Ministry for Primary Industries
Manatū Ahu Matua

Indicator based analysis of the status of eight shark and chimaera species in New Zealand waters

New Zealand Fisheries Assessment Report 2016/65

M. P. Francis
J. Roberts
D. J. MacGibbon

ISBN 978-1-77665-437-6 (online)
ISSN 1179-5352 (online)

December 2016

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

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

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

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

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Francis, M. P.; Roberts, J.; MacGibbon, D. J. (2016). Indicator based analysis of the status of eight shark and chimaera species in New Zealand waters.

***New Zealand Fisheries Assessment Report 2016/65.* 87 p.**

Cartilaginous fishes generally have low productivity because of their low to moderate growth rates, and their low fecundity. Despite their vulnerability to over-fishing, a lack of suitable data means that conventional stock assessments are rarely possible. To address that limitation, this report performs indicator analyses for eight shark and chimaera species: carpet shark (*Cephaloscyllium isabellum*), Baxter's dogfish (*Etmopterus granulosus*), seal shark (*Dalatias licha*), longnose velvet dogfish (*Centroselachus crepidater*), Plunket's shark (*Scymnodon plunketi*), leafscale gulper shark (*Centrophorus squamosus*), shovelnose dogfish (*Deania calcea*), and longnose spookfish (*Harriotta raleighana*). These species were identified as being at high risk from commercial fisheries by a recent qualitative risk assessment analysis that classified all New Zealand species of cartilaginous fishes. The main data sources used were the Ministry for Primary Industries' commercial catch-effort database, observer database, and research trawl database. The following indicators (with data sources in parentheses) were calculated:

- relative biomass (trawl surveys);
- median shark length (trawl surveys);
- proportion of male sharks (trawl surveys);
- distribution (proportion of half-degree rectangles having unstandardised catch per unit effort (CPUE) greater than a specified threshold, and the proportion of half-degree rectangles having zero reported catches in a fishing year) (commercial catch-effort data);
- species composition (percent composition of catch and proportion of zeroes) (commercial catch-effort data);
- concentration (a measure of whether fishing effort focuses on or avoids areas of high shark abundance) (commercial catch-effort data);
- nominal and standardised CPUE (commercial catch-effort and observer data).

Data limitations meant that not all indicators could be applied to each species, and for some species only one indicator (trawl survey biomass) could be applied. For carpet shark, indicators were available for FMAs 2, 3, 5, 7 and 8, areas that are covered by inshore trawl surveys or that support the larger inshore fisheries. For the remaining seven deepwater species, most of the indicators were developed for FMAs 3–6, reflecting the availability of trawl survey series, and larger quantities of commercial and observer data, from those regions. No indicators were available for any species from FMAs 1, 9 and 10.

Seal shark: Trawl survey and commercial trawl abundance indicators produced conflicting results. The status of seal shark in FMAs 3–6 is uncertain. The fishery-independent trawl survey indicators suggest that there has been no major change over a long period of time in the abundance of juvenile seal shark. Adult seal sharks are not well monitored by the surveys.

Shovelnose dogfish: Most indicators showed no significant recent trends in FMAs 3–7, but conflicting signals make interpretation difficult. Trawl survey indicators suggest that there is no immediate concern for shovelnose dogfish in FMAs 3–6, but male median length and standardised observer CPUE should be monitored closely in future for signs of ongoing decline.

Baxter's dogfish: Only indicators derived from trawl surveys in FMAs 3–6 were available. No trends were found in any indicators.

Longnose velvet dogfish: Only indicators derived from trawl surveys in FMAs 3–6 were available. No trends were found in any indicators. However, Chatham Rise surveys monitor this species poorly (coefficient of variation (CV) of biomass estimates greater than 40%).

Plunket's shark: The only indicators available were trawl survey relative biomass, which showed no trends in FMAs 3–6. However both surveys monitor this species poorly (CV of biomass estimates greater than 40%).

Leafscale gulper shark: The only indicators available were trawl survey relative biomass, which showed no trends in FMAs 3–6. However, Chatham Rise surveys monitor this species poorly (CV of biomass estimates greater than 40%).

Longnose spookfish: Only indicators derived from trawl surveys in FMAs 3–6 were available. The Chatham Rise survey indicated an up/down biomass trajectory in FMAs 3 and 4, and relative biomass in the 2010s was similar to that in the early 1990s. There was no trend in the Sub-Antarctic survey (FMAs 5 and 6). There was a down/up trend in the median length of males in FMAs 3 and 4, indicating a decrease in the proportion of juvenile males. This trend should be monitored carefully for ongoing signs of poor recruitment.

Carpet shark: Most indicators showed either no trend or an increase. Carpet shark may have increased in abundance in FMAs 2, 3, 7 and 8, and declined in FMA 5; the latter should be monitored closely for further evidence of a decline.

None of the species covered by this study showed clear and consistent evidence of recent declines in abundance. However, estimated trends were often uncertain, inconsistent among indicators, based on indicators that may be unreliable (e.g. trawl survey biomass estimates for species that are not well surveyed), and based on too few indicators (only trawl survey indicators were available for five out of eight species). For a number of species, one or more indicators showed signs of decline, and ongoing monitoring is recommended. This is especially true for the deepwater shark species, which are known to have low productivity and to be especially vulnerable to intensive fishing effort. Our results suggest that the species covered in this study have not suffered major declines, despite their being classified as being at high risk from fishing in a recent risk assessment(Ford et al. 2015).

The utility of indicator analyses could be greatly enhanced in future through improvements in data quality and quantity, exploring different spatial (and possibly temporal) scales, and modifying or extending the indicator analyses. Specific recommendations are made to enable these improvements. Some indicators were derived from relatively short time series and their value will increase substantially through time.

1. INTRODUCTION

Cartilaginous fishes (sharks, skates, rays and chimaeras) generally have low productivity because of their low to moderate growth rates, and their low fecundity which results from small litter sizes and long (frequently multi-year) reproductive cycles. About 112 cartilaginous species occur in New Zealand waters (Roberts et al. 2015), of which 11 are managed under the Quota Management System (QMS) as 27 management units or "stocks". The status of these stocks is poorly understood. A full quantitative stock assessment, integrating information on catch, catch rates, age, and length data into an assessment model, is available for only one of the 27 management units (rig in SPO 7) (Ministry for Primary Industries 2014, 2015). Less data-intensive assessments using standardised catch-per-unit-effort (CPUE) analyses are available for 20 stocks of 7 QMS species (Ministry for Primary Industries 2016).

Recognizing the data-poor nature of many of the world's shark fisheries, scientists have developed alternative methods for assessing threats to the sustainable utilisation of chondrichthyan resources. These methods have the advantage of being more forgiving of data gaps, less reliant on assumptions structuring population dynamics, and more readily updated than traditional stock assessments. One type of approach has involved various forms of ecological risk assessment (Ford et al. 2015). Another approach is to apply a series of stock status indicators to assess the response of the population to fishing pressure. Such indicators are usually straightforward to compute (except for standardised CPUE) and track over time, thus providing the opportunity to observe trends which can serve as signals of overexploitation. Interpreted as a suite, indicators of stock status can be useful for initial assessments and/or for prioritising future data collection or analytical work (Clarke et al. 2013).

Recently, a series of stock status indicators was developed for three highly migratory pelagic shark species (blue shark *Prionace glauca*; porbeagle shark *Lamna nasus*; and shortfin mako shark *Isurus oxyrinchus*) in the New Zealand Exclusive Economic Zone (EEZ) (Francis et al. 2014). Five types of indicators were developed for each species: distribution, percentage species composition, standardised CPUE, median size, and sex ratio. The present project conducts indicator analyses on eight further chondrichthyans (seven sharks and one chimaera) using the same five types of indicators, plus three additional indicators (unstandardised CPUE, research trawl abundance and concentration). These indicators are developed as annual time series and assessed for their utility in describing trends in stock abundance or status. The indicators can be updated at regular intervals in the future to monitor changes in population status in response to fishing and other impacts, and existing and new management measures.

The Research Objectives of this study were:

1. To monitor trends in indicators of abundance for selected high-risk non-QMS sharks or skates using any available trawl survey data, commercial catch effort and landings data, or observer data.
2. To make recommendations for observer or research trawl recording that could enable low-cost indicators of abundance to be used more in the future to monitor trends in selected high-risk non-QMS sharks or skates.

2. GENERAL METHODS

The eight species analysed in this study were non-targeted species identified as being at high risk from commercial fisheries by a recent qualitative risk assessment analysis that classified all New Zealand species of cartilaginous fishes (Ford et al. 2015). They are carpet shark (CAR, *Cephaloscyllium isabellum*), Baxter's dogfish (ETB, *Etmopterus granulosus*), seal shark (BSH, *Dalatias licha*), longnose velvet dogfish (CYP, *Centroselachus crepidater*), Plunket's shark (PLS, *Scymnodon plunketi*), leafscale gulper shark (CSQ, *Centrophorus squamosus*), shovelnose dogfish (SND, *Deania calcea*), and longnose spookfish (LCH, *Harriotta raleighana*).

The eight types of indicators used in this study are described below (Sections 3−8). Median size and sex ratio were combined in one section because they are derived from the same stratified scaling of trawl survey length measurements. Unstandardised and standardised CPUE analyses were also combined into one section because the latter is an extension of the former. The scope of the study is New Zealand-wide, but we focus on specific Fisheries Management Areas (FMAs; Appendix 1) where the availability of data or the distribution of fisheries render EEZ-wide analyses inappropriate.

The main data sources used for this study were the Ministry for Primary Industries (MPI) catch-effort database *warehou*, the MPI observer database *COD* and the MPI research *trawl* database. Data were extracted from all databases and constrained as required to periods containing sufficient data for analysis (detailed below). Hereafter, all years are reported as fishing years (1 October to 30 September), and they are labelled after the second of the two years (e.g. 2004−05 is referred to as 2005). Our analyses are restricted to bottom trawl and the inshore set net data, as these fishing methods take most of the reported catch of the species of interest.

The significance of any temporal trend in an indicator was assessed using a randomisation test of the ranks of the indices (O'Driscoll et al. 2011). Each indicator series was divided into two or three consecutive time periods (see sections below for details) and the mean rank of the indices within each time period was calculated. These mean ranks were then compared with a test statistic calculated from the 2.5th and 97.5th percentiles of a random arrangement of 1000 samples of the ranks across the whole indicator series. That is, the pattern of actual ranks among time periods was compared with the distribution of ranks chosen randomly from the whole time series (without replacement). If the mean rank within a specific time period fell below the 2.5th percentile or above the 97.5th percentile, the period in question was deemed to have had significantly lower or higher biomass respectively than one or more other time periods. Significance patterns across a time series were accordingly used to score trends in indices as increasing, decreasing, increasing-then-decreasing, decreasing-then-increasing, or no-clear-trend (see O'Driscoll et al. 2011, figure 2, for an illustration of this procedure).

3. RESEARCH TRAWL ABUNDANCE

3.1 INTRODUCTION

Research trawl surveys have been used worldwide to estimate the relative abundance of demersal fish species for decades. In New Zealand, trawl survey abundance estimates are routinely generated for QMS fish species from series of surveys carried out at the same time of year in specific regions, and then used in stock assessments for those species (Ministry for Primary Industries 2015). Abundance estimates are obtained using a stratified random trawling design (Francis 1981, 1984). Relative biomass is estimated by calculating the density of fish in each trawl tow (catch weight divided by area swept by the trawl doors), estimating the overall mean density for all tows, and then scaling the mean density estimate up to the area of seabed in the survey region (Francis & Fu 2012). Survey stratification and allocation of stations to strata are optimised to generate biomass estimates with the lowest possible CVs for the target species. Such optimisation will not necessarily produce low CVs for non-target species, which are the subject of the present study.

For trawl survey abundance estimates to be valid, they must accurately track year-to-year variations, and therefore must consistently sample the same component of the population. They should also survey a significant part of the stock's geographical range to guard against inter-annual variation in the distribution of fish. The usefulness of a time series of surveys depends on the length of the series, the variance of the biomass indices, the availability (vertical and areal) and vulnerability of the stock to the survey technique and whether these are constant among years (Beentjes & Stevenson 2001), and whether the survey optimisation is appropriate for the species of interest. Variations in catchability are known to occur in some survey series, as indicated by multiple species having extreme biomass estimates in the same survey year(s) (Beentjes & Stevenson 2001; Francis et al. 2001; Beentjes et al. 2004). Nevertheless, as these time series become longer, short-term fluctuations in catchability become less important in relation to identifying long-term trends in abundance.

Current trawl survey series that can potentially generate time series of relative biomass estimates for non-QMS chondrichthyan species are carried out on the Chatham Rise (CHAT, FMAs 3 and 4), Sub-Antarctic (Campbell Plateau and Stewart–Snares Islands Shelf) (SUBA, FMAs 3, 5 and 6), east coast South Island (ECSI, FMA 3), and west coast South Island (FMA 7) (Beentjes & Stevenson 2000; Stevenson & Hanchet 2000; Beentjes & Stevenson 2001; O'Driscoll et al. 2011; Bagley et al. 2013). Relative biomass estimates for some of the species of interest on the Chatham Rise and Sub-Antarctic were previously presented for the period up to 2005 or 2006 by Blackwell (2010) and 2009 or 2010 by O'Driscoll et al. (2011), Parker & Francis (2012) and Bagley et al. (2013). However, such biomass estimates may not be considered reliable for a variety of reasons, including when the survey area does not cover the full habitat range of the species, and when CVs frequently exceed 40% (O'Driscoll et al. 2011; Bagley et al. 2013).

3.2 METHODS

Details of the trawl survey series used to generate time series of relative abundance estimates are shown in Table 1. Further details of the trawl survey series and the trawling methodology are provided by the sources cited in Section 3.1. For all survey series, biomass estimates were made for a set of core strata that were sampled during every survey. For three survey series additional strata were added part-way through the time series and were sampled regularly thereafter; therefore biomass estimates were also calculated for the core plus additional strata for years in which the latter were sampled. For ECSI, the additional strata were in shallow water inside the core survey area; for CHAT the additional strata were in deeper water on the northern Chatham Rise; and for SUBA the additional strata were in deeper water on the northern Campbell Plateau.

Table 1: Details of trawl survey series used for the estimation of relative biomass. The Sub-Antarctic survey area encompasses only a small fraction of FMA 3 and is therefore regarded as a survey of FMAs 5 and 6.

Region	Vessel	FMAs	Species	Time of year	Strata	Years	Depth range
East coast South Island (ECSI)	*Kaharoa*	3	CAR	May–Jun	Core	1991–94, 1996, 2007–09, 2012, 2014	30–400 m
					Shallow	2007, 2012, 2014	10–30 m
West coast South Island (WCSI)	*Kaharoa*	7	CAR	Mar–Apr	Core	1992, 1994–95, 1997, 2000, 2003, 2005, 2007, 2009, 2011, 2013, 1015	20–400 m
Chatham Rise (CHAT)	*Tangaroa*	3, 4	BSH, CSQ, CYP, ETB, PLS, SND, LCH	Dec–Feb (mainly Jan)	Core	1992–2014*	200–800 m
					Deep	2010–14	800–1,000 m
Subantarctic (SUBA)	*Tangaroa*	3, 5, 6	BSH, CSQ, CYP, ETB, PLS, SND, LCH	Nov–Dec	Core	1991–93, 2000–09, 2011–12, 2014	300–1,000 m
					Deep	2000–09, 2011–12, 2014	800–1,000 m

* Year in which the January part of survey fell.

Relative biomass was estimated using the NIWA custom software *SurvCalc*, a C++ computer program developed in 2008 which analyses data from stratified random surveys (Francis & Fu 2012). Its primary purpose is to estimate biomass and/or length frequencies, and associated CVs from survey data. *SurvCalc* extracts data from the *trawl* database for all stations on these surveys which fulfil the criteria for 'biomass' tows (i.e., daylight tows with the standard bottom trawl where gear performance was satisfactory). Data were extracted from *trawl* and analyses run in December 2015.

Sharks frequently school by size and sex, and the habitats and distribution of these sub-populations may be quite different. It is therefore important to assess trends in sub-population abundance wherever possible, in case the effects of fishing are more intense on one sex or one size group than on others. Consequently we estimated relative biomass separately for males and females where possible. Sharks caught on trawl surveys were often measured and sexed from 2002 onwards (2001 for shovelnose dogfish) (Appendix 2). Sufficient length and sex measurements were available for Baxter's dogfish, longnose velvet dogfish, shovelnose dogfish and longnose spookfish (CHAT only) to permit estimation of biomass by sex. Carpet shark measurements were too few for biomass estimation by sex (67 sharks were measured and sexed in the ECSI series; 730 were measured and sexed in the WCSI series, but most of them came from one survey).

Regression relationships between shark length and weight are required in order to estimate sex-specific biomass and scaled length-frequency distributions in trawl surveys (Francis & Fu 2012). Analyses of covariance (ANCOVAs) were conducted in *R* (R Development Core Team 2008) to test for differences in the parameters of the length-weight relationships by sex. For carpet shark, data from both ECSI and WCSI surveys were combined because there were too few ECSI data to analyse separately. Of the 15 species-survey combinations (seven species covered by two survey series and one species covered by the combined ECSI/WCSI surveys), 12 combinations had significant differences between the regression slopes ($p < 0.001$) and one additional combination had a significant difference between the regression intercepts. Females start growing heavier than males of the same length at about the time they reach sexual maturity. The two non-significant combinations were attributable to small sample sizes or the small length range of sharks (a paucity of adults). Consequently, length-weight differences between the two sexes are the norm for sharks. We therefore conducted two sets of biomass estimations:

1. Total biomass estimates for both sexes combined. Length-weight regression parameters are not required for these analyses.

2. Sex-specific biomass estimates for each survey series from 2002 onwards using sex-specific length-weight parameters calculated from all surveys within a series (see Appendix 3). These estimates were made only for species having adequate length and sex data (CYP, ETB, SND, and LCH (CHAT only)).

The temporal spans of the time periods used for the randomisation tests were selected to be as equal as possible, subject to the requirement that large gaps between surveys were not incorporated within a period (Table 2). A large gap occurred between 1996 and 2007 in the ECSI series. Another large gap between 1993 and 2000 in the SUBA series was avoided by omitting the three SUBA surveys in the early 1990s from the randomisation test. This also allowed us to use the core-plus-deep strata for the test, which was important for species having a considerable proportion of their biomass in the deep strata (see Section 3.3).

Table 2: Groups of years used to define time periods for the randomisations tests for trawl survey trends in biomass.

Region	Strata	Period	Years	No. of surveys
East coast South Island (ECSI)	Core	Group 1	1991–96	5
		Group 2	2007–14	5
West coast South Island (WCSI)	Core	Group 1	1992–97	4
		Group 2	2000–07	4
		Group 3	2009–15	4
Chatham Rise (CHAT)	Core	Group 1	1992–99	8
		Group 2	2000–07	8
		Group 3	2008–14	7
Sub-Antarctic (SUBA)	Core + Deep	Group 1	2000–04	5
		Group 2	2005–09	5
		Group 3	2011–14	3

3.3 RESULTS

Relative biomass estimates for seven sharks and one chimaera in four trawl survey series are shown in Figures 1–6. Where available, estimates are shown for core-plus-deep or core-plus-shallow strata in addition to estimates for the core strata. Some species were poorly monitored by one or more survey series for a variety of reasons (see Section 3.4 for further discussion). Sex-specific biomass estimates are shown for a subset of species in Chatham Rise and Sub-Antarctic survey series in Figures 4 and 6. The results of randomisation tests of the temporal patterns in the biomass indices are shown in Appendix 4A.

East coast South Island (Figure 1, Appendix 4A)

Carpet shark
Only a small amount of carpet shark biomass occurred in the shallow (10–30 m) strata, and adding these to the core strata made little difference to the overall biomass estimates. There was a large gap of 11 years between the two time periods, and carpet shark biomass increased significantly between the two periods by about 47%, from a mean of 685 t in the 1990s to a mean of 1009 t in the 2000s and 2010s.

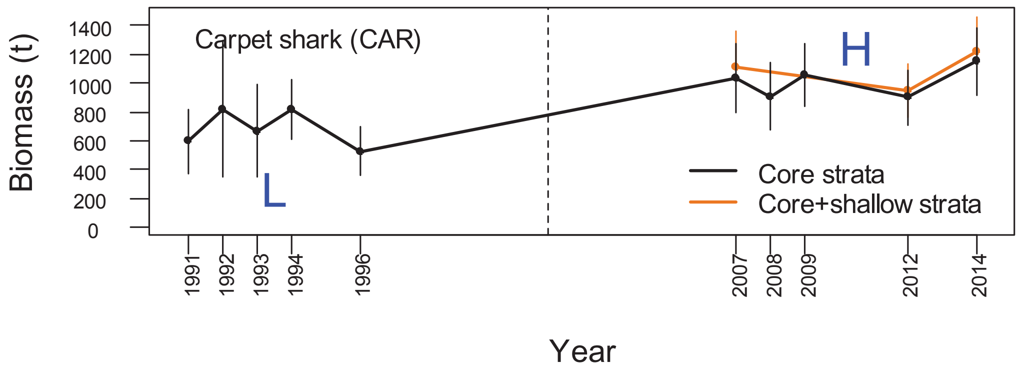


Figure 1: Relative biomass estimates for carpet shark in east coast South Island trawl surveys. Estimates are shown for core strata, and core-plus-shallow strata. Error bars represent two standard errors. Dashed vertical line indicates demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods.

West coast South Island (Figure 2, Appendix 4A)

Carpet shark

There was no significant difference in carpet shark biomass estimates among the three time periods. However the estimates fluctuated considerably among years, sometimes significantly, indicating that the survey may not be adequately monitoring this species. Large inter-annual fluctuations in biomass are not plausible for species such as sharks that produce small numbers of young each year, and are therefore unlikely to have significant recruitment variability.

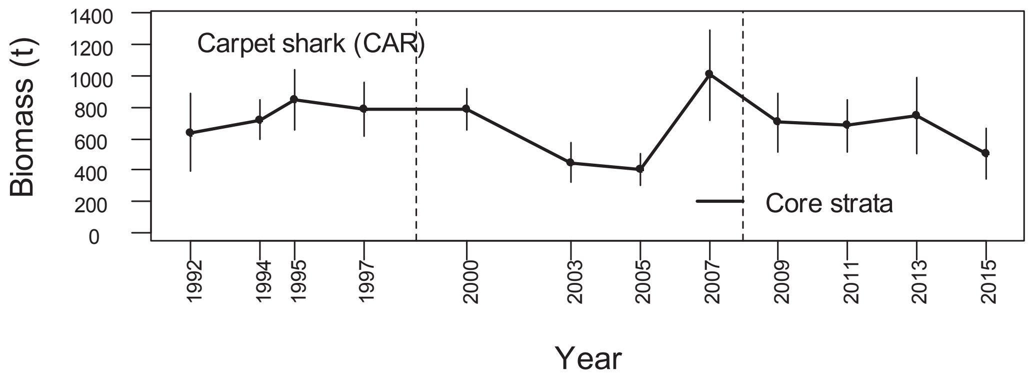


Figure 2: Relative biomass estimates for carpet shark in west coast South Island trawl surveys (core strata). Error bars represent two standard errors. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. There were no significant differences among time periods.

Chatham Rise (Figures 3 and 4)

The additional deep strata sampled from 2010 onwards added considerably more biomass for longnose velvet dogfish, shovelnose dogfish and seal shark (in some years), but only minor amounts for the other four species. The deep strata have only been sampled for the last five of the 23 survey years, and do not yet provide a long enough time series to be useful in monitoring abundance. Nevertheless, the core-plus-deep trends since 2010 were qualitatively similar to the core trends for the same years, suggesting that including the deep strata would not affect the results much.

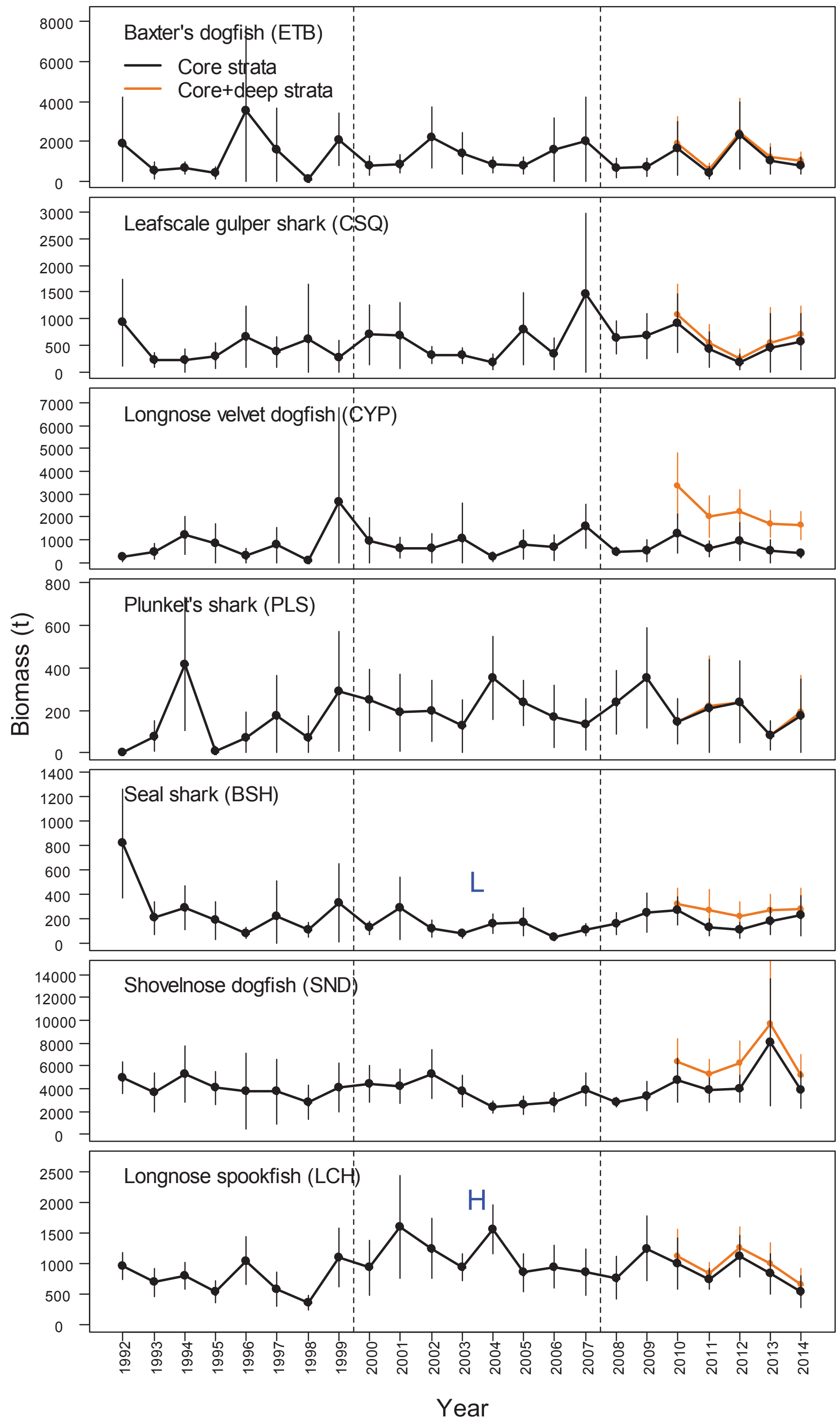


Figure 3: Relative biomass estimates for six sharks and one chimaera in Chatham Rise trawl surveys. Estimates are shown for core strata, and core-plus-deep strata. Error bars represent 2 standard errors. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods.

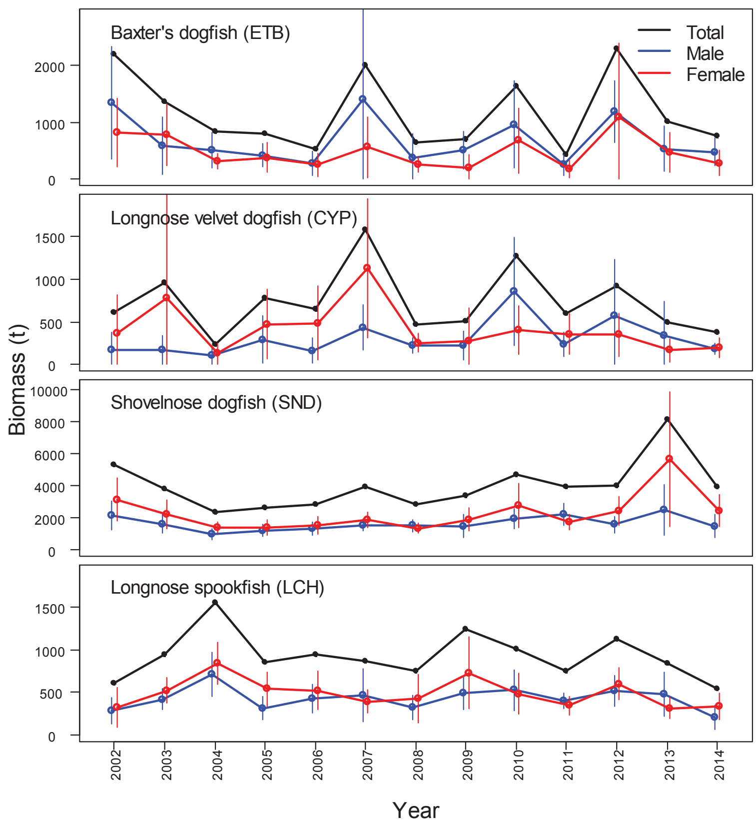


Figure 4: Relative biomass estimates by sex for three sharks and one chimaera in Chatham Rise trawl surveys. Estimates are shown for core strata. Error bars represent 2 standard errors.

Two species showed significant biomass trends. Seal shark was significantly less abundant in the 2000s (group 2) than during the previous and following periods, thus showing a down-then-up trend. The first point in the seal shark time series looks anomalously high (Figure 3) and may have resulted from misidentification of other ‘black sharks’ as seal shark. However removal of the first survey did not affect the trend conclusion. Longnose spookfish was significantly more abundant in the 2000s (group 2) than during the previous and following periods, thus showing an up-then-down trend.

Shovelnose dogfish and longnose spookfish typically had similar biomass levels for males and females (apart from an apparent spike in the abundance of female shovelnose dogfish in 2013, albeit with a large CV). Male Baxter’s dogfish were more abundant than females in some years, but otherwise the sexes were similarly abundant. Male longnose velvet dogfish were less abundant than females in the first half of the time series but thereafter the two sexes showed variable relative abundance, with males sometimes being more abundant than females.

Sub-Antarctic (Figures 5 and 6)

The additional deep strata sampled from 2000 onwards added considerably more biomass for Baxter’s dogfish and longnose velvet dogfish, but only minor amounts for the other five species. The deep strata have been sampled for long enough (13 years) to provide a useful time series for monitoring abundance.

Ignoring the three surveys in the early 1990s, only one species showed a significant trend in biomass. Baxter’s dogfish had significantly lower biomass in the early 2000s (group 1) than in the subsequent two time periods. This indicates an increasing biomass trend for this species.

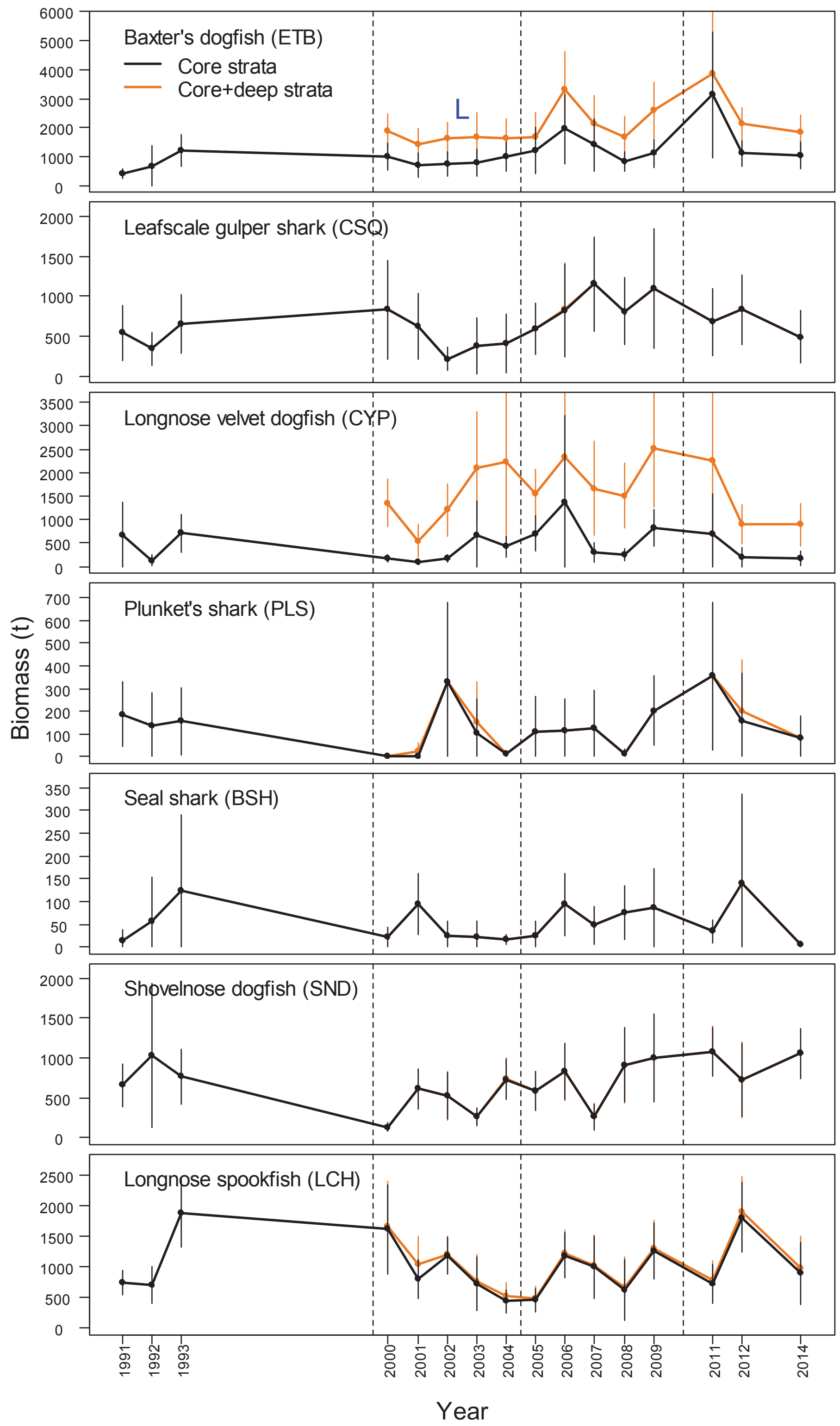


Figure 5: Relative biomass estimates for six sharks and one chimaera in Sub-Antarctic trawl surveys. Estimates are shown for core strata, and core-plus-deep strata. Error bars represent 2 standard errors. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" indicates significantly low time period.

