Ministry for Primary Industries
Manatū Ahu Matua

Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–90 to 2010–11

New Zealand Aquatic Environment and Biodiversity Report No. 142

J. Black,
R. Tilney

ISSN 1179-6480 (online)
ISBN 978-0-477-10528-6 (online)

January 2015

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

1 EXECUTIVE SUMMARY

Black, J.; Tilney, R. (2015). Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–1990 to 2010–2011.

New Zealand Aquatic Environment and Biodiversity Report No. 142. 56 p.

This report presents the results of project DAE 2010/04B, monitoring New Zealand's trawl footprint[1] over the time period 1989/90 to 2010/11. Trawl Catch Effort Processing Return (TCEPR) data provided by the Ministry for Primary Industries were analysed for bottom trawling for all target species. Eleven key target species (hake, hoki, jack mackerel, ling, orange roughy, oreo-dory, scampi, southern blue whiting, squid, barracouta and silver warehou) were analysed separately and all other species as an aggregate, as well as all target species combined. This represents approximately 90% of the effort for these species over the last five years (species by year averages ranged from 61 to 100% over that time).

Statistics provided include the estimate of swept area in the exclusive economic zone (EEZ) and territorial sea (TS), and estimates of trawled area in relation to depth zones, fishable area, habitat class (from the Benthic-optimised Marine Environment Classification (BOMEC)) and the preferred habitat of each species (using the demersal fish layers in the Marine Environment Classification (MEC), where these exist).

Summary results are provided in this report, while the complete set of 221 spreadsheet and pdf pages are provided separately in 117 documents, on a CD (Appendix 3).

The swept area for all species from 1989/90 to 2010/11 is estimated to be 387 990 km^2 (about 9% of the EEZ and TS), an increase of 2958 km^2 on 1989/90 to 2009/10. This area is estimated to be 27% of the area available for bottom trawling, defined as that part of the TS and EEZ shallower than 1600 m and outside all Benthic Protection areas (BPAs), Seamount Closure and Marine Reserve areas.

The 15 BOMEC zones cover areas shallower than 3000 m (2 627 073 km²), approximately 63% of the EEZ and TS. The swept area from 1989/90 to 2010/11 for all species is estimated to comprise about 15% of the BOMEC zones, but ranges from 0.3 to 73% for individual BOMEC zones.

Almost 85% of the swept area in this period was in the depth ranges 0–400 m and 400–800 m. Slighty over half (55%) of this was in the 0–400 m depth range (179 996 km^2, 44% of the depth range). In the 400–800 m the swept area was 147 724 km^2 (31% of the depth range).

Analysis included assessment of trawling effort per unit area in which the EEZ and TS was divided into 5 km by 5 km cells and the number of tows and cumulative area of sea floor contacted by bottom fishing were estimated for each cell. Approximately 24% of the cells in the EEZ and TS have been contacted by trawls from 1989/90 to 2010/11. Less than 8% of the

[1] 'Trawl footprint' is a generic term used to reflect the area of seabed contacted by trawl nets. In this study two terms are used. The first, 'swept area', is the area of seabed contacted one or more times by a trawl net. The second, 'cumulative swept area', is used as an indicator of trawl fishing effort, and is the additive area of all trawls regardless of overlap.

cells in the EEZ and TS have been contacted in the 2010/11 fishing year. The cumulative swept area in 2010/11 is 94 904 km^2, 15 301 km^2 more than in 2009/10.

1 INTRODUCTION

1.1 Overview

The New Zealand Ministry for Primary Industries' (MPI) Trawl Catch Effort and Processing Return (TCEPR) database contains information about trawls made by vessels greater than 28 m in length, and provides the most precise information about where bottom trawling has occurred in New Zealand's Exclusive Economic Zone (EEZ). TCEPR reporting documents the bulk of effort for the 11 key deepwater fisheries examined here (see the Methods section for more details). This report describes how these data were used to estimate the location and frequency of trawling in the area within the 200 nautical mile (M) line (i.e., in the territorial sea (TS) and EEZ), to provide insight into temporal and spatial changes in fishing practice, potentially as a guide for managing the effects of fishing on the benthic environment. For the purposes of this report the two enclaves of international water that are surrounded by the EEZ, one on the Chatham Rise and the other on the Campbell Plateau, are included in the analyses.

This work updates the deepwater trawl footprint analyses reported by Black et al. (2013), which were based on TCEPR data from 1989/90 to 2009/10. This report is a continuation of that work, using the same methodology, and including data from the 2010/11 fishing year. An earlier study was conducted by Baird et al. (2011) where trawl effort from TCEPRs from 1989/90 to 2004/05 was used to map the temporal and spatial extent of seafloor contact.

Trawl swept area estimates and trawl frequency are provided for a range of parameters including: depth zones, fishable area, habitat class and preferred habitat area. Habitat class analysis uses the Benthic-optimised Marine Environment Classification (BOMEC) which was developed to classify fifteen benthic habitat groups on broad scales within the EEZ (Leathwick et al. 2012). The BOMEC zones are based on analyses of demersal fish species distributions from trawl catch data and eleven environmental variables characterising the sea floor morphology and oceanographic conditions. The demersal fish probability of capture layers from the Marine Environment Classification (MEC), (Leathwick et al. 2006) are used as indicators of preferred habitat for the key species/species groups. Where these do not exist (i.e. for squid or scampi) the National Aquatic Biodiversity Information System (NABIS[2]) normal and full distribution ranges[3] are used (Francis et al. 2003).

1.2 Objectives

This report presents the results of the second year of DAE2010/04, *to monitor the "footprint" of bottom contacting trawl fishing for deepwater and middle-depth species*, and addresses the following objectives:

[2] http://www.nabis.govt.nz/Pages/default.aspx

[3] The full range contains all known records of that species and the normal range the area in which 90% of the population is estimated to occur

1. To estimate the 2010/11 trawl footprint and map the spatial and temporal distribution of bottom contact trawling throughout the EEZ between 1989/90 and 2010/11.
2. To produce summary statistics, for major deepwater fisheries and the aggregate of all deepwater fisheries, of the spatial extent and frequency of fishing by year, by depth zone, by fishable area, and by habitat class, and to identify any trends or changes.

2 METHODS

This study analyses data from the TS and EEZ, including two enclaves of international waters on the Chatham Rise and Campbell Plateau.

Swept areas are determined separately for 11 key target species (i.e. the nine deepwater Fisheries Plan[4] Tier 1 species plus silver warehou and barracouta), (Table 1) and for the aggregate of an additional 89 species recorded as being target species on TCEPRs ("minor" target species), (Appendix 1). Finally, the aggregate swept area for all species recorded as being targeted on TCEPRs was determined. The above analyses were undertaken for the 2010/11 fishing year and for all years in the period 1989/90 to 2010/11 combined. The methodology is similar to that described in Black et al. (2013). This report extends the data set to include the 2010/11 fishing year.

Table 1: Key target species and reporting codes. A list of the "minor" target species covered in this report is given in Appendix 1.

Common name	Reporting code
Hake	HAK
Ling	LIN
Hoki	HOK
Southern blue whiting	SBW
Oreo	OEO
Jack mackerel	JMA
Orange roughy	ORH
Squid	SQU
Scampi	SCI
Silver warehou	SWA
Barracouta	BAR

2.1 Trawl Data

This project is concerned with trawl effort that has had contact with the seafloor. All data in this category were provided by the Ministry for Primary Industries as extracts from the TCEPR database. The input data include all bottom trawls, and mid-water trawls for which the ground rope depth is equal to the water depth.

TCEPR data record individual trawl positions, primarily for vessels operating in waters deeper than 200 m. Catch effort landing return (CELR) and trawl catch effort return (TCER)

[4] The National Fisheries Plan for deepwater and Middle-depth fisheries http://www.fish.govt.nz/en-nz/Consultations/Archive/2010/National+Fisheries+Plan+for+Deepwater+and+Middle-Depth+Fisheries/default.htm

data were not used because it is impossible to extract precise position information about individual trawls from those records. TCERs only record tow start positions and CELRs only provide the statistical reporting area (general area) of tows, not their start and end locations.

For the fishing year 2010/11, the database contains 352 294 records of bottom tows and of mid-water tows for which the ground rope depth is equal to the water depth. This is added to the existing data from 1989/90 to 2009/10. The entire data base from 1989/90 to 2010/11 contains 1 270 561 records. On 1 October 1988 the Ministry of Fisheries changed from the old Fisheries Statistic Unit (FSU) to the Catch and Effort system. The old FSU forms were replaced with the CELR, CLR, TCEPR, SJCER and TLCER forms. The TCEPR data from the 1989/90 fishing year are not a full record for that year and these data may overlap with the FSU data. In 1991 the TCEPR, TLCER and SJCER forms were replaced with new versions; the CELR and CLR forms stayed the same. Therefore the footprint of bottom trawling prior to 1 October 1989 is not considered in this report.

