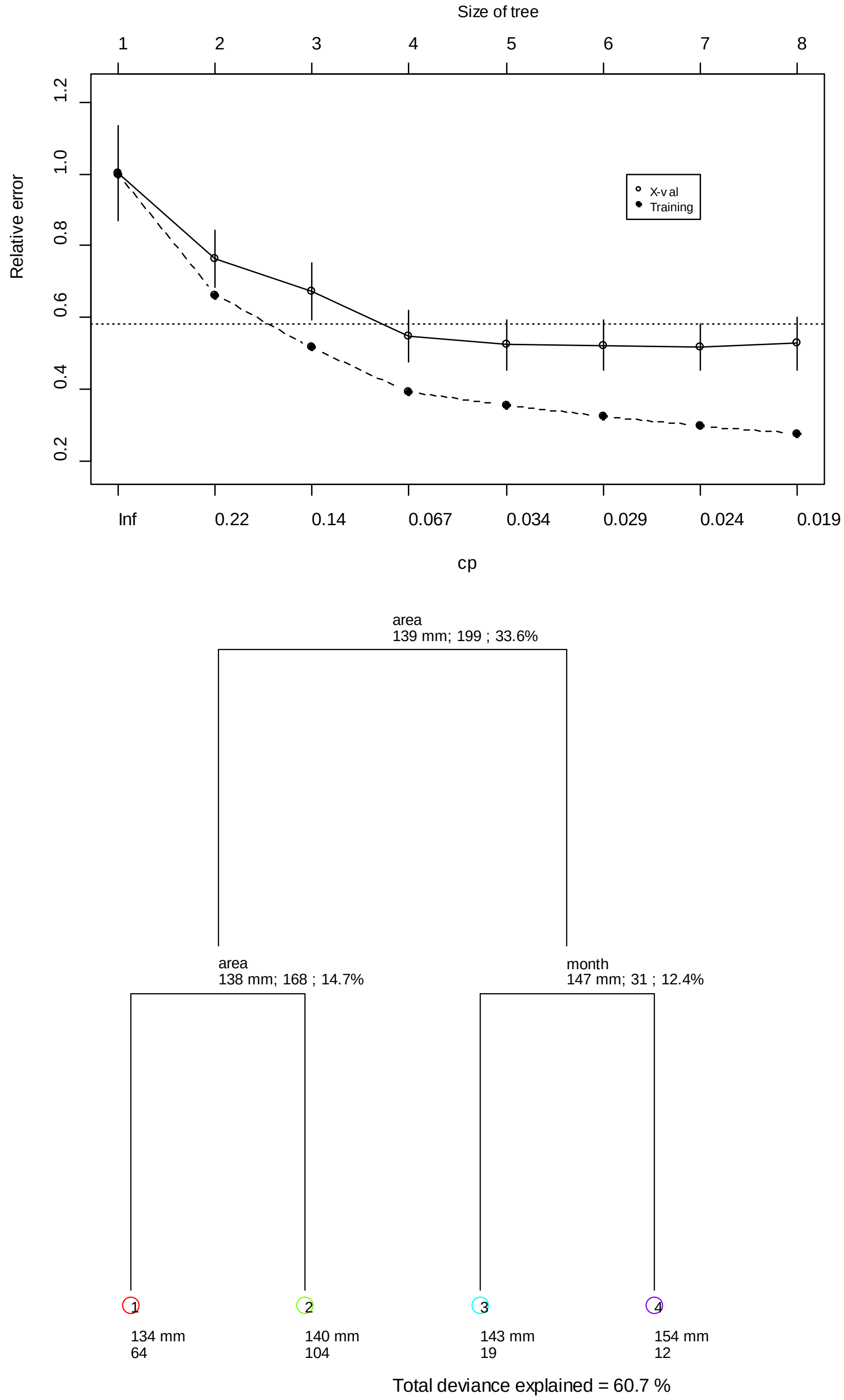

Figure B1: Stratifying the PAU 5A catch length samples from fishing years 2008–2013 using model 5A–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