Male and female Baxter's dogfish were usually similarly abundant, although females were more abundant than males in some years. Females comprised most of the biomass of longnose velvet dogfish, with males having very low abundance in all years. Female shovelnose dogfish were usually more abundant than males, with the gap between the sexes increasing through time as females became more abundant.

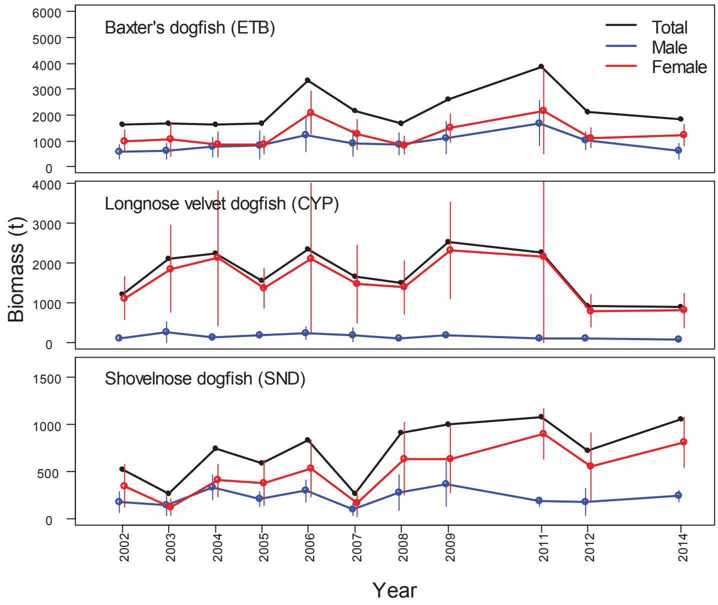


Figure 6: Relative biomass estimates by sex for three sharks in Sub-Antarctic trawl surveys. Estimates are shown for core-plus-deep strata. Error bars represent 2 standard errors.

3.4 CONCLUSIONS

Twelve out of 16 species-survey combinations showed no significant change in relative biomass. Carpet shark biomass increased on the east coast South Island from the 1990s to the 2000s and 2010s. On the Chatham Rise, seal shark biomass decreased then increased, whereas longnose spookfish biomass increased then decreased. The Chatham Rise trawl surveys were judged to survey these two species "moderately well" and "very well" respectively (O'Driscoll et al. 2011). In the Sub-Antarctic, Baxter's dogfish biomass increased from the early 2000s to the present. The Sub-Antarctic trawl surveys were judged to survey this species "well" (Bagley et al. 2013).

Adult female sharks and chimaeras typically grow considerably larger (in both length and weight) than adult males (Compagno 1984). Therefore if males and females are equally numerous in the survey area, we would expect female biomass to exceed male biomass. This was not always the case, with male biomass sometimes exceeding that of females. Conversely, in some cases females outweighed males more than would have been expected based simply on their larger size. In the Sub-Antarctic, females completely dominated the population of longnose velvet dogfish, and female shovelnose dogfish abundance increased through time relative to male abundance. These results indicate that sexual segregation occurs for some species in some regions, and that the survey area does not cover the population's entire geographical and/or depth range. This issue will be explored further following the analysis of sex ratios in Section 4.

An important caveat accompanying the above conclusions is that the trawl surveys analysed here do not necessarily index the population abundance of a species. Reviews of the Chatham Rise and Sub-Antarctic trawl surveys up to 2010 and 2009 respectively concluded that the biomasses of some of the species analysed here were poorly estimated (O'Driscoll et al. 2011; Bagley et al. 2013). They were Plunket's shark in both survey series, and leafscale gulper and longnose velvet dogfish in the Chatham Rise surveys. The criterion for distinguishing between 'poor' and 'good' estimation was a mean CV across all surveys in the series of greater than or less than 40%. 'Poor' estimates often resulted from a species being relatively uncommon in the catches, unevenly distributed across the survey area, or the bulk of the population not being sampled (e.g. all seal sharks measured from the Sub-Antarctic surveys up to 2009 were juveniles) (O'Driscoll et al. 2011; Bagley et al. 2013).

Our conclusions about biomass trends were consistent with those from the earlier reviews except as follows:

1. Chatham Rise seal shark abundance decreased then increased, compared with no change between 1992 and 2010 reported by O'Driscoll et al. (2011).
2. Chatham Rise longnose spookfish abundance increased then decreased, compared with no change between 1992 and 2010 reported by O'Driscoll et al. (2011).
3. Sub-Antarctic leafscale gulper shark showed no change, compared with an increase between 1991 and 2009 reported by Bagley et al. (2013).
4. Sub-Antarctic shovelnose dogfish showed no change, compared with an increase between 1991 and 2009 reported by Bagley et al. (2013). However our randomisation test approached the significance level for an increase – the mean rank during the third period (10.7) was equal to the upper confidence limit (Appendix 4A).

We attribute the differences between our results and those of the earlier reviews to the longer time series available to us, and the greater power of our randomisation tests resulting from larger sample sizes.

Our analyses of trends were based on the point estimates of biomass, and we haven't taken into account the uncertainty in these, as expressed by their CVs. CVs were sometimes high, especially for the less common species. A more sophisticated randomisation test could rank biomasses drawn from the statistical distribution of possible biomasses (i.e. from across the 95% confidence range) rather than from the point estimates.

4. MEDIAN SIZE AND SEX RATIO

4.1 INTRODUCTION

Exploitation of a fish population may lead to a reduction in the mean age of individuals in the population, and this in turn can lead to a shift in the length distribution towards smaller size classes (Goodyear 2003). Consequently, trends in fish size can be a useful indicator of population status (Clarke et al. 2011a), and may even provide information on the level of exploitation that a fish stock is experiencing (Francis & Smith 1995). Clarke et al. (2011a) examined trends in median length of five species of sharks in tropical waters north of New Zealand, including blue and shortfin mako sharks. They found significant declines in most combinations of spatial strata and sex for blue and mako sharks. Francis et al. (2014) analysed trends in the median lengths of New Zealand blue, porbeagle and shortfin mako sharks sampled by observers. They found no consistent trends, but did identify fluctuations resulting from changes in the proportions of immature and adult sharks. Because the sizes of sharks differ by sex (females typically grow larger and heavier than males), it is important to examine indicators on a sex-specific basis where possible (Clarke et al. 2011a). Length is a better measure of size than is weight because the former does not fluctuate with reproductive or other seasonal factors. The median length is preferred over the mean length as the median is less likely to be influenced by outliers.

The sex ratio of a shark population may also be a useful indicator of its status. Heavy exploitation could lead to a preferential loss of females because they tend to be larger and older than males. Thus if the median length in a population declines, it may also impact on the sex ratio. Additionally, male and female sharks often segregate spatially (Mucientes et al. 2009), and this has been reported in pelagic sharks in New Zealand waters: around south-western New Zealand, blue shark catches are dominated by females and mako shark catches by males (Francis 2013; Francis et al. 2014). If fishing activity is concentrated in areas favoured by one sex, then an imbalance in the sex ratio could be created.

In this section we analyse trends in median length and the proportion of males over time.

4.2 METHODS

An extract from the MPI *COD* database on 11 November 2015 showed that there were insufficient observer length and sex measurements for the species of interest to warrant analysis (seal shark 110, shovelnose dogfish 85, Baxter's dogfish 66, leafscale gulper shark 9, and longnose spookfish 2). We instead analysed length and sex data from two of the four research trawl survey series (CHAT, SUBA) described in Section 3, as they had consistently collected relevant and adequate data for four of the species since 2001 or 2002 (Baxter's dogfish, longnose velvet dogfish, shovelnose dogfish and longnose spookfish (CHAT only); Appendix 2). Too few carpet sharks were measured on inshore trawl survey series (ECSI and WCSI) for analysis. Core strata were used, except in Sub-Antarctic region for which core-plus-deep strata were used. For each survey, scaled length-frequency distributions were generated by sex across the entire survey region using *SurvCalc* (see Section 3.2 for further details). We then calculated the median and 5th and 95th percentiles of total length (TL) by year and sex. We also calculated the proportion of males as the scaled number of males divided by the sum of the scaled numbers of males and females. The time periods used for conducting randomisation tests for trends in median length and proportion of males (Table 3) differed from those used for testing for relative biomass trends in the same survey series (see Table 2). This was because length and sex were not routinely recorded in the early surveys, resulting in shorter time series for analysis.

Table 3: Groups of years used to define time periods for the randomisations tests for trawl survey trends in median length and sex ratio.

Region	Strata	Period	Years	No. of surveys
Chatham Rise (CHAT)	Core	Group 1	2002–06	5
		Group 2	2007–11	5
		Group 3	2012–14	3
Sub-Antarctic (SUBA)	Core + Deep	Group 1	2002–05	4
		Group 2	2006–09	4
		Group 3	2011–14	3

4.3 RESULTS

The proportions of males, and the medians lengths for three sharks and one chimaera, in two trawl survey series are shown in Figures 7–10. For Chatham Rise, estimates are for core strata, and for Sub-Antarctic, estimates are for core-plus-deep strata. The results of randomisation tests of the temporal patterns in the sex ratios and median lengths are shown in Appendices 4B and 4C.

Chatham Rise (Figures 7 and 8, Appendices 4B and 4C)

Over the full time series, the estimated proportions of males in the survey area were Baxter's dogfish 63.7%, longnose velvet dogfish 52.4%, shovelnose dogfish 44.2% and longnose spookfish 54.2%. Some species showed considerable inter-annual variability: Baxter's dogfish ranged between 51% and 74% males, longnose velvet dogfish 33–69% males, and longnose spookfish 40–65% males. Shovelnose dogfish had a narrower range with 37–56% males. Only one species showed a significant temporal pattern in the proportion of males: shovelnose dogfish had a higher proportion of males during group 2 (2007–2011) than in the previous and following periods.

Median length declined significantly in the third time period for male shovelnose dogfish. The absolute decline was small (3.3 cm between the means of 2007–2011 and 2012–2014) but sample sizes were large. The 5th percentile for both male and female shovelnose dogfish increased steadily through the time series, indicating that the proportion of juveniles was declining. The median length of male longnose spookfish declined then increased significantly, but the absolute changes were small and sample sizes were only moderate. The 5th percentile also increased for male longnose spookfish, particularly during the last two years of the series. Other species/sex combinations showed no significant trends. The median lengths for longnose velvet dogfish were highly variable, in agreement with the conclusion that that species was poorly surveyed (O'Driscoll et al. 2011).

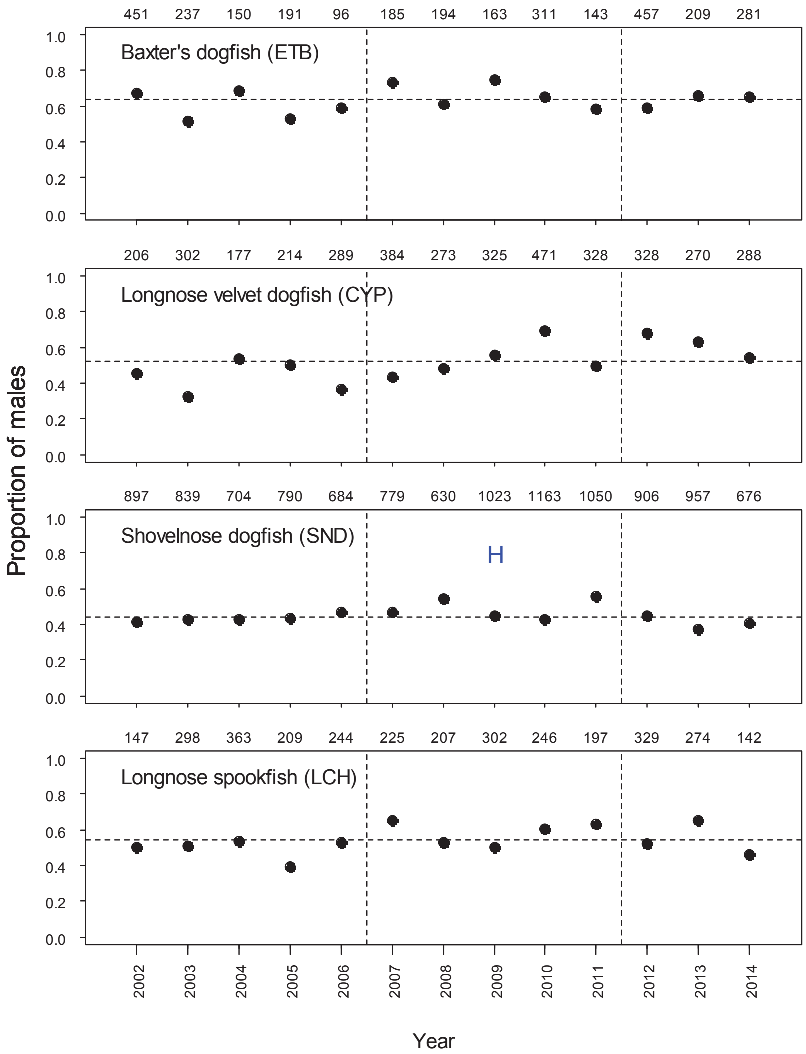


Figure 7: Proportions of males by species and survey from Chatham Rise trawl survey series. The horizontal dashed lines indicate the proportions of males for the whole time series. Numbers above each panel show the numbers of sexed fish. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "H" indicates significantly high time period.

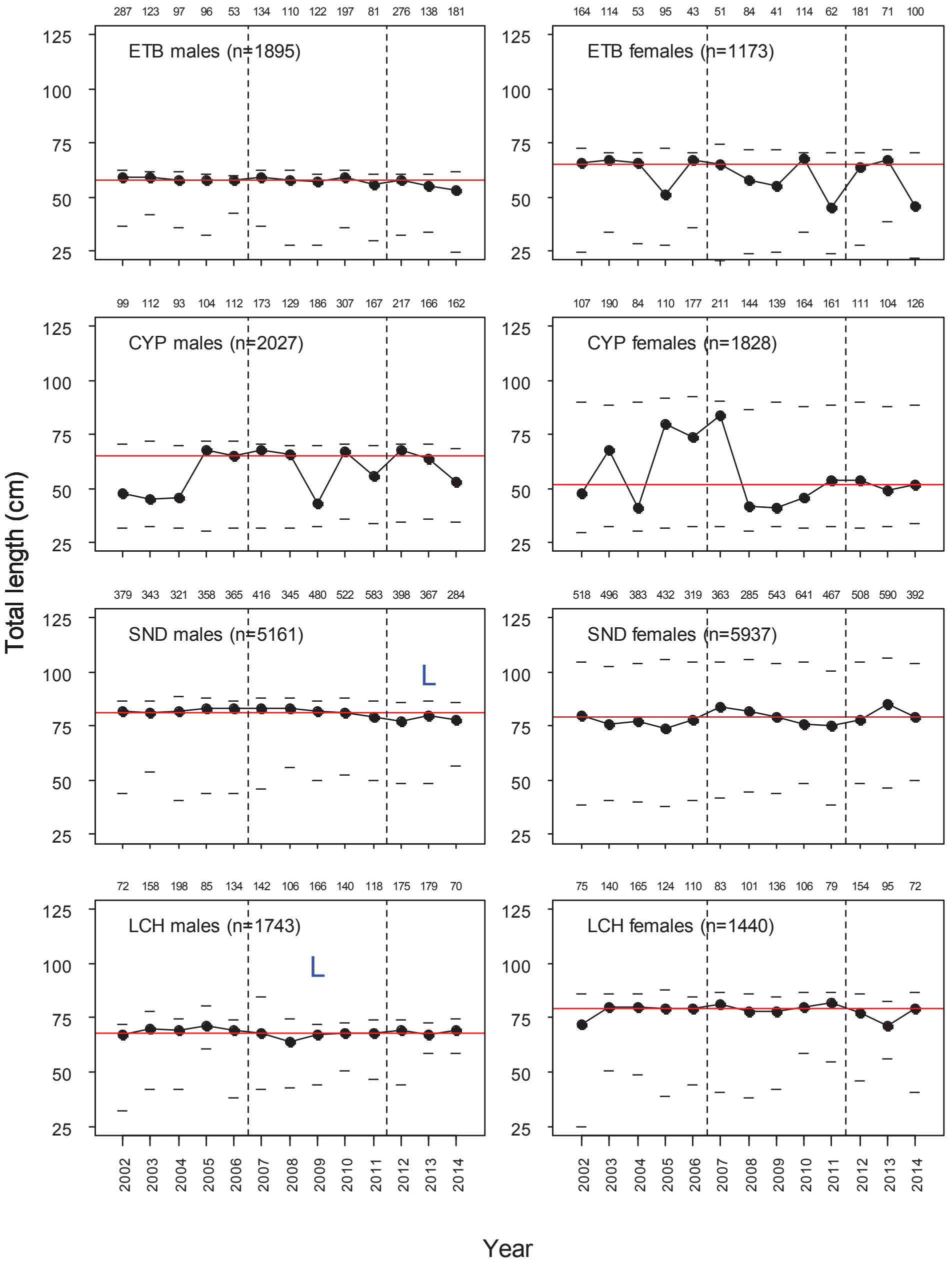


Figure 8: Median lengths by species, sex and survey from Chatham Rise trawl survey series. The horizontal red lines indicate the medians for the whole time series. The dashes show the 5th and 95th percentiles of the length ranges. Numbers above each panel show the numbers of measured fish. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" indicates significantly low time period.

Sub-Antarctic (Figures 9 and 10, Appendices 4B and 4C)
Over the full time series, the estimated proportions of males in the survey area were: Baxter's dogfish 49.9%, longnose velvet dogfish 20.3%, and shovelnose dogfish 38.9%. The proportion of males was relatively stable among surveys for Baxter's dogfish (44–59% males) and longnose velvet dogfish (13–30% males) and showed no temporal trends. Shovelnose dogfish had a broader range with 24–58% males. The proportion of male shovelnose dogfish declined significantly through time, from about 50% in the early 2000s to about 30% in the early 2010s. That decline is also evident from the increased gap between male and female relative biomass in the last few surveys (Figure 6).

Median lengths were stable through time for Baxter's dogfish, longnose velvet dogfish and shovelnose dogfish. The decline in median length for male longnose velvet dogfish during the last few surveys was significant, but sample sizes were small and therefore the trend is not considered reliable. The 5th percentile for female shovelnose dogfish increased during the last three surveys, suggesting that there may have been a decline in the proportion of juveniles present in the survey area.

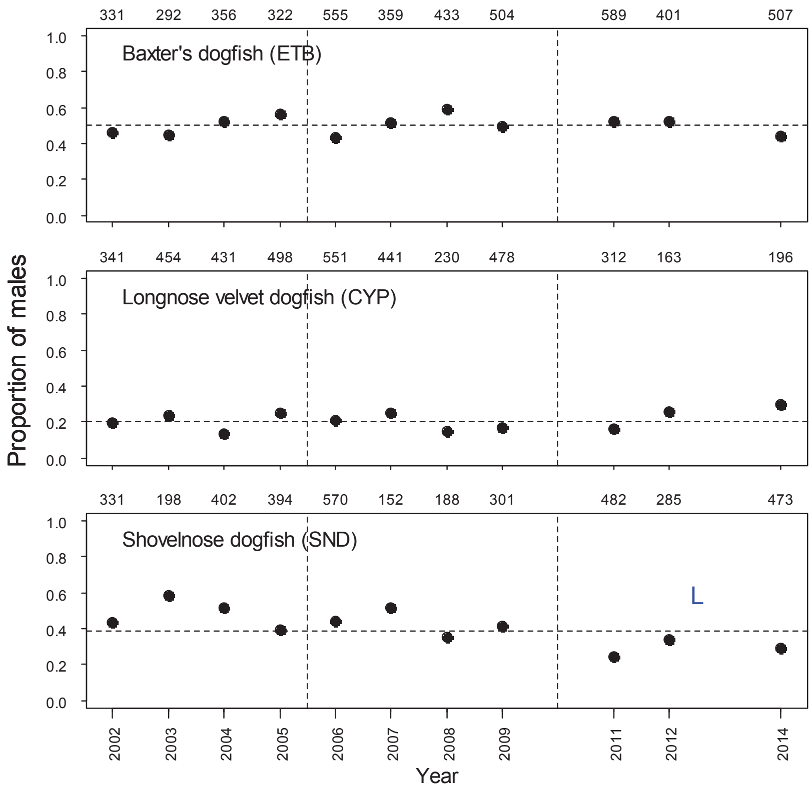


Figure 9: Proportions of males by species and survey from Sub-Antarctic trawl survey series. The horizontal dashed lines indicate the proportions of males for the whole time series. Numbers above each panel show the numbers of sexed fish. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" indicates significantly low time period.

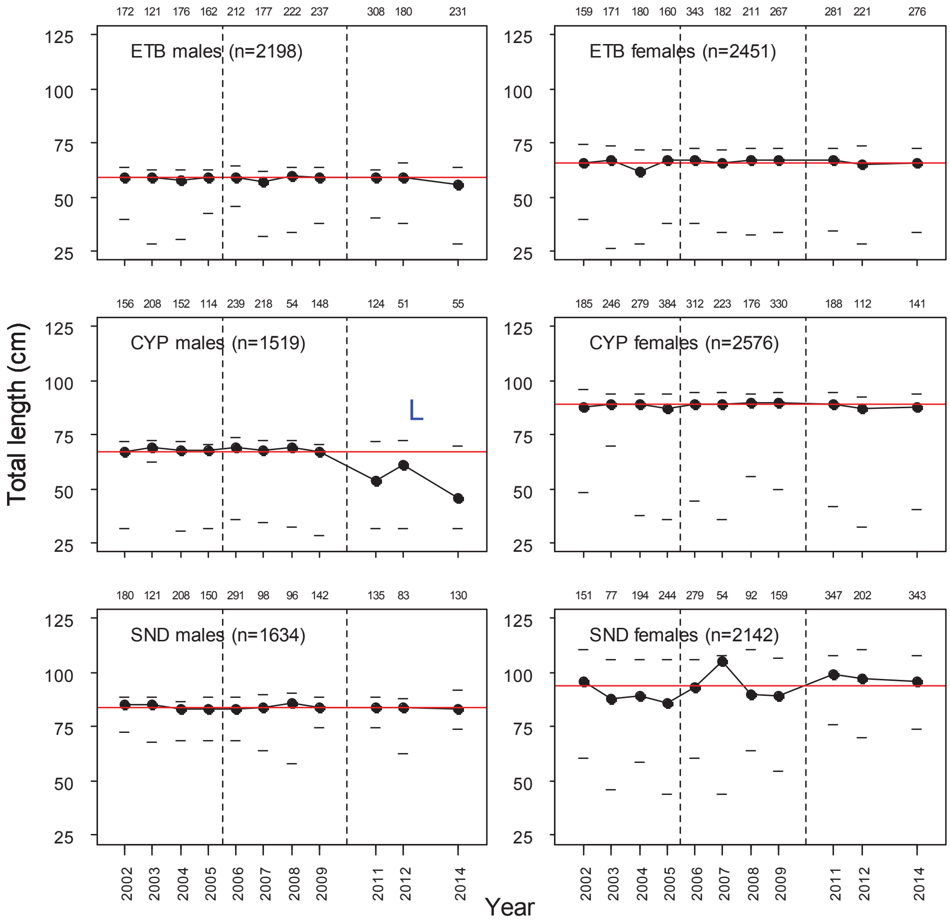


Figure 10: Median lengths by species, sex and survey from Sub-Antarctic trawl survey series. The horizontal red lines indicate the medians for the whole time series. The dashes show the 5th and 95th percentiles of the length ranges. Numbers above each panel show the numbers of measured fish. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" indicates significantly low time period.

4.4 CONCLUSIONS

Most combinations of species and survey region showed no significant temporal trends in sex ratio or median size. The proportion of male shovelnose dogfish declined significantly in the Sub-Antarctic region, but this was attributable to an increase in the abundance of females rather than a drop in the abundance of males (Figure 6). A significant increase in the proportion of male shovelnose dogfish on the Chatham Rise in the late 2000s was minimal in scale and was subsequently reversed, so it may not have been biologically important.

The overall proportion of males estimated across all surveys in a series usually fell between 40% and 60%. This suggests that there was usually no major gender bias in the sampled sharks, and that the surveys may have been sampling both sexes representatively. A notable exception was longnose velvet dogfish in Sub-Antarctic region, which averaged 20% males across all surveys. The sex ratio of this species was close to 50:50 on Chatham Rise, so there appears to be something unusual about the Sub-Antarctic region which we recommend should be investigated further. Similarly, Baxter's dogfish in the Chatham Rise region was dominated by males (64%), suggesting that the survey may not cover the entire habitat range of that species.

There were few trends in median length of Baxter's dogfish, longnose velvet dogfish, shovelnose dogfish and longnose spookfish. There were insufficient length data for other species to develop median length indicators. The few significant trends were either small in absolute size, or attributable to small sample sizes. However, these and increases in the 5^{th} percentile, particularly for shovelnose dogfish, we recommend for close monitoring in future as they may indicate a reduction in the recruitment of small sharks to the populations.

5. DISTRIBUTION

5.1 INTRODUCTION

A distribution indicator seeks to monitor trends in the status of a stock by assessing changes in the spatial distribution of the fish (Clarke et al. 2011a). An increase in stock abundance may become apparent as an expansion of the range inhabited by the fish, and a decrease may be signalled by a contraction of the range. Distribution indicators have been used successfully to monitor the abundance of blue, porbeagle and shortfin mako sharks in the New Zealand EEZ (Francis et al. 2014).

5.2 METHODS

In this study, we calculated two distribution indicators from commercial fishery data:

- The *high-CPUE indicator* was the proportion of half-degree rectangles having unstandardised CPUE greater than a specified threshold in the commercial *warehou* data. It was calculated as the number of high-CPUE rectangles divided by the total number of rectangles with reported effort. This indicator acts as a measure of the spatial extent of high abundance areas.
- A *proportion-zeroes indicator* was calculated as the number of half-degree rectangles having zero reported catches in a fishing year divided by the total number of rectangles with reported effort in that year.

The distribution indicators were estimated from bottom trawl data (including pair trawl), and set net data for carpet sharks only, because all the species of interest are largely or completely demersal in their behaviour. We used catch and effort data from Trawl Catch Effort Processing Returns (TCP forms), Trawl Catch Effort Returns (TCE forms), and Netting Catch Effort Landing Returns (NCE forms). Records from Catch Effort Landing Returns (CELRs) were not used because most fishers using these forms report location by statistical area only, so the location information was not precise enough for our purpose. TCP forms are used by large trawlers, mainly those fishing in deeper offshore waters, and TCE forms are used mainly by smaller inshore trawlers. Trawl-caught carpet shark was mainly reported on TCEs whereas all other species of interest were mainly reported on TCP forms (Table 4).

Each analysis was restricted to one form type (i.e. trawl data were not combined across TCP and TCE forms) because (a) most of the trawl catch of each species was reported on only one of the forms, and (b) the two trawl form types differ in format, leading to potential biases if the data are combined (most importantly, catches are estimated for up to eight species on TCE forms but only five species on TCP forms).

Table 4: Number of estimated catch records of eight shark and chimaera species reported on trawl (TCE and TCP) forms.

Species	Records on TCE	Records on TCP	Total records	Percent on TCP
BSH	946	23023	23969	96.1
CAR	39060	1938	40998	4.7
CSQ	1	222	223	99.6
CYP	0	30	30	100.0
ETB	0	1320	1320	100.0
LCH	73	3001	3074	97.6
PLS	0	24	24	100.0
SND	445	7480	7925	94.4

The annual number of tows or sets reported on three different form types are shown in Figure 11. TCP data were available from 1990 but TCE and NCE form types are more recent, beginning in 2008 and 2007 respectively. TCP records peaked in 1998 and have declined since then to 38% of the maximum level, mainly due to declining fishing effort in the hoki fishery. TCE and NCE records have been relatively constant throughout the period since their introduction.

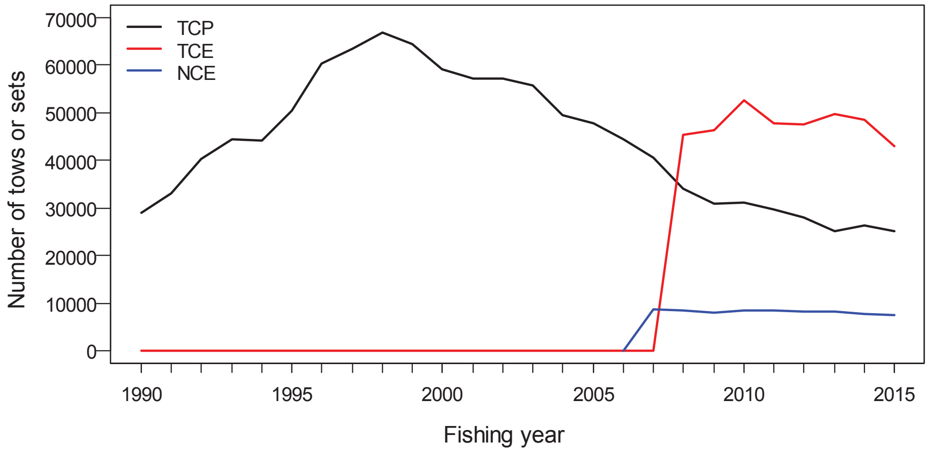


Figure 11: Number of commercial records (tows or sets) reported on trawl (TCP, TCE) and set net (NCE) forms by year.

Estimated catches of sharks were dominated by three generic codes – 'deepwater dogfish' (DWD), 'other sharks and dogfishes' (OSD) and 'sharks' (SHA). The sum of the estimated catches from these three codes increased rapidly in the late 1990s to peak at 711 t in 2001 (Figure 12), presumably as fishers reported more of their previously discarded bycatch. Generic shark catches then declined steadily to 230–250 t in 2013–15, possibly in response to MPI efforts to encourage the use of species-specific codes, and the development of species identification guides that included deepwater sharks (Tracey & Shearer 2002; McMillan et al. 2011a; McMillan et al. 2011b), although there was no apparent concomitant increase in catches of other species over the same period (Figure 12). An alternative explanation is that the trend in generic shark catches reflects the decline in fishing effort in the hoki fishery, and a resulting reduction in the numbers of fishing events reported on TCP forms (Figure 11).

Only three species (seal shark, shovelnose dogfish and carpet shark) were caught in sufficient amounts and reported consistently enough for distribution analyses (Figure 12). Analyses began in the years in which significant amounts of catch were first reported, viz. 1999 for seal shark on TCPs, 2001 for shovelnose dogfish on TCPs, 2008 for carpet shark on TCEs, and 2007 for carpet shark on NCEs (Figure 12, top panel).

For TCP forms, the trawl location was taken as the mean of the start and finish positions; for TCE and NCE forms, the fishing location was taken as the start position because those forms do not record finish positions. Tows and sets were assigned to half-degree rectangles using their locations. A rectangle has a north–south distance of 55.6 km (30 n.m.) and variable east-west distance depending on its latitude.