In order to determine the proportion of catches reported using TCEPRs, an analysis of fishing returns for the most recent 6-year period (i.e. 2005/06 to 2010/11), and for the 11 major species is provided (Dave Foster 2012, pers. comm., 7 March; Table 2 and Appendix 2). It shows that on average more than 90% of the estimated catches of hoki, hake, orange roughy, oreos, scampi, silver warehou, squid and southern blue whiting were recorded on TCEPR forms. On average 61% of the ling catch, 78% of the jack mackerel catch, and 84% of the barracouta catch was recorded on TCEPR forms.

The statistics for 2009/10 and 2010/11 are very similar and several species have the same percentage of catch reported on TCEPR forms in each year. Only two species show a decrease: squid (from 96% to 95% of catch) and barracouta (from 85% to 83% of catch), (Table 2), with three species showing an increase of between 1 and 3 percentage points (LIN, ORH and SWA).

Table 2: Percentage of catch reported on TCEPR forms.

Fishing year	HOK	HAK	LIN	SBW	JMA	ORH	OEO	SCI	SQU	BAR	SWA
2010/11	93%	98%	55%	100%	78%	100%	100%	100%	95%	83%	96%
2009/10	93%	98%	52%	100%	78%	99%	100%	100%	96%	85%	95%
2008/09	93%	100%	58%	100%	74%	99%	96%	100%	97%	81%	96%
2007/08	92%	99%	63%	100%	75%	100%	96%	100%	96%	83%	97%
2006/07	92%	100%	69%	100%	86%	98%	96%	100%	95%	89%	99%
2005/06	95%	100%	67%	100%	77%	97%	94%	100%	90%	84%	99%
2005/06 to 2010/11	93%	99%	61%	100%	78%	98%	97%	100%	95%	84%	97%

Data reported on TCEPR forms provide individual trawl information including vessel identification, date, start and end position of the vessel, duration and speed of the tow, water depth, wingspread, and target species. The start and end positions are reported to a precision of one minute.

The data are projected into an equal-area projection to allow accurate computation of areas throughout the region of interest (Black et al. 2013). All maps and charts in this report are plotted using this projection.

2.2 Trawl Data correction and editing

Some errors in data entry are expected with the large number of records analysed. The data correction here focuses on the main sources of error that can be corrected without intensive, time consuming effort. A small number of records that remain in the analysis but appear to have an incorrect target species are identified in Appendix 1 (and therefore use of these data in isolation may require further checking). Given the large number of records utilised it is believed the effect of these errors on the overall findings is likely to be negligible.

The original TCEPR data included records outside the EEZ (beyond the 200 M line). These were not used in the analysis (Figure 1). Unlike some previous studies (e.g. Black & Wood 2009), tows in the TS were kept in the database.

The TCEPR data are known to contain errors. Potential errors considered for the analyses in this report were:

1. tows with identical start/end coordinates,
2. tows with NULL start/end coordinates,
3. tows outside the EEZ,
4. tows that cross land, and
5. tows longer than expected for normal NZ fishing practice.

We apply the same edit criteria as described in Black et al. (2013) to the 2010/11 data, and combine this with the 1989/90 to 2009/10 data (Table 3).

Table 3: Criteria used to identify likely errors in the input data, and the number of records that met those criteria.

Edit Steps	Number of Records Footprint analysis	Percentage of Analysed Footprint Records	Number of Records Frequency analysis	Percentage of Analysed Frequency Records
NULL start/end coordinates	351	0.03%	351	0.03%
Identical start/end coordinates	46 840	4.10%	N/A	N/A
Tows outside EEZ	39 052	3.42%	48 391	4.10%
Long tows	39 872	3.49%	39 872	3.38%
Tows that cross coastline	8 866	0.78%	8 930	0.76%
TOTAL flagged	129 184*	11.32%	90 715*	7.69%
TOTAL analysed	1 141 377		1 179 846	

*Does not equal sum of above numbers, as some records fall into multiple categories of "Tows outside EEZ", "Long tows", and "Tows that cross coastline".

Over the last ten fishing years, the number of records flagged and edited out has progressively decreased. Only "long tows" has more flagged records in 2010/11 than in 2009/10, this is an increase of less than 80 tows and is lower than the years 2001/02 to 2007/08 inclusive (Figure 1). The relatively small increase in the number of "long tows" in the last year, and the general decrease over the last decade, suggests that our edit criteria are still suitable. If fishing practice was changing such that tows were increasing in length, we would expect to observe a progressively increasing number of tows flagged as "long tows".

The general decrease in the number of tows to be flagged and edited out suggests an improvement in the accuracy of data recorded on the TCEPR.

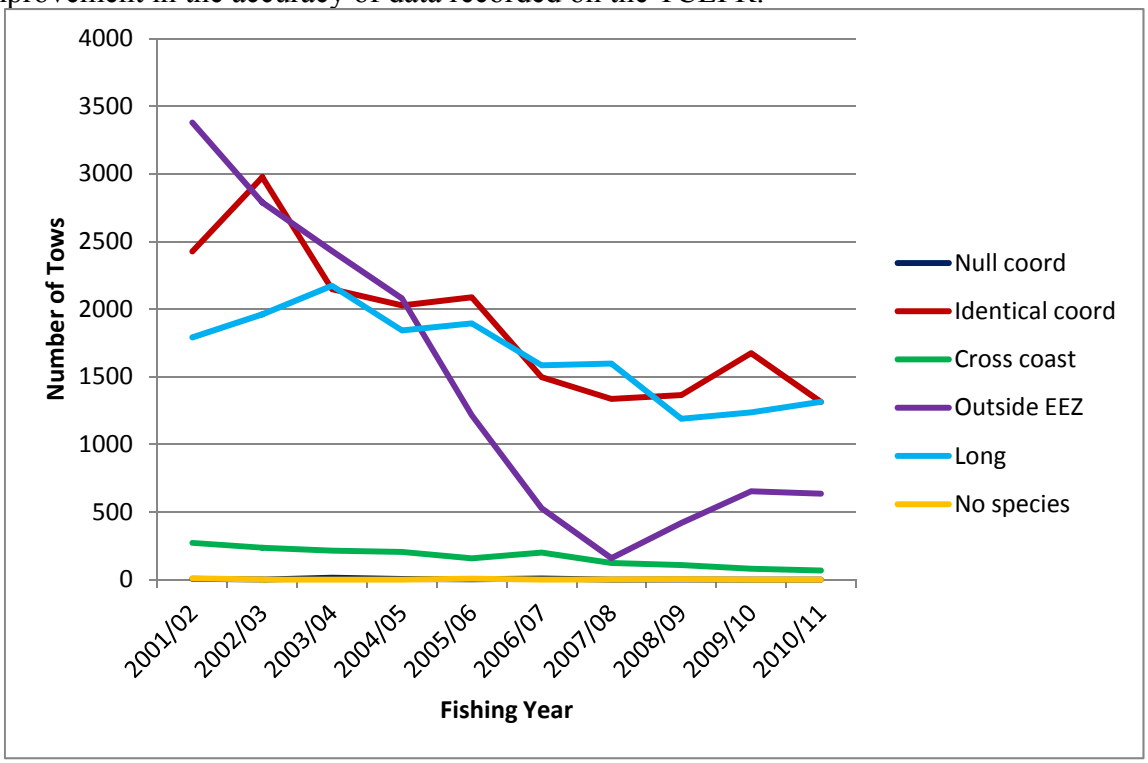

Figure 1: Number of tows flagged to be edited out in each of the last ten fishing years.

2.2.1 East-West error correction

Records were corrected for obvious east-west longitude transpositions as described in Black et al. (2013). In the 2010/11 dataset only five tows were identified for possible east-west longitude corrections. A decision about which end of the tow to move was based on the assumption that these tows conformed to the fishing practice in the area and so the longitude value of the position outside the total trawl foot print, or beyond the area of fishable depths (Section 2.5), was changed. For the five tows identified it was impossible to decide which end was in need of correction as either both or neither of the ends fitted with recorded fishing practice. For the tows where neither end conformed to current fishing practice, it is likely that the error was not an East-West error, but a different kind of transcription error. For the tow where correcting either end would fit with current fishing practice, there is insufficient information to make a correction. In total, none of these long trawls was corrected thus having no effect on the number of useable records in the dataset.