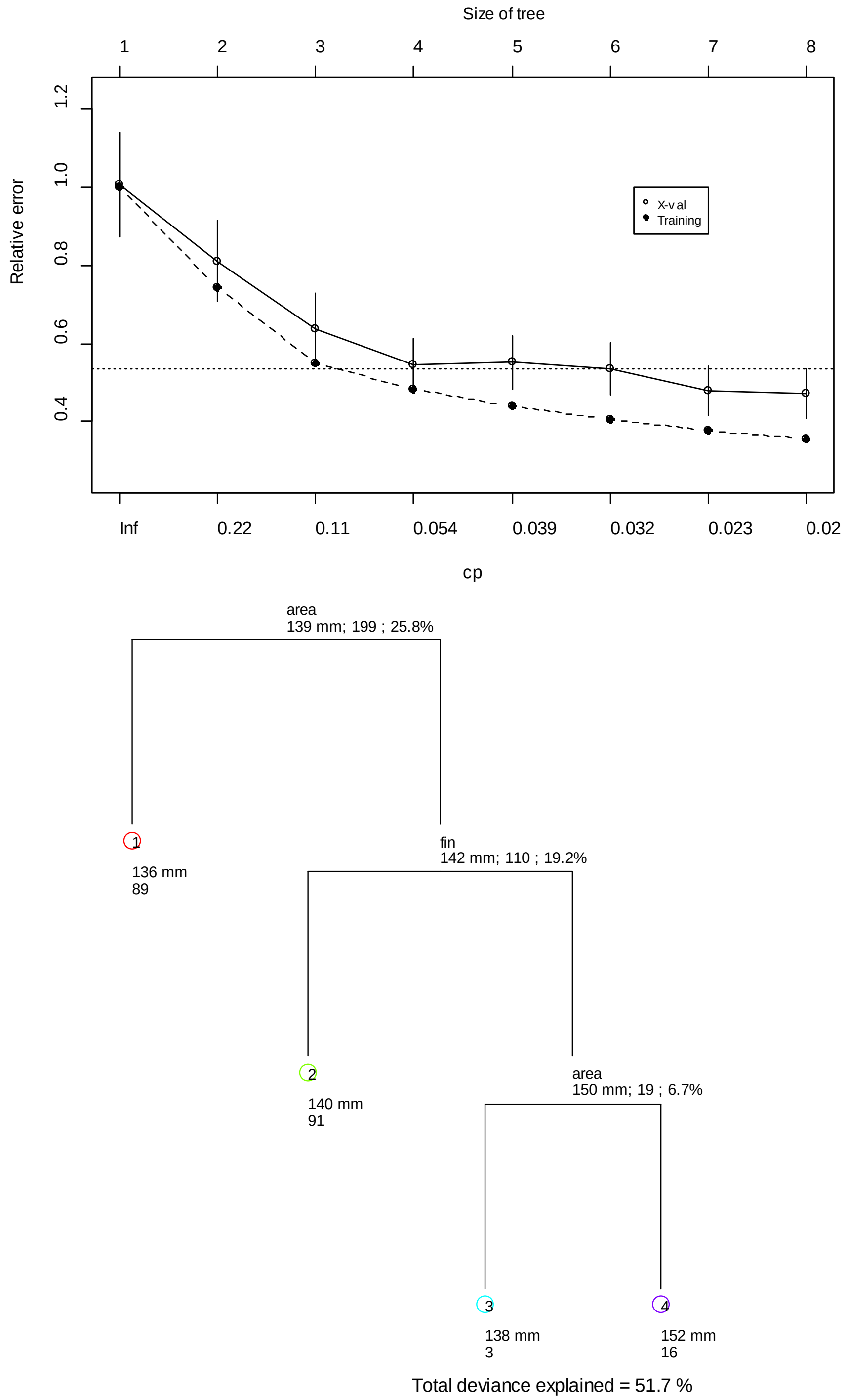

Figure B2: Stratifying the PAU 5A catch length samples from fishing years 2008–2013 using model 5A–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

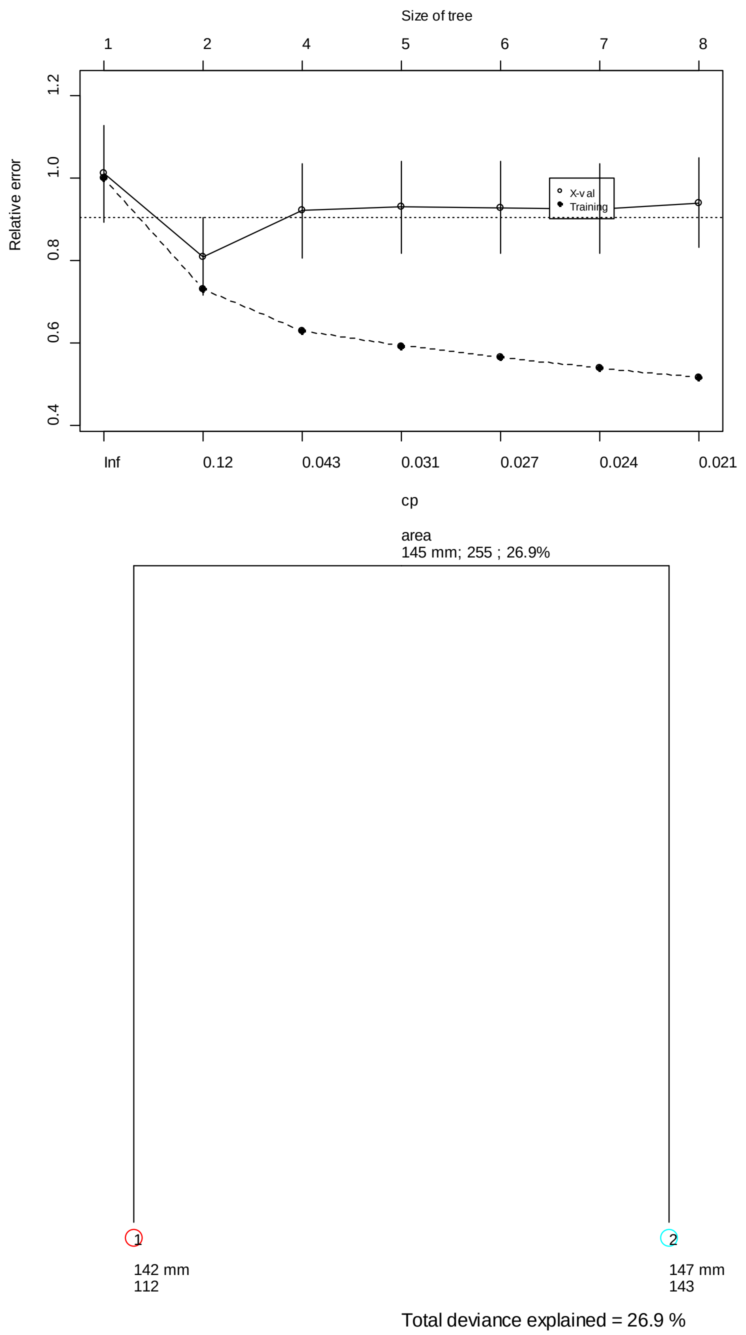

Figure B3: Stratifying the PAU 5B catch length samples from fishing years 2008–2013 using model 5B–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