Estimated catches were summed and CPUE calculated for half-degree rectangles having more than three trawl tows (TCPs and TCEs) or 5 km of set net (NCEs). This was done for confidentiality reasons, and also to ensure that there was enough fishing effort in each rectangle from which to estimate the CPUE (extreme catch rates from a small number of tows or sets could bias the results). CPUE was calculated as the weight of sharks caught per rectangle divided by the total number of tows (for trawl) or kilometres of net (for set net) in each fishing year. CPUE thresholds were selected separately for each species by trial and error, our aim being to generate distribution indices (proportions) that were not too close to zero or one in more than a few years. The actual thresholds used in each case are shown in the relevant figure legends in Section 5.3.

Distribution indicators were calculated for both the entire EEZ, and for the FMAs (singly or in groups) that produced the highest catches. Both of the distribution indicators could be affected by inter-annual variation in the amount and distribution of fishing effort, and targeting. Ideally, the analyses should be restricted to a standard area that was fished every year, although this inevitably and dramatically reduces the number of rectangles available for analysis. To assess the potential impact of inter-annual variation, we calculated the high-CPUE indicator for both the full dataset (i.e. all rectangles fished in a given year) and a reduced dataset of rectangles that were fished every year.

The temporal spans of the time periods used for the randomisation tests were selected to be as equal as possible (Table 5). Only two time periods were used for carpet shark because of the short time series available for TCE and NCE forms. Four time periods were used for CPUE analyses of observer data (see Section 8) because of the long time series available (1987–2015).

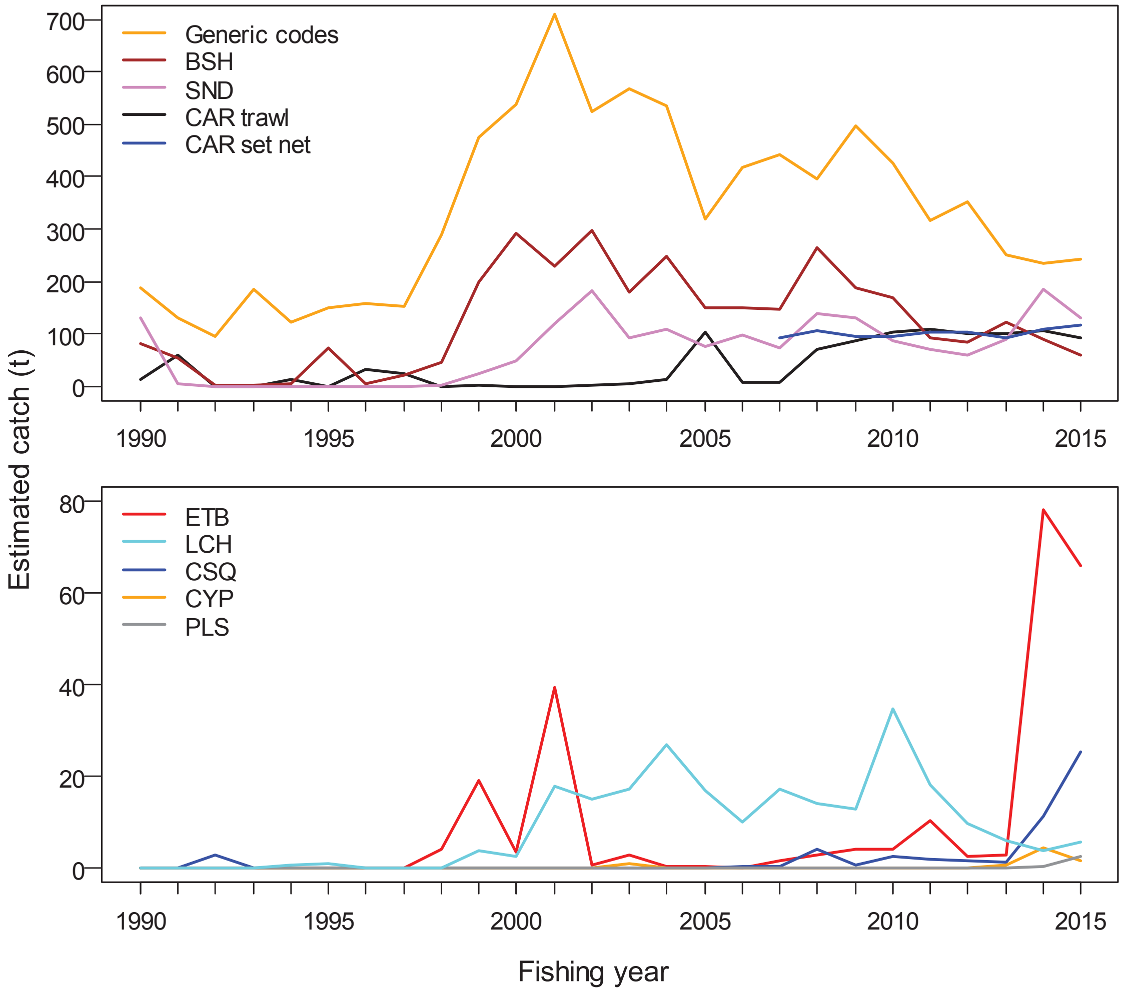


Figure 12: Estimated trawl catches of eight sharks and chimaeras by year reported on TCP and TCE forms combined, and estimated set net catches of carpet shark reported on NCE forms. Generic codes are the sum of 'deepwater dogfish' (DWD), 'other sharks and dogfishes' (OSD) and 'sharks' (SHA). Note the different Y-axis scales in the two panels.

Table 5: Groups of years used to define time periods for the randomisations tests for trends in indicators based on commercial fishing returns and observer data.

Species	Form type	Period	Years	No. of years
Seal shark (BSH)	TCP	Group 1	1999–2004	6
		Group 2	2005–10	6
		Group 3	2011–15	5
Shovelnose dogfish (SND)	TCP	Group 1	2001–05	5
		Group 2	2006–10	5
		Group 3	2011–15	5
Carpet shark (CAR)	TCE	Group 1	2008–11	4
		Group 2	2012–15	4
Carpet shark (CAR)	NCE	Group 1	2007–11	5
		Group 2	2012–15	4
Shovelnose dogfish (SND)	Observer	Group 1	1987–94	8
		Group 2	1995–2001	7
		Group 3	2002–08	7
		Group 4	2009–15	7

5.3 RESULTS

Fishing effort

Over the entire time series, TCP records were distributed widely around New Zealand, including on the Chatham Rise, the Stewart–Snares Shelf and the Auckland Islands Shelf (Appendix 5). The main regions in descending order were FMAs 3, 4 and 1, which contributed 19%, 17% and 15% of the records respectively. TCE records were also distributed widely in coastal waters (Appendix 6). The main regions in descending order were FMAs 7, 3 and 2, which contributed 30%, 28% and 18% of the records respectively. NCE records were widely but variably distributed in coastal waters (Appendix 7). The main regions in descending order were FMAs 3, 1, 9, 2 and 8, which contributed 43%, 13%, 10%, 10% and 9% of the records respectively. There was essentially no effort off the west coast of South Island from 2011 onwards.

CPUE

The annual spatial distributions of CPUE between 1999 (or when the fishing return form was first introduced) and 2015 are shown in Appendices 8–11. Seal sharks were caught around much of New Zealand, and CPUE was greatest on the Chatham Rise, west coast South Island, Challenger Plateau (early years only) and northern Campbell Plateau (intermediate years) (Appendix 8). Shovelnose dogfish catches were less widespread, with CPUE being greatest on the northern Chatham Rise, and low elsewhere (Appendix 9). Trawl catches of carpet shark came mostly from northern and central New Zealand in 2008–11 and central and southern New Zealand in 2012–15. CPUE was greatest in Tasman Bay/Golden Bay, the east coast of North Island, and to a lesser extent South Taranaki Bight and Fiordland (Appendix 10). Set net CPUE of carpet sharks showed two clear hotspots: Tasman Bay/Golden Bay to South Taranaki Bight; and Southland/Fiordland to Stewart Island (Appendix 11). Kaikoura set net CPUE became important from 2012 onwards.

Indicators

In all bottom trawl and set net comparisons, the high-CPUE indicator calculated for rectangles sampled in all years closely matched the indicator calculated for all rectangles containing effort (Figures 13–16). Consequently we consider only the latter in the rest of this section, because it was derived from much larger sample sizes.

Seal shark (Figure 13, Appendices 4D and 4E)

Several of the indicators showed significant temporal trends. For all FMAs combined, and for FMAs 3 and 4 combined (Chatham Rise), the high-CPUE indicators increased and then decreased significantly, and the proportion zeroes indicators increased significantly. For FMAs 5 and 6 (Sub-Antarctic region), the high-CPUE indicator decreased significantly, and the proportion zeroes indicators increased significantly. Taken together, these indicators point to a decline in seal shark abundance since 2011 in FMAs 3–6.

Shovelnose dogfish (Figure 14, Appendices 4D and 4E)
The high-CPUE indicators showed a general upwards trend, and the proportion-zeroes indicators a general downward trend, but only one pair (for FMAs 3 and 4) was significant. These indicators point to an increase in shovelnose dogfish abundance since 2011 in FMAs 3 and 4.

Carpet shark (Figures 15 and 16, Appendices 4D and 4E)
For bottom trawl, carpet shark showed a significant increase in high-CPUE, and a significant decrease in proportion-zeroes, in FMAs 2 and 3 (east coast of North and South islands). For set net, carpet shark showed a significant decrease in proportion-zeroes in FMAs 7 and 8 (west coast of South Island and southwest coast of North Island) (and a corresponding but non-significant increase in the high-CPUE indicator). Other FMA/method combinations showed no significant changes.

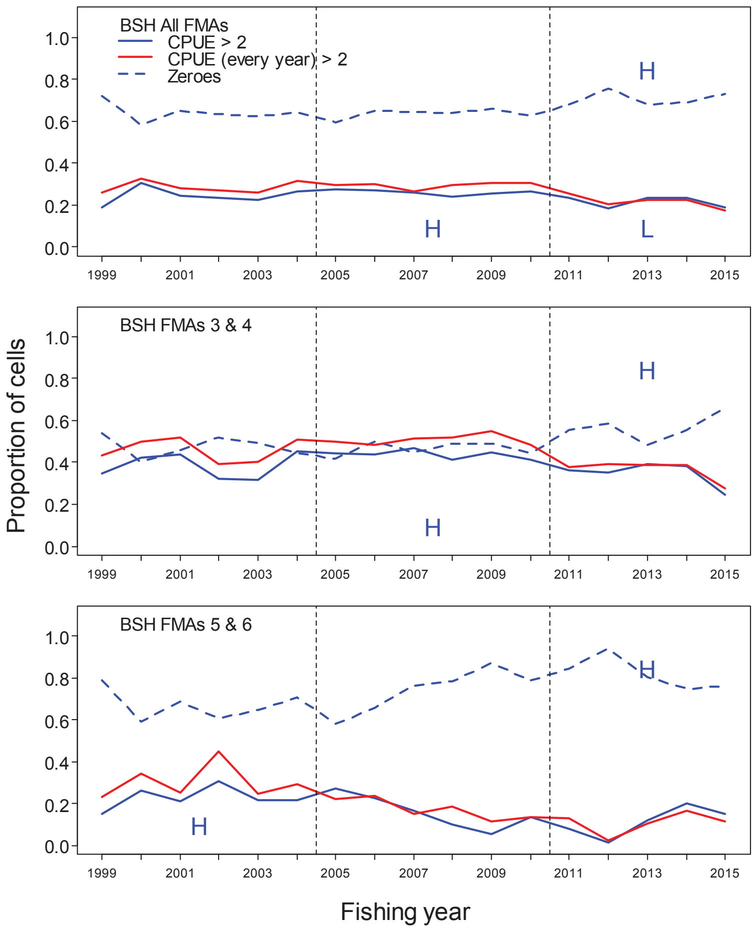


Figure 13: High-CPUE and proportion zeroes indicators for trawl-caught seal shark in all FMAs (top panel) and important FMA groupings (middle and bottom panels). The high-CPUE indicator is shown for all fished rectangles (blue lines), and for only those rectangles fished every year in the time series (red lines). The CPUE threshold is shown in the legend in kilograms per tow. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods for zeroes (letters in upper part of plot) and high CPUE (letters in lower part of plot).

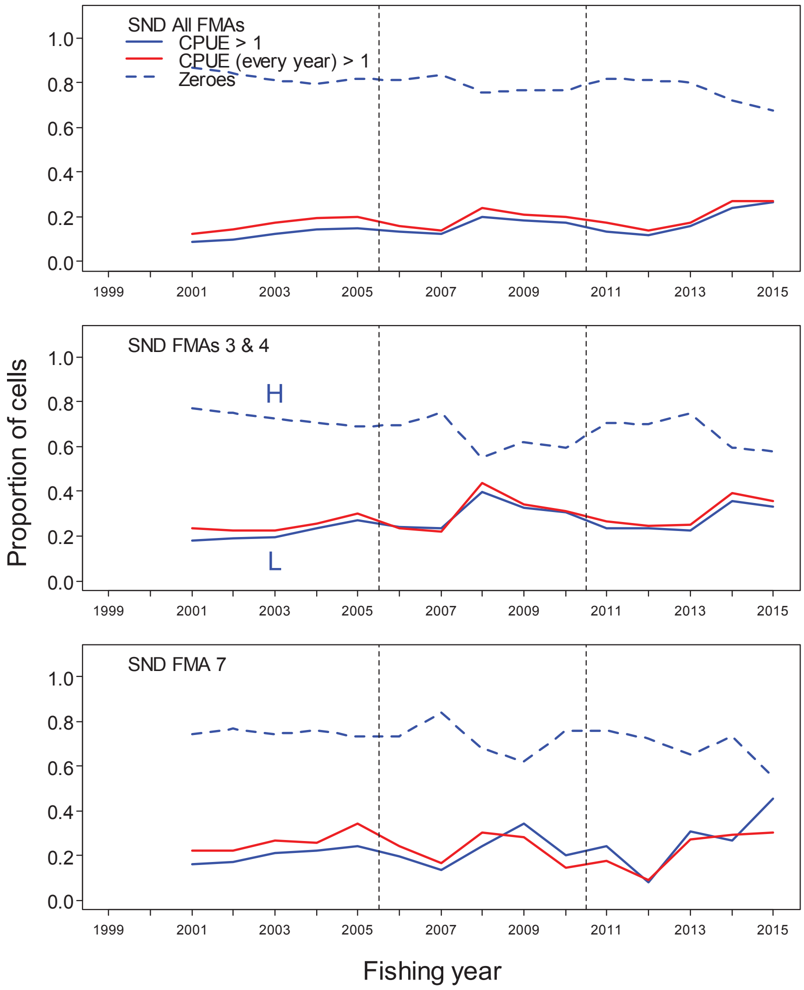


Figure 14: High-CPUE and proportion zeroes indicators for trawl-caught shovelnose dogfish in all FMAs (top panel) and important FMA groupings (middle and bottom panels). The high-CPUE indicator is shown for all fished rectangles (blue lines), and for only those rectangles fished every year in the time series (red lines). The CPUE threshold is shown in the legend in kilograms per tow. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods for zeroes (letters in upper part of plot) and high CPUE (letters in lower part of plot).

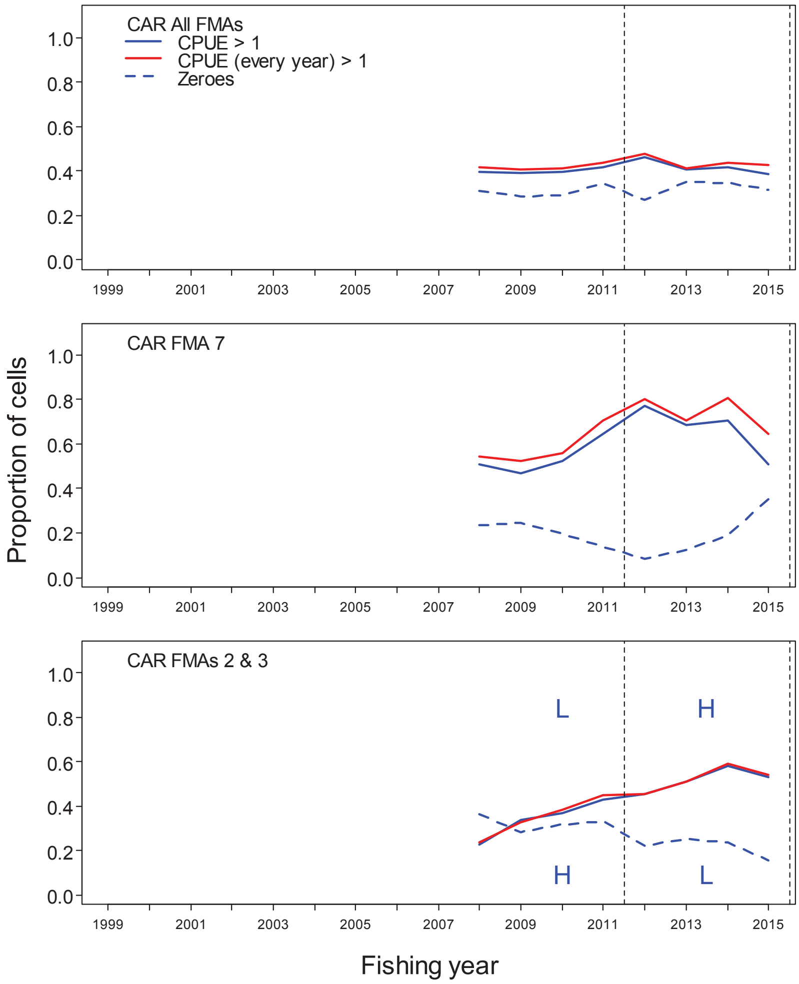


Figure 15: High-CPUE and proportion zeroes indicators for trawl-caught carpet shark in all FMAs (top panel) and important FMA groupings (middle and bottom panels). The high-CPUE indicator is shown for all fished rectangles (blue lines), and for only those rectangles fished every year in the time series (red lines). The CPUE threshold is shown in the legend in kilograms per tow. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods for zeroes (letters in lower part of plot) and high CPUE (letters in upper part of plot).

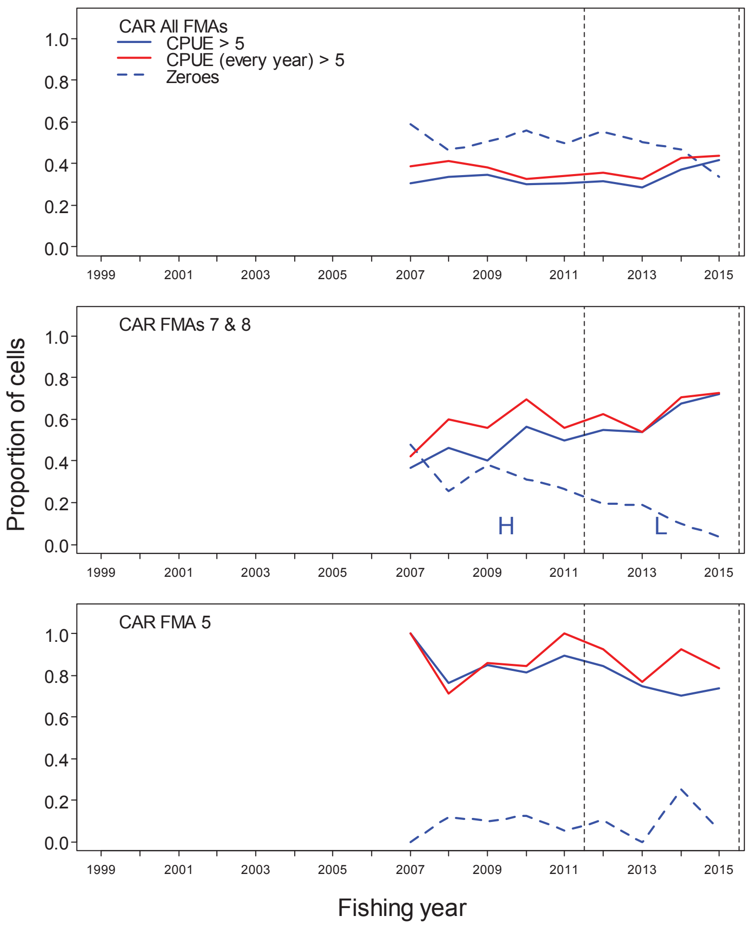


Figure 16: High-CPUE and proportion zeroes indicators for set-net-caught carpet shark in all FMAs (top panel) and important FMA groupings (middle and bottom panels). The CPUE threshold is shown in the legend in kilograms per kilometre of net. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods for zeroes.

5.4 CONCLUSIONS

Assuming that the data provided by commercial fishers on their returns are accurate, and that the indicators index stock abundance, we draw the following conclusions:

- Seal shark has been declining gradually in recent years in FMAs 3–6
- Shovelnose dogfish increased gradually in FMAs 3 and 4, but there was no significant trend in FMA 7 (although FMA 7 indicators qualitatively resembled the indicators in FMAs 3 and 4)
- Carpet shark increased strongly in FMAs 2 and 3. Indicators for FMA 7 were contradictory with trawl indicators showing no clear trend and set net indicators (for FMAs 7 and 8 combined) showing a strong increase. FMA 5 showed no clear trend.

We note however that other interpretations are possible for some or all of the trends. The observed patterns may have been affected by the quality and quantity of data reported by fishers, or by the relative abundance of other species (which might influence whether the species of interest falls within the top five or eight species recorded on fishing returns). Species identification problems may have resulted in species other than seal shark being recorded under the code BSH (which may be mistaken by some fishers as an acronym for 'black shark' resulting in other black deepwater dogfish being lumped with seal shark). Also the degree of reporting may have waxed or waned over time, as markets for shark products developed or disappeared, resulting in the apparent trends being spurious. Concordance of fishery-dependent and fishery-independent indicators is discussed further in Section 9.

6. SPECIES COMPOSITION

6.1 INTRODUCTION

In contrast to the other indicators estimated in this study, a species composition indicator operates at a multi-species, rather than a single-species, level. By assessing whether certain shark species are becoming more or less dominant in the catch, and assuming that catches reflect abundance, a species composition indicator can indicate whether the community as a whole is changing over time. Minimising the risk that fishing activities are driving irreversible changes in natural assemblages is one of the key tenets of ecosystem based fisheries management (Pikitch et al. 2004).

The concept of species composition is often intertwined with that of biodiversity (e.g., see Tuomisto 2010). Considerable progress has been made, particularly in terrestrial ecosystems, in developing quantitative measures of community structure, such as species richness and evenness, as a means of monitoring and reducing the loss of biodiversity (Magurran & McGill 2011). When applying such methods to fisheries data, differences relating to the non-random nature of the sampling (i.e. data potentially influenced by shifts in targeting and derived only from areas where fishing operations have occurred) and in some cases the lack of taxonomic discrimination (e.g. when using commercial fishing returns) must be considered. Furthermore, fished ecosystems may need to be managed for economic productivity and sustainability as well as for the number and relative abundance of species *per se*. For these reasons, terrestrial biodiversity assessment approaches may differ from those which are most appropriate for an active fishery.

This section addresses how the proportion of each species of interest changes relative to the remainder of the catch. The analyses are restricted to species and regions (FMAs) having sufficient data to allow reliable interpretations. That is only possible if a species is both caught in reasonable quantities that represent its abundance, and is reported consistently on fishing returns. For such analyses it would be ideal if changes in species composition represent changes in the natural assemblage rather than changes in the efficiency of fishing operations, e.g. catchability or targeting. Commercial fishery data were analysed, rather than trawl survey data, because of the much greater spatial and temporal coverage of the former.

6.2 METHODS

The data used for species composition analyses were the same as those used for the distribution indicator analyses (see Section 5.2): i.e. commercial trawl (TCE and TCP forms) and set net (NCE forms) estimated catches. Analyses for each species included data from only one form type, and were restricted to an appropriate time period (see Figure 12 and Table 5). Only three species had sufficient data for analysis (seal shark, shovelnose dogfish and carpet shark) (see Figure 12 and Table 4).

The advantages and disadvantages of a wide range of species composition indices have been reviewed in recent years (Buckland et al. 2005; Lamb et al. 2009; Van Strien et al. 2012). Among those frequently evaluated are the traditional Simpson and Shannon diversity indices which give low values when a few species dominate and high values when no species dominate. In the reviews both indices were found to perform poorly in two respects: i) the direction of change in the index is not always consistent with the direction of change in the abundances of the species (monotonicity); and ii) the proportion of change in the index is not always consistent with the degree of change in the abundances of the species (proportionality) (Van Strien et al. 2012). A modified Shannon index was proposed by Buckland et al. (2005) to remedy these issues. The modified index is, like the original Shannon index, based on the proportions of species present, but annual Shannon values are scaled to a base year to allow the modified index to decrease if the overall abundance decreases but the proportions of species remain the same. However, as discovered by Van Strien et al. (2012), when abundances in years subsequent to the base year increase by as little as a factor of three the index becomes unstable. All three studies noted the robust performance of an index based on the geometric mean of the species' abundances, although

Lamb et al. (2009) highlighted its inability to handle zero counts. In the Van Strien et al. (2012) analysis the geometric mean was found to have the most favourable properties of the ten indicators evaluated.

The geometric mean index was used successfully in a recent indicators study of the species composition of blue, porbeagle and mako sharks (Francis et al. 2014). Unfortunately, however, the datasets for the species of interest in the present study had high proportions of zeroes, rendering the geometric mean index inappropriate. We instead calculated temporal trends in two simple measures of the presence and proportional abundance of each species in the commercial catches:

- the *proportion of zero occurrences* in the catches
- the *percentage composition* of each species (by weight) in the total catch

The percentage composition indices were calculated after removal of one or two dominant target species to prevent fluctuations in their abundance driving changes in the percentage of the shark species of interest. Dominant species were removed if they exceeded 24% by weight of the summed catch over all species and years in a time series and region. Species removed were: hoki in TCP data for FMAs 3 & 4, 5 & 6, and 7; squid in TCP data for FMAs 5 & 6; tarakihi in TCE data for FMA 2; barracouta in TCE data for FMA 3; and school shark in NCE data for FMAs 5 and 7 & 8.

We note that the estimated catches reported on fishing return forms cover only the top few species by weight (five or eight species depending on the form type). Consequently zeroes in the data may represent small catches that fall outside the top few species, thus introducing a positive bias in the proportion zeroes indicator (the number of true zero catches will be over-estimated).

6.3 RESULTS

Seal shark (Figure 17, Appendix 4F)
For FMAs 3 and 4, the percent composition indicator showed no significant trend, whereas the proportion zeroes indicator decreased and then increased significantly. For FMAs 5 and 6, the percent composition indicator decreased significantly, and the proportion zeroes indicator increased significantly. Taken together, these indicators point to a decline in seal shark abundance since about 2002 in FMAs 5 and 6, and an unclear situation in FMAs 3 and 4.

Shovelnose dogfish (Figure 18, Appendix 4F)
The proportion zeroes indicator showed a significant decline in FMAs 3 & 4 but this was not matched by a significant increase in the percent composition indicator, which was quite variable. The percentage composition indicator declined significantly in FMA 7.

Carpet shark (Figures 19 and 20, Appendix 4F)
For bottom trawl, there were no significant trends in FMAs 2, 3 or 7, despite an apparent increase in percent composition and decrease in proportion zeroes in FMA 2. For set net, carpet shark showed a significant decrease in proportion zeroes in FMAs 7 & 8 (and a corresponding but non-significant increase in the percent composition indicator). FMA 5 showed no significant changes.

6.4 CONCLUSIONS

Species composition can serve, along with other simple indicators, to identify trends in shark populations. In this study, the comparative rarity of the species of interest generated a high proportion of zero catches, which meant that the most useful distribution indicator (the geometric mean index) could not be applied. Nevertheless the proportion of zero fishing events may itself be a useful indicator, provided that it is not seriously affected by inconsistencies in species identification and reporting, or inconsistent biases caused by the fact that rarer species are not reported on fishing returns. Significant declines in proportion zeroes were observed for carpet shark in FMAs 7 & 8 (set net), with a non-significant decline also suggested in FMA 2 (bottom trawl). Some of these trends were corroborated by non-significant increases in percent composition. Species composition indicators also suggested changes in abundance of seal shark, most notably a decline in abundance in FMAs 5 & 6.

As the time series of reliable data extend, trends in species composition indicators may become clearer through the increased statistical power provided by larger sample sizes.

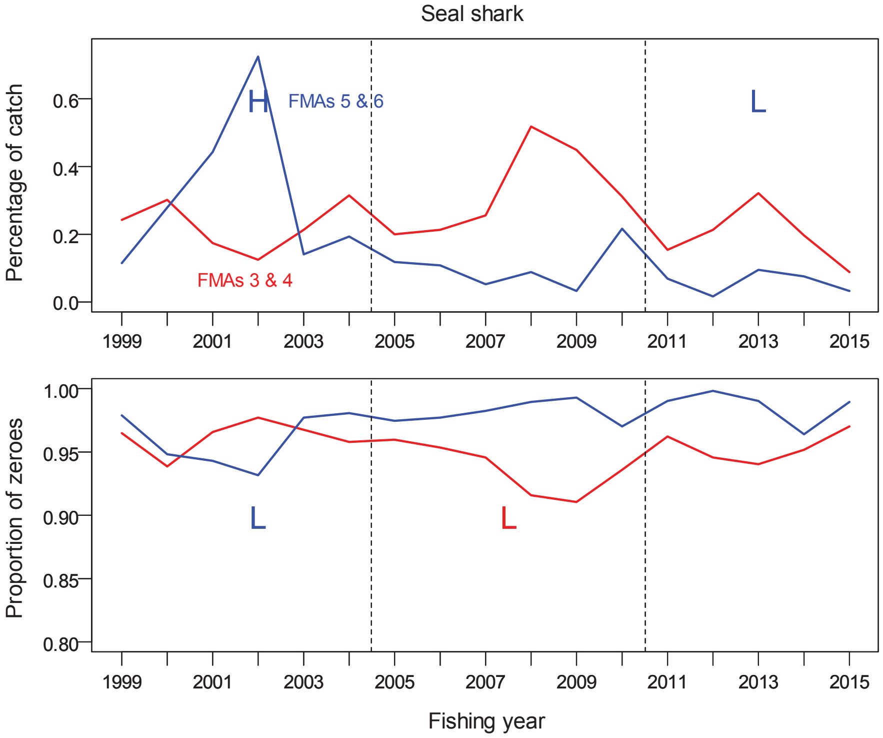


Figure 17: Species composition indicators for trawl-caught seal shark reported on TCP forms in FMAs 3 & 4 and FMAs 5 & 6. Top panel shows the percentage of the catch composed of seal shark and the bottom panel shows the proportion of zero catches. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods; letter colour is the same as its associated line.

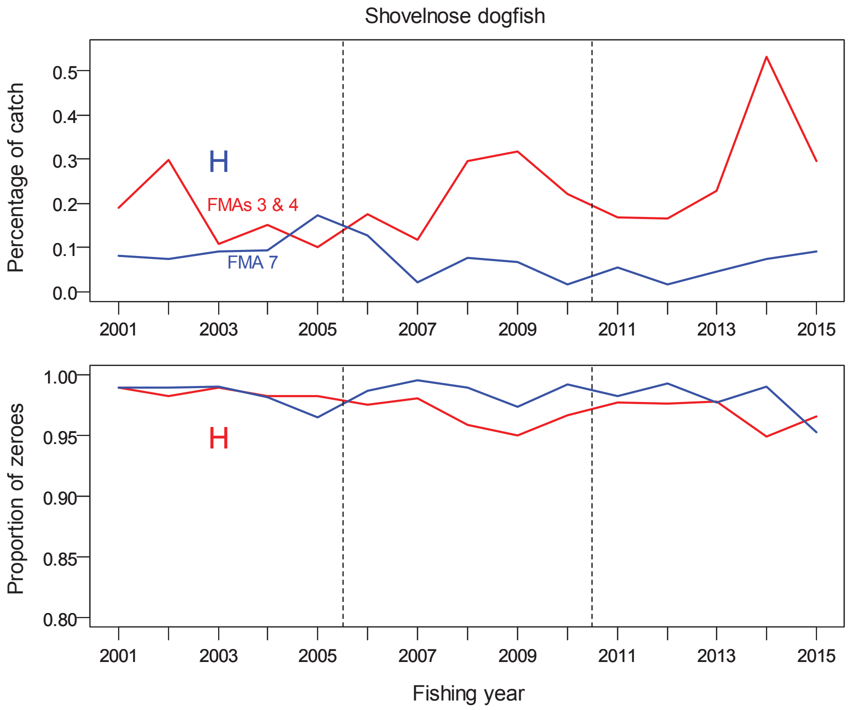


Figure 18: Species composition indicators for trawl-caught shovelnose dogfish reported on TCP forms in FMAs 3 & 4 and FMA 7. Top panel shows the percentage of the catch composed of shovelnose dogfish and the bottom panel shows the proportion of zero catches. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "H" indicates significantly high time period; letter colour is the same as its associated line.