2.2.2 Tow position offsets

Tow start and end positions are submitted to the TCEPR database rounded to the nearest arc-minute. This precision creates an unrealistic estimate of the swept area. To counter this we applied a random offset or "jitter" of between -0.5 and +0.5 minutes to the start and end co-ordinates of each tow to approximate a realistic pattern of start and end positions, in the same way as Black et al (2013). In regions where fishing is carried out on marks (features of limited geographic extent) there could be a genuine clustering of trawl start/end locations and possibly very short tows. In these locations the application of offsets may make the estimated footprint area larger than it really is, but the effect on a national scale is unlikely to be significant.

The fishing effort per unit area calculations assume that tows with the same start and end positions may be legitimate short tows. For these calculations the same random offset was applied to records with identical start/end coordinates, so the tow continued to have zero length but its position could be moved into another cell.

2.3 Calculation of swept area

Using the projected tow lines, the next step estimated the area of sea floor contacted by each tow. Estimation of area swept by each tow required three assumptions that reasonably reflect common fishing practices in the New Zealand deep water fishery:

1. The vessel location was a reasonable proxy for the net location;
2. The vessel travelled in a straight line between start and end positions;
3. The width of sea floor contacted by the trawl gear was a function of target species and trawl gear type (single- or double-rig).

After discussion with experienced representatives of the fishing industry, characteristic door-to-door trawl widths were assigned to each target species and trawl gear type (Table 4). These widths were chosen to reflect common fishing practice in New Zealand and are a conservative (i.e., wide) estimate of the door-to-door widths of the trawl gears compared to the mean wingspread in the TCEPR database (Table 4).

Table 4: Door-to-door trawl gear widths used to estimate the area of sea floor contacted by individual tows in the TCEPR database. The mean wingspread in the TCEPR database is included for comparison. Refer to Table 1 and Appendix 1 for species abbreviations.

Species	Door-to-door width (m)	Mean wingspread in TCEPR database (m)
GUR, JDO, SCI, SKI, SNA, TAR, TRE, KIN, LIN	70	36
BNS, BYX, RCO	100	39
BAR, BOE, CDL, JMA, LIN, OEO, ORH, SBW, SQU, SSO, SWA, WAR, WWA	150	50
HAK, HOK	200	46
Trawl gear type DOUBLE	2 × trawl width	-

For the 2010/11 tows, twin-rig information is taken from MPI's data on the number of nets used for each tow. This information is based on whether a vessel is known to have twin-rig capability rather than whether it was used on that particular tow, so potentially results in a slight over estimation of the total fishing area.

Each of the edited tow lines was made into a polygon by buffering it with the appropriate door-to-door width from Table 4, based on the target species and on the tow type in the input record. Valid tows that crossed the EEZ boundary were buffered and then clipped to the EEZ.

We have previously created databases containing the trawl data for the period 1989/90 to 2009/10. There is a database for each major species and for the two species aggregates (i.e. for all minor species and for all species combined). The tows for 2010/11 were extracted and placed into new files in the relevant databases. Finally, the individual tows for each database were merged (Figure 2) to derive an estimate of the footprint area of seafloor contacted by bottom trawling, i.e. the swept area.

Each file for the 2010/11 year is combined with the appropriate file in the 1989/90 to 2009/10 database (Black et al. 2013) so that the database used in these analyses covers the full time period (i.e. 1989/90 to 2010/11).

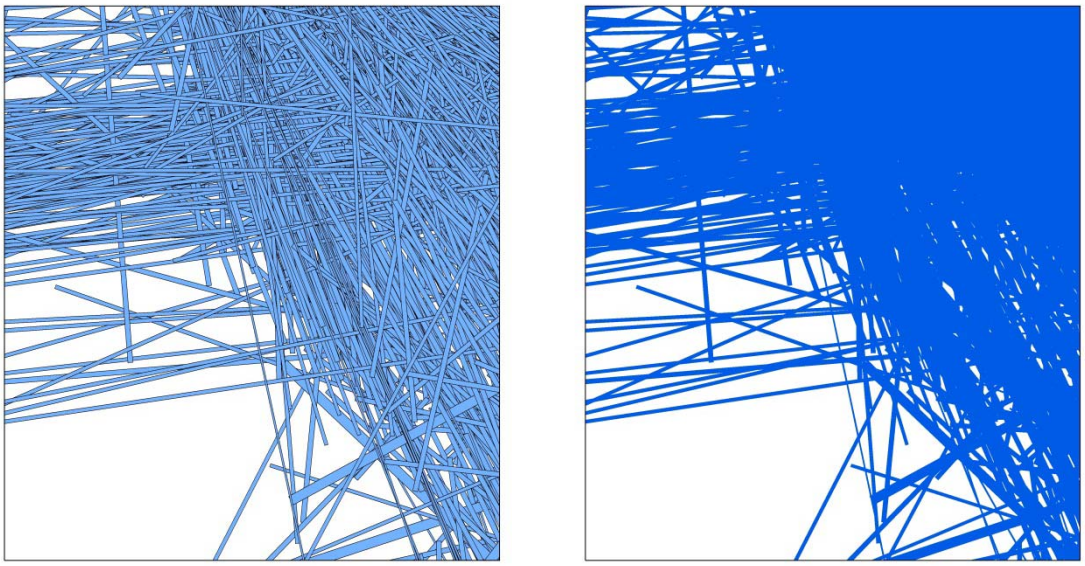

Figure 2: An example of individual tow paths (left), merged for species or species aggregate (right).

The GIS used the swept area for each species to estimate the area and percentage of the EEZ and TS that has been swept by bottom trawling targeting that species. The swept area is then compared with a series of other parameters as discussed in the following sections.

The imprecision of start and end locations and the assumption of a straight trawl path are likely to result in an underestimate of the total trawl footprint. The assumed trawl widths are very conservative, probably leading to an overestimate of the total trawl footprint. In heavily trawled areas both over- and underestimates are irrelevant as the entire area is predicted to have been affected (Black & Wood, 2014). We conclude that the uncertainty arising from the

combination of over- and underestimates is likely to be small, of the order of a few percent of the total footprint area.

2.4 Effort per unit area analysis

The EEZ was divided into a grid of 164 823 cells, 5 km × 5 km in dimension. To calculate the effort per unit area the trawl polygons described above were used along with the trawls of zero length, which were added as points. The number of trawls to intersect each cell was calculated and added as an attribute. The cumulative swept area of trawls in each cell was also calculated and added as another attribute (Figure 3). Each trawl adds to the total area value regardless of overlap with other trawls, thus the cumulative swept area in each cell will always be equal to or greater than the swept area. A file is made for each target species or species group for the 2010/11 fishing year and added to our database. A second set of files is made combining this data with the 1989/90 to 2009/10 data to provide information on the entire time period (i.e. 1989/90 to 2010/11).

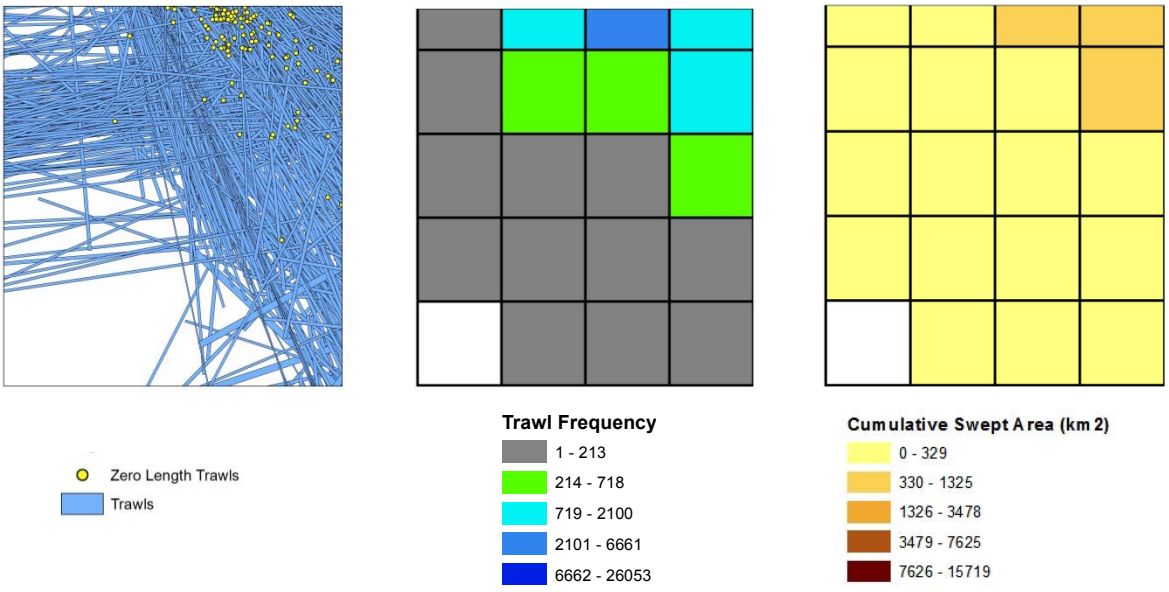

Figure 3: An example of individual tow paths (left), number of tows per cell (centre) and cumulative swept area per cell (right).