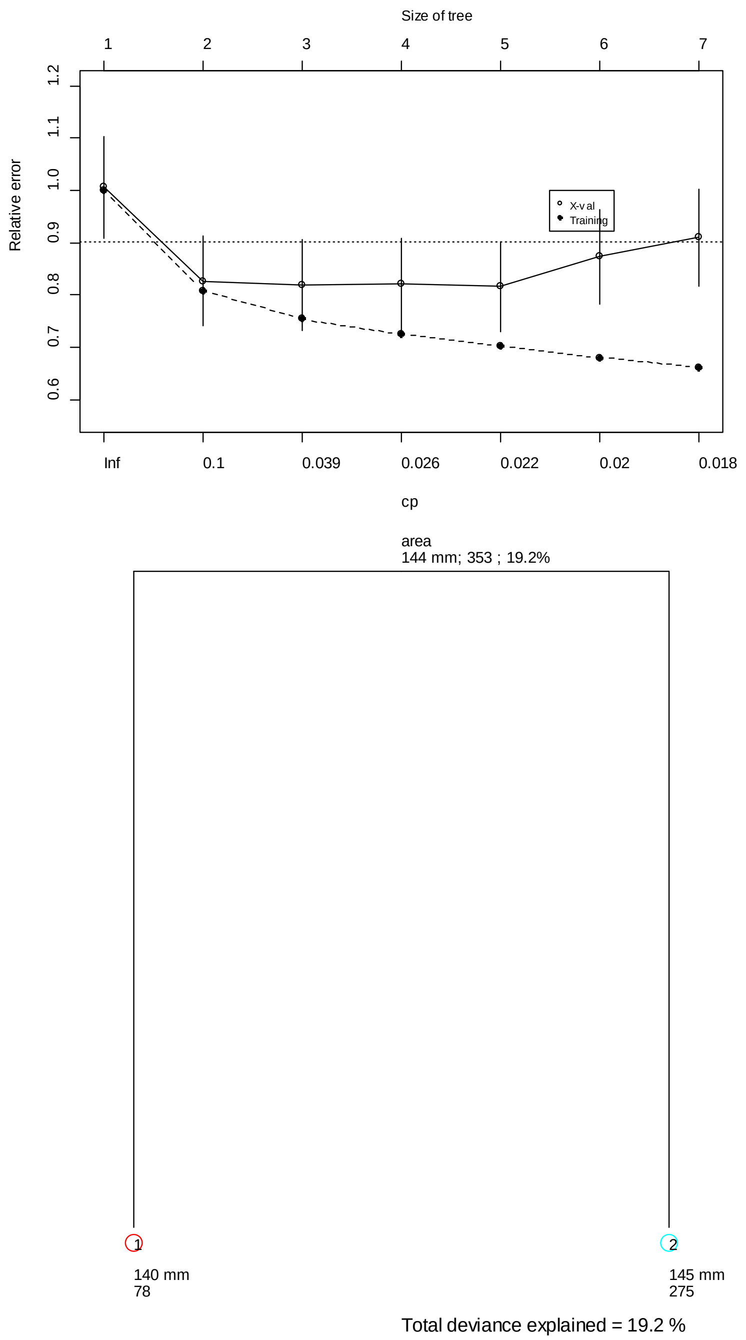

Figure B4: Stratifying the PAU 5B catch length samples from fishing years 2008–2013 using model 5B–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

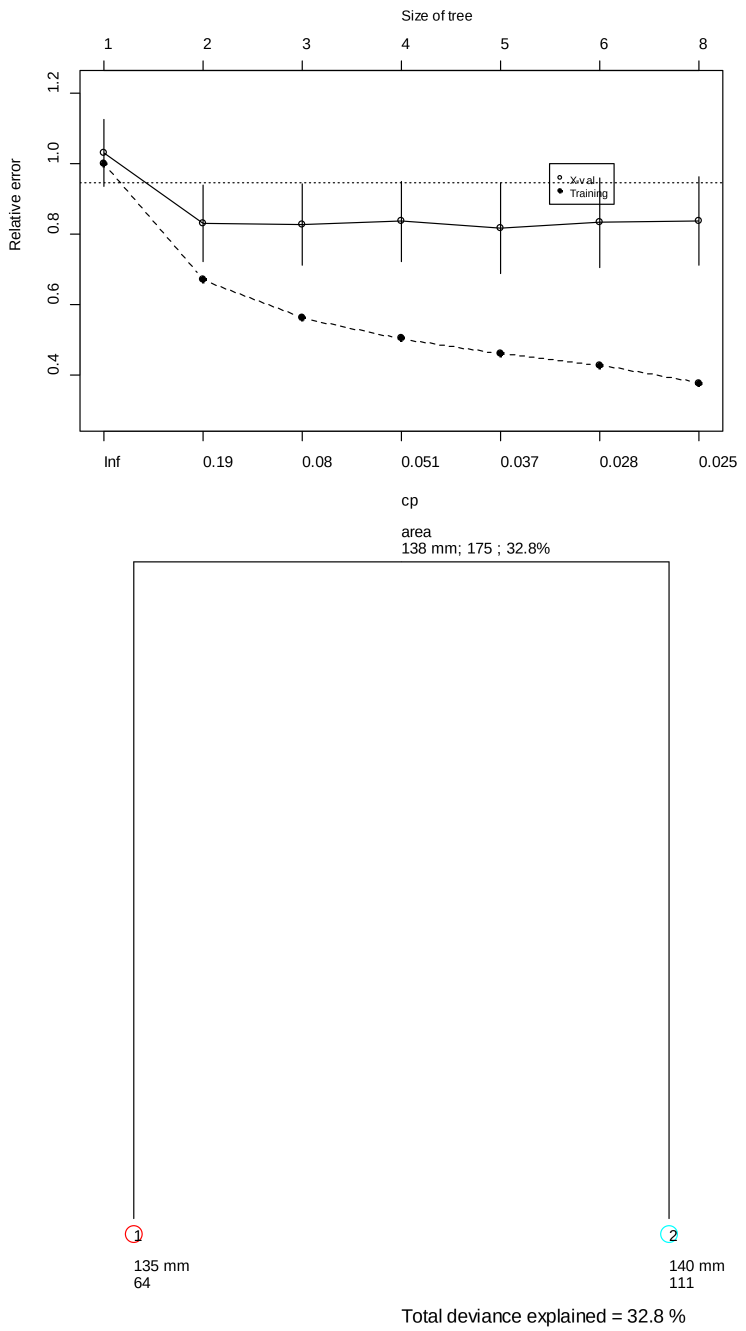

Figure B5: Stratifying the PAU 5D catch length samples from fishing years 2008–2013 using model 5D–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