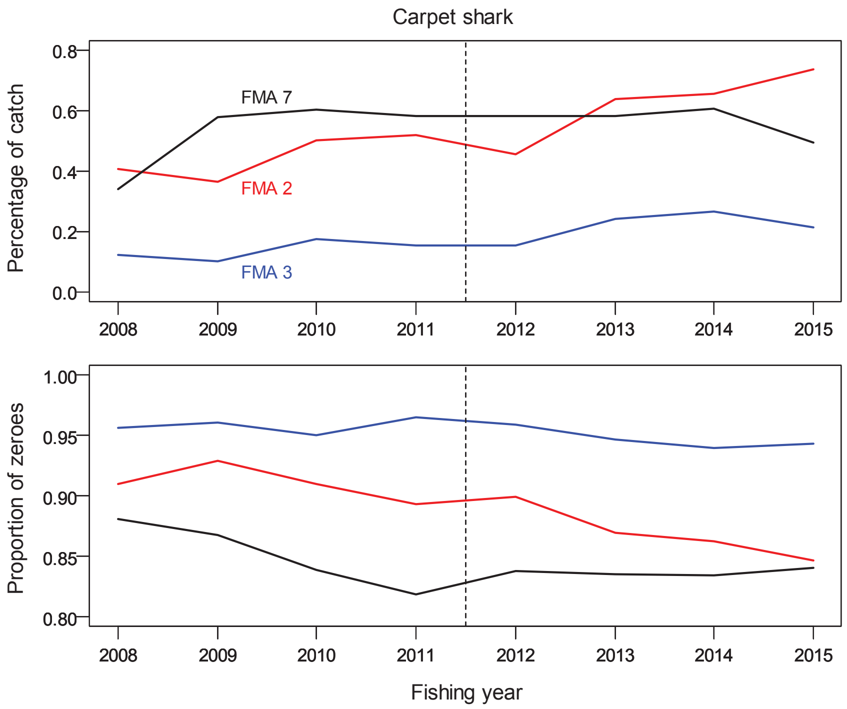


Figure 19: Species composition indicators for trawl-caught carpet shark reported on TCE forms in FMAs 2, 3 and 7. Top panel shows the percentage of the catch composed of carpet shark and the bottom panel shows the proportion of zero catches. Dashed vertical line indicates demarcation between time periods used for rank randomisation test.

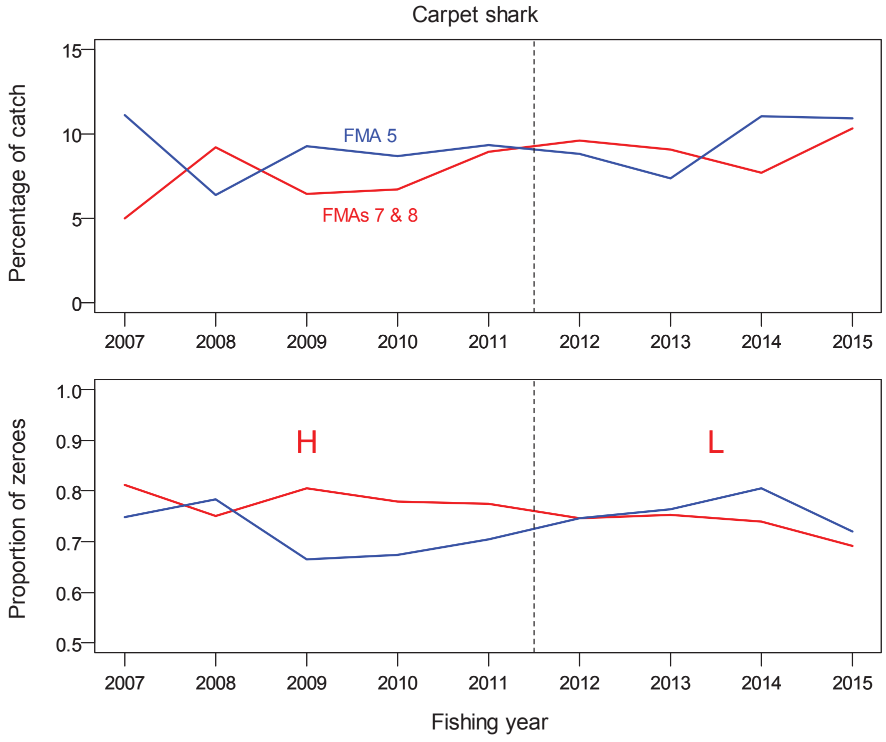


Figure 20: Species composition indicators for set-net-caught carpet shark reported on NCE forms in FMA 5 and FMAs 7 & 8. Top panel shows the percentage of the catch composed of carpet shark and the bottom panel shows the proportion of zero catches. Dashed vertical line indicates demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods; letter colour is the same as its associated line.

7. CONCENTRATION

7.1 INTRODUCTION

In target fisheries, fishing effort is typically focussed in areas supporting the greatest abundance of the target species, leading to higher catch rates than if the effort was randomly distributed. One way to measure the degree of effort concentration is the ‘concentration index’, also known as the ‘targeting index’, developed by Gulland (1956). That index is calculated as the ratio of two other indices involving catch and effort (see Section 7.2). When the concentration index exceeds 1, fishing effort is concentrated in areas having higher than average CPUE, and when it is less than 1, fishing effort is concentrated in areas having lower than average CPUE (Harley 2009; Clarke et al. 2011b). An index of 1 indicates a random distribution of fishing effort.

None of the species considered in the present study is known to be targeted by commercial fisheries. However they may associate with species that are targeted, and calculation of the concentration index for bycatch species can provide useful information on the degree to which they are caught incidentally by fisheries targeting other species. Concentration indices greater than 1 might indicate that the bycatch species associates with the target species and is heavily exploited, whereas indices less than 1 might indicate the species is negatively associated with the target species, or is avoided by the fishing fleet, and is therefore lightly exploited. Concentration indices have been used to assess the degree to which pelagic sharks might be targeted by the Pacific tuna longline fishery (Clarke et al. 2011b).

As in previous sections relying on commercial fishery data, the analyses in this section are restricted to species and regions having sufficient data to allow reliable interpretations. That is only possible if a species is both caught in reasonable quantities that represent its abundance, and is reported consistently on fishing returns.

7.2 METHODS

The concentration index is calculated as the ratio of two other indices called the unweighted and weighted indices (Harley 2009; Clarke et al. 2011b). The unweighted index is the total catch across a number of spatial strata divided by total effort, and the weighted index is the average stratum CPUE:

$$Concentration\ index = \frac{\sum_{i=1}^{n} catch_i}{\sum_{i=1}^{n} effort_i} \Big/ \left(\sum_{i=1}^{n} \frac{catch_i}{effort_i} / n \right)$$

where *i* indexes the *n* exploited strata. A concentration index was calculated separately for each year to form an annual index. The spatial strata used for this analysis were $1^{o} \times 1^{o}$ rectangles within each region (one or two FMAs). Rectangles having less than 100 km of total trawled distance (TCP and TCE data) or 100 km of net set (NCE data) were omitted to avoid artefacts caused by small amounts of effort in a stratum.

7.3 RESULTS

Sample sizes for the concentration indices (i.e. the number of one-degree rectangles per species/ method/region/year stratum) ranged from small for carpet shark (often less than 20) to moderately large for seal shark and shovelnose dogfish (often more than 30) (Table 6). This reflects the smaller area covered by the inshore fisheries (trawl and set net) for carpet shark within each FMA compared with the deepwater fisheries for seal shark and shovelnose dogfish.

Seal shark (Figure 21, Appendix 4G)
For FMAs 3 and 4, the concentration indicator was high initially and then decreased significantly. For FMAs 5 and 6, the concentration indicator was highly variable, but the rank randomisation test showed that it decreased significantly from 2005. The FMA 3 & 4 annual indices were all less than 1, as were 13 out of 17 of the FMA 5 & 6 indices. Thus for both regions, seal sharks were generally caught at

lower concentrations in strata having the greatest fishing effort than in strata having lower fishing effort, and that pattern increased through time.

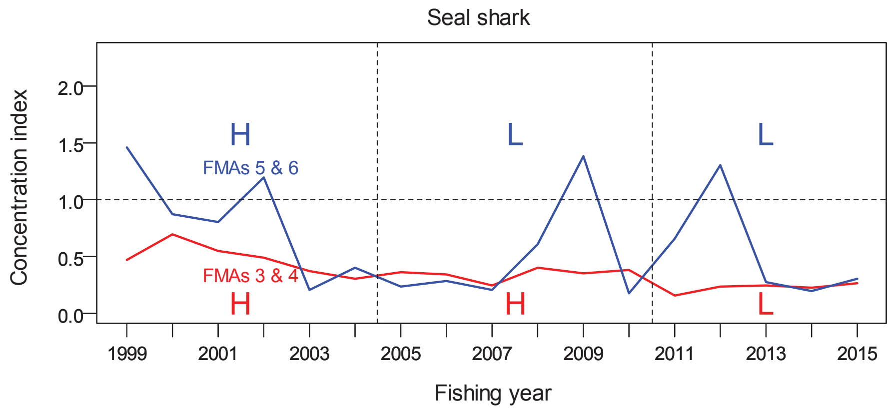


Figure 21: Concentration indicators for trawl-caught seal shark reported on TCP forms in FMAs 3 & 4 and FMAs 5 & 6. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods; letter colour is the same as its associated line.

Table 6: Annual sample sizes (number of one-degree rectangles) for the concentration indicator analyses.

Species	Method	Region	Range	Mean
Seal shark	Bottom trawl	FMAs 3 & 4	37–53	44.2
		FMAs 5 & 6	26–56	38.1
Shovelnose dogfish	Bottom trawl	FMAs 3 & 4	37–47	43.3
		FMA 7	10–21	14.1
Carpet shark	Bottom trawl	FMA 2	11–12	11.6
		FMA 3	10–14	12.3
		FMA 7	19–24	20.6
Carpet shark	Set net	FMA 5	7–10	8.6
		FMAs 7 & 8	15–26	20.4

Shovelnose dogfish (Figure 22, Appendix 4G)
In both FMAs 3 & 4 and in FMA 7, the concentration indicators showed a significant decline followed by a small but significant increase. Most annual indices were less than 1. Thus for both regions, shovelnose dogfish were generally caught at lower concentrations in strata having the greatest fishing effort than in strata having lower fishing effort, and that pattern increased but then reversed slightly through time.

Carpet shark (Figures 23 and 24, Appendix 4G)
For bottom trawl in FMAs 2, 3 and 7, the carpet shark concentration indicators showed no significant changes. Indices were usually greater than 1 for FMAs 3 and 7, and less than 1 for FMA 2.

For set net in FMAs 7 & 8, the carpet shark concentration indicator showed a significant decline, although the annual indices were quite variable. In FMA 5, the set net indices showed a steady decline that was almost significant (the mean ranks were equal to either the upper or lower confidence interval; see Appendix 4G). The indices were sometimes above and sometimes below 1.

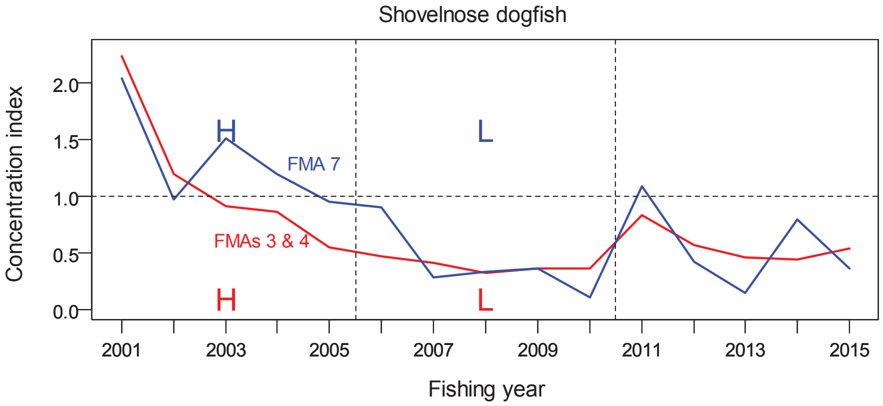


Figure 22: Concentration indicators for trawl-caught shovelnose dogfish reported on TCP forms in FMAs 3 & 4 and FMA 7. Dashed vertical lines indicate demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods; letter colour is the same as its associated line.

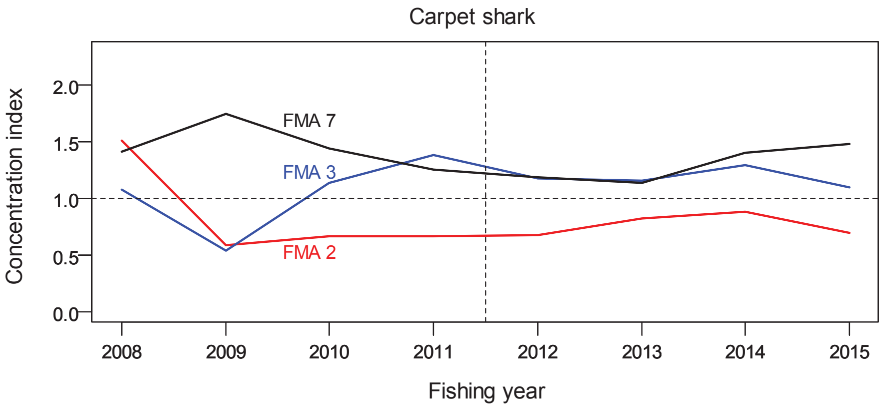


Figure 23: Concentration indicators for trawl-caught carpet shark reported on TCE forms in FMAs 2, 3 and 7. Dashed vertical line indicates demarcation between time periods used for rank randomisation test.

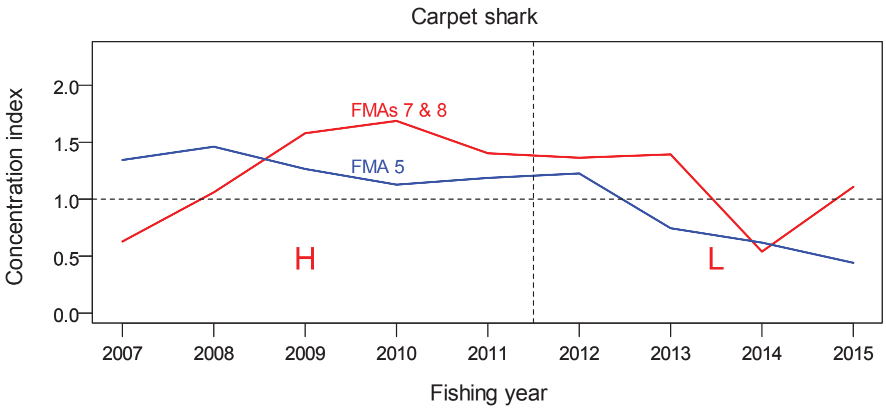


Figure 24: Concentration indicators for set-net-caught carpet shark reported on NCE forms in FMA 5 and FMAs 7 & 8. Dashed vertical line indicates demarcation between time periods used for rank randomisation test. "L" and "H" indicate significantly low or high time periods; letter colour is the same as its associated line.

7.4 CONCLUSIONS

Most of the concentration indicators were usually less than 1. This suggests that the shark species analysed here are typically not associating with target fish species, and therefore they are not being caught at higher than average rates; i.e. the heaviest fishing effort does not occur where the bycatch species are most abundant. Most of the indices were stable or declining over time, suggesting that fishing effort was moving away from the regions of greatest shark abundance. However, an alternative explanation for downward trends is that the abundance of the bycatch species is declining in the areas with greatest effort, but is not declining (or is declining at a slower rate) elsewhere. These hypotheses could be tested by exploring the temporal variation in the spatial distribution of high-CPUE cells, and whether effort has moved to low-CPUE cells over time. Reduced reporting of bycatch species could also affect the indices. Interpretation of trends in the concentration indicator are therefore not simple.

The trawl concentration indices for carpet shark in FMAs 3 and 7 were usually greater than 1, indicating that the greatest fishing effort of the inshore trawl fleet is occurring in areas of highest carpet shark abundance. However there were no trends in those indices over time. The set net concentration indices were generally greater than 1, but were near or below 1 in the last few years.

8. CATCH PER UNIT EFFORT

8.1 INTRODUCTION

Nominal CPUE is simple to compute as the mean weight of each shark species caught per unit of effort. If average catchability is assumed to be constant through time and CPUE is not strongly hyper-stable relative to actual density, then the resulting nominal CPUE time trend should relate to the trajectory of stock abundance. However, this relationship can be skewed by factors that alter catchability, obscuring the abundance signal. These factors may include changes in fishing techniques (e.g. gear, bait or time of day), changes in spatial and temporal distribution of effort (e.g. area, season or depth), or changes in the vessel composition of the fleet (Maunder & Punt 2004). In order to remove the annual variation in the data not attributable to changes in abundance, standardised CPUE series are produced using statistical models. These models are used to estimate coefficients representing the variation due to year alone.

We conducted CPUE standardisations of vessel reported data from three commercial form types (NCE set net, TCE trawl and TCP trawl) with the objective of producing time series of catch rate representative of shark species' relative abundance through time. Only three species had sufficient catch across all available fishing years to determine year-trends from CPUE: seal shark, shovelnose dogfish and carpet shark (see Figure 12 and Table 4). CPUE standardisations were conducted separately by form type, species and FMA subset (Table 7).

In addition, we explored the use of observer data collected aboard commercial vessels for CPUE standardisation. Observers cover only a fraction of the commercial effort, but they potentially provide a longer time series of catches that have been accurately identified to species, and better recording of discarded bycatch. Only shovelnose dogfish in FMAs 3 & 4 provided sufficient data for analysis (Appendix 12).

Table 7: CPUE standardisations conducted in this study by form type, shark species and FMA subset

Method	Form	Species	FMAs
Trawl	TCE	Carpet shark	2 & 3; 7
Set net	NCE	Carpet shark	5; 7 & 8
Trawl	TCP	Shovelnose dogfish	3 & 4
Trawl	TCP	Seal shark	3 & 4; 5 & 6
Trawl	Observer	Shovelnose dogfish	3 & 4

8.2 METHODS

Data Description

The catch rate standardisation analysis used vessel-reported catch and effort data from commercial trawl reported on TCP (1998–2015) and TCE forms (2008–2015); set-net-reported data on NCE forms (2007–2015); and observer-reported trawl data (1987–2015). Data were checked for gross outliers with respect to all continuous variables offered to the GLM by the optimisation routine, although none were identified (see Table 9). For vessel-reported data, a subset of core vessels was taken and used for all CPUE standardisations; they were defined as vessels that had conducted a minimum of 10 gear deployments per fishing year in at least five fishing years (except for shovelnose dogfish in FMA 7 using TCP data, for which core vessels comprised those with a minimum of five tows in each of five years – due to the very large proportion of zero tows). Trawl observer records do not record vessel ID and so all tows were used for the CPUE standardisation.

The number of tows by fishing year for the core vessel dataset and respective catch by species for all vessels and just core vessels is given in Table 8. In nearly all cases the core vessel catch by year was more than half of the total catch, with the exception of shovelnose dogfish in FMA 7 (TCP) for which core vessels comprised less than 50% of the total reported catch in all fishing years (excluding 2012) since 2007.

Modelling approach
The CPUE standardisation analysis was undertaken using Generalised Linear Models (GLMs) in the *R* programming language. A standard two-step combined normal/binomial model approach was adopted to deal with the high incidence of zero catches for all shark species assessed and to produce standardised CPUE time series (catch weight per tow) for all species/form type/area combinations. The normal model predicts the logarithm of catch weight (in kilograms) on all positive tows, using a Gaussian error distribution and the identity link function, and the binomial model predicts the probability of a non-zero catch, using a binomial error and a logit link function.

A forward stepwise model optimisation routine was followed with fishing year fixed as the first explanatory term in all models. The criterion used for determining which predictor variable to add to the model at each stage was the maximum decrease in the Akaike Information Criterion (AIC). Terms were added sequentially according to this rule until the increase in percentage deviance explained on adding this term was less than 1%. Quantile-quantile (Q-Q) plots were visually inspected for catch rate GLMs to check that residuals met the assumption of normality.

Explanatory variables
A list of explanatory variables offered to the GLM optimisation routine is given in Table 9. These included variables as reported in the forms and a number of derived variables – the method for calculating/assigning values is also given in Table 9. Third order polynomials were used for locational variables (start latitude, start longitude and effort depth), and also for fishing duration in observer models, because shark catch rate was assumed to have a non-linear response to those predictors.

8.3 RESULTS

GLM structures
Model terms retained by the GLM optimisation routine described above are shown in Table 10. The number of core vessels available for modelling SND in FMA 7 was highly variable, and no core vessels fished in 2007 or 2014; these data were considered to be inadequate for modelling this stock. Vessel key was retained for all models and frequently explained more of the deviance than any other predictor variable (recalling that fishing year was fixed as the first term). Final catch rate GLM structures explained between 29% and 58% of the total deviance depending on form type, species and FMA (Table 9).

Table 8: Vessel-reported gear deployments and catch (t) of carpet shark and seal shark by fishing year for core and all vessels; NCE set net, TCE trawl and TCP trawl.

Fishing year	NCE FMA 5 Core set net deployments	NCE FMA 5 Core catch CAR	NCE FMA 5 Total catch CAR	NCE FMA 7 & 8 Core set net deployments	NCE FMA 7 & 8 Core catch CAR	NCE FMA 7 & 8 Total catch CAR
2007	326	45.1	48.6	526	31.4	32.5
2008	389	29.7	30.4	634	54	59.6
2009	337	40.9	40.9	402	38.1	42.3
2010	366	41	41	444	46.2	48.5
2011	373	41.9	41.9	531	56.5	56.9
2012	381	33.9	33.9	500	52.1	60.4
2013	451	28	28	420	39.7	45.1
2014	527	39.4	39.4	489	43.7	46.8
2015	468	36.2	36.2	554	46.9	48.8

Fishing year	TCE FMAs 2 & 3 Core trawl deployments	TCE FMAs 2 & 3 Core catch CAR	TCE FMAs 2 & 3 Total catch CAR	TCE FMA 7 Core trawl deployments	TCE FMA 7 Core catch CAR	TCE FMA 7 Total catch CAR
2008	4 743	8.3	17.6	8 290	27.9	32
2009	5 123	9.9	15.7	8 352	53.1	57.4
2010	5 631	14.5	26.5	9 671	53.6	59.3
2011	5 694	12.9	24	8 646	50.6	55.9
2012	4 994	15.8	24.9	8 567	54.8	60.6
2013	5 234	26.3	38.2	8 616	53.1	57.2
2014	5 218	19.7	43.4	8 647	49	53
2015	4 845	19.7	33.4	8 460	41.9	44.8

Fishing year	TCP FMAs 3 & 4 Core trawl deployments	TCP FMAs 3 & 4 Core catch BSH	TCP FMAs 3 & 4 Total catch BSH	TCP FMAs 5 & 6 Core trawl deployments	TCP FMAs 5 & 6 Core catch BSH	TCP FMAs 5 & 6 Total catch BSH
1998	7 249	11.3	20.9	1 403	5.7	16.5
1999	6 886	116	138.1	1 357	25.9	27.7
2000	7 649	119.2	167.2	2 755	65.3	70.9
2001	8 060	82.3	104.9	2 322	99	115.9
2002	7 815	49.9	62.2	3 180	206.9	219.7
2003	8 464	92.9	114.7	2 055	28.1	41.1
2004	8 054	107.6	161.4	1 572	50.3	54.9
2005	7 681	82.1	95.2	1 547	32.4	35.1
2006	7 187	89.5	94.4	1 035	28	31.2
2007	6 902	121.6	123.9	857	10.3	15.3
2008	6 934	210.4	211.9	1 445	22.8	23.6
2009	6 432	154.9	157	1 430	7.8	7.8
2010	6 100	103.2	105.1	1 545	47	47
2011	4 877	50.2	52.1	1 348	12.3	12.4
2012	5 201	70	70.1	862	0.5	4.1
2013	4 317	82.6	84.2	1 237	7.1	18
2014	4 420	50.6	53.9	1 653	9.8	12.9
2015	4 632	23	28.9	1 363	1.8	4.8

Table 8 continued: Vessel-reported gear deployments and catch (t) of shovelnose dogfish by fishing year for core and all vessels; TCP trawl.

	TCP FMA 3 & 4			TCP FMA 7		
Fishing year	Core trawl deployments	Core catch SND	Total catch SND	Core trawl deployments	Core catch SND	Total catch SND
1998	4 862	0	0	–	–	–
1999	5 943	2.4	20.6	679	0.7	4
2000	6 179	17.8	46.6	984	0.1	0.1
2001	5 229	76.4	107.2	801	5.7	6.2
2002	5 817	50.7	147.4	772	3.6	6.5
2003	6 102	48.6	57.9	810	5.4	7.8
2004	4 926	56.1	78	538	5.4	9.1
2005	4 890	40	48.6	646	14.9	17
2006	4 571	71.1	78.2	531	9.3	11.3
2007	5 188	50.6	56.9	300	0	2.3
2008	4 959	115.4	120.7	118	2	6
2009	4 750	107.4	110.8	238	1.6	4.9
2010	3 340	65.9	74.2	378	0.5	1.2
2011	3 568	40.8	58.8	547	1.2	4.4
2012	3 108	41.7	54.1	448	1.4	1.5
2013	4 134	35.7	59.7	390	0.2	3.6
2014	4 050	113.8	144.6	550	0	3.8
2015	4 862	39.6	91.6	790	0.9	7.3

Table 8 continued: Vessel-reported gear deployments and catch (t) of shovelnose dogfish by fishing year for core and all vessels; Observer trawl; All tows used (no core subset).

	Observer FMA 3 & 4	
Fishing year	Trawl deployments	Catch SND
1987	1 892	104.1
1988	1 738	94
1989	2 262	32.5
1990	951	18.9
1991	1 781	65.6
1992	1 178	26.1
1993	1 022	15.2
1994	2 261	42.2
1995	1 788	5.5
1996	1 185	6.9
1997	1 061	3.6
1998	2 489	24.9
1999	1 833	13.9
2000	1 861	56.8
2001	2 797	30.1
2002	2 144	95.8
2003	2 213	32
2004	1 648	28.1
2005	1 953	43.5
2006	1 658	80
2007	1 882	54.9
2008	2 005	92.8
2009	1 746	48.8
2010	1 503	41.4
2011	1 158	33.5
2012	1 446	18.5
2013	2 189	61.4
2014	2 157	59
2015	1 844	12.4

Table 9: List of variables used in GLMs for estimating standardised CPUE of shark species in trawl and set net deployments. NCE, set net; TCE and TCP, trawl.

Variable	Description	Forms
Listed variables		
Fishing year	Fishing year (from 1 October to 30 September)	All
Vessel key	Unique vessel identification number	NCE, TCE, TCP
Primary method	Fishing gear type	All
Effort depth	Fishing effort depth	TCP
Bottom depth	Fishing bottom depth	Observer
Target species	Target species	All
Vessel length	Overall vessel length in metres	NCE, TCE, TCP
Engine kilowatts	Vessel engine power	NCE, TCE, TCP
Start latitude	Latitude at the start of fishing effort	NCE, TCE, TCP
Start longitude	Longitude at the start of fishing effort	NCE, TCE, TCP
Fishing duration	Temporal duration of fishing effort	All
Start stats area code	Fishery Statistical Area code at the start of fishing	NCE, TCE, TCP
Effort width	Width of fishing gear at deployment in metres	TCP, TCE
Effort height	Height of fishing gear at deployment in metres	TCP, TCE
Total net length	Total length of set net	NCE
Reg type	Registration type	Observer
Flag nationality	Vessel flag nationality	Observer
Headline height	Headline height of fishing gear	Observer
Catch	Catch (kilograms) per gear deployment	All
Derived variables		
Quarter	Year quarter of reported fishing effort date: Q1 = Jan–Mar; Q2 = Apr–Jun; Q3 = Jul–Sep; Q4 = Oct–Dec	All
Time	Time of day at the midpoint of fishing effort (the mean of start and end times)	All
Presence	Binary variable indicating if the catch on a gear deployment was non-zero	All
Duration	Length of time in hours between the start and end times of fishing	Observer
Mid latitude	The mean of reported latitude at the start and end of fishing	Observer
Mid longitude	The mean of reported longitude at the start and end of fishing	Observer
FMA	Derived from key relating start_obs_fma to numerical FMAs	Observer

Table 10: Model terms retained in GLM models for catch per gear deployment (Gaussian) and the probability of zero catch deployments models (binomial, response labelled "presence"). R-squared = proportion of deviance explained. NCE, set net; TCE and TCP, trawl.

Form/Species/FMA	GLM structure	R-squared
TCP BSH 3 & 4	$log(catch) \sim year + vessel\ key + target\ species$	0.34
	$presence \sim year + vessel\ key + \text{poly}(effort\ depth, 3)$	0.23
TCP BSH 5 & 6	$log(catch) \sim year + vessel\ key + fishing\ duration + \text{poly}(start\ latitude, 3)$	0.58
	$presence \sim year + \text{poly}(effort\ depth, 3) + vessel\ key + vessel\ length$	0.28
TCP SND 3 & 4	$log(catch) \sim year + fishing\ duration + vessel\ key + effort\ width$	0.54
	$presence \sim year + \text{poly}(start\ latitude, 3) + vessel\ key + \text{poly}(effort\ depth, 3)$	0.22
TCE CAR 2 & 3	$log(catch) \sim year + vessel\ key + target\ species$	0.41
	$presence \sim year + vessel\ key + target\ species$	0.09
TCE CAR 7	$log(catch) \sim year + vessel\ key + target\ species$	0.41
	$presence \sim year + vessel\ key + target\ species$	0.23
NCE CAR 5	$log(catch) \sim year + vessel\ key + fishing\ duration + \text{poly}(start\ latitude, 3)$	0.32
	$presence \sim year + target\ species + vessel\ key + fishing\ duration$	0.10
NCE CAR 7 & 8	$log(catch) \sim year + vessel\ key + \text{poly}(start\ longitude, 3) + fishing\ duration + time$	0.29
	$presence \sim year + vessel\ key + quarter + \text{poly}(start\ latitude, 3) + net\ length$	0.24
Observer SND 3 & 4	$log(catch) \sim year + \text{poly}(mid\ latitude, 3) + \text{poly}(duration, 3) + \text{poly}(depth, 3) + \text{target species} + \text{poly}(mid\ longitude, 3) + gear + quarter + flag\ nationality$	0.37
	$presence \sim year + target\ species + \text{poly}(mid\ latitude, 3) + \text{poly}(depth, 3) + \text{poly}(duration, 3)$	0.28

Standardised year effect on CPUE

Seal shark, TCP trawl (Figure 25, Appendix 4H)
For trawl deployments reported on TCP forms there was an increasing trend in the standardised CPUE of seal sharks in FMAs 3 & 4 and a declining trend in FMAs 5 & 6. An abrupt increase in CPUE was estimated in 2008 in FMAs 3 & 4, driven by an upward shift in CPUE on positive tows, although this may have reversed in 2014–15. Standardised CPUE in FMAs 5 & 6 does not appear to be well-estimated, with abrupt shifts from one fishing year to the next, although estimated CPUE has been low in all years since 2007 (with the exception of a single fishing year – 2010), driven by a decline in the proportion of positive tows.

Shovelnose dogfish, TCP trawl (Figure 26, Appendix 4H)
The standardised CPUE estimates of shovelnose dogfish in FMAs 3 & 4 increased from 1999, driven by an increase in the proportion of positive tows (0.005 in 1999, 0.069 in 2015), although the standardised CPUE estimates on positive tows showed no time trend.

Shovelnose dogfish, Observer trawl (Figure 27, Appendix 4H)
The standardised CPUE estimates of shovelnose dogfish in FMAs 3 & 4 from observer data decreased significantly between periods 1 and 2 (1987−96 and 1997−2006 respectively), driven by a decrease in catch rate on positive tows, then increased significantly in period 3 (2007−15). Examining the trend in finer detail suggests that CPUE increased from 1996 to 2008 and then declined thereafter.

Carpet shark, TCE trawl (Figure 28, Appendix 4H)
The standardised series indicated an increasing trend in the CPUE of carpet shark from 2008 to 2015 in FMAs 2 & 3 and FMA 7, in agreement with the nominal CPUE series. In FMAs 2 & 3 this was driven by an increase in the proportion of positive tows since 2011 and a slight increasing trend in standardised CPUE in positive tows from 2009 to 2015. In FMA 7, the proportion of positive tows increased from 2008 to 2011 and has remained stable since.

Carpet shark, NCE set net (Figure 29, Appendix 4H)
There was a significant decreasing trend in standardised CPUE in set net deployments in FMA 5 driven by a decrease in the CPUE of positive tows. CPUE did not change significantly in FMAs 7 & 8, although there was a non-significant increase from 2008 to 2011.