Using the two attributes (number of trawls, and cumulative swept area of trawls) recorded for each cell, a series of statistics are calculated for the file. These include: number of cells contacted by trawls (Cells Contacted), largest number of trawls in a cell (Highest Trawl Frequency), mean number of trawls across cells that contain trawls (Mean Frequency of Trawled Cells), mean number of trawls across all cells (Mean Frequency of All Cells) and total area of all trawls (Cumulative Swept Area of Trawls).

The results can be directly compared not only with Black et al. (2013) but also with the analyses of Baird & Wood (2009) and Baird et al. (2011).

2.5 Parameters

In this report, the trawl footprint and the fishing effort per unit area are each compared against a series of parameters. These are:

- **Depth zones**: 0 to 400 m, 400 to 800 m, 800 to 1200 m, and deeper than 1200 m (GEBCO 2010)
- **Fishable area**: the region shallower than 1600 m that is not closed to bottom trawling
- **Habitat class**: Benthic-optimised Marine Environment Classification (BOMEC) (Leathwick et al. 2012)
- **Species specific preferred habitat**: Where possible the probability of capture layers for fish distribution from the demersal fish based Marine Environment Classification (MEC) were used as a proxy for preferred habitat (Leathwick et al. 2006). A series of polygons was created for which the probability of capture is greater than: 0%, 1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, and for which the probability of capture is equal to 99%. The preferred habitat for oreo was constructed by taking the union (spatial combination) of the predicted probability of capture layers for black oreo (BOE) and smooth oreo (SSO). Similarly, the preferred habitat for jack mackerel used the union of *Trachurus murphyi* (JMM), *Trachurus novaezelandiae* (JMN) and *Trachurus declivus* (JMD) layers.

  Demersal fish layers are not available for squid or scampi. The National Aquatic Biodiversity Information System (NABIS) database of marine species distributions (Francis et al. 2003) includes normal and full distribution ranges for these species, and these were utilised for squid and scampi for this project.

  The analysis of swept area for the aggregation of all species, and of minor species, was not undertaken against any proxy for preferred habitat, following the advice of MPI.

For more information regarding these parameters, see Black et al. (2013).

For the effort per unit area calculations, the analysis is based on the parameter at the centre of the cell (Figure 4).

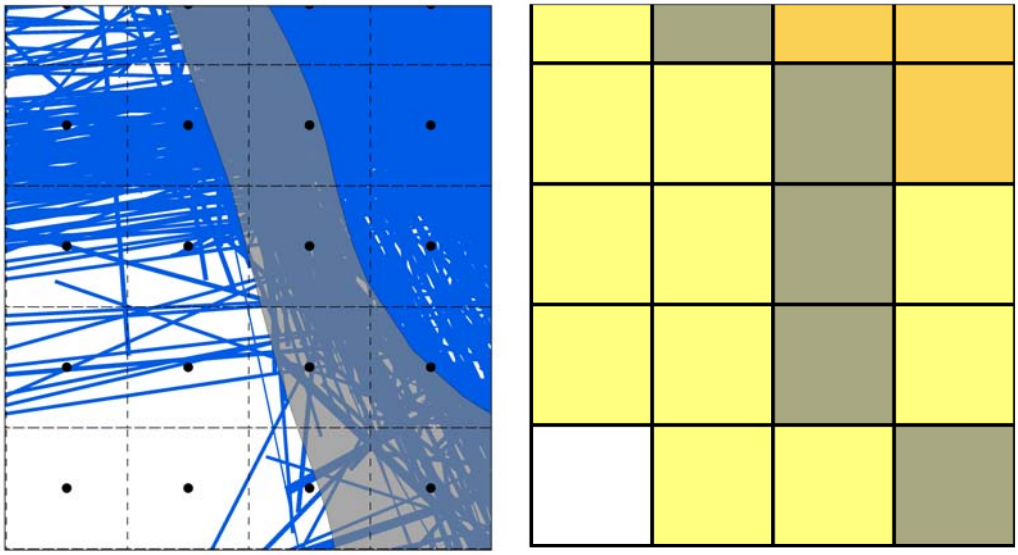

Figure 4: Swept area in blue overlain by the exact boundary of the 400–800 m depth band in grey (left). Cell boundaries are marked by dashed lines and cell centres by black dots.
Cumulative swept area, with cells in the 400–800 m depth band shaded grey (right), for key see Figure 3.

3 RESULTS

The results of two types of analysis that were conducted for eleven target species, and for aggregates of all other (minor) species and for all species are presented here.

A total of 1 141 377 TCEPR records were used to estimate the swept area (footprint area contacted by bottom trawling) in New Zealand's TS and EEZ for the fishing years 1989/90 to 2010/11. A total of 1 179 846 tows were used to analyse the effort per unit area (i.e. 5 × 5 km cells).

For both analyses, statistics are provided for the 2010/11 fishing year and for the entire period (1989/90 to 2010/11). Summary statistics were calculated regarding spatial extent and frequency of bottom-contact fishing by year, depth zone, fishable area, preferred habitat and habitat class. A representative range of bottom trawl effort analysis results are presented in this section and the complete set of 221 pages of statistics and maps are separately provided on DVD for all species and species aggregates (Appendix 3). All maps in Appendix 3 are plotted at a scale of 1:3 000 000, i.e. 1 cm on the map (viewed at 100%) represents 30 km on the ground.

3.1 TCEPR Swept Area

The area within New Zealand's EEZ and TS contacted by bottom trawling between 1989/90 and 2010/11 is estimated to be 387 990 km^2 (Figure 5). This is about 9.4% of the area inside the 200 M line. The increase in swept area (i.e. the approximate area of seafloor that was trawled in 2010/11 for the first time) is 2 958 km^2 (Figure 6). The swept area has increased in size each year since 1989/90, but the increase has been getting steadily smaller since 2002/03.

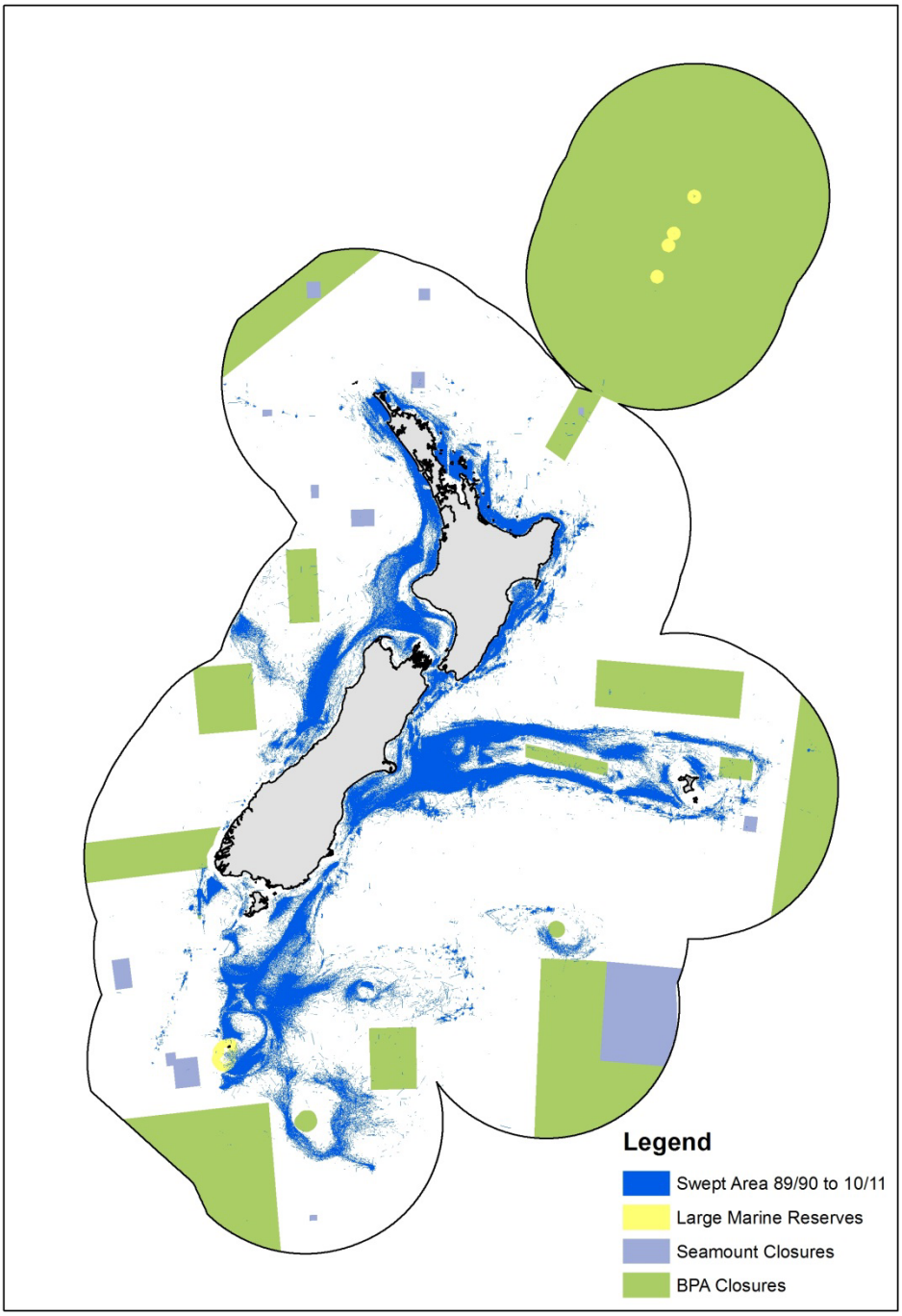

Figure 5: Estimated swept area for the period 1989/90 to 2010/11.