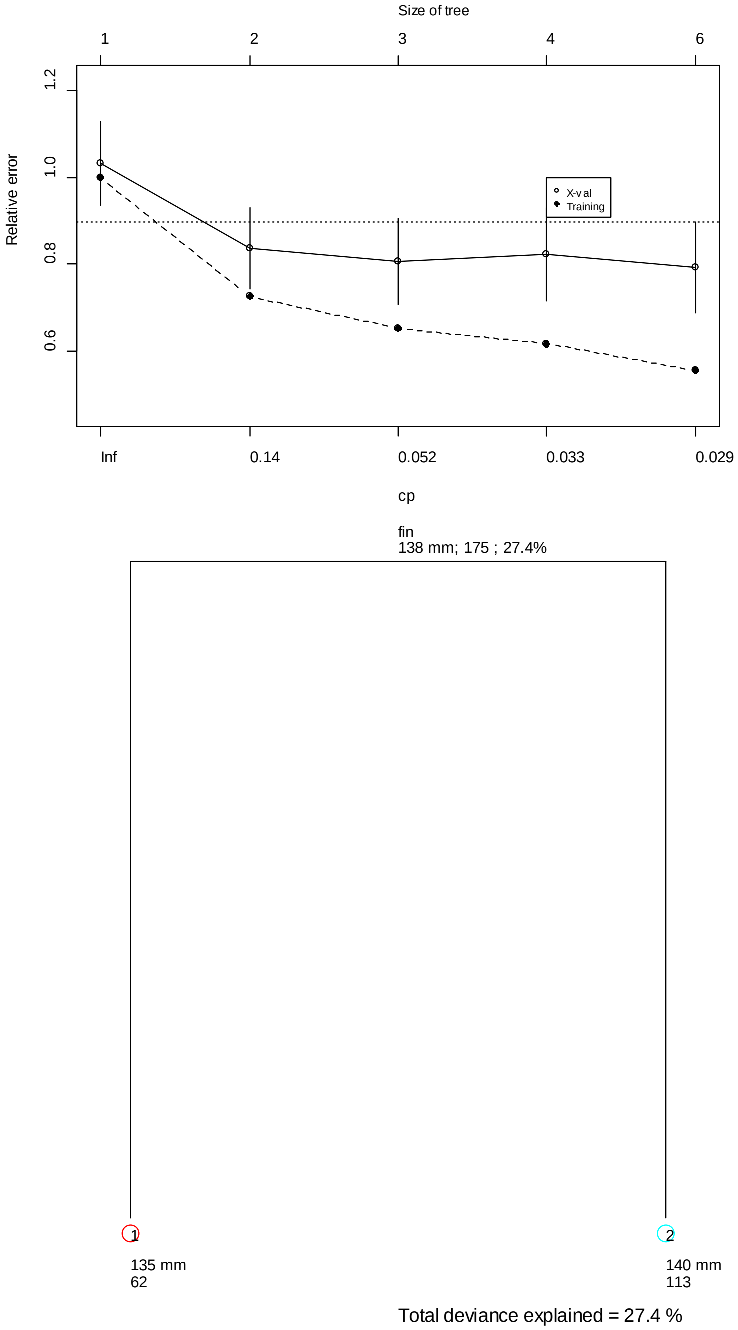

Figure B6: Stratifying the PAU 5D catch length samples from fishing years 2008–2013 using model 5D–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

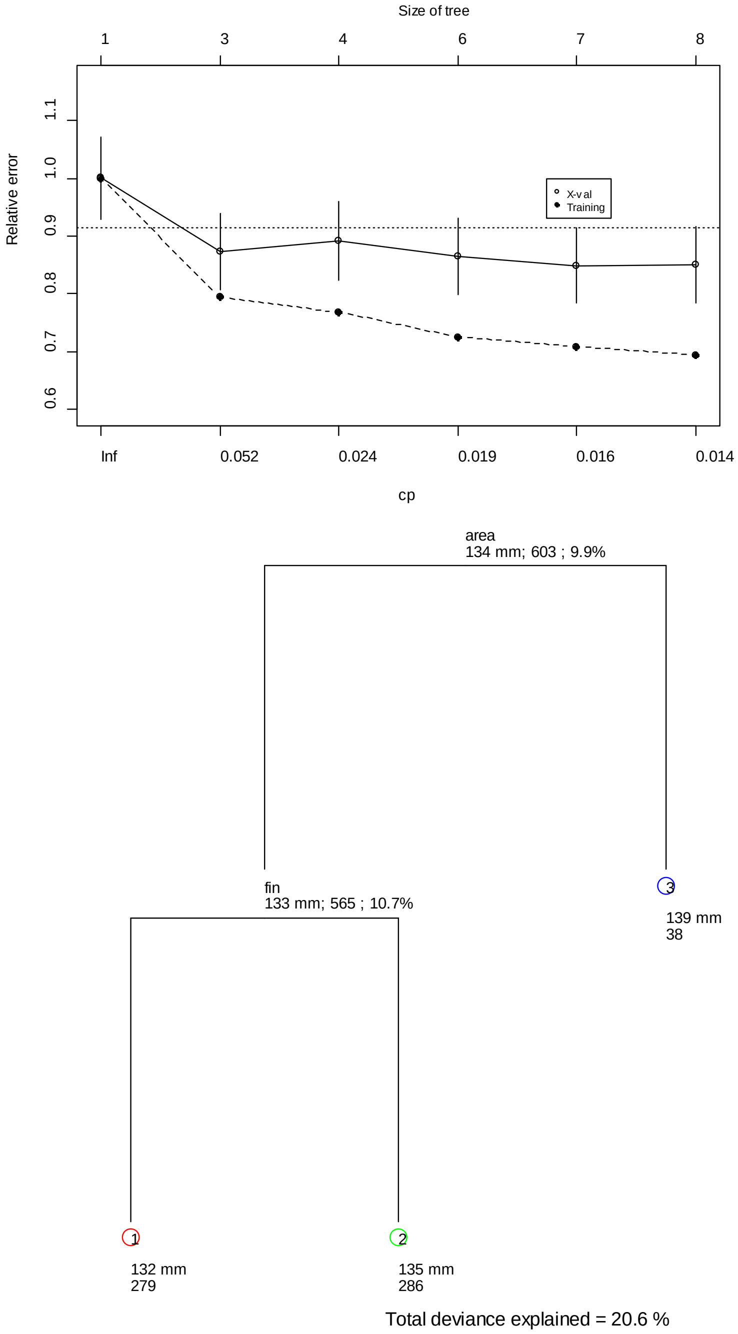

Figure B7: Stratifying the PAU 2 catch length samples from fishing years 2008–2013 using model 2–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