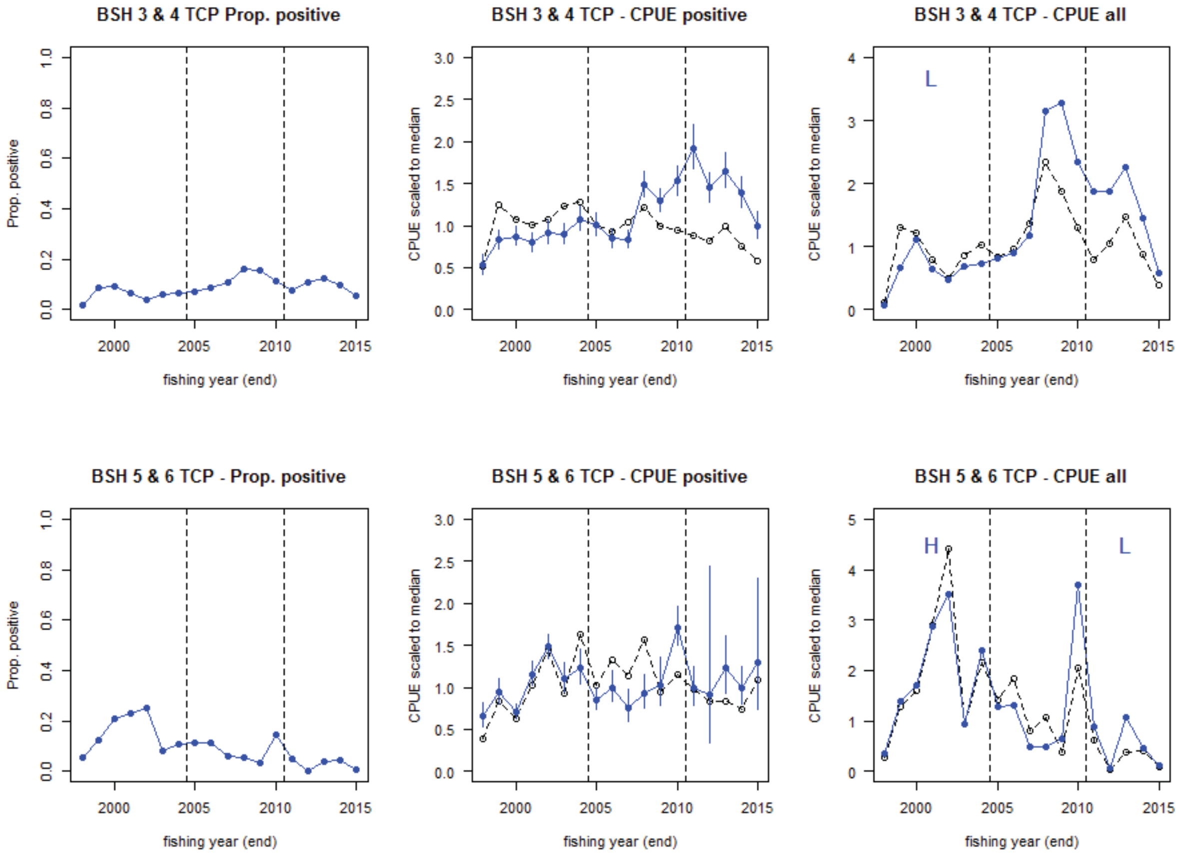


Figure 25: Proportion of positive trawl tows (left), standardised CPUE for all positive tows (middle) and standardised CPUE for all tows (right) estimated for seal shark reported on TCP forms in FMAs 3 & 4 (top) and FMAs 5 & 6 (bottom). Blue lines are the standardised series and whiskers are 95% confidence intervals; black lines are the nominal CPUE series. "L" and "H" indicate significantly low or high time periods.

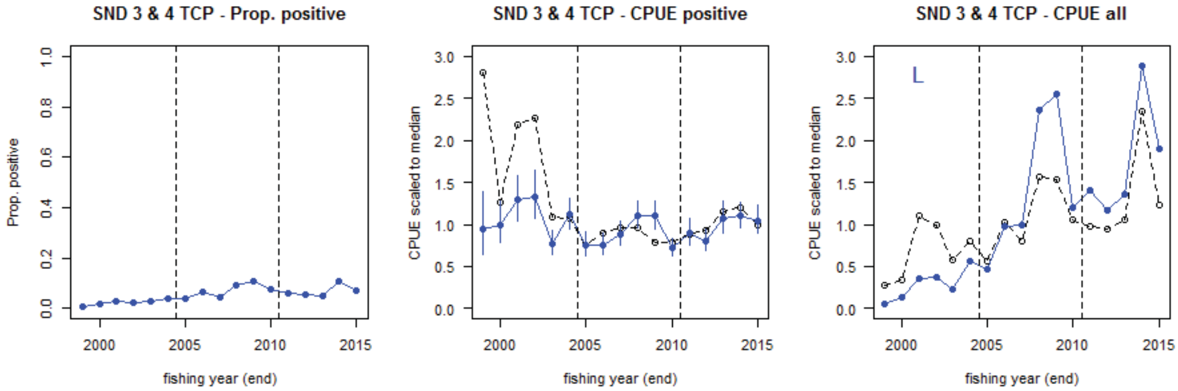


Figure 26: Proportion of positive trawl tows (left), standardised CPUE for all positive tows (middle) and standardised CPUE for all tows (right) estimated for shovelnose dogfish reported on TCP forms in FMAs 3 and 4. Blue lines are the standardised series and whiskers are 95% confidence intervals; black lines are the nominal CPUE series.

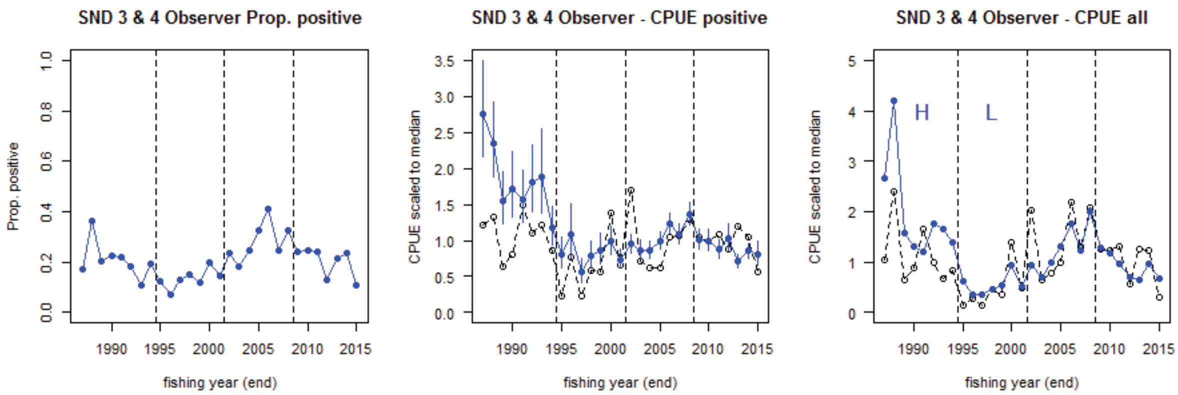


Figure 27: Proportion of positive trawl tows (left), standardised CPUE for all positive tows (middle) and standardised CPUE for all tows (right) estimated for shovelnose dogfish reported by observers in FMAs 3 and 4. Blue lines are the standardised series and whiskers are 95% confidence intervals; black lines are the nominal CPUE series. "L" and "H" indicate significantly low or high time periods.

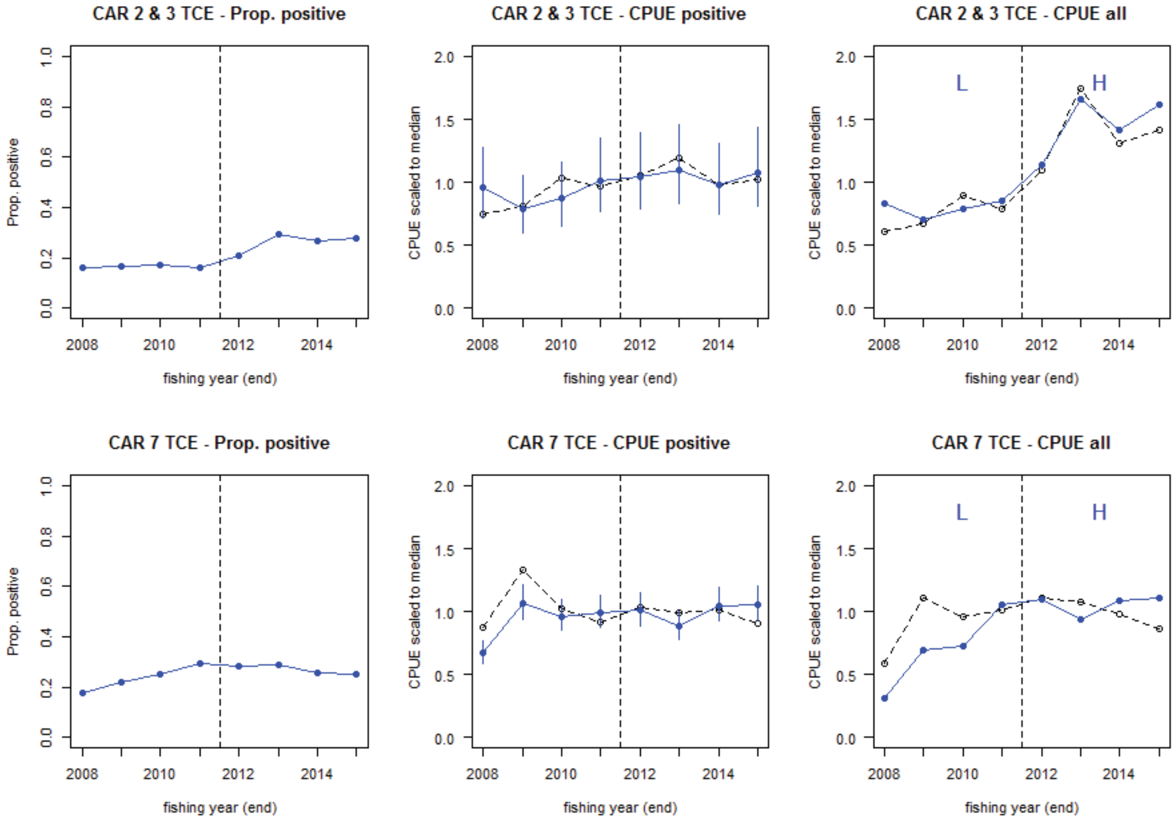


Figure 28: Proportion of positive trawl tows (left), standardised CPUE for all positive tows (middle) and standardised CPUE for all tows (right) estimated for carpet shark reported on TCE forms in FMAs 2 & 3 (top) and FMA 7 (bottom). Blue lines are the standardised series and whiskers are 95% confidence intervals; black lines are the nominal CPUE series. "L" and "H" indicate significantly low or high time periods.

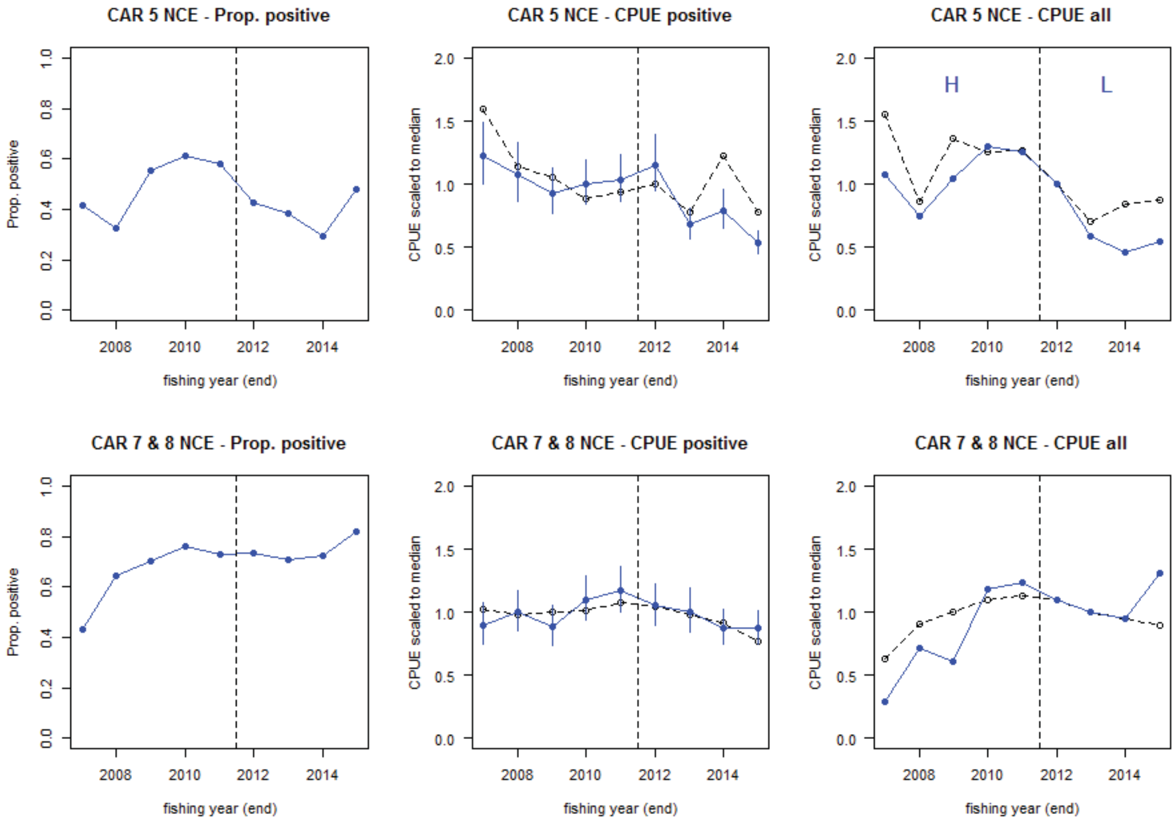


Figure 29: Proportion of positive set-net deployments (left), standardised CPUE for all positive deployments (middle) and standardised CPUE for all deployments (right) estimated for carpet shark reported on NCE forms in FMA 5 (top) and FMAs 7 & 8 (bottom). Blue lines are the standardised series and whiskers are 95% confidence intervals; black lines are the nominal CPUE series. "L" and "H" indicate significantly low or high time periods.

8.4 CONCLUSIONS

Assuming that the data provided by commercial fishers on their returns are accurate and that standardised CPUE indexed stock abundance, we draw the following conclusions:

- Carpet shark abundance has increased in FMAs 2, 3 and 7, but has decreased in FMA 5 since a high in 2010.
- The abundance of seal shark increased abruptly in FMA 3 & 4 in 2008 and may have decreased in the latest fishing year (2015). In FMAs 5 & 6, the abundance of seal sharks has declined since a high in 2002.
- Shovelnose dogfish has increased in abundance since 1999 in FMAs 3 & 4 according to the vessel-reported data and observer data. However, the observer data (which were based on a smaller subset of tows) suggest that abundance has declined since 2008.

We note that other interpretations are possible for some or all of these trends (a brief discussion of potential caveats with respect to catch reporting is given in Section 9.1). In addition, vessel catch reporting is only for the top five species by weight on TCP and NCE forms, and top eight species on TCE forms, leading to potential biases if a shark species was not abundant enough to be recorded, or if changes in the abundance of other species affected the relative importance of sharks.

9. DISCUSSION

9.1 DATA ISSUES

The validity and accuracy of the indicators presented here rely strongly on the quality and representativeness of the data used in their calculation. Unfortunately, all of the data sources used suffer from some serious problems and limitations.

Each trawl survey series was always carried out at the same time of year, and each survey typically involved fewer than 130 trawl tows (Beentjes & Stevenson 2000; Stevenson & Hanchet 2000; O'Driscoll et al. 2011; Bagley et al. 2013). The restricted timing of each survey means that they cannot account for seasonal variations in abundance of sharks caused by migration or changes in behaviour (e.g. sharks may move off the seabed and into the water column to look for food or mates, thus reducing their vulnerability to bottom trawls). The low numbers of trawl tows completed per survey, and the fact that surveys are optimised for valuable target teleosts rather than shark bycatch, may lead to large CVs around each point estimate, making it difficult to detect trends. The spatial extent of each survey was large, but did not necessarily cover the entire population ranges of the species of interest. Most sharks, and possibly also chimaeras, aggregate by size and sex. Consequently, some components of the population may not be sampled properly if they are distributed mainly outside the spatial or depth range of the survey. For example, the Chatham Rise and Sub-Antarctic surveys sample few adult seal sharks (most are shorter than 50 cm total length) and the Sub-Antarctic surveys catch few male longnose velvet dogfish (O'Driscoll et al. 2011; Bagley et al. 2013). The big advantages of trawl surveys are that they use consistent methodology, are fisheries-independent, and they employ random stratified survey designs, thus avoiding biases inherent in commercial fishery data.

Commercial fishery data are much more numerous and extensive in time and space than are trawl surveys, enabling integration across entire FMAs and whole years. This makes them a powerful source of information for developing indicators. However, the species of interest in the present study are not managed under the QMS, are not particularly valuable, and often do not fall in the top five or eight species per tow, for which estimated catch weights are reported. Furthermore, some of the species may be hard to identify. Consequently the quality of reporting of these species may vary markedly across vessels, years, locations, etc. The weight of sharks reported under generic codes (i.e. not identified to species) has considerably exceeded the weights of each of the species of interest throughout the available time series (see Figure 12). The high proportion of sharks reported under generic codes, and a declining trend in the weight of generic sharks reported, raise the risk of time-related trends in reporting of the species of interest, which would bias the indicators produced. For example, if the proportion of seal sharks reported under the code BSH increased through time in a particular FMA, it is likely to generate a positive bias in all indicators derived from commercial data. Conversely, some fishers historically used the seal shark code BSH to apply to a variety of 'black sharks' and the code therefore includes other deepwater shark species. Better identification of sharks in recent years may have reduced the amount of other species lumped under the BSH code. There is clear evidence that the reporting of the species of interest increased in the late 1990s (see Figure 12), but the extent and direction of any reporting biases since them cannot be determined.

Observers are likely to record most of the low-value, low-quantity, and discarded shark species caught on observed vessels. Observers are also more likely than fishers to have identified shark species accurately, leading to higher quality data. However, observer identification has probably also improved through time, especially since suitable identification guides were made available (Tracey & Shearer 2002; McMillan et al. 2011a; McMillan et al. 2011b). Observer coverage of the main deepwater fisheries which catch sharks has been low historically, but increased substantially from 2008. For vessels targeting hoki, hake and ling, observer coverage between 1991 and 2013 averaged 11% of tows and 17% of the target species catch; these values increased to 23% and 28% respectively for the last 6 years of that period (2008–2013) (Ballara & O'Driscoll 2015). Similarly, in the target orange roughy fisheries, observer coverage between 1991 and 2009 averaged 14% of tows and 20% of the target species catch, but increased to 44% and 53% respectively for the last two years of that period (2008–2009) (Anderson 2011). Thus indicators for deepwater sharks and chimaeras based on observer data are likely to be more reliable from 2008 onwards. Observer coverage of inshore fisheries that catch carpet shark was low until 2011, when the amount of carpet shark observed increased quickly in FMAs 3 and 5 (Appendix 12). As this time series lengthens in future, it may become possible to derive useful observer-based abundance indicators for carpet shark.

9.2 SPECIES SUMMARIES

A summary of trends in indicators is shown in Table 11. Most of the indicators for deepwater sharks and chimaeras came from FMAs 3–6, reflecting the availability of trawl survey series, and larger quantities of commercial and observer data, from those regions. Carpet shark indicators were available for FMAs 2, 3, 5, 7 and 8, areas that are covered by inshore trawl surveys or that support the larger inshore fisheries. No indicators were available for any species from FMAs 1, 9 and 10, although the lack of demersal fisheries in FMA 10 means that only FMAs 1 and 9 represent gaps that need to be filled.

In the rest of this section we focus particularly on recent trends; i.e. the existence or not of significant changes between the last two time periods analysed for each dataset. The period covered by the last two time periods varied with the length of the time series, and ranged from 7 to 15 years (see Tables 2, 3 and 5 for details).

Seal shark
In FMAs 3 and 4, trawl survey relative biomass for seal shark declined during the middle time period (early 2000s) and then increased during the last period (from 2008). However, absolute changes in biomass were small, and taking account of the CVs around the estimates, the significant trend is not considered biologically important (see Figure 3; the first point in the time series is considered anomalous, perhaps resulting from mis-identification of sharks). In contrast, standardised commercial trawl CPUE showed no significant trend between the second and third time periods, but that may reflect the use of time periods for significance testing that do not capture the dynamic pattern in the CPUE estimates: Figure 25 suggests a strong decline in abundance since 2009, although the 2015 index is similar to those experienced during the early–mid 2000s. Distribution and species composition (proportion zeroes) indicators also indicated significant declines in the 2010s. In FMAs 5 and 6, trawl survey biomass showed no trend, whereas most of the commercial indicators (standardised CPUE, distribution, and species composition (percent composition)) showed declines in abundance.

Research trawl survey and commercial trawl abundance indicators produced conflicting results. The Chatham Rise trawl surveys are believed to monitor seal shark abundance ‘moderately well’ (O'Driscoll et al. 2011), but the Sub-Antarctic surveys are ‘poor’ for monitoring abundance because the mean CV across surveys was greater than 40% (Bagley et al. 2013). We also note that both surveys catch mainly juveniles, so adult biomass was not well monitored. Indicators based on commercial data may be unreliable for reasons discussed in Section 9.1. Thus the status of seal shark in FMAs 3–6 is uncertain, but we give most weight to the fishery-independent trawl survey indicators, which suggest that there has been no major change over a long period of time in the abundance of juvenile seal shark in FMAs 3 and 4 at least, and possibly also in FMAs 5 and 6.

Table 11: Summary of indicator trends for eight shark and chimaera species. Cell colour shows most recent trend. Note that a downward trend in proportion zeroes is considered a positive trend (shaded green), and an upward trend in proportion zeroes is considered a negative trend (shaded red).

Species	Indicator	FMA 2	FMA 3	FMA 4	FMA 5	FMA 6	FMA 7	FMA 8
Seal shark	Trawl survey biomass		Down/Up		Nil			
	Distribution (high CPUE)		Up/Down		Down			
	Distribution (prop. zeroes)		Nil/Up		Nil/Up			
	Species comp (percent comp)		Nil		Down			
	Species comp (prop. zeroes)		Down/Up		Up/Nil			
	Concentration		Nil/Down		Down/Nil			
	Standardised CPUE (trawl)		Up/Nil		Down			
Shovelnose dogfish	Trawl survey biomass		Nil		Nil			
	Median length (males)		Nil/Down		Nil			
	Median length (females)		Nil		Nil			
	Proportion males		Up/Down		Nil/Down			
	Distribution (high CPUE)		Up/Nil				Nil	
	Distribution (prop. zeroes)		Down/Nil				Nil	
	Species comp (percent comp)		Nil				Down/Nil	
	Species comp (prop. zeroes)		Down/Nil				Nil	
	Concentration		Down/Up				Down/Up	
	Standardised CPUE (trawl)		Up/Nil					
	Standardised CPUE (observer trawl)		Down/Up/Down					
Baxter's dogfish	Trawl survey biomass		Nil		Up/Nil			
	Median length (males)		Nil		Nil			
	Median length (females)		Nil		Nil			
	Proportion males		Nil		Nil			
Longnose velvet dogfish	Trawl survey biomass		Nil		Nil			
	Median length (males)		Nil		Nil/Down			
	Median length (females)		Nil		Nil			
	Proportion males		Nil		Nil			
Plunket's shark	Trawl survey biomass		Nil		Nil			
Leafscale gulper shark	Trawl survey biomass		Nil		Nil			
Longnose spookfish	Trawl survey biomass		Up/Down		Nil			
	Median length (males)		Down/Up					
	Median length (females)		Nil					
	Proportion males		Nil					
Carpet shark	Trawl survey biomass		Up				Nil	
	Distribution (trawl high CPUE)	Up					Nil	
	Distribution (trawl prop. zeroes)	Down					Nil	
	Distribution (set net high CPUE)				Nil		Nil	
	Distribution (set net prop. zeroes)				Nil		Down	
	Species comp (trawl percent comp)	Nil	Nil				Nil	
	Species comp (trawl prop. zeroes)	Nil	Nil				Nil	
	Species comp (set net percent comp)				Nil		Nil	
	Species comp (set net prop. zeroes)				Nil		Down	
	Concentration (trawl)	Nil	Nil				Nil	
	Concentration (set net)				Nil		Down	
	Standardised CPUE (trawl)	Up					Up	
	Standardised CPUE (set net)				Down		Nil	

Legend: Shading colour shows trend between last two time periods

Trend positive in recent years

No trend in recent years

Trend negative in recent years

See text for interpretation

Blanks = none or unreliable

Shovelnose dogfish
Most indicators showed no significant recent trends in FMAs 3–7. Neither Chatham Rise nor Sub-Antarctic trawl surveys identified significant biomass trends, although the overall pattern of relative biomass in the latter (FMAs 5 and 6) was upwards (see Figure 5). Both trawl survey series monitor the abundance of shovelnose dogfish 'well' (O'Driscoll et al. 2011; Bagley et al. 2013). Standardised commercial CPUE in FMAs 3 and 4 increased early in the time series before becoming highly variable with no trend (Figure 26). Conversely, there was a down/up/down trend in standardised observer CPUE in FMAs 3 and 4 (see Figure 27). As discussed in Section 9.1, observer data are most reliable from 2008 onwards, and the standardised observer CPUE year index has dropped by more than half since then. There was also a downward trend in the median length of males in FMAs 3 and 4, and although the decline was small in absolute size, the sample sizes were large and there was also an increase in the 5th percentile, suggesting a decline in the proportion of juveniles. There were significant declines in the proportion of males in both FMAs 3 and 4 and FMAs 5 & 6, but in the latter region at least, the decline was driven by an increase in female abundance rather than a decrease in male abundance (Figures 4 and 6).

Conflicting signals make interpretation of shovelnose dogfish indicators difficult. Commercial reports of this species are less likely to be affected by species identification issues than the other deepwater sharks considered here, because shovelnose dogfish are relatively easily identified. But reporting rates, and any changes over time, may have compromised the commercial data. Trawl survey indicators suggest there is no immediate concern for shovelnose dogfish in FMAs 3–6, but male median length and standardised observer CPUE should be monitored closely in future for signs of ongoing decline.

Baxter's dogfish
No trends were found in any of the Baxter's dogfish indicators, all of which were derived from trawl survey data in FMAs 3–6. Trawl surveys monitor the abundance of Baxter's dogfish 'well' or 'moderately well' (O'Driscoll et al. 2011; Bagley et al. 2013).

Longnose velvet dogfish
No trends were found in any of the longnose velvet dogfish indicators, all of which were derived from trawl survey data in FMAs 3–6. A significant decline in male median length in FMAs 5 and 6 is regarded as unreliable because of small sample sizes and was ignored. Sub-Antarctic trawl surveys monitor the abundance of longnose velvet dogfish 'moderately well' but Chatham Rise surveys monitor this species 'poorly' (CV of biomass estimates over 40%) (O'Driscoll et al. 2011; Bagley et al. 2013).

Plunket's shark
The only indicators available were trawl survey relative biomass, which showed no trends in FMAs 3–6. However both surveys monitor this species 'poorly' (CV of biomass estimates over 40%) (O'Driscoll et al. 2011; Bagley et al. 2013).

Leafscale gulper shark
The only indicators available were trawl survey relative biomass, which showed no trends in FMAs 3–6. Sub-Antarctic trawl surveys monitor the abundance of this species 'moderately well' but Chatham Rise surveys monitor this species 'poorly' (CV of biomass estimates over 40%) (O'Driscoll et al. 2011; Bagley et al. 2013).

Longnose spookfish
Only indicators derived from trawl surveys in FMAs 3–6 were available for longnose spookfish. Trawl surveys monitor the abundance of this species 'very well' or 'well' (O'Driscoll et al. 2011; Bagley et al. 2013). The Chatham Rise survey indicated an up/down biomass trajectory in FMAs 3 and 4, and relative biomass in the 2010s was similar to that in the early 1990s (see Figure 3). There was no trend in the Sub-Antarctic survey (FMAs 5 and 6). There was a down/up trend in the median length of males in FMAs 3 and 4, with the upward trend coinciding with an increase in the 5th percentile, indicating a decrease in the proportion of juvenile males. This trend should be monitored carefully for ongoing signs of poor recruitment.

Carpet shark

Most carpet shark indicators showed either no trend or an increase in FMAs 2, 3, 5, 7 and 8. The east coast South Island trawl survey series in FMA 3 showed a doubling of biomass between the 1990s and the 2000s/2010s (Figure 1). Standardised CPUE and the two distribution indicators for FMAs 2 and 3 corroborated that trend. There was no trend in the west coast South Island survey series in FMA 7 (Figure 2), but standardised CPUE and some of the distribution and species composition indicators showed increasing trends. The only downward trend was for standardised set net CPUE in FMA 5 (Figure 29), but the short time series and variability in the indices mean that that trend is uncertain.

Carpet shark may have increased in abundance in FMAs 2, 3, 7 and 8, and declined in abundance in FMA 5; the latter should be monitored closely for further evidence of a decline.

Overall summary

None of the species covered by this study showed clear and consistent evidence of recent declines in abundance. However, estimated trends were often uncertain, inconsistent among indicators, based on indicators that may be unreliable (e.g. trawl survey biomass estimates for species that are not well surveyed), and based on too few indicators (only trawl survey indicators were available for five out of eight species). For a number of species, one or more indicators showed signs of decline, and ongoing monitoring is recommended. This is especially true for the deepwater shark species, which are known to have low productivity and to be especially vulnerable to intensive fishing effort. Major declines in the abundance of a number of deepwater shark species have been reported from eastern Australia and the northeastern Atlantic, including leafscale gulper shark and longnose velvet dogfish in the latter (Graham et al. 2001; Neat et al. 2015). The whitefin swell shark (*Cephaloscyllium albipinnum*), a close relative of the New Zealand carpet shark, showed large declines in some eastern Australian regions (Graham et al. 2001). Our results suggest that the species covered in this study have not suffered major declines, despite their being classified as being at high risk from fishing (Ford et al. 2015).

10. RECOMMENDATIONS FOR FUTURE INDICATOR ANALYSES

The utility of indicator analyses could be greatly enhanced in future through improvements in data quality and quantity, exploring different spatial (and possibly temporal) scales, and modifying or extending the indicator analyses. Some indicators were derived from relatively short time series and their value will increase substantially through time. Other specific recommendations for improving indicator analyses on shark bycatch species are given below.

Commercial fisheries

1. Encourage continued species-specific reporting of catches (including discards) by industry.
2. Remove generic codes (particularly OSD and DWD) from the list of permitted species codes. Good identification guides are now available to fishers, enabling them to easily and accurately identify their shark catch to species.
3. Explore ways of allocating generic shark catches to species-specific codes (for example, by developing predictive models of species distribution and species composition in geographical and depth strata using trawl survey and/or observer data).

Observer programme

4. Increase observer coverage, particularly in inshore trawl and set net fisheries catching carpet shark. Data from inshore fisheries could also be used to develop indicators for a number of other inshore shark and ray species.
5. Increase the priority given to measuring and sexing shark and chimaera bycatch.
6. Assess accuracy of observer species identifications (starting under project ENV201503).
7. Improve species identification resources available to observers (proposed under project ENV201501).

Research trawl

8. Increase priority for measuring and sexing shark bycatch on all trawl surveys. In particular, carpet shark should be measured and sexed on inshore trawl surveys.
9. Explore the application of species composition indicators to trawl survey data.
10. Examine trends in total shark biomass in trawl surveys.

Indicator analyses

11. Validate commercial data by comparing species composition and catch rates reported on fishing returns with those recorded by observers, both on the same vessel and between observed and unobserved vessels.
12. Compare commercial and trawl survey indicators after restricting the datasets for the former to the same season and spatial extent as the trawl surveys. This will enable a more direct comparison of commercial and research tows made at the same time and place.
13. Explore the value of using TCP daily catch records (sum of processed and discarded catch) instead of tow-by-tow estimated catch. Daily records should record actual rather than estimated weights.
14. Explore finer scale spatial variability in commercial and observer indices. Some deepwater sharks prefer seamounts and others prefer open slope habitats (Tracey et al. 2004). Stratification of commercial and observer data (for example by target species, depth range or tow length) to reflect such spatial differences in abundance may reduce variability and improve the power to detect trends.
15. Assess the utility of an alternative distribution indicator. A spatial occupancy indicator is estimated as the proportion of the total fishery or range area that contributes the highest fixed percentage (e.g. 95%) of the overall summed CPUE (Trenkel et al. 2013).

Frequency of analyses

16. Update indicator analyses every four years. This study has developed R code that permits rapid calculation of indicators using standard and repeatable methodology. This enables the indicators presented here to be updated quickly at frequent intervals. However, the three trawl survey series used in the present study are all conducted at 2-year intervals, so a 4-year update cycle for indicators will allow the addition of two new trawl surveys from each series in each update

11. ACKNOWLEDGMENTS

We thank Fred Wei and Chris Dick for providing database extracts, Richard O'Driscoll for advice on the ranks randomisation test and information on trawl survey series, and Emma Jones for comments on the draft report. This study was funded by the Ministry for Primary Industries under project code INS201401.

12. REFERENCES

Anderson, O.F. (2011). Fish and invertebrate bycatch and discards in orange roughy and oreo fisheries from 1990–91 until 2008–09. *New Zealand Aquatic Environment and Biodiversity Report* 67. 61 p.