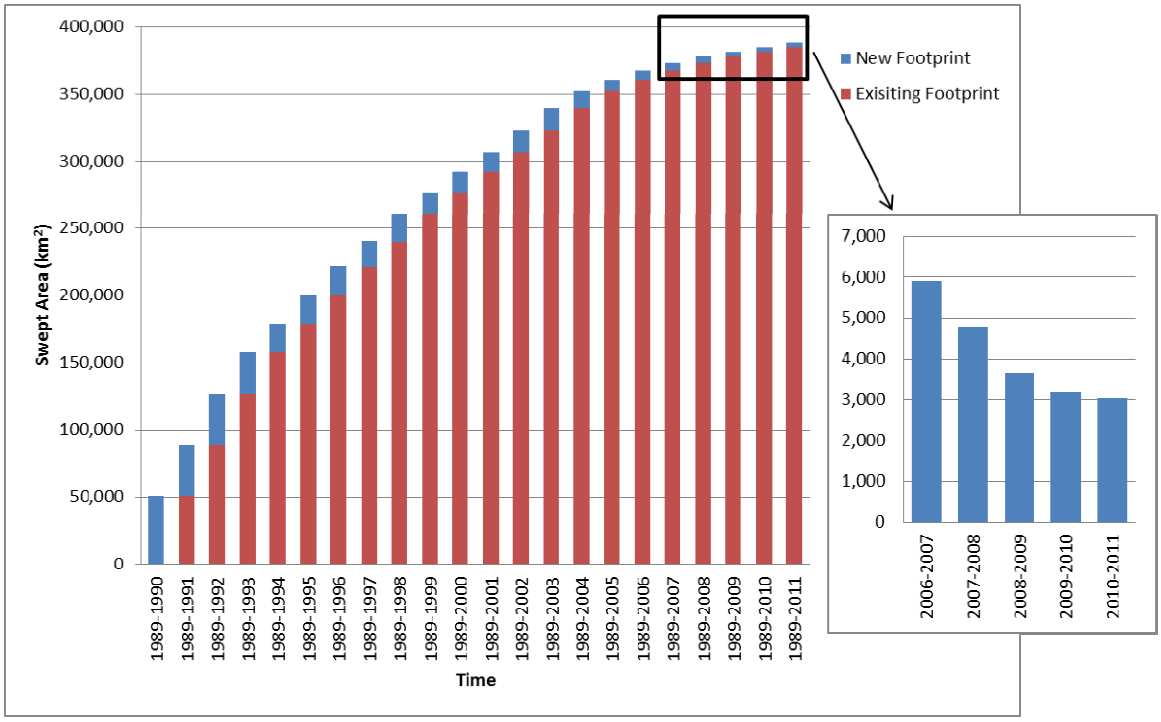

Figure 6: The change in swept area between 1989/90 and 2010/11. Red shows the component of the swept area that had been trawled before each fishing year, blue is the area trawled for the first time that year. The inset graph shows the area trawled for the first time in each of the last five fishing years.

Note that trawls that occurred before 1989/90 were not reported using TCEPR forms and are therefore not represented. The zero on the y-axis should therefore not be taken literally.

The swept area in 2010/11 was 53 031 km^2. This is approximately 1.3% of the EEZ and TS combined and 3.8% of the fishable area. Despite the lowest yet recorded amount of newly trawled area in a single fishing year, the swept area in 2010/11 is larger than in the previous year (49 708 km^2 in 2009/10).

Tables and plots showing the estimated swept areas for each species are in Appendix 3:

- Tables are in files <species id>2011_footprint_stats.pdf and <species id>2011_footprint_stats.xls, e.g., barracouta data are in BAR2011_footprint_stats.pdf and BAR2011_footprint_stats.xls
- Plots are in files <species id>2011_BOMEC_fig.pdf and <species id>2011_fig.pdf, e.g. BAR2011_BOMEC_fig.pdf and BAR2011_fig.pdf.
- See file README.doc in Appendix 3 for more information.

Results are provided for each of the key target species and the minor and all species aggregates for the 2010/11 fishing year and for the entire period (1989/90 to 2010/11).

The calculated statistics for bottom trawling can be used to monitor changes in fishing activity. The swept area for orange roughy is considerably lower in 2010/11 than in any other fishing year during the period of analysis. The swept area in 2010/11 was 1031 km^2, less than half that of the previous fishing year (Figure 7). The number of tows and the cumulative swept area also show a significant decrease (from 2489 to 1545 tows and from 3006 km^2 to 1239 km^2 respectively), suggesting that the decrease in swept area is due to a reduction in fishing effort rather than a concentration of trawl location.

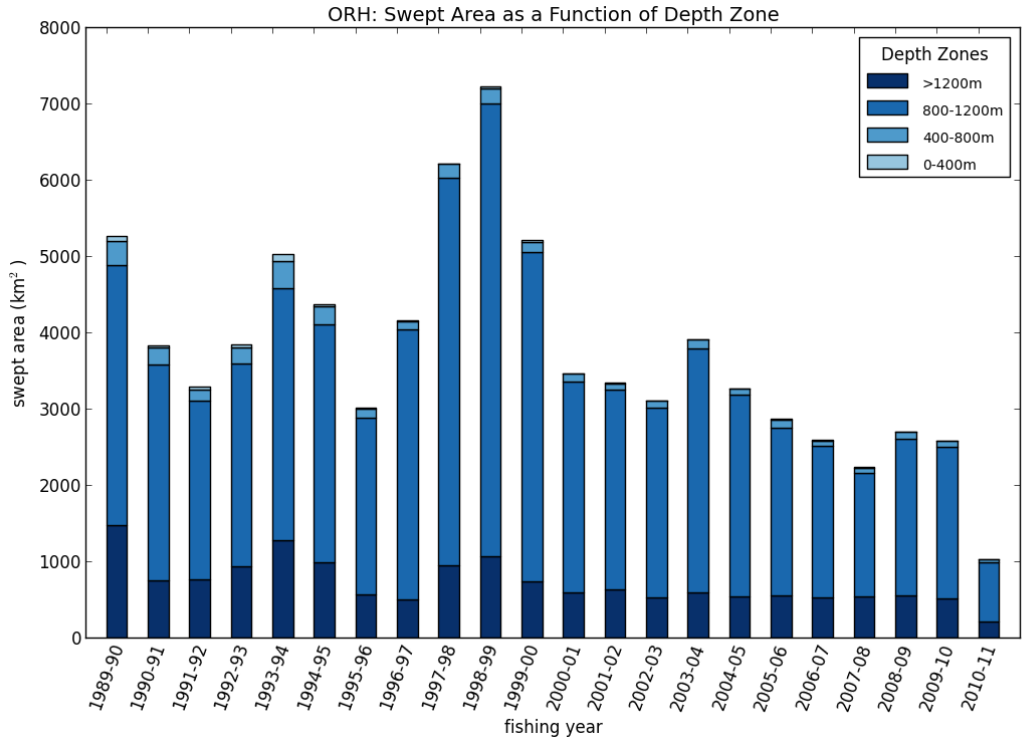

Figure 7: Swept area (km^2) for trawls targeting orange roughy as a function of depth (m) for each fishing year.

The swept area for tows targeting squid has seen a year-on-year increase since 2007/08 (Figure 8). However the swept area in 2010/11 (5 246 km^2) is lower than any year before 2007/08, and considerably lower than the peak of 9 217 km^2 in 2000/01.