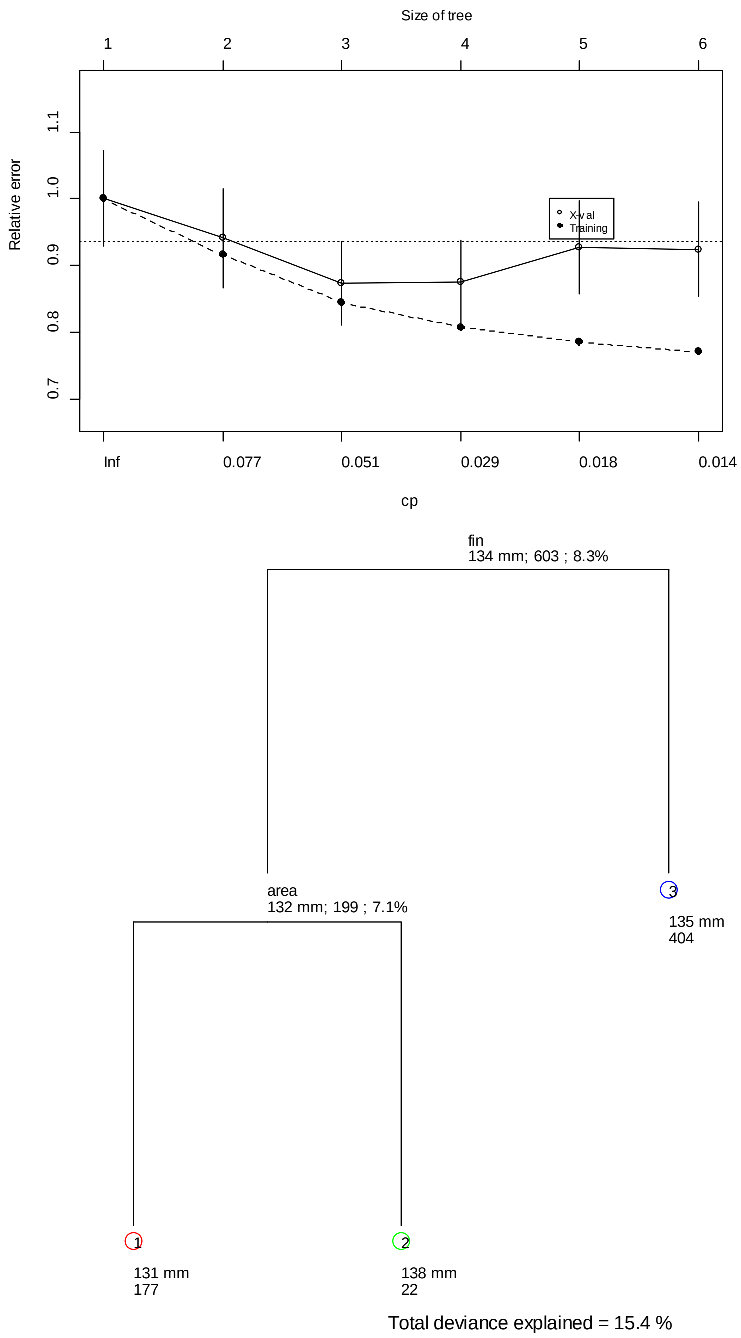

Figure B8: Stratifying the PAU 2 catch length samples from fishing years 2008–2013 using model 2–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

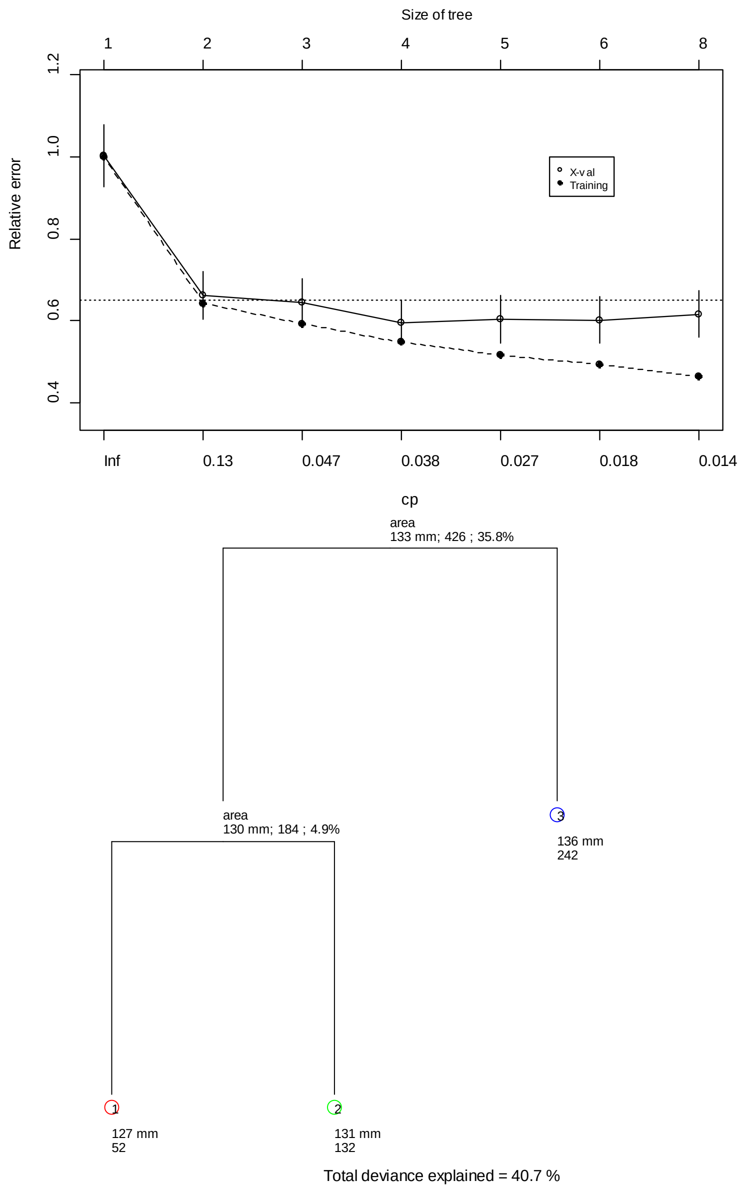

Figure B9: Stratifying the PAU 3 catch length samples from fishing years 2008–2013 using model 3–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