Bagley, N.W.; Ballara, S.L.; O'Driscoll, R.L.; Fu, D.; Lyon, W. (2013). A review of hoki and middle depth summer trawl surveys of the Sub-Antarctic, November December 1991–1993 and 2000–2009. *New Zealand Fisheries Assessment Report* 2013/41. 63 p.

Ballara, S.L.; O'Driscoll, R.L. (2015). Fish and invertebrate bycatch and discards in New Zealand hoki, hake, or ling trawl fisheries from 1990–91 until 2012–13. *New Zealand Aquatic Environment and Biodiversity Report* 163. 120 p.

Beentjes, M.P.; Smith, M.; Phillips, N.L. (2004). Analysis of catchability for east coast South Island trawl surveys and recommendations on future survey design. *New Zealand Fisheries Assessment Report* 2004/5. 68 p.

Beentjes, M.P.; Stevenson, M.L. (2000). Review of the east coast South Island winter trawl survey time series, 1991-96. *NIWA Technical Report* 86. 64 p.

Beentjes, M.P.; Stevenson, M.L. (2001). Review of the east coast South Island summer trawl survey time series, 1996-97 to 1999-2000. *NIWA Technical Report* 108. 92 p.

Blackwell, R.G. (2010). Distribution and abundance of deepwater sharks in New Zealand waters, 2000–01 to 2005–06. *New Zealand Aquatic Environment and Biodiversity Report* 57. 51 p.

Buckland, S.T.; Magurran, A.E.; Green, R.E.; Fewster, R.M. (2005). Monitoring change in biodiversity through composite indices. *Philosophical Transactions of the Royal Society of London B360*: 243–254.

Clarke, S.; Harley, S.; Hoyle, S.; Rice, J. (2011a). An indicator-based analysis of key shark species based on data held by SPC-OFP. *Western Central Pacific Fisheries Commission Scientific Committee Seventh Regular Session* WCPFC-SC7-EB-WP-01. 88 p.

Clarke, S.; Yokawa, K.; Matsunaga, H.; Nakano, H. (2011b). Analysis of North Pacific shark data from Japanese commercial longline and research/training vessel records. *Western Central Pacific Fisheries Commission Scientific Committee Seventh Regular Session* WCPFC-SC7-EB-WP-02. 89 p.

Clarke, S.C.; Francis, M.P.; Griggs, L.H. (2013). Review of shark meat markets, discard mortality and pelagic shark data availability, and a proposal for a shark indicator analysis. *New Zealand Fisheries Assessment Report* 2013/65. 74 p.

Compagno, L.J.V. (1984). Sharks of the world. An annotated and illustrated catalogue of shark species known to date. *FAO Fisheries Synopsis* 125, vol. 4. 655 p.

Ford, R.B.; Galland, A.; Clark, M.R.; Crozier, P.; Duffy, C.A.J.; Dunn, M.; Francis, M.P.; Wells, R. (2015). Qualitative (Level 1) risk assessment of the impact of commercial fishing on New Zealand chondrichthyans. *New Zealand Aquatic Environment and Biodiversity Report* 157. 111 p.

Francis, M.P. (2013). Commercial catch composition of highly migratory elasmobranchs. *New Zealand Fisheries Assessment Report* 2013/68. 79 p.

Francis, M.P.; Clarke, S.C.; Griggs, L.H.; Hoyle, S.D. (2014). Indicator based analysis of the status of New Zealand blue, mako and porbeagle sharks. *New Zealand Fisheries Assessment Report* 2014/69. 109 p.

Francis, R.I.C.C. (1981). Stratified random trawl surveys of deep-water demersal fish stocks around New Zealand. *Fisheries Research Division Occasional Publication* 32. 28 p.

Francis, R.I.C.C. (1984). An adaptive management strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18*: 59–71.

Francis, R.I.C.C.; Fu, D. (2012). SurvCalc user manual v1.2-2011-09-28. *NIWA Technical Report* 134. 54 p.

Francis, R.I.C.C.; Hurst, R.J.; Renwick, J.A. (2001). An evaluation of catchability assumptions in New Zealand stock assessments. *New Zealand Fisheries Assessment Report* 2001/1. 37 p.

Francis, R.I.C.C.; Smith, D.C. (1995). Mean length, age, and otolith weight as potential indicators of biomass depletion for Chatham Rise orange roughy. New Zealand Fisheries Assessment Research Document 95/13. 8 p. (Unpublished document held by NIWA library, Wellington.)

Goodyear, C.P. (2003). Blue marlin mean length: simulated response to increasing fishing mortality. *Marine and Freshwater Research 54*: 401–408.

Graham, K.J.; Andrew, N.L.; Hodgson, K.E. (2001). Changes in relative abundance of sharks and rays on Australian South East Fishery trawl grounds after twenty years of fishing. *Marine and Freshwater Research 52*: 549–561.

Gulland, J.A. (1956). A study of fish populations by the analysis of commercial catches. *Rapports et procès-verbaux des réunions, Conseil Permanent International pour l'Exploration de la Mer 140*: 21–29.

Harley, S. (2009). Spatial distribution measures for the analysis of longline catch and effort data. Western Central Pacific Fisheries Commission Scientific Committee fifth regular session WCPFC-SC5-2009 SA-IP-2.

Lamb, E.G.; Bayne, E.; Holloway, G.; Schieck, J.; Boutin, S.; Herbers, J.; Haughland, D.L. (2009). Indices for monitoring biodiversity change: Are some more effective than others? *Ecological Indicators 9*: 432–444.

Magurran, A.E.; McGill, B.J. (2011). Biological diversity. Oxford University Press, Oxford, United Kingdom. 368 p.

Maunder, M.N.; Punt, A.E. (2004). Standardizing catch and effort data: a review of recent approaches. *Fisheries Research 70*: 141–159.

McMillan, P.J.; Francis, M.P.; James, G.D.; Paul, L.J.; Marriott, P.J.; Mackay, E.; Wood, B.A.; Griggs, L.H.; Sui, H.; Wei, F. (2011a). New Zealand fishes. Volume 1: A field guide to common species caught by bottom and midwater fishing. *New Zealand Aquatic Environment and Biodiversity Report* 68. 329 p.

McMillan, P.J.; Francis, M.P.; Paul, L.J.; Marriott, P.J.; Mackay, E.; Baird, S.-J.; Griggs, L.H.; Sui, H.; Wei, F. (2011b). New Zealand fishes. Volume 2: A field guide to less common species caught by bottom and midwater fishing. *New Zealand Aquatic Environment and Biodiversity Report* 78. 181 p.

Ministry for Primary Industries. (2014). Fisheries Assessment Plenary, November 2014: stock assessments and stock status. Compiled by the Fisheries Science Group, Ministry for Primary Industries, Wellington, New Zealand. 618 p.

Ministry for Primary Industries. (2015). Fisheries Assessment Plenary, May 2015: stock assessments and stock status. Ministry for Primary Industries, Wellington, New Zealand, Wellington. 1475 p.

Ministry for Primary Industries. (2016). Aquatic environment and biodiversity annual review 2015. Ministry for Primary Industries, Wellington, New Zealand, Wellington. 682 p.

Mucientes, G.R.; Queiroz, N.; Sousa, L.L.; Tarroso, P.; Sims, D.W. (2009). Sexual segregation of pelagic sharks and the potential threat from fisheries. *Biology Letters 5*: 156–159.

Neat, F.C.; Burns, F.; Jones, E.; Blasdale, T. (2015). The diversity, distribution and status of deep-water elasmobranchs in the Rockall Trough, north-east Atlantic Ocean. *Journal of Fish Biology 87*: 1469–1488.

O'Driscoll, R.L.; MacGibbon, D.; Fu, D.; Lyon, W.; Stevens, D.W. (2011). A review of hoki and middle-depth trawl surveys of the Chatham Rise, January 1992–2010. *New Zealand Fisheries Assessment Report* 2011/47. 72 p.

Parker, S.J.; Francis, M.P. (2012). Productivity of two species of deepwater sharks, *Deania calcea* and *Centrophorus squamosus* in New Zealand. *New Zealand Aquatic Environment and Biodiversity Report* 103. 44 p.

Pikitch, E.K.; Santora, E.A.; Babcock, A.; Bakun, A.; Bonfil, R.; Conover, D.O.; Dayton, P.; Doukakis, P.; Fluharty, D.; Heheman, B.; Houde, E.D.; Link, J.; Livingston, P.A.; Mangel, M.; McAllister, M.K.; Pope, J.; Sainsbury, K. (2004). Ecosystem-based fishery management. *Science 305*: 346–347.

R Development Core Team. (2008). R: A language and environment for statistical computing. http://www.R-project.org. R Foundation for Statistical Computing, Vienna, Austria. p.

Roberts, C.D.; Barker, J.J.; Stewart, A.L.; Struthers, C.D.; Kortet, S. (2015). Checklist of the fishes of New Zealand. *In*: Roberts, C.D.; Stewart, A.L.; Struthers, C.D. (eds). The fishes of New Zealand, edition, pp. S147-S178, Te Papa Press, Wellington.

Stevenson, M.L.; Hanchet, S. (2000). Review of the inshore trawl survey series of the west coast South Island and Tasman and Golden Bays, 1992-97. *NIWA Technical Report* 82. 79 p.

Tracey, D.; Shearer, P. (2002). An identification guide for deepwater shark species. National Institute of Water and Atmospheric Research, Wellington. 14 p.

Tracey, D.M.; Bull, B.; Clark, M.R.; Mackay, K. (2004). Fish species composition on seamounts and adjacent slope in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research 38*: 163–182.

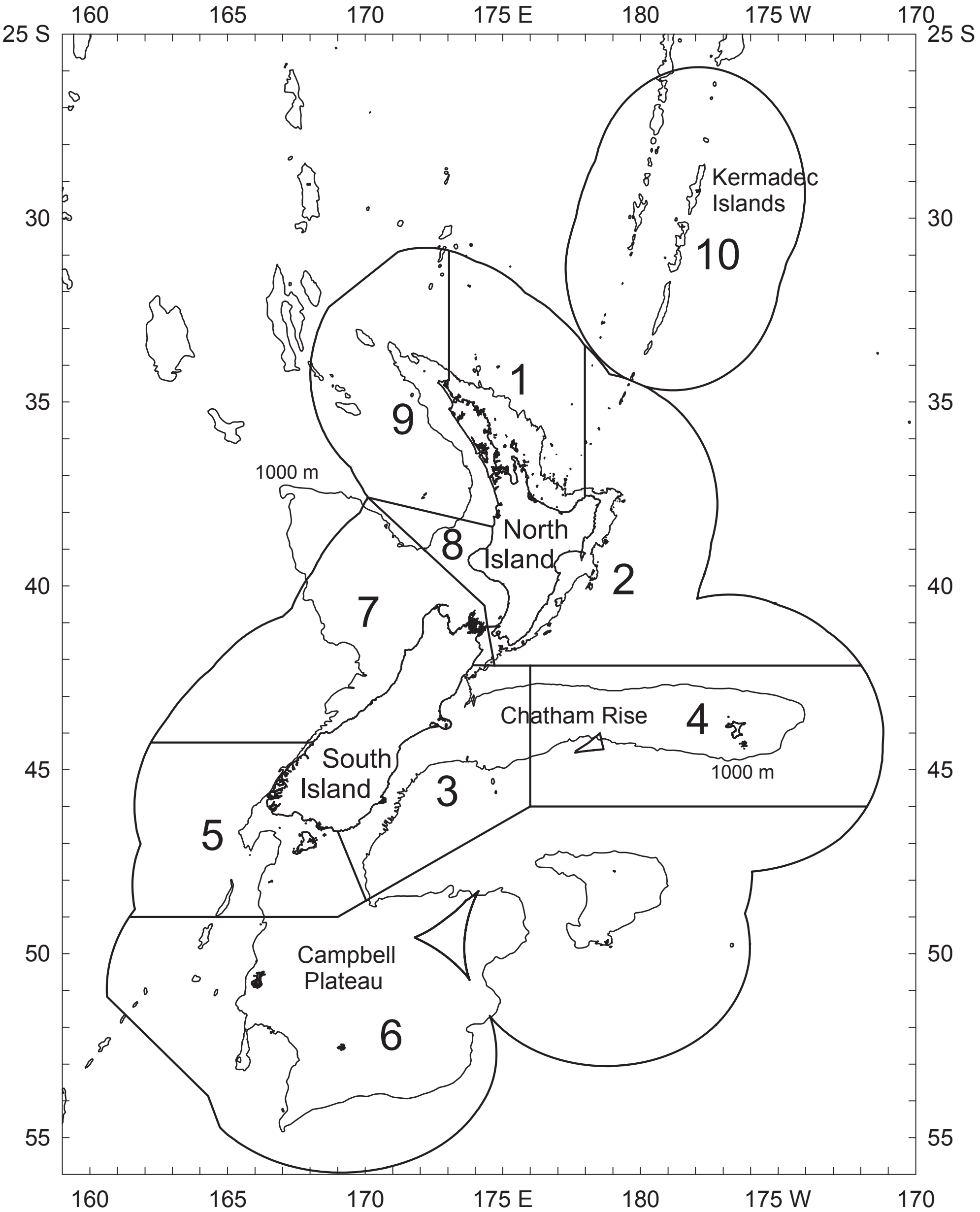
Trenkel, V.M.; Beecham, J.A.; Blanchard, J.L.; Edwards, C.T.T.; Lorance, P. (2013). Testing CPUE-derived spatial occupancy as an indicator for stock abundance: application to deep-sea stocks. *Aquatic Living Resources 26*: 319–332.

Tuomisto, H. (2010). A consistent terminology for quantifying species diversity? Yes, it does exist. *Oecologia 164*: 853–860.

Van Strien, A.J.; Soldaat, L.L.; Gregory, R.D. (2012). Desirable mathematical properties of indicators for biodiversity change. *Ecological Indicators 14*: 202–208.

APPENDICES

Appendix 1: Map of the New Zealand Exclusive Economic Zone showing numbered Fisheries Management Areas.



Appendix 2: Number of sharks measured during Chatham Rise (CHAT) and Sub-Antarctic (SUBA) trawl surveys.

Survey	Year	BSH	CSQ	CYP	ETB	PLS	SND	LCH
CHAT								
tan9106	1992	–	–	–	–	–	–	–
tan9212	1993	–	–	–	–	–	–	–
tan9401	1994	–	–	–	–	–	–	–
tan9501	1995	–	–	–	–	–	–	–
tan9601	1996	–	–	–	–	–	–	–
tan9701	1997	–	–	–	–	–	–	–
tan9801	1998	–	–	–	–	–	309	–
tan9901	1999	3	–	169	136	1	500	66
tan0001	2000	–	–	–	–	–	911	–
tan0101	2001	–	–	–	–	–	1104	16
tan0201	2002	–	4	376	562	2	1536	205
tan0301	2003	55	15	332	238	10	865	307
tan0401	2004	66	14	177	150	4	713	363
tan0501	2005	46	33	217	192	16	793	210
tan0601	2006	33	19	291	256	13	822	251
tan0701	2007	40	57	638	193	6	875	299
tan0801	2008	56	45	475	199	16	773	217
tan0901	2009	52	43	327	163	26	1049	304
tan1001	2010	64	67	1042	705	18	1742	374
tan1101	2011	67	69	742	227	13	1336	282
tan1201	2012	82	31	988	743	16	1478	466
tan1301	2013	68	33	836	408	7	1398	424
tan1401	2014	80	59	1052	546	18	1429	404
SUBA								
tan9105	1991	–	–	–	–	–	–	–
tan9211	1992	–	–	–	–	–	–	–
tan9310	1993	–	–	–	–	–	–	–
tan0012	2000	3	–	–	–	–	93	–
tan0118	2001	4	4	4	14	3	408	19
tan0219	2002	10	82	382	365	1	331	37
tan0317	2003	15	28	454	319	11	201	19
tan0414	2004	27	149	431	373	26	402	61
tan0515	2005	24	79	511	341	7	395	66
tan0617	2006	45	118	563	561	9	572	60
tan0714	2007	13	42	463	380	6	162	94
tan0813	2008	10	134	248	459	–	188	89
tan0911	2009	35	97	483	527	11	301	116
tan1117	2011	22	87	337	667	51	482	103
tan1215	2012	30	126	182	419	14	286	182
tan1412	2014	10	91	197	509	6	478	147

Appendix 3: Length-weight regression parameters, sample sizes, and size ranges of sharks by survey series, species and sex. *a* and *b* are the length-weight parameters in the regression equation weight = *a*×length*^b^*. CHAT, Chatham Rise; SUBA, Sub-Antarctic.

Survey series	Species	Sex	*a*	*b*	R^2	N	Min length (cm)	Max length (cm)	Min weight (g)	Max weight (g)
CHAT	BSH	Females	0.00162	3.26308	99.13	365	37.4	151.2	195	23600
CHAT	BSH	Males	0.00206	3.20814	97.30	268	35.7	123.0	190	11590
CHAT	CSQ	Females	0.00114	3.35748	99.08	301	42.3	144.9	280	23200
CHAT	CSQ	Males	0.00214	3.20040	98.92	144	38.1	130.0	260	19300
CHAT	CYP	Females	0.00202	3.19124	98.68	2227	29.6	103.6	100	5840
CHAT	CYP	Males	0.00432	2.99604	97.86	1818	28.0	91.8	100	3890
CHAT	ETB	Females	0.00338	3.10954	98.52	1283	16.6	85.8	14	3090
CHAT	ETB	Males	0.00547	2.97830	98.08	1357	18.8	72.5	37	1840
CHAT	LCH	Females	0.00281	3.04042	97.27	1382	26.1	94.7	60	2750
CHAT	LCH	Males	0.00828	2.75572	95.52	1488	19.9	88.3	35	2470
CHAT	PLS	Females	0.00169	3.27908	96.87	73	43.5	143.0	610	23000
CHAT	PLS	Males	0.00290	3.14739	98.52	73	45.2	128.6	535	12200
CHAT	SND	Females	0.00153	3.20569	98.44	4583	29.2	126.5	85	8700
CHAT	SND	Males	0.00335	3.01414	97.24	4064	30.2	105.5	100	4135
SUBA	BSH	Females	0.00093	3.40126	99.35	140	38.8	153.6	245	31500
SUBA	BSH	Males	0.00183	3.22550	98.26	64	41.1	115.1	300	6600
SUBA	CSQ	Females	0.00092	3.40837	99.34	456	39.0	142.5	220	23600
SUBA	CSQ	Males	0.00184	3.22920	99.29	403	25.0	131.2	70	15700
SUBA	CYP	Females	0.00160	3.26135	98.28	1769	25.3	102.9	80	6490
SUBA	CYP	Males	0.00370	3.03686	98.18	920	28.9	92.6	88	3530
SUBA	ETB	Females	0.00262	3.17454	98.06	2076	20.3	82.4	40	3375
SUBA	ETB	Males	0.00378	3.07449	97.30	1881	22.0	75.3	50	2540
SUBA	LCH	Females	0.00350	2.99417	98.32	446	23.2	97.9	40	3195
SUBA	LCH	Males	0.00690	2.80135	96.80	482	24.4	91.8	45	2830
SUBA	PLS	Females	0.00381	3.10260	99.41	76	30.1	150.2	130	25200
SUBA	PLS	Males	0.00466	3.05473	99.34	55	29.0	125.7	140	11300
SUBA	SND	Females	0.00072	3.37635	97.78	1035	28.9	116.9	75	8010
SUBA	SND	Males	0.00214	3.11418	95.30	961	28.5	107.1	70	6500

Appendix 4: Rank randomisation test results for trends in indicators.

Appendix 4A: Rank randomisation tests for significant differences in trawl survey biomass among two or three time periods. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Survey series	Species	Strata	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
ECSI	Carpet shark	Core	FMA 3	1	group1	3.0	3.6	7.4	*	NS
					group2	8.0	3.6	7.4	NS	*
WCSI	Carpet shark	Core	FMA 7	2	group1	8.0	3.8	9.5	NS	NS
					group2	6.0	3.8	9.3	NS	NS
					group3	5.5	3.8	9.5	NS	NS
CHAT	Baxter's dogfish	Core	FMAs 3 & 4	3	group1	11.1	8.3	15.9	NS	NS
					group2	14.0	8.0	15.8	NS	NS
					group3	10.7	8.0	16.0	NS	NS
	Leafscale gulper shark	Core	FMAs 3 & 4	3	group1	10.0	8.3	15.8	NS	NS
					group2	13.2	8.2	15.6	NS	NS
					group3	12.9	7.8	16.3	NS	NS
	Longnose velvet dogfish	Core	FMAs 3 & 4	3	group1	10.9	8.2	15.7	NS	NS
					group2	14.1	8.3	15.6	NS	NS
					group3	10.9	8.0	16.3	NS	NS
	Plunket's shark	Core	FMAs 3 & 4	3	group1	8.8	8.3	15.6	NS	NS
					group2	13.6	8.3	16.0	NS	NS
					group3	13.9	8.0	16.0	NS	NS
	Seal shark	Core	FMAs 3 & 4	3	group1	15.0	8.0	15.8	NS	NS
					group2	8.1	8.3	15.8	*	NS
					group3	13.0	8.0	16.3	NS	NS
	Shovelnose dogfish	Core	FMAs 3 & 4	3	group1	12.6	8.1	15.8	NS	NS
					group2	10.6	8.3	15.9	NS	NS
					group3	12.9	7.9	16.0	NS	NS
	Longnose spookfish	Core	FMAs 3 & 4	3	group1	8.8	8.3	15.7	NS	NS
					group2	15.7	8.4	15.6	NS	*
					group3	11.5	7.7	16.3	NS	NS
SUBA	Baxter's dogfish	Core + Deep	FMAs 5 & 6	5	group1	3.6	4.4	9.6	*	NS
					group2	8.8	4.2	9.6	NS	NS
					group3	9.7	3.3	11.0	NS	NS
	Leafscale gulper shark	Core + Deep	FMAs 5 & 6	5	group1	4.4	4.4	9.6	NS	NS
					group2	9.4	4.6	9.6	NS	NS
					group3	7.3	3.3	10.7	NS	NS
	Longnose velvet dogfish	Core + Deep	FMAs 5 & 6	5	group1	5.8	4.4	9.6	NS	NS
					group2	9.2	4.6	9.8	NS	NS
					group3	5.3	3.3	11.0	NS	NS
	Plunket's shark	Core + Deep	FMAs 5 & 6	5	group1	5.6	4.2	9.8	NS	NS
					group2	6.8	4.2	9.6	NS	NS
					group3	9.7	3.0	11.0	NS	NS
	Seal shark	Core + Deep	FMAs 5 & 6	5	group1	5.3	4.5	9.5	NS	NS
					group2	8.7	4.3	9.7	NS	NS
					group3	7.0	3.0	10.8	NS	NS
	Shovelnose dogfish	Core + Deep	FMAs 5 & 6	5	group1	4.4	4.2	9.6	NS	NS
					group2	7.4	4.2	9.6	NS	NS
					group3	10.7	3.3	10.7	NS	NS
	Longnose spookfish	Core + Deep	FMAs 5 & 6	5	group1	7.0	4.4	9.8	NS	NS
					group2	6.4	4.4	9.6	NS	NS
					group3	8.0	3.3	11.0	NS	NS

Appendix 4B: Rank randomisation tests for significant differences in proportions of males caught in trawl surveys among three time periods. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Survey series	Species	Strata	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
CHAT	Baxter's dogfish	Core	FMAs 3 & 4	7	group1	5.8	4.4	9.6	NS	NS
					group2	8.4	4.4	9.6	NS	NS
					group3	6.7	3.0	10.7	NS	NS
	Longnose velvet dogfish	Core	FMAs 3 & 4	7	group1	4.4	4.4	9.8	NS	NS
					group2	7.4	4.2	9.6	NS	NS
					group3	10.7	3.0	10.7	NS	NS
	Shovelnose dogfish	Core	FMAs 3 & 4	7	group1	6.0	4.4	9.8	NS	NS
					group2	9.8	4.4	9.6	NS	*
					group3	4.0	3.3	10.7	NS	NS
	Longnose spookfish	Core	FMAs 3 & 4	7	group1	5.4	4.4	9.6	NS	NS
					group2	8.8	4.2	9.6	NS	NS
					group3	6.7	3.3	10.7	NS	NS
SUBA	Baxter's dogfish	Core + Deep	FMAs 5 & 6	9	group1	6.3	3.5	8.5	NS	NS
					group2	5.8	3.5	8.5	NS	NS
					group3	6.0	2.7	9.0	NS	NS
	Longnose velvet dogfish	Core + Deep	FMAs 5 & 6	9	group1	5.3	3.5	8.5	NS	NS
					group2	5.3	3.5	8.5	NS	NS
					group3	8.0	3.0	9.0	NS	NS
	Shovelnose dogfish	Core + Deep	FMAs 5 & 6	9	group1	8.0	3.5	8.5	NS	NS
					group2	7.0	3.5	8.5	NS	NS
					group3	2.0	3.0	9.0	*	NS

Appendix 4C: Rank randomisation tests for significant differences in median lengths of male and female sharks caught in trawl surveys among three time periods. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Survey series	Species	Sex	Strata	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
CHAT	Baxter's dogfish	male	Core	FMAs 3 & 4	8	group1	8.8	4.4	9.7	NS	NS
						group2	7.4	4.4	9.7	NS	NS
						group3	3.3	3.3	10.0	NS	NS
		female	Core	FMAs 3 & 4	8	group1	8.4	4.5	9.7	NS	NS
						group2	6.0	4.2	9.7	NS	NS
						group3	6.3	3.0	10.8	NS	NS
	Longnose velvet dogfish	male	Core	FMAs 3 & 4	8	group1	5.8	4.2	9.6	NS	NS
						group2	7.6	4.6	9.6	NS	NS
						group3	8.0	3.0	10.7	NS	NS
		female	Core	FMAs 3 & 4	8	group1	7.9	4.4	9.7	NS	NS
						group2	6.0	4.5	9.6	NS	NS
						group3	7.2	3.2	10.8	NS	NS
	Shovelnose dogfish	male	Core	FMAs 3 & 4	8	group1	8.9	4.3	9.6	NS	NS
						group2	7.9	4.6	9.6	NS	NS
						group3	2.3	3.2	10.3	*	NS
		female	Core	FMAs 3 & 4	8	group1	5.2	4.3	9.5	NS	NS
						group2	7.4	4.4	9.6	NS	NS
						group3	9.3	3.7	11.2	NS	NS
	Longnose spookfish	male	Core	FMAs 3 & 4	8	group1	9.4	4.5	9.5	NS	NS
						group2	4.4	4.5	9.4	*	NS
						group3	7.3	3.3	10.7	NS	NS
		female	Core	FMAs 3 & 4	8	group1	7.2	4.6	9.5	NS	NS
						group2	8.8	4.3	9.6	NS	NS
						group3	3.7	3.3	11.0	NS	NS
SUBA	Baxter's dogfish	male	Core + Deep	FMAs 5 & 6	10	group1	6.0	3.3	8.0	NS	NS
						group2	6.8	4.3	8.0	NS	NS
						group3	5.0	3.3	8.3	NS	NS
		female	Core + Deep	FMAs 5 & 6	10	group1	5.5	3.9	8.5	NS	NS
						group2	7.4	3.9	8.5	NS	NS
						group3	4.8	3.0	8.5	NS	NS
	Longnose velvet dogfish	male	Core + Deep	FMAs 5 & 6	10	group1	7.1	3.6	8.5	NS	NS
						group2	7.9	3.6	8.5	NS	NS
						group3	2.0	2.8	9.0	*	NS
		female	Core + Deep	FMAs 5 & 6	10	group1	4.8	3.4	8.8	NS	NS
						group2	8.8	3.4	8.8	NS	NS
						group3	4.0	3.3	9.3	NS	NS
	Shovelnose dogfish	male	Core + Deep	FMAs 5 & 6	10	group1	6.0	3.5	8.4	NS	NS
						group2	6.6	3.5	8.4	NS	NS
						group3	5.2	2.5	9.0	NS	NS
		female	Core + Deep	FMAs 5 & 6	10	group1	3.5	3.5	8.6	NS	NS
						group2	6.4	3.5	8.4	NS	NS
						group3	8.8	2.7	9.2	NS	NS

Appendix 4D: Rank randomisation tests for significant differences in high-CPUE distribution indicator among 2–3 time periods as illustrated in Figures 13–16. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Species	Method	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
Seal shark	Bottom trawl	All FMAs	13	group1	9.2	5.8	12.3	NS	NS
BSH				group2	12.7	5.7	12.2	NS	*
				group3	4.4	5.2	12.6	*	NS
		FMAs 3 & 4	13	group1	8.0	5.7	12.2	NS	NS
				group2	13.0	6.0	12.3	NS	*
				group3	5.4	5.2	12.6	NS	NS
		FMAs 5 & 6	13	group1	12.5	5.8	12.2	NS	*
				group2	8.5	5.8	12.2	NS	NS
				group3	5.4	5.2	12.6	NS	NS
Shovelnose dogfish	Bottom trawl	All FMAs	14	group1	4.8	4.8	11.2	NS	NS
SND				group2	9.4	4.6	11.2	NS	NS
				group3	9.8	4.8	11.0	NS	NS
		FMAs 3 & 4	14	group1	4.4	5.0	11.1	*	NS
				group2	10.9	5.0	11.1	NS	NS
				group3	8.7	4.8	11.1	NS	NS
		FMA 7	14	group1	6.6	4.8	11.2	NS	NS
				group2	7.4	5.0	11.0	NS	NS
				group3	10.0	4.8	11.2	NS	NS
Carpet shark	Bottom trawl	All FMAs	15	group1	4.0	2.8	6.3	NS	NS
CAR				group2	5.0	2.8	6.3	NS	NS
		FMA 7	15	group1	3.3	2.8	6.3	NS	NS
				group2	5.8	2.8	6.3	NS	NS
		FMAs 2 & 3	15	group1	2.5	2.8	6.0	*	NS
				group2	6.5	3.0	6.3	NS	*
Carpet shark	Set net	All FMAs	16	group1	4.4	3.6	6.6	NS	NS
CAR				group2	5.8	3.0	6.8	NS	NS
		FMAs 7 & 8	16	group1	3.4	3.4	6.6	NS	NS
				group2	7.0	3.0	7.0	NS	NS
		FMA 5	16	group1	6.6	3.4	6.6	NS	NS
				group2	3.0	3.0	7.0	NS	NS

Appendix 4E: Rank randomisation tests for significant differences in proportion zeroes distribution indicator among 2–3 time periods as illustrated in Figures 13–16. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Species	Method	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
Seal shark	Bottom trawl	All FMAs	13	group1	6.8	5.8	12.2	NS	NS
BSH				group2	6.7	5.8	12.2	NS	NS
				group3	14.4	5.2	12.6	NS	*
		FMAs 3 & 4	13	group1	7.7	5.7	12.2	NS	NS
				group2	6.3	5.8	12.3	NS	NS
				group3	13.8	5.4	12.6	NS	*
		FMAs 5 & 6	13	group1	5.8	5.8	12.3	NS	NS
				group2	9.0	5.7	12.2	NS	NS
				group3	12.8	5.4	12.6	NS	*
Shovelnose dogfish	Bottom trawl	All FMAs	14	group1	11.0	5.0	11.2	NS	NS
SND				group2	6.8	4.8	11.2	NS	NS
				group3	6.2	4.8	11.0	NS	NS
		FMAs 3 & 4	14	group1	11.2	4.6	11.0	NS	*
				group2	6.0	4.8	11.2	NS	NS
				group3	6.8	4.8	11.2	NS	NS
		FMA 7	14	group1	10.1	4.8	11.4	NS	NS
				group2	8.1	4.9	11.0	NS	NS
				group3	5.8	4.7	11.1	NS	NS
Carpet shark	Bottom trawl	All FMAs	15	group1	3.8	2.8	6.0	NS	NS
CAR				group2	5.3	3.0	6.3	NS	NS
		FMA 7	15	group1	5.3	2.8	6.3	NS	NS
				group2	3.8	2.8	6.3	NS	NS
		FMAs 2 & 3	15	group1	6.5	2.8	6.3	NS	*
				group2	2.5	2.8	6.3	*	NS
Carpet shark	Set net	All FMAs	16	group1	5.6	3.4	6.6	NS	NS
CAR				group2	4.3	3.0	7.0	NS	NS
		FMAs 7 & 8	16	group1	7.0	3.4	6.6	NS	*
				group2	2.5	3.0	7.0	*	NS
		FMA 5	16	group1	5.0	3.5	6.7	NS	NS
				group2	5.0	2.9	6.9	NS	NS