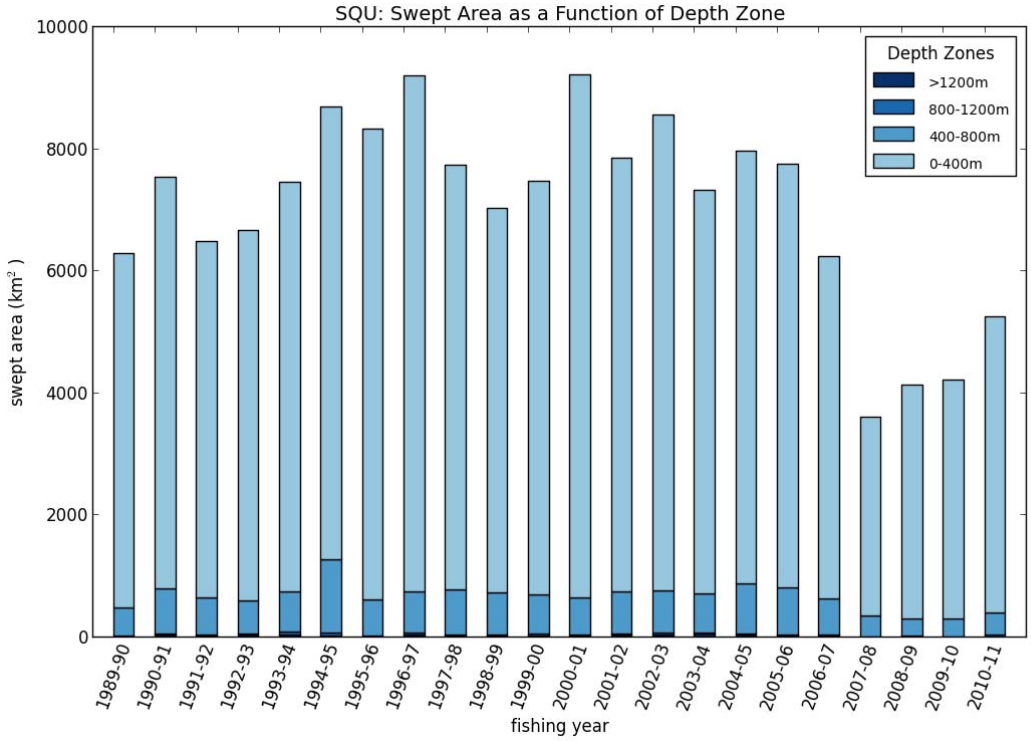

Figure 8: Swept area (km^2) by year for trawls targeting squid, as a function of depth (m).

3.2 TCEPR Trawl Frequency

Tables and plots showing the estimated trawl frequency for each species are in Appendix 3:

- Tables are in files <species id>2011_freq_stats.pdf and <species id>2011_freq_stats.xls, e.g., barracouta data are in BAR2011_freq_stats.pdf and BAR2011_freq_stats.xls.
- Plots are in files <species id>2011_freq_fig.pdf and <species id>2011_area_fig.pdf, e.g. BAR2011_freq_fig.pdf and BAR2011_area_fig.pdf.
- See file README.doc in Appendix 3 for more information.

Results are provided for the 2010/11 fishing year and for the entire period (1989/90 to 2010/11).

The cumulative swept area between 1989/90 and 2010/11 is 3 295 423 km^2. The cumulative swept area in 2010/11 (94 904 km^2) is 19% greater than it was in 2009/10 (79 603 km^2). Although the total area of trawls is larger, the number of 5 × 5 km cells contacted has decreased from 12 866 (7.8% of the total number of cells) to 12 600 (7.6%), a decrease of 266 cells.

For the period 1989/90 to 2010/11 tows were reported in 39 838 cells, about 24% of the 167 477 5 × 5 km cells that cover the EEZ and TS (Figure 9). Of these 39 838 cells, 107 were trawled for the first time in 2010/11. For the full time period (1989/90 to 2010/11) the highest tow frequency in a cell was 16 837, the mean frequency of tows for all fished cells was 171, and the mean frequency of tows in all cells was 41.

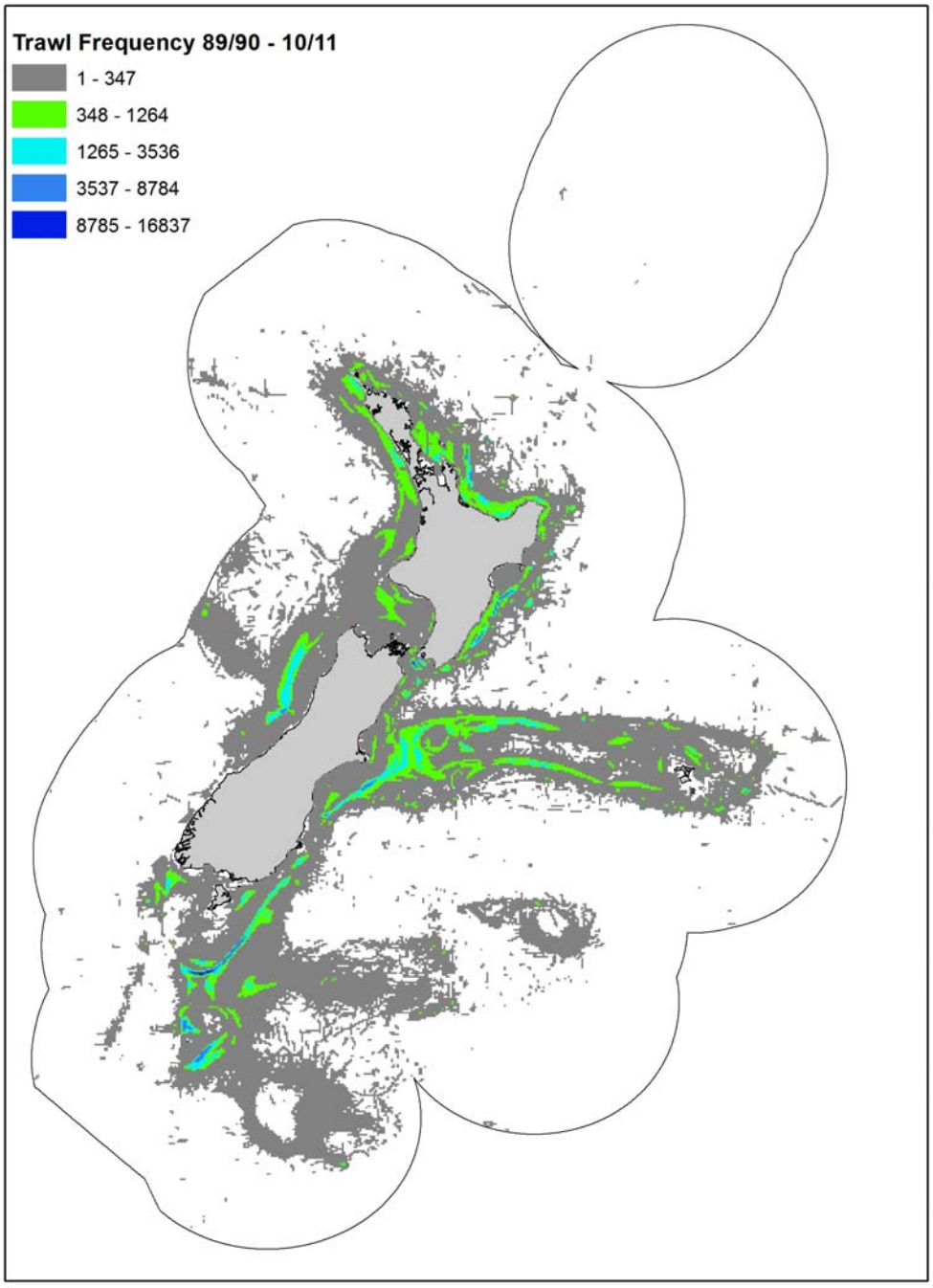

Figure 9: Trawl frequency for the period 1989/90 to 2010/11

The mean frequency for 2010/11 was 15.6 for the trawled cells, and 1.2 for all cells. The mean frequency for trawled cells is lower now than in the mid-1990s, however, it has increased slightly over the last three years from a minimum of 14.7 in 2008/09 (Figure 10).