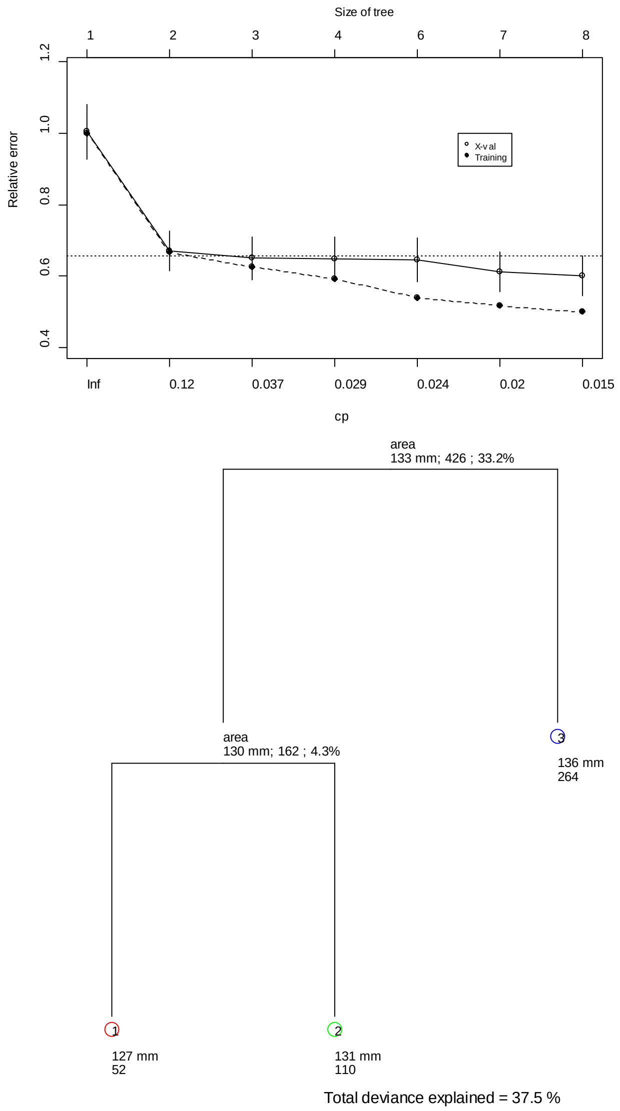

Figure B10: Stratifying the PAU 3 catch length samples from fishing years 2008–2013 using model 3–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

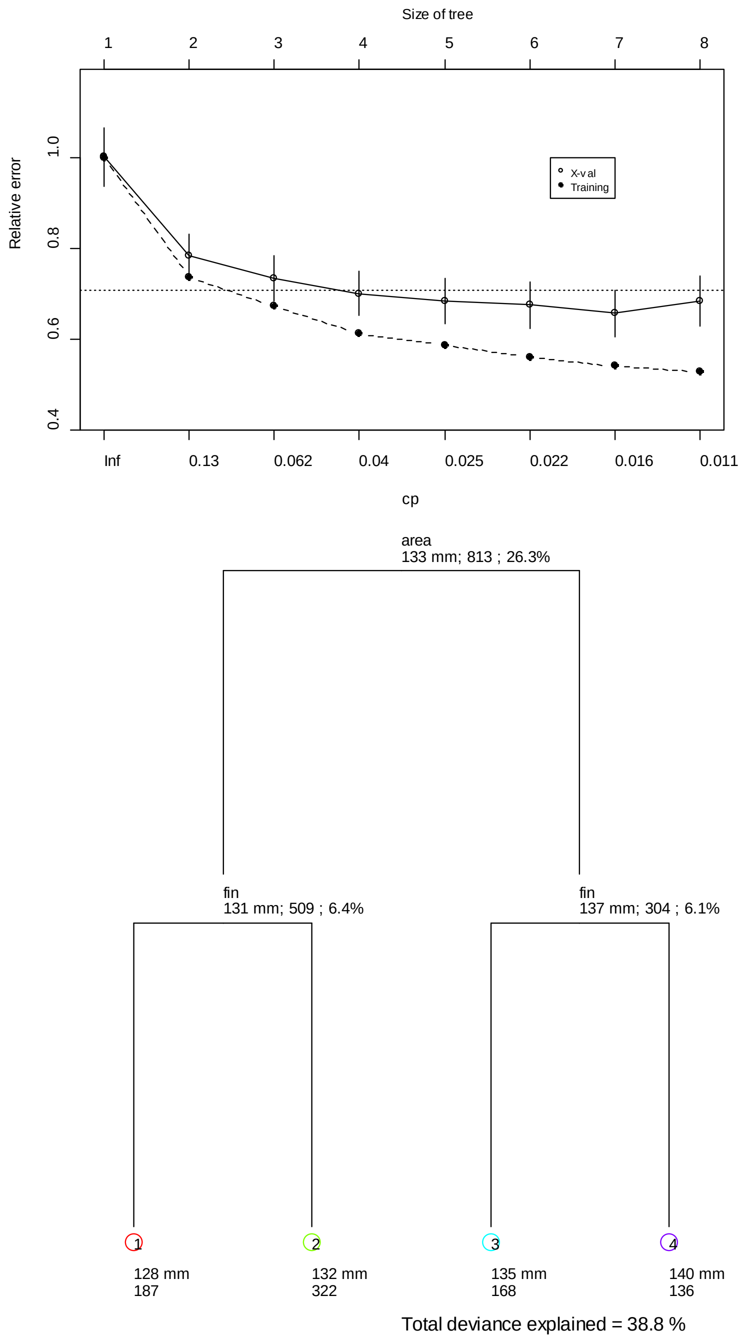

Figure B11: Stratifying the PAU 4 catch length samples from fishing years 2008–2013 using model 4–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