Appendix 4F: Rank randomisation tests for significant differences in species composition indicators among 2–3 time periods as illustrated in Figures 17–20. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Species	Method	Indicator	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
Seal shark	Bottom trawl	Proportion zeroes	FMAs 3 & 4	17	group1	12.2	5.7	12.3	NS	NS
BSH					group2	5.3	5.8	12.2	*	NS
					group3	9.6	5.2	12.6	NS	NS
			FMAs 5 & 6	17	group1	5.3	5.7	12.2	*	NS
					group2	9.7	5.8	12.2	NS	NS
					group3	12.6	5.2	12.8	NS	NS
		Percent composition	FMAs 3 & 4	17	group1	8.5	5.7	12.2	NS	NS
					group2	11.8	5.8	12.3	NS	NS
					group3	6.2	5.4	12.8	NS	NS
			FMAs 5 & 6	17	group1	13.8	5.8	12.3	NS	*
					group2	7.8	6.0	12.2	NS	NS
					group3	4.6	5.4	12.8	*	NS
Shovelnose dogfish	Bottom trawl	Proportion zeroes	FMAs 3 & 4	18	group1	13.0	5.0	11.2	NS	*
SND					group2	5.2	4.6	11.2	NS	NS
					group3	5.8	4.8	11.0	NS	NS
			FMA 7	18	group1	7.2	4.8	11.2	NS	NS
					group2	9.4	4.6	11.0	NS	NS
					group3	7.4	4.8	11.0	NS	NS
		Percent composition	FMAs 3 & 4	18	group1	5.6	4.4	11.2	NS	NS
					group2	8.8	4.8	11.2	NS	NS
					group3	9.6	4.8	11.2	NS	NS
			FMA 7	18	group1	11.4	5.0	11.0	NS	*
					group2	6.8	4.6	11.2	NS	NS
					group3	5.8	4.8	11.2	NS	NS
Carpet shark	Bottom trawl	Proportion zeroes	FMA 2	19	group1	6.3	2.8	6.3	NS	NS
CAR					group2	2.8	2.8	6.3	NS	NS
			FMA 3	19	group1	6.0	3.0	6.3	NS	NS
					group2	3.0	2.8	6.0	NS	NS
			FMA 7	19	group1	5.3	2.8	6.0	NS	NS
					group2	3.8	3.0	6.3	NS	NS
		Percent composition	FMA 2	19	group1	3.0	2.8	6.3	NS	NS
					group2	6.0	2.8	6.3	NS	NS
			FMA 3	19	group1	3.0	2.8	6.3	NS	NS
					group2	6.0	2.8	6.3	NS	NS
			FMA 7	19	group1	3.8	3.0	6.3	NS	NS
					group2	5.3	2.8	6.0	NS	NS
Carpet shark	Set net	Proportion zeroes	FMAs 7 & 8	20	group1	6.8	3.4	6.6	NS	*
CAR					group2	2.8	3.0	7.0	*	NS
			FMA 5	20	group1	4.0	3.4	6.6	NS	NS
					group2	6.3	3.0	7.0	NS	NS
		Percent composition	FMAs 7 & 8	20	group1	3.6	3.4	6.6	NS	NS
					group2	6.8	3.0	7.0	NS	NS
			FMA 5	20	group1	4.8	3.4	6.6	NS	NS
					group2	5.3	3.0	7.0	NS	NS

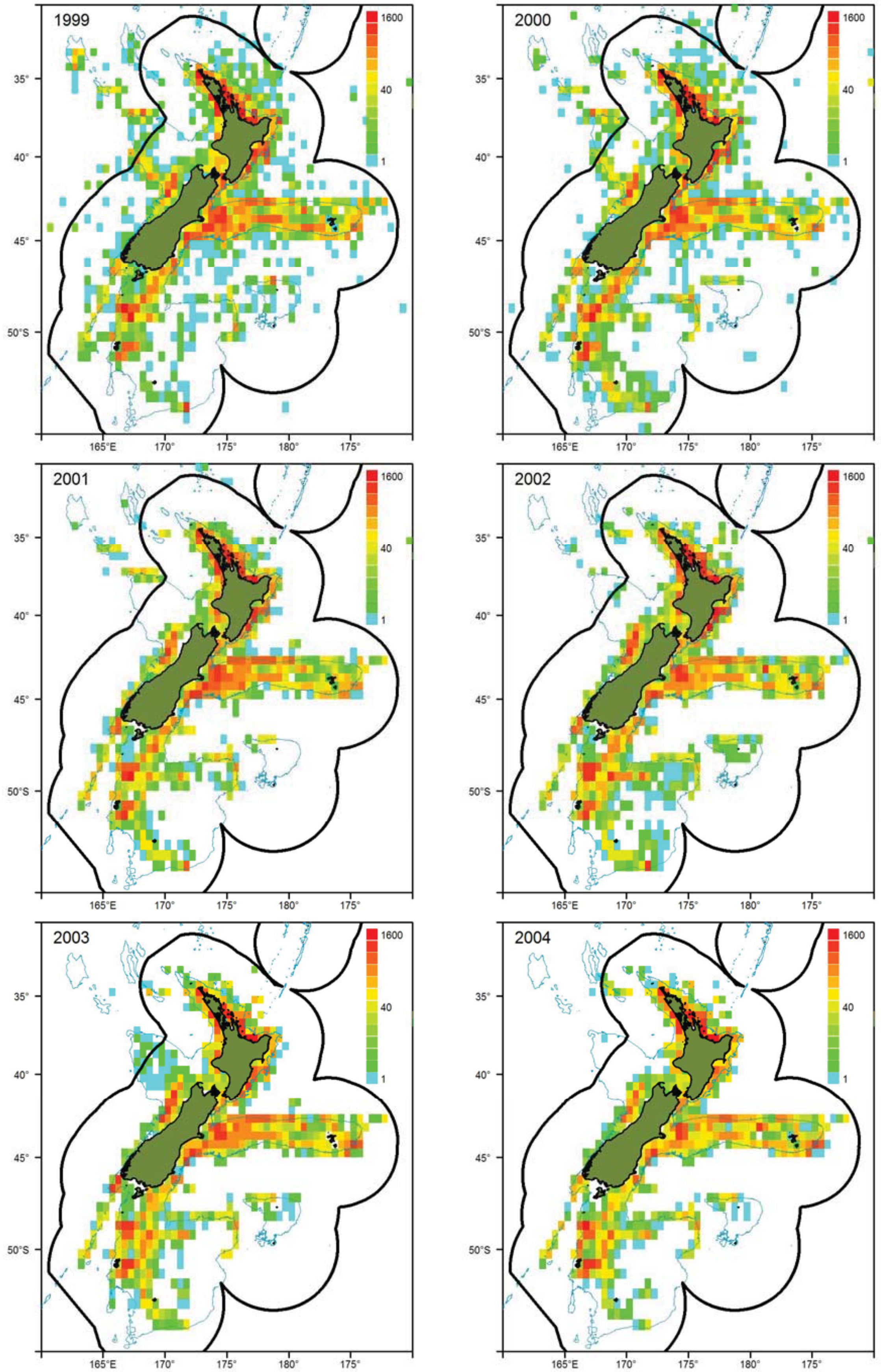
Appendix 4G: Rank randomisation tests for significant differences in concentration indicators among 2–3 time periods as illustrated in Figures 21–24. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Species	Method	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
Seal shark	Bottom trawl	FMAs 3 & 4	21	group1	13.3	9.0	9.0	NS	*
BSH				group2	9.5	9.0	9.0	NS	*
				group3	3.2	9.0	9.0	*	NS
		FMAs 5 & 6	21	group1	11.3	9.0	9.0	NS	*
				group2	7.2	9.0	9.0	*	NS
				group3	8.4	9.0	9.0	*	NS
Shovelnose dogfish	Bottom trawl	FMAs 3 & 4	22	group1	12.6	8.0	8.0	NS	*
SND				group2	3.4	8.0	8.0	*	NS
				group3	8.0	8.0	8.0	NS	NS
		FMA 7	22	group1	12.6	4.8	11.4	NS	*
				group2	4.6	5.0	11.0	*	NS
				group3	6.8	4.8	11.2	NS	NS
Carpet shark	Bottom trawl	FMA 2	23	group1	3.5	2.8	6.0	NS	NS
CAR				group2	5.5	3.0	6.3	NS	NS
		FMA 3	23	group1	3.8	3.0	6.3	NS	NS
				group2	5.3	2.8	6.0	NS	NS
		FMA 7	23	group1	5.5	2.8	6.3	NS	NS
				group2	3.5	2.8	6.3	NS	NS
Carpet shark	Set net	FMA 5	24	group1	6.6	3.4	6.6	NS	NS
CAR				group2	3.0	3.0	7.0	NS	NS
		FMAs 7 & 8	24	group1	5.8	5.0	5.0	NS	*
				group2	4.0	5.0	5.0	*	NS

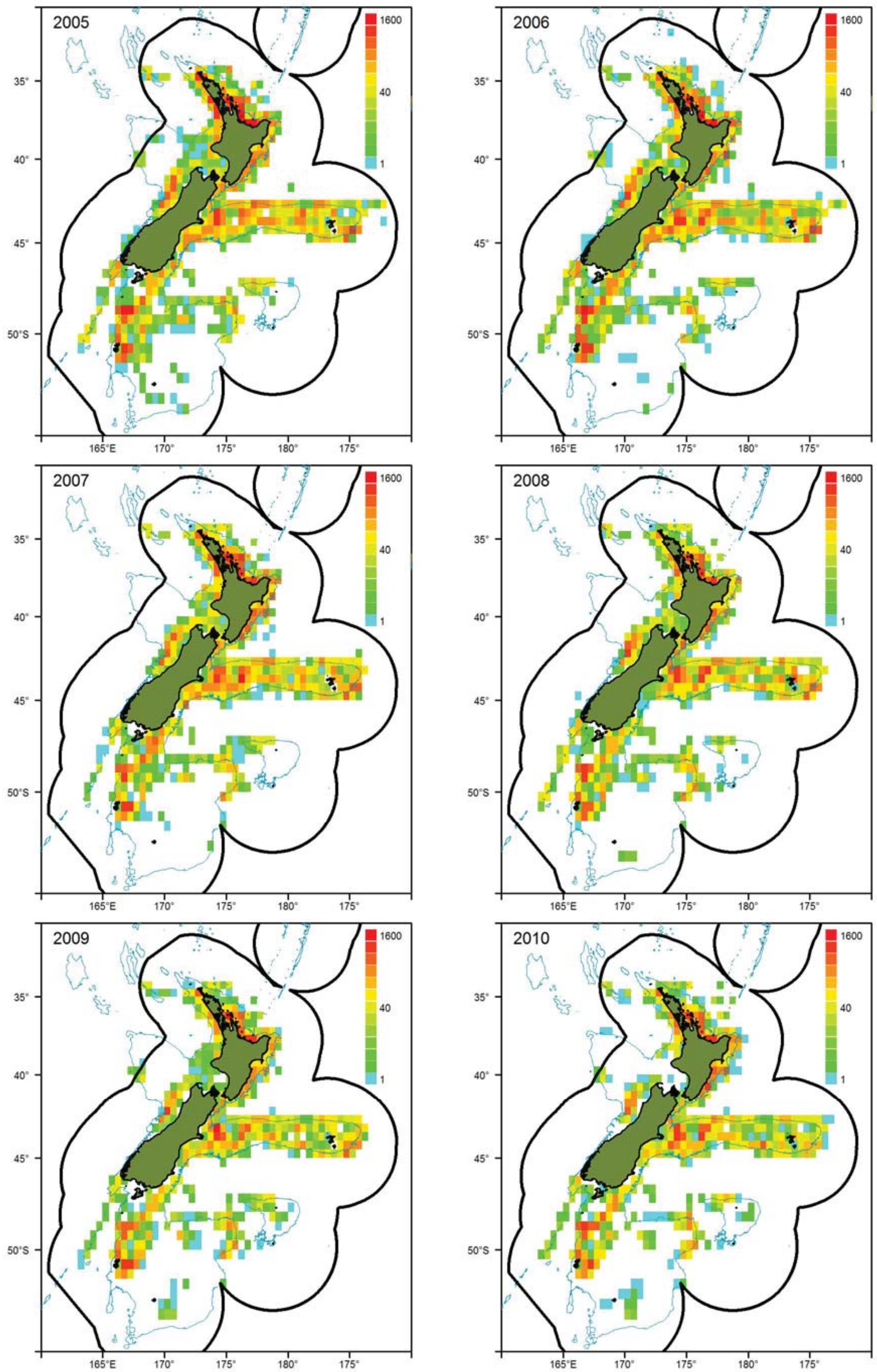
Appendix 4H: Rank randomisation tests for significant differences in standardised commercial and observer CPUE (recomposed – all tows) among 2–4 time periods as illustrated in Figures 25–29. CI, 95% confidence interval. NS, not significant; *, mean rank is below the lower confidence bound (Signif. Low) or above the upper confidence bound (Signif. High).

Species	Method	Region	Figure	Period	Mean rank	Lower CI	Upper CI	Signif. Low	Signif. High
Seal shark	Bottom trawl	FMAs 3 & 4	25	group1	4.7	5.7	12.2	*	NS
BSH				group2	12.2	5.5	12.2	NS	NS
				group3	10.4	5.2	12.6	NS	NS
		FMAs 5 & 6	25	group1	13.0	5.7	12.2	NS	*
				group2	8.8	5.7	12.0	NS	NS
				group3	4.4	5.2	12.8	*	NS
Shovelnose dogfish	Bottom trawl	FMAs 3 & 4	26	group1	3.0	5.0	11.0	*	NS
SND				group2	9.8	4.8	11.0	NS	NS
				group3	11.2	4.8	11.4	NS	NS
Shovelnose dogfish	Observer bottom trawl	FMAs 3 & 4	27	group1	23.6	10.5	20.0	NS	*
SND				group2	4.6	10.0	20.4	*	NS
				group3	18.3	9.9	20.7	NS	NS
				group4	12.3	9.3	20.1	NS	NS
Carpet shark	Bottom trawl	FMAs 2 & 3	28	group1	2.5	2.8	6.3	*	NS
CAR				group2	6.5	2.8	6.3	NS	*
		FMA 7	28	group1	2.8	3.0	6.3	*	NS
				group2	6.3	2.8	6.0	NS	*
Carpet shark	Set net	FMA 5	29	group1	6.8	3.4	6.6	NS	*
CAR				group2	2.8	3.0	7.0	*	NS
		FMAs 7 & 8	29	group1	4.2	3.4	6.6	NS	NS
				group2	6.0	3.0	7.0	NS	NS

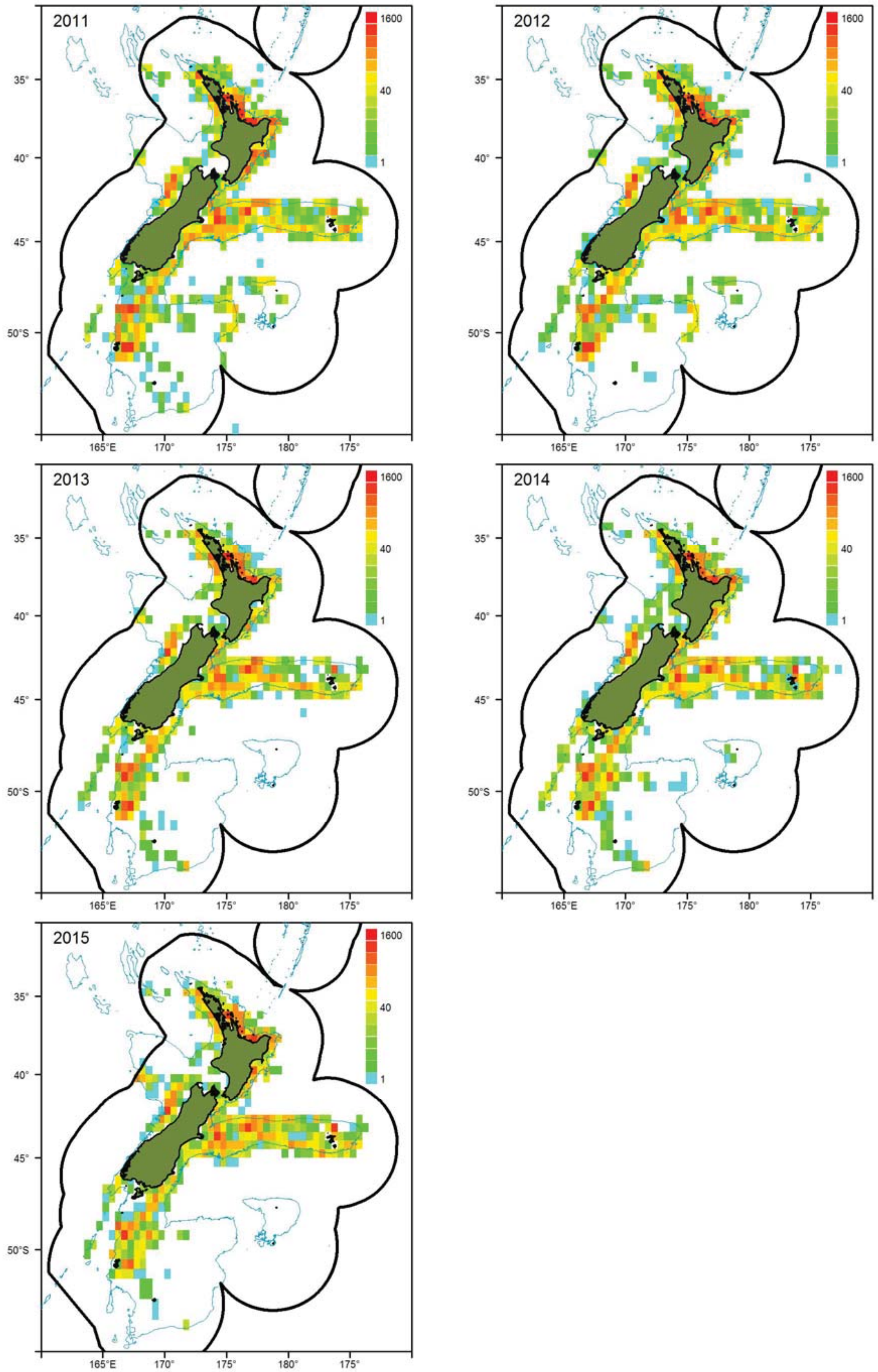
Appendix 5: Distribution of bottom trawl fishing effort reported on TCP forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



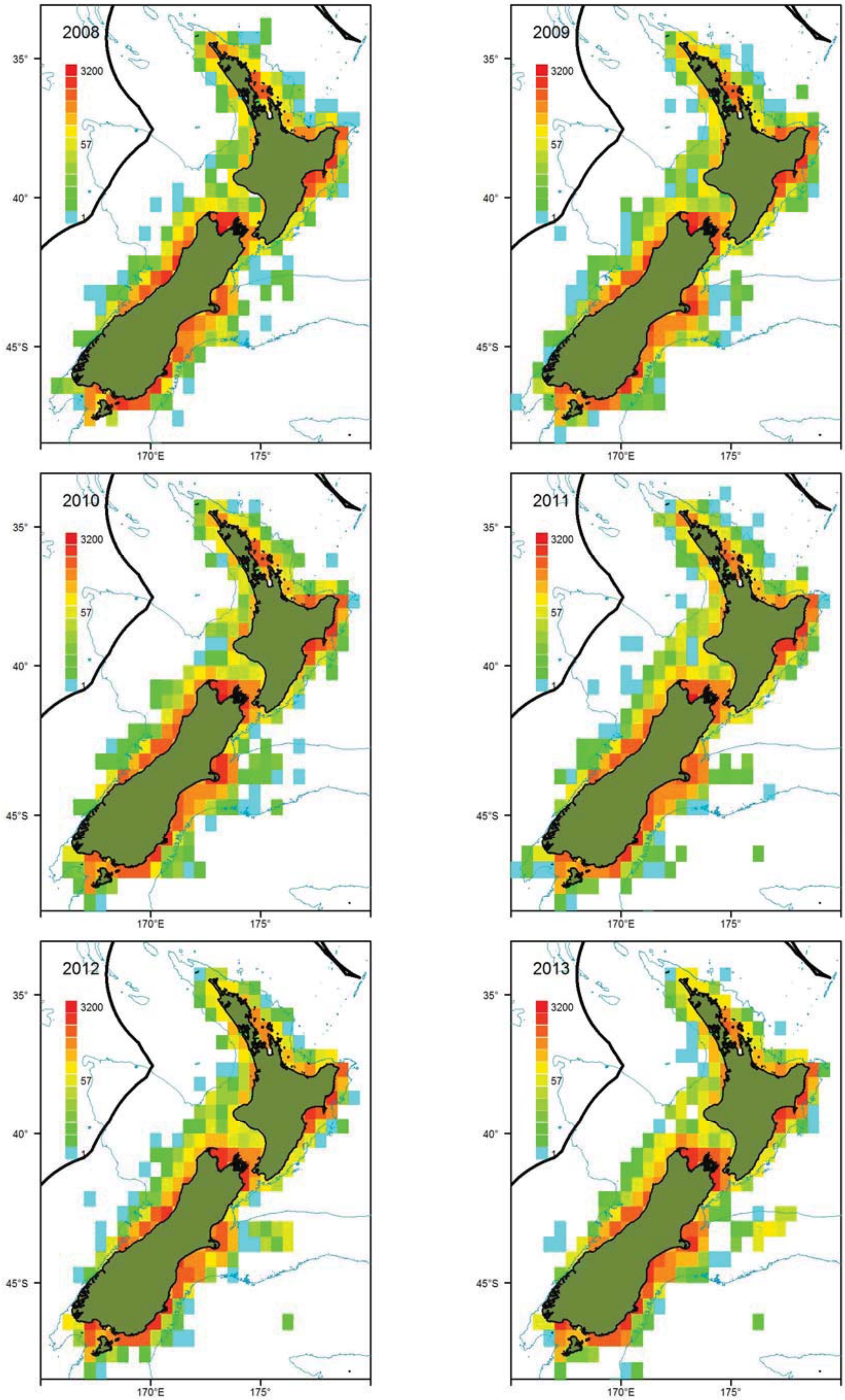
Appendix 5 (continued):



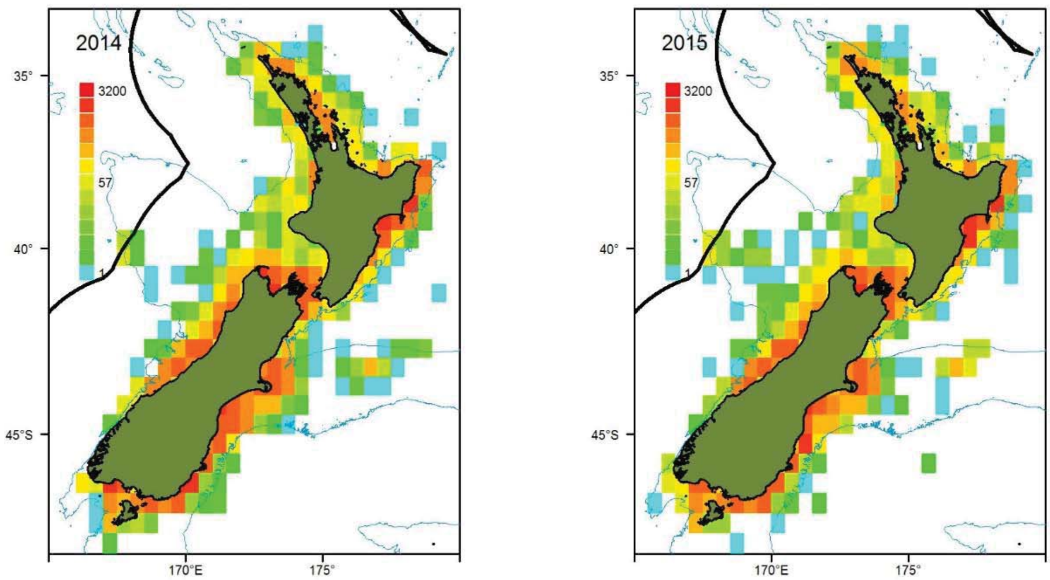
Appendix 5 (continued):



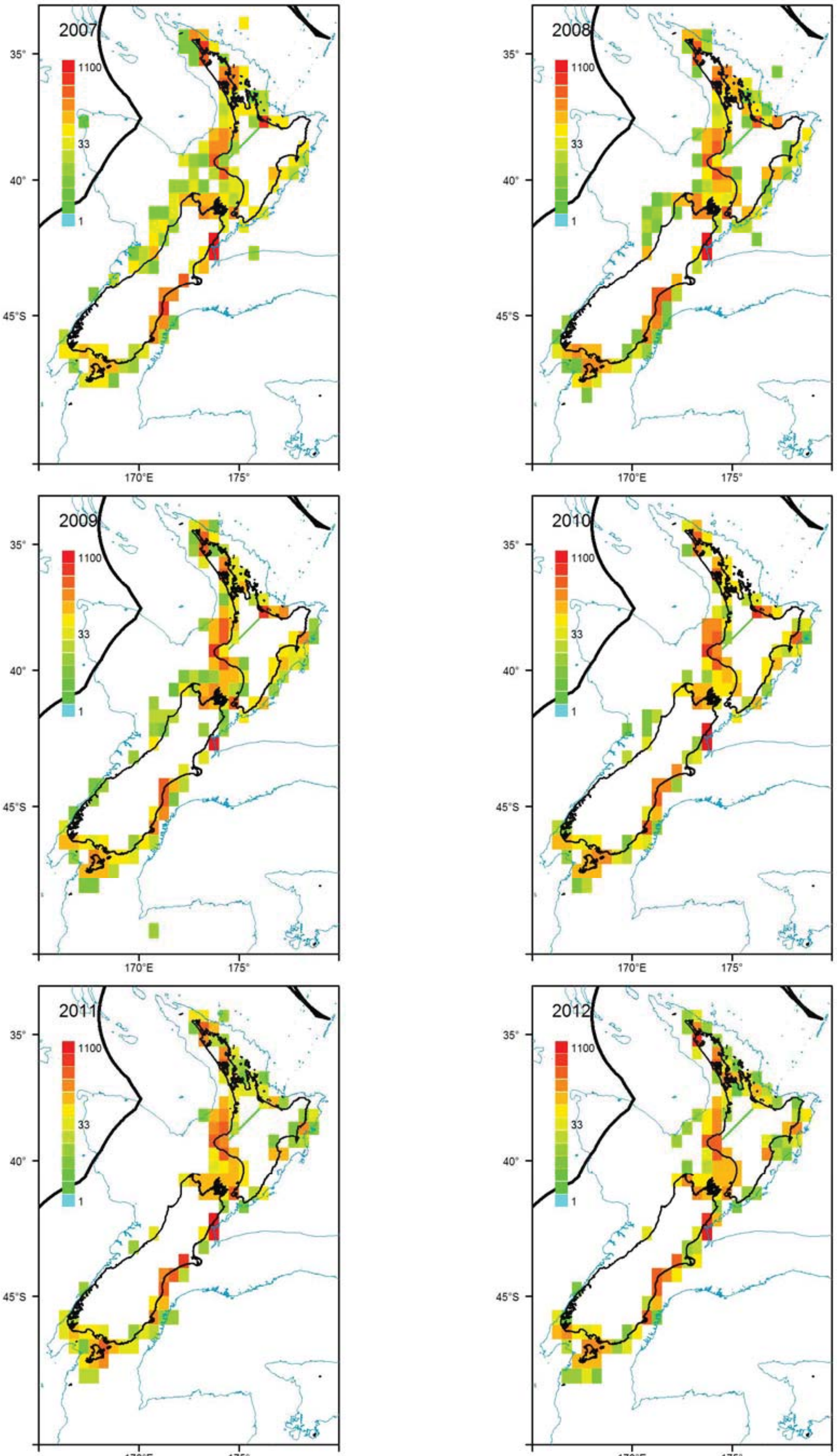
Appendix 6: Distribution of bottom trawl fishing effort reported on TCE forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



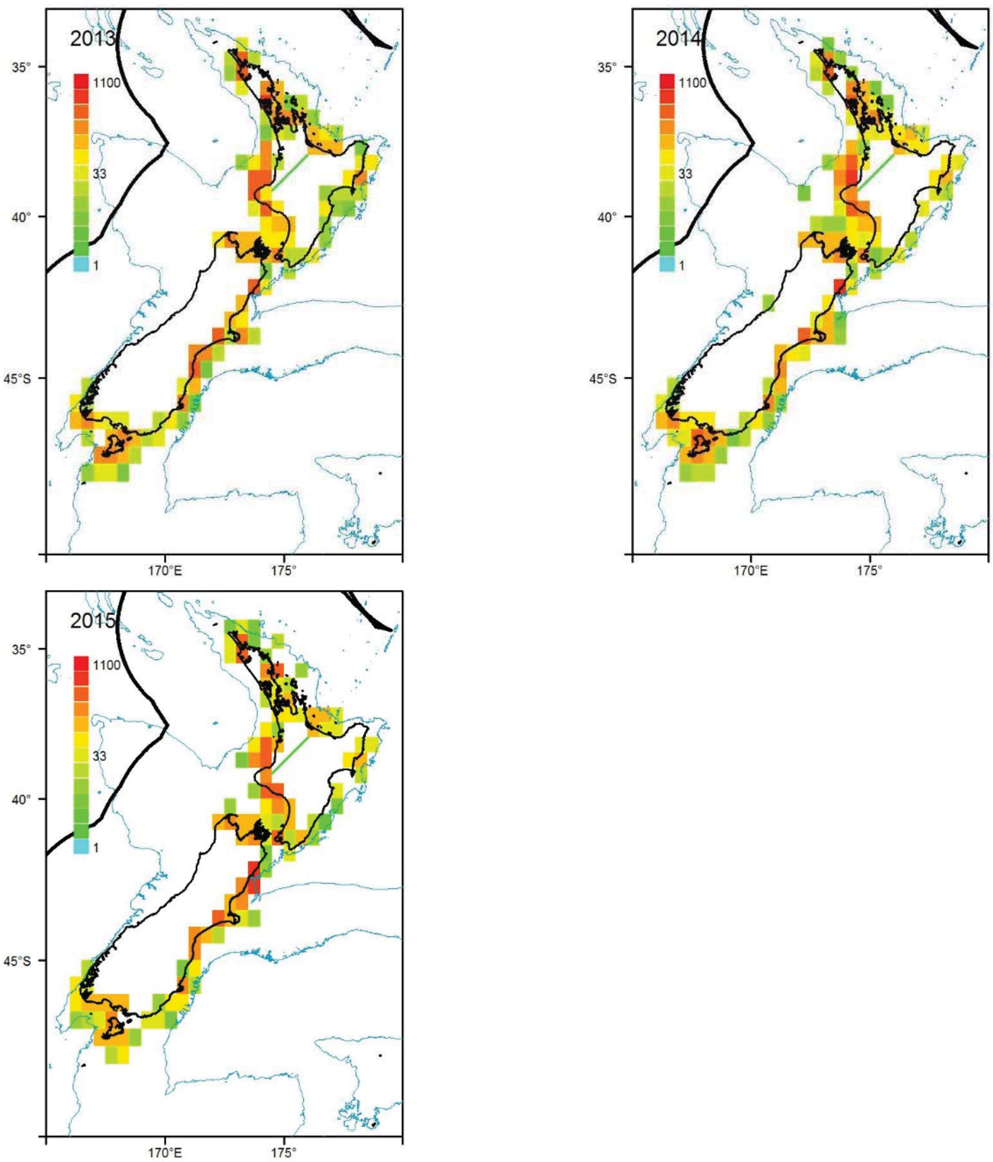
Appendix 6 (continued):



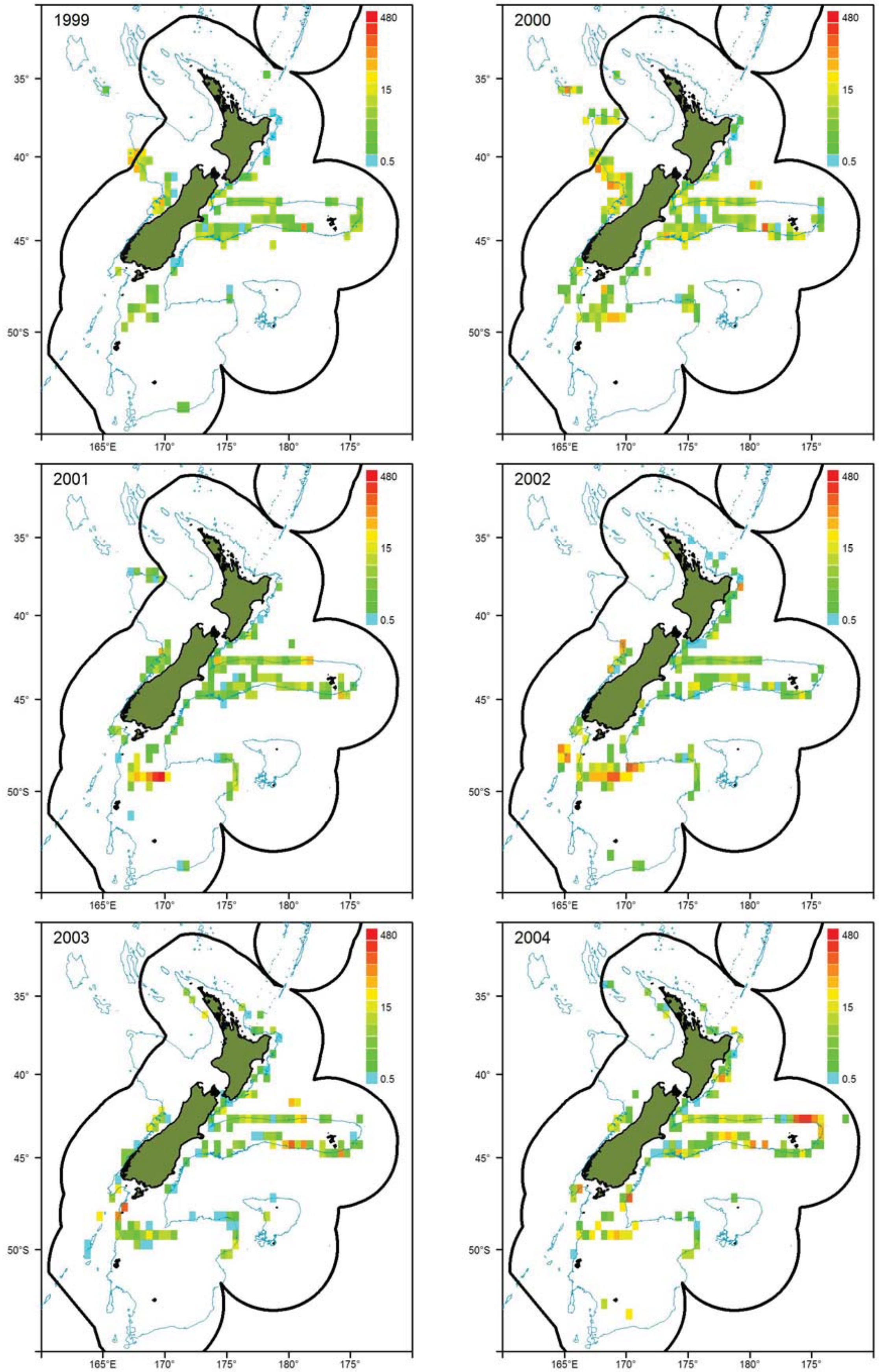
Appendix 7: Distribution of set net fishing effort reported on NCE forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