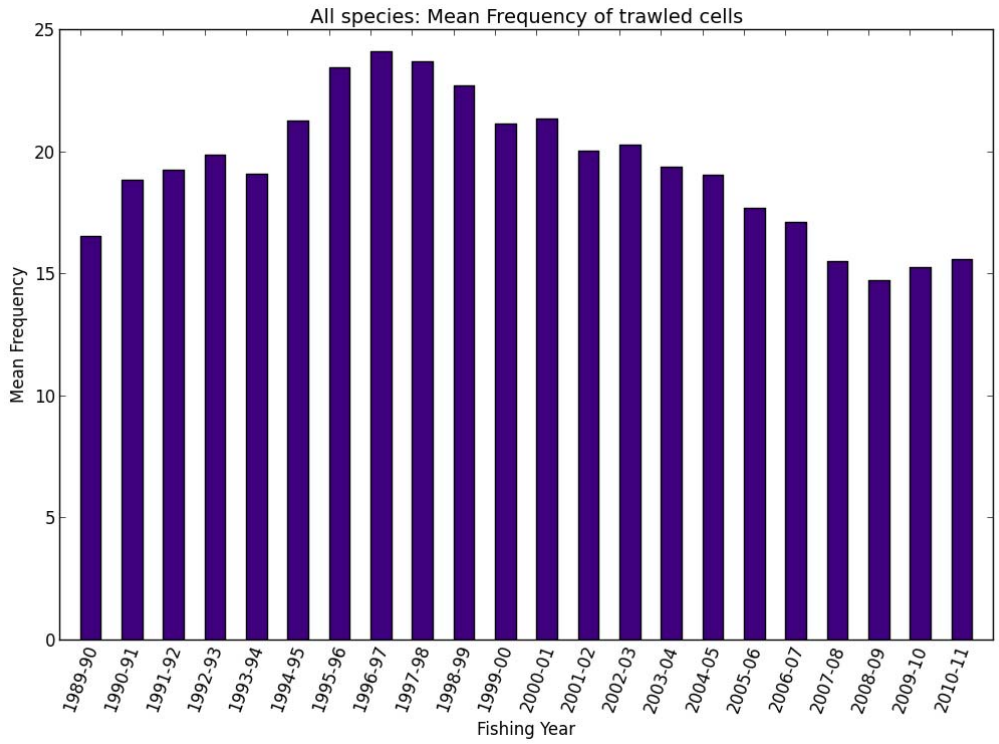

Figure 10: Mean trawl frequency of trawled cells for all species.

The maximum trawl frequency for the aggregate of all species has decreased slightly (from 501 in 2009/10 to 468 in 2010/11). The maximum trawl frequency has stayed fairly constant over the last five fishing years. Before 2005/06 it was higher, while the maximum of 2294 trawls occurred in 1990/91 (Figure 11).

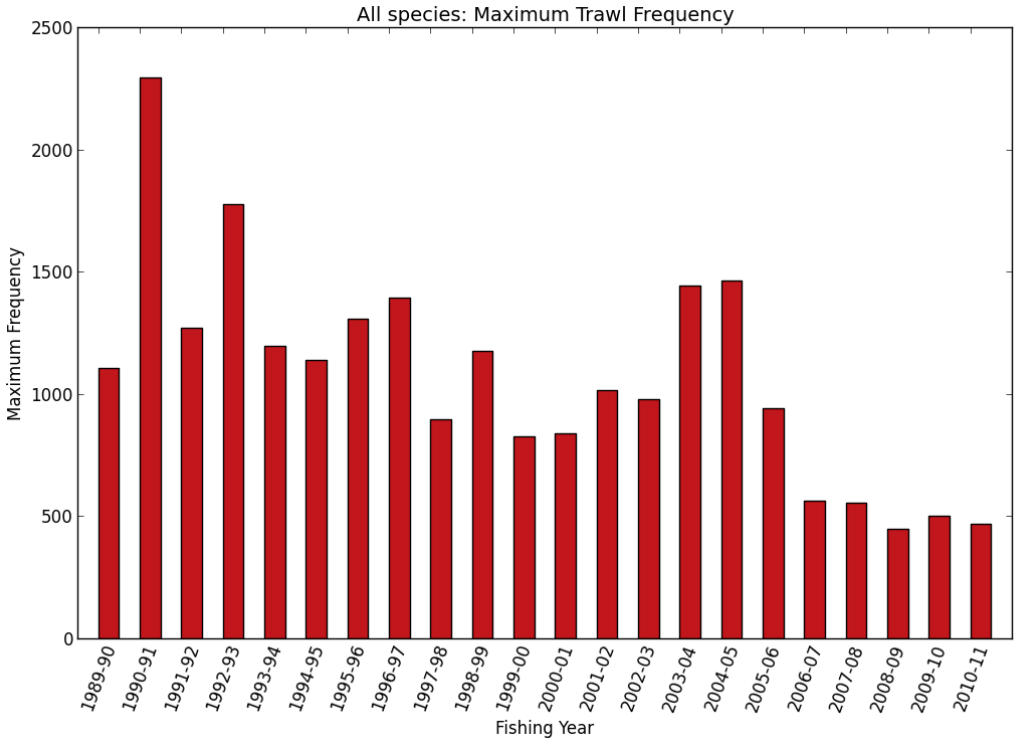

Figure 11: Maximum trawl frequency per 5 × 5 km cell for the aggregate of all species.

For the 1989/90 to 2010/11 period, a total of 67 cells have a cumulative swept area of more than 100 times the area of the cell (i.e. greater than 2 500 km^2). A further 322 cells have a cumulative swept area between 50 and 100 times the area of the cell (i.e. between 1250 and 2500 km^2). These cells are all on or close to the 400 m depth contour (Figure 12), the cells with more than 2500 km^2 are primarily located around the east of the South Island and to the south of Stewart Island. Trawls targeting hoki and squid have been the main contributers to the swept area in these cells.

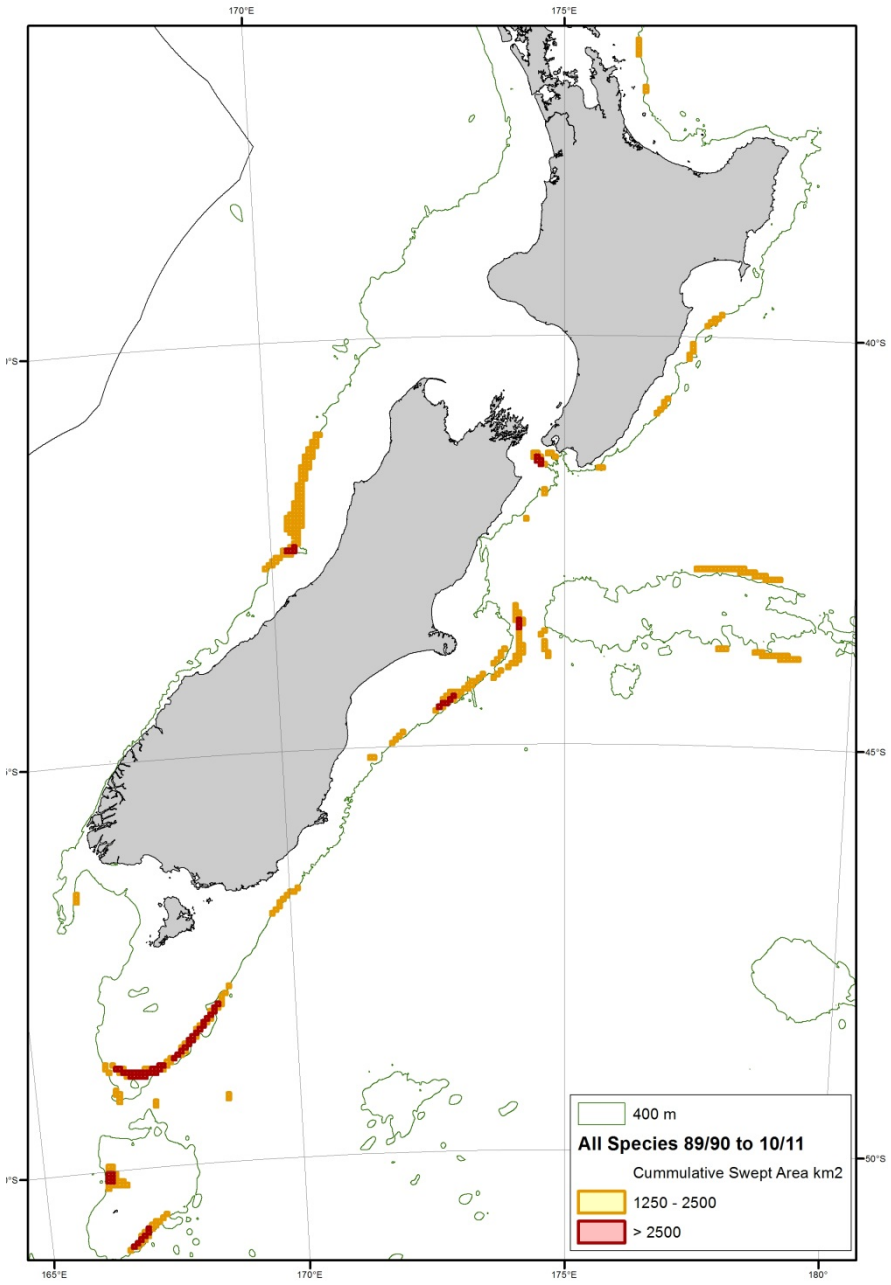

Figure 12: Cells with a cumulative swept area between 50 and 100 times the area of the cell (between 1250 and 2500 km^2) in orange, and cells with a cumulative swept area more than 100 times the area of the cell (more than 2500 km^2) in red.