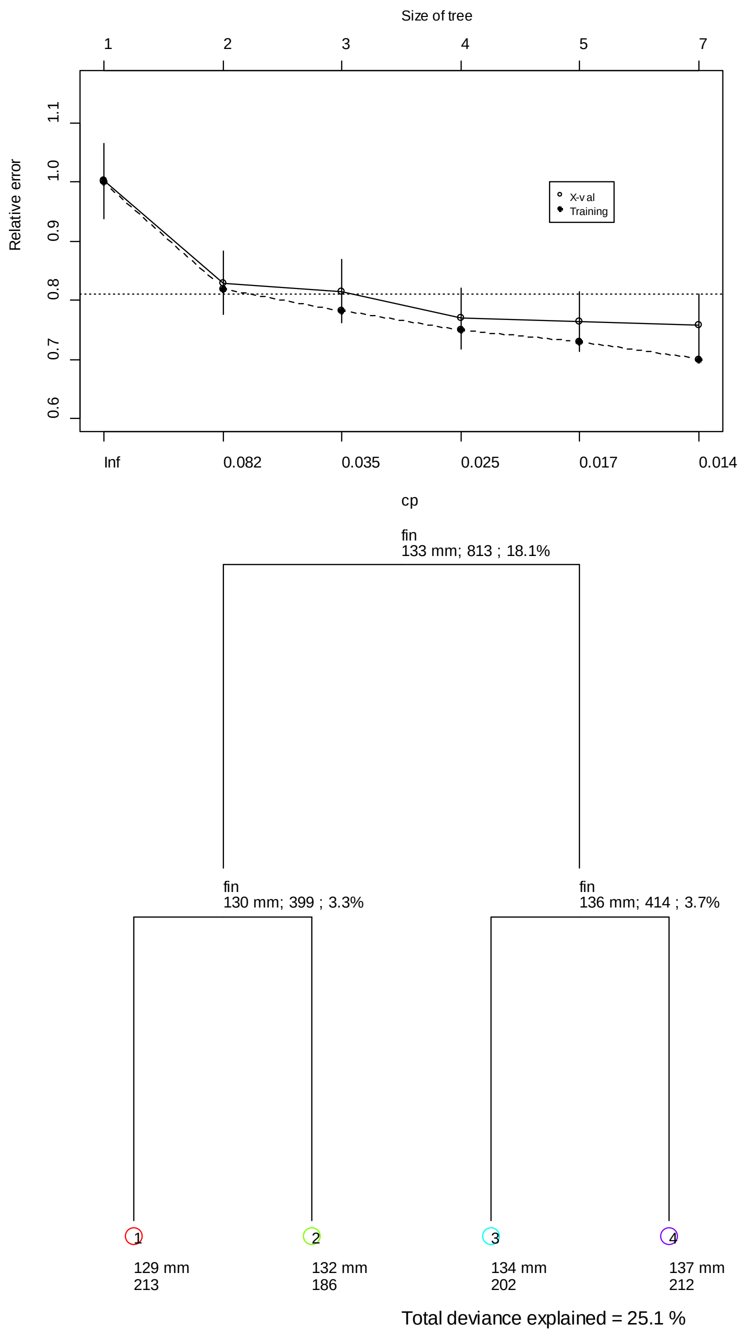

Figure B12: Stratifying the PAU 4 catch length samples from fishing years 2008–2013 using model 4–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