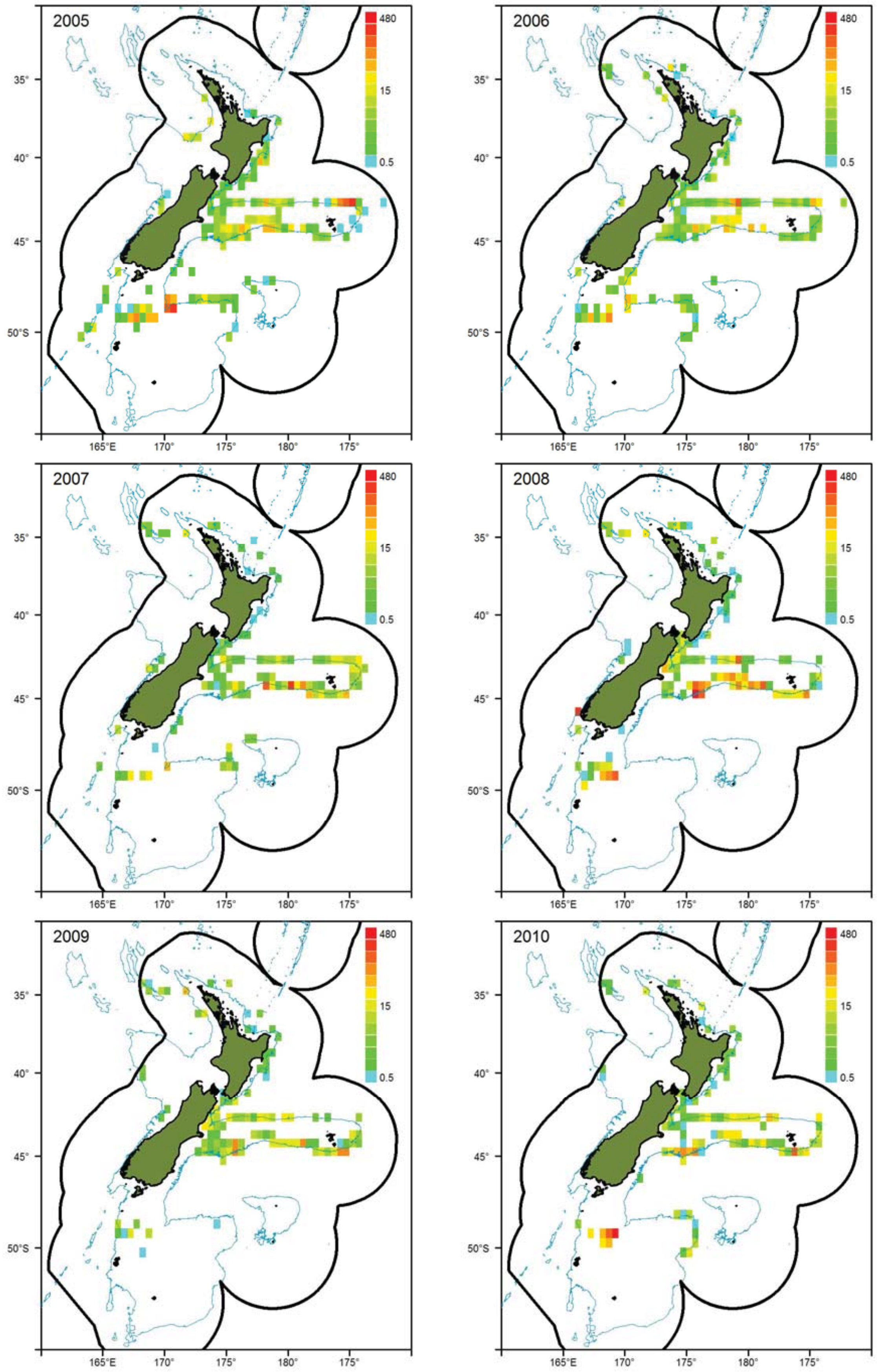
Appendix 7 (continued):



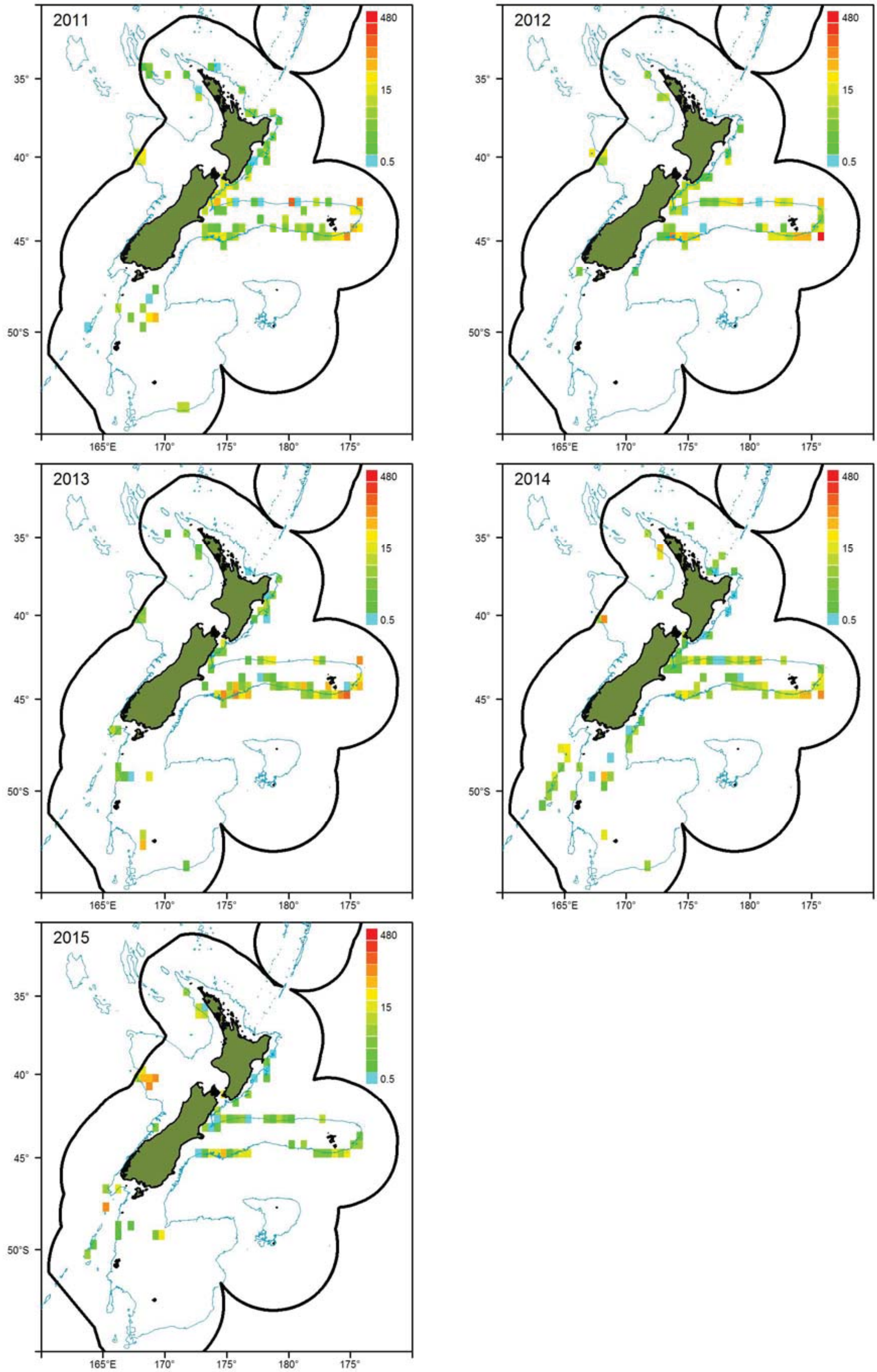
Appendix 8: Distribution of seal shark CPUE reported on TCP forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



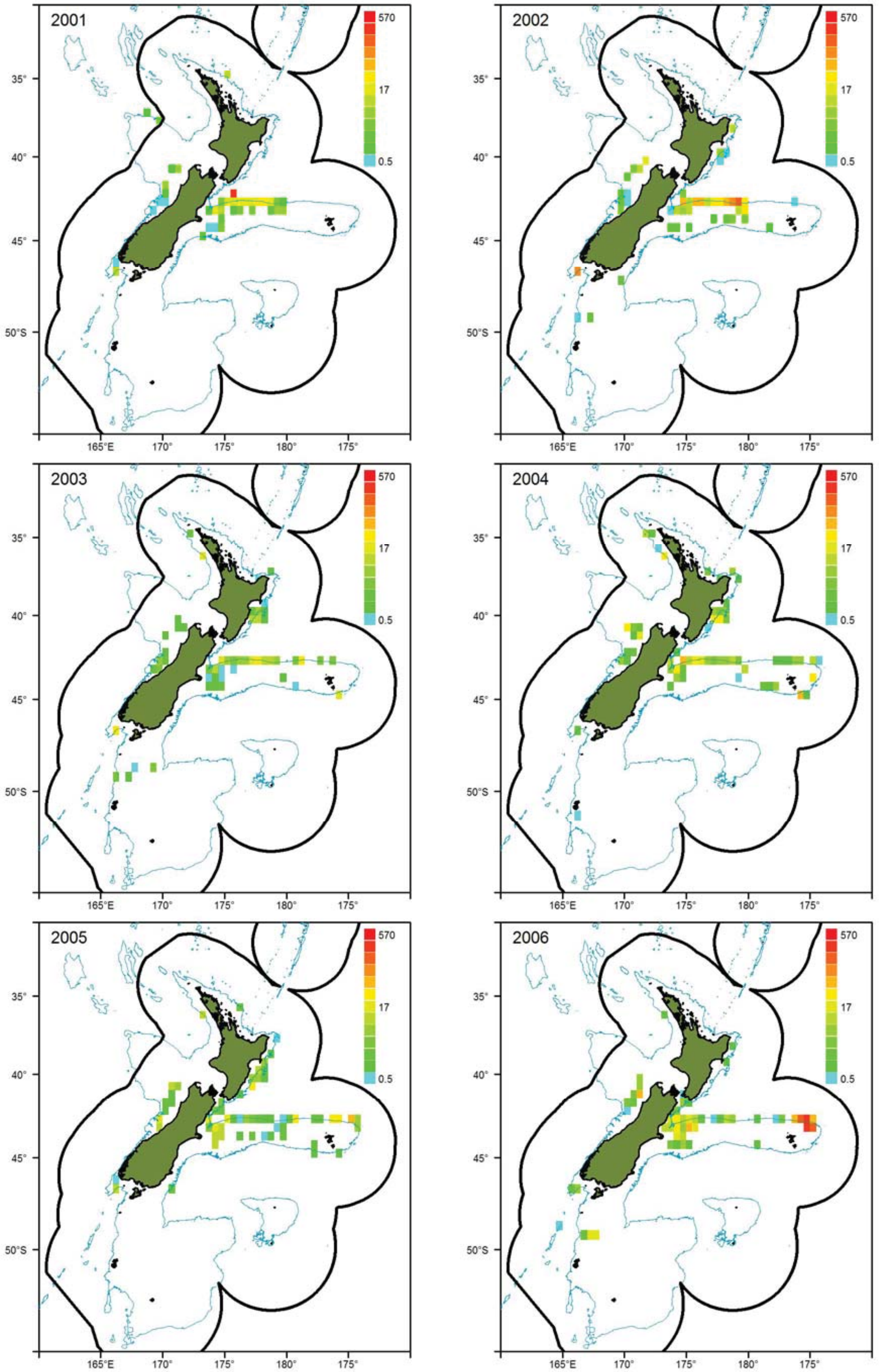
Appendix 8 (continued):



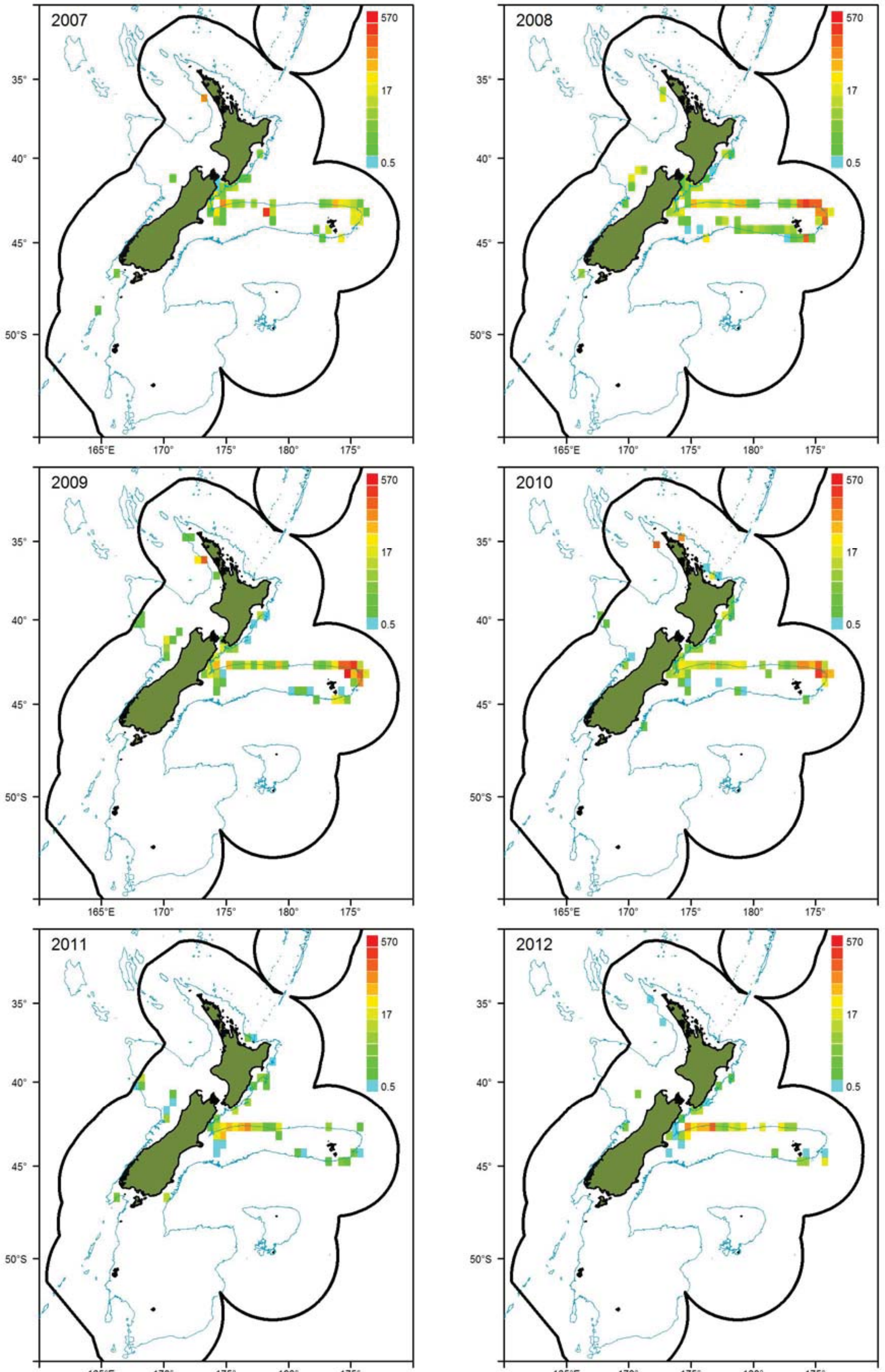
Appendix 8 (continued):



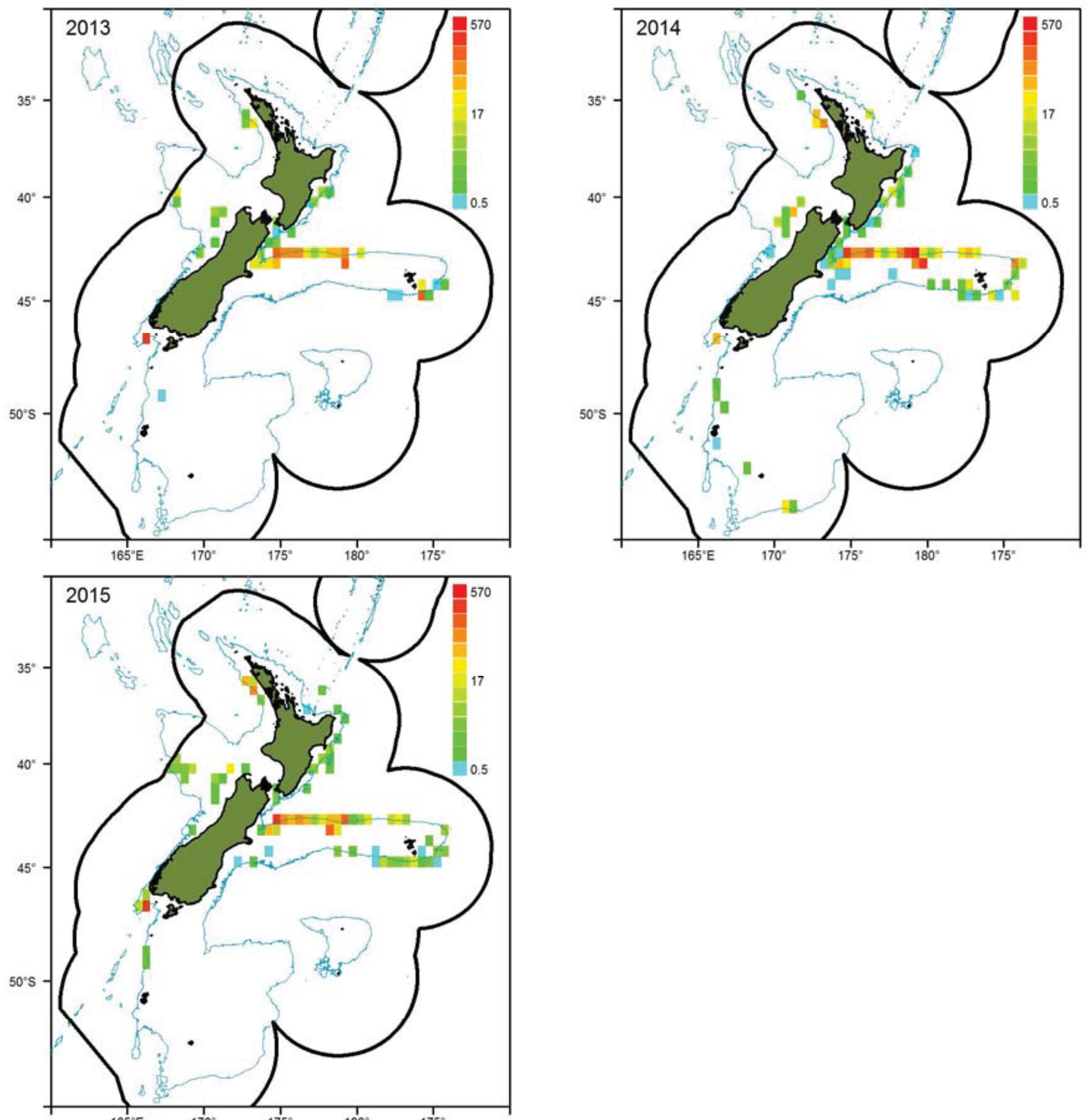
Appendix 9: Distribution of shovelnose dogfish CPUE reported on TCP forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



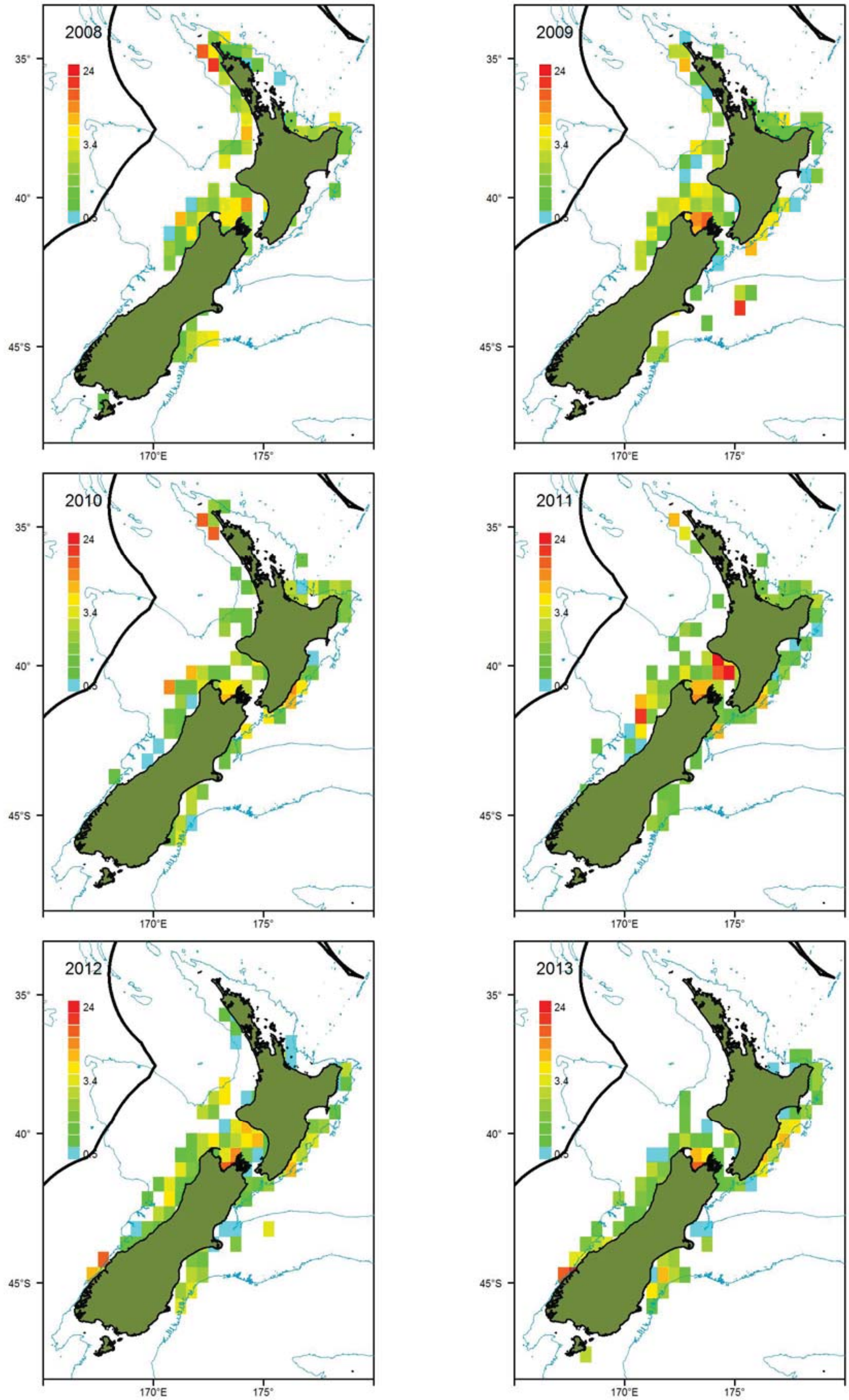
Appendix 9 (continued):



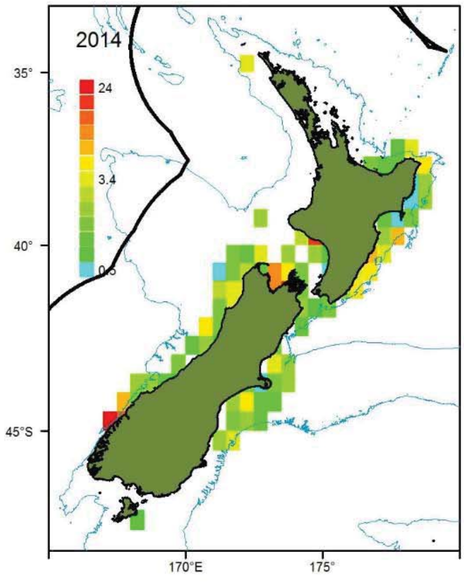
Appendix 9 (continued):

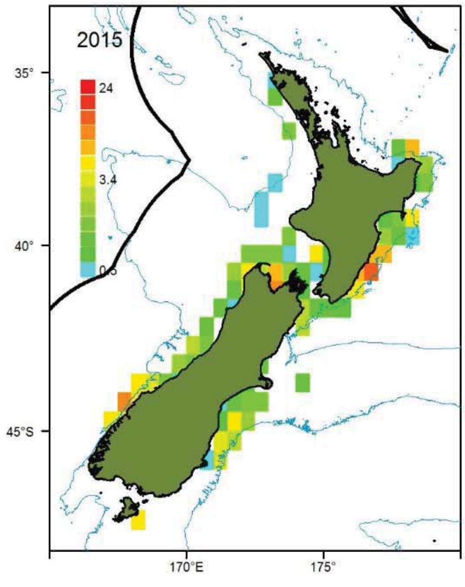


Appendix 10: Distribution of carpet shark CPUE reported on TCE forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.

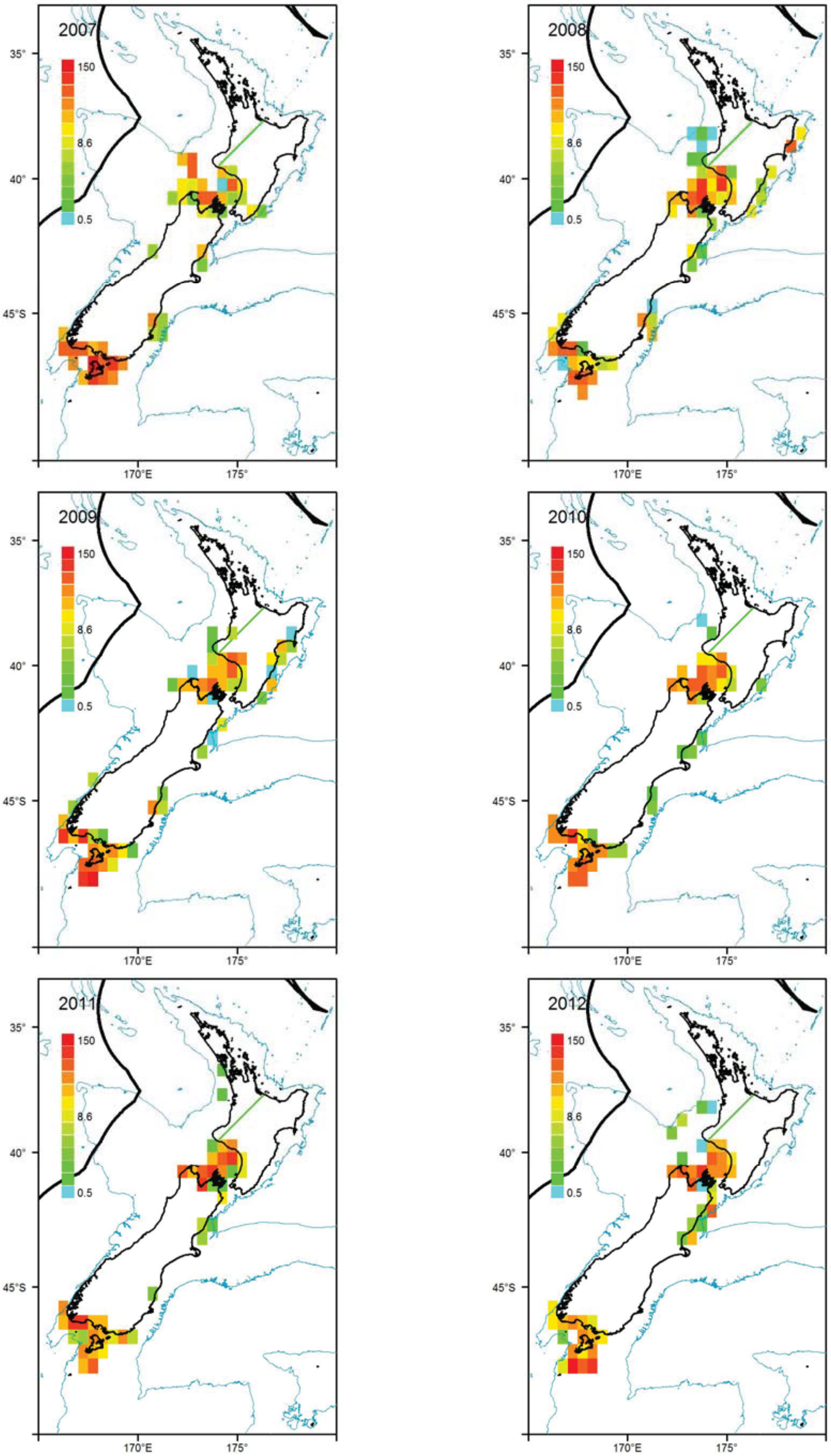


Appendix 10 (continued):

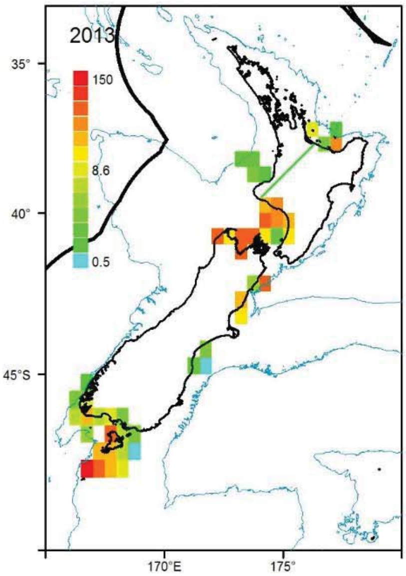


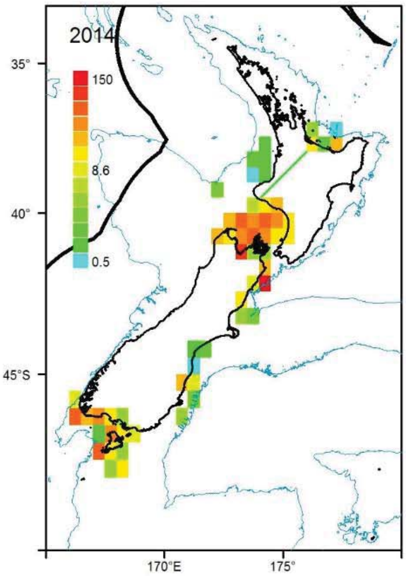


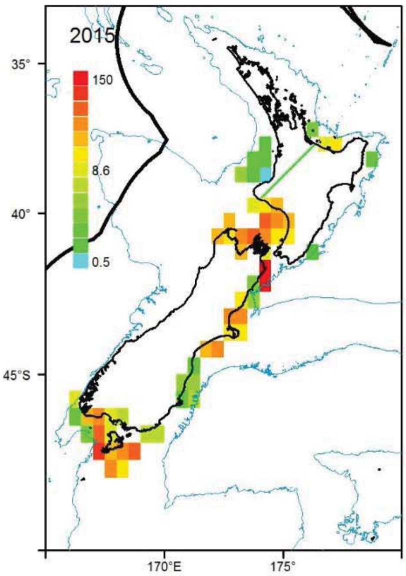
Appendix 11: Distribution of carpet shark CPUE reported on NCE forms in 0.5 degree rectangles by fishing year. Note the log scale used for the colour palette. Depth contour = 1000 m.



Appendix 11 (continued):







Appendix 12: Observed annual catches of eight shark and chimaera species.