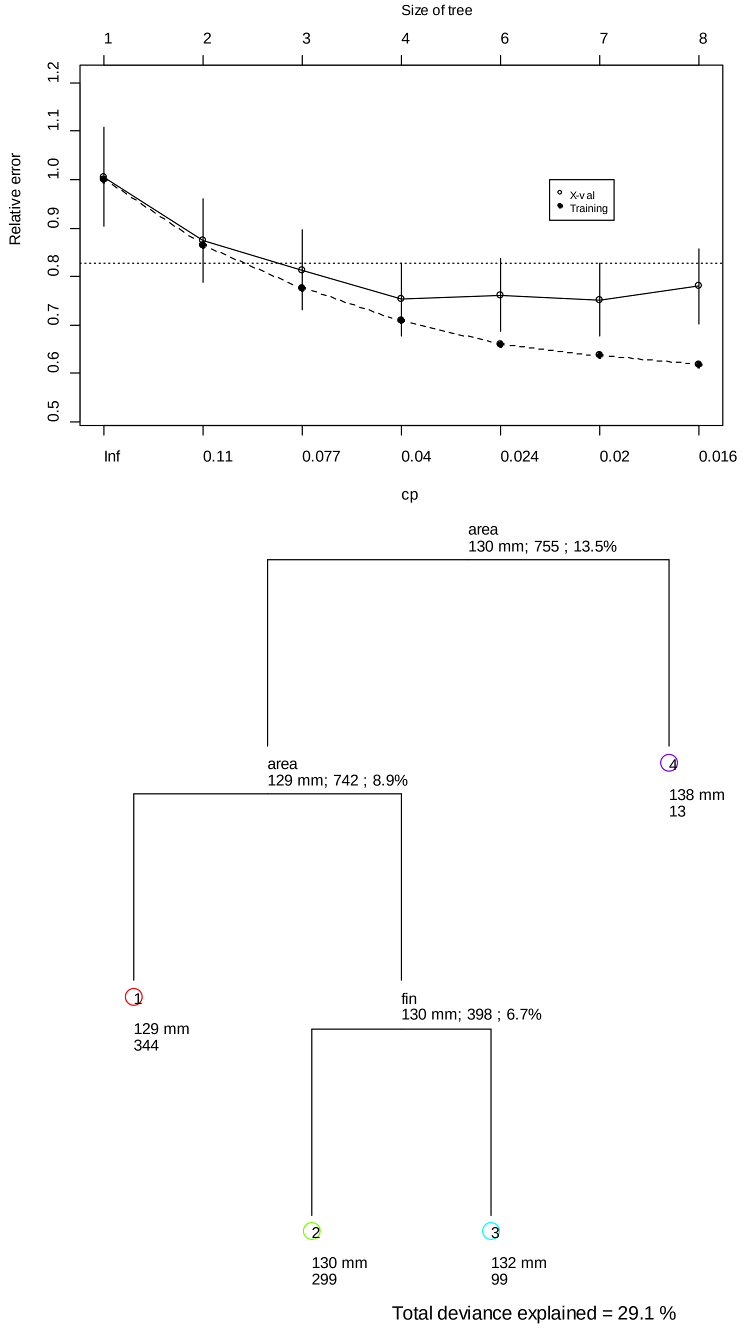

Figure B13: Stratifying the PAU 7 catch length samples from fishing years 2008–2013 using model 7–1. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

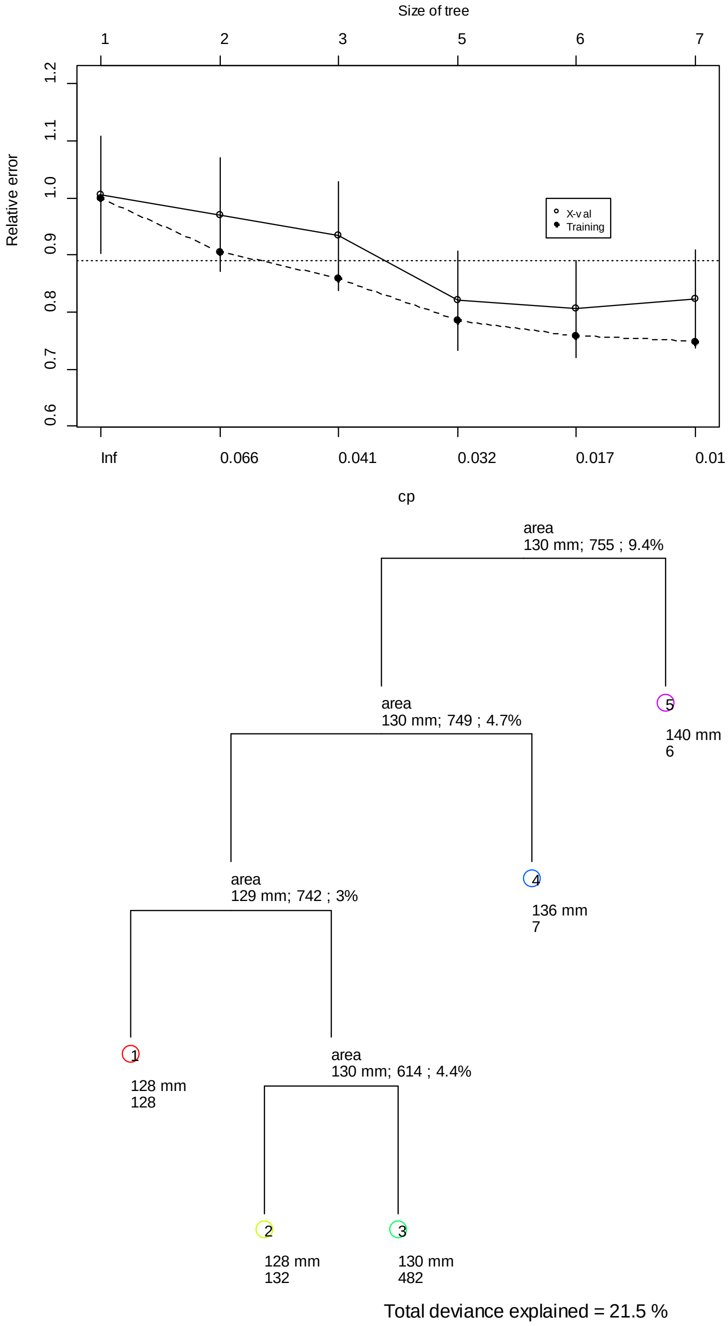

Figure B14: Stratifying the PAU 7 catch length samples from fishing years 2008–2013 using model 7–2. The upper panel gives the relative error from the 10-fold won-validation (solid line) and the dotted horizontal line is the minimum mean relative error plus 1 standard deviation. The dashed line is calculated relative error for the whole data set. The axis label cp refers to the complexity parameter value for each tree size. The lower panel is the dendrogram of the tree that gives the splitting variables selected in the stratification. The numbers in the non-terminal nodes (underneath the variable name) are: mean length, number of observations, and deviance explained. The circled numbers in the terminal node are the stratum numbers and the numbers underneath is the mean length. The split conditions are not shown here.

APPENDIX C: Voluntary minimum harvest size currently in place in some QMA

Table C1: Voluntary minimum harvest size placed on each of the management zones in PAU 5A since October 2006.

Zones	Milford	George	Central	Dusky	Chalky	South Coast
Statistical Area	F01– F06	F07 –F14	F15– F25	F26 – F33	F34 – F38	F39 – F49
MHS (mm)	125	127	130	130	130	130

Table C2: Voluntary minimum harvest size placed on each of the management zones in PAU 5D since October 2006.

Zones	North of Moeraki Boulders to PAU 3 boundary	Warrington Beach North to Moeraki Boulders	Warrington Beach South to PAU 5A boundary
Statistical Area	H44 – H47	H38 – H43	H37 – H1
MHS (mm)	125	127	130

Table C3: Voluntary minimum harvest size placed in PAU 7 since October 2006.

Zones	Kahurangi Point to Cape Farewell	Wairau River to Clarence River	Ocean Bay and Robin Hood Bay	Other parts of PAU 7
MHS (mm)	130	130	127	125

Table C4: Voluntary minimum harvest size placed in PAU 3 for 2012–13**.**

Statistical Area	301–303	304	305–306	307, 308, 311	309, 310	312–317	318	319–339
MHS (mm)	130	125	127	127	130	125	127	125