In the 2010/11 year, two cells have a cumulative swept area of more than ten times the area of the cell (i.e. greater than 250 km^2). A further 28 cells have a cumulative swept area of

between five and ten times the area of the cell (i.e. between 125 and 250 km^2). The numbers for the 2009/10 fishing year are similar: no cells have a cumulative swept greater than 250 km^2, and 25 cells have a cumulative swept area between 125 and 250 km^2.

The largest cumulative swept area in a cell for the period 1989/90 – 2010/11 was 10 148 km^2. This cell lies south of Stewart Island (Figure 13) and is the same cell that had the largest swept area for the period 1989/90 – 2009/10 (i.e. 10 010 km^2). In this cell the majority (96%) of trawls targeted squid. In 2010/11 the cell with the largest cumulative swept area occurs in the same region south of Stewart Island. This cell had 292 km^2 in the fishing year – over 11 times the area of the cell. The majority (99%) of trawls that crossed this cell in 2010/11 were targeting squid; the remaining trawls targeted hoki.

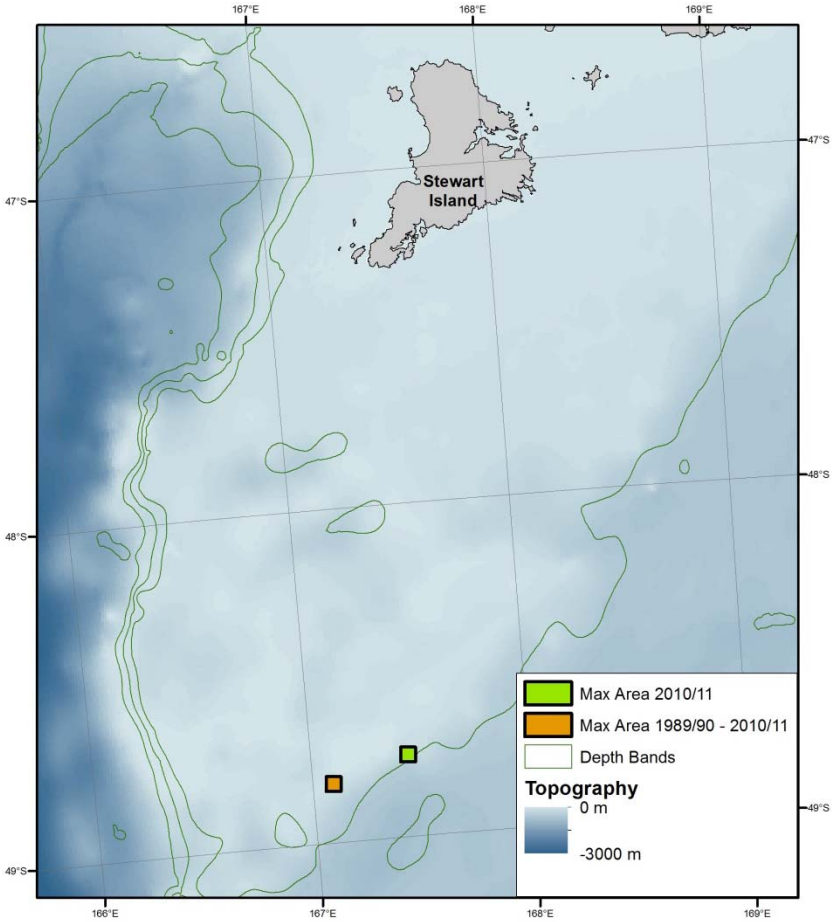

Figure 13: The location of the cells with the largest cumulative swept area (orange for the period 1989/90 to 2010/11, green for 2010/11). The 400, 800 and 1200 m contours are plotted (dark green), along with the bathymetry (blue, GEBCO 2010).

For 2010/11, 12 600 cells were contacted by bottom tows, about 8% of the total number of cells and 266 less than in 2009/10. For 2010/11 the cell with the highest number of tows in a cell is the same cell that has the largest cumulative swept area (the green square in Figure 13)

The calculated statistics for bottom trawling can be used to monitor changes in fishing activity. For trawls targeting southern blue whiting, both the mean frequency of all cells and the cumulative swept area are fairly similar in 2009/10 and 2010/11. However, the maximum trawl frequency increased significantly in 2010/11, following five years of fairly constant

values. This demonstrates that the different statistics need to be considered together to give a full picture of what is happening (Figure 14).

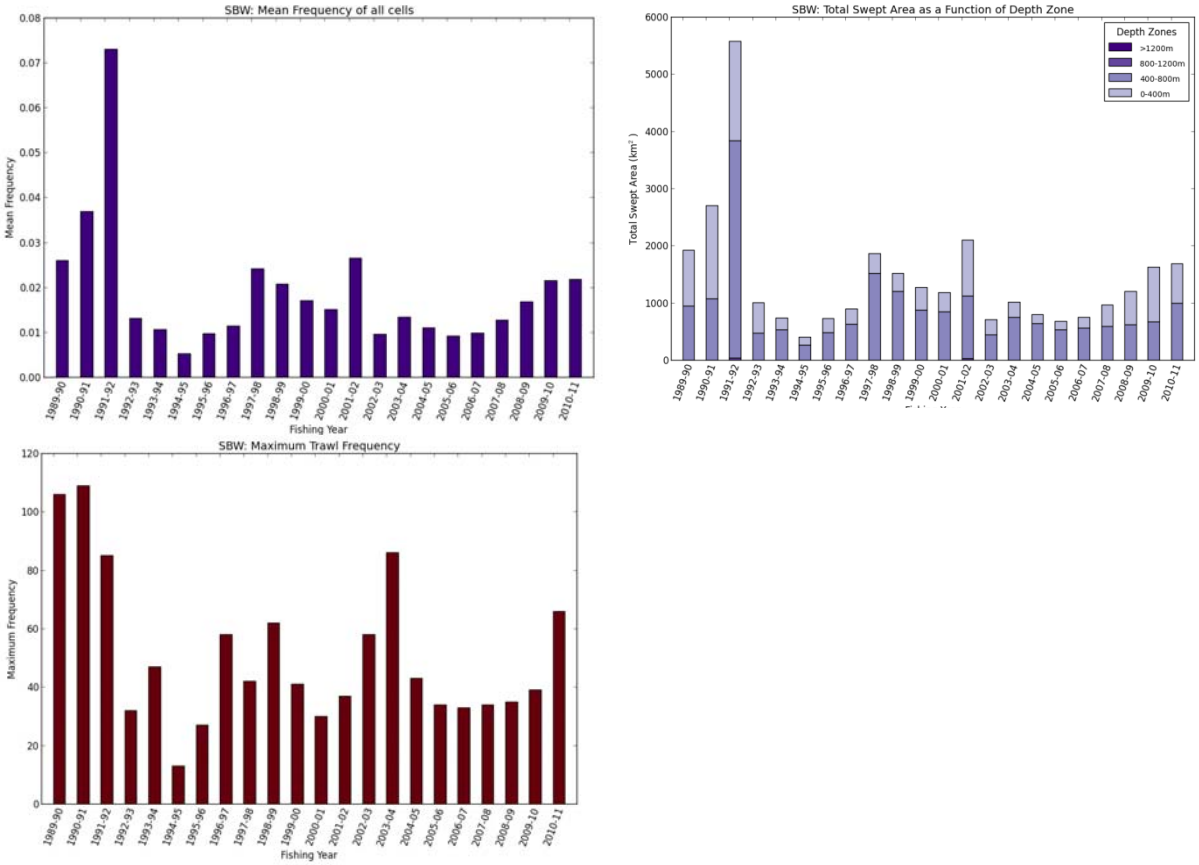

Figure 14: Mean frequency of all cells in the EEZ and TS (top left), maximum frequency (bottom left), and cumulative swept area (top right) by year for trawls targeting southern blue whiting.

3.3 TCEPR Data and Depth Zone

The swept area (for all species) in each depth band is shown in Figure 15 and Figure 16. The 2010/11 data show a similar pattern as seen in the previous few fishing years, with the largest swept area occurring in the 0–400 and 400–800 m depth bands (24 605 km^2 and 25 999 km^2 respectively). The swept area in the 800–1200 m and deeper than 1200 m depth bands is 2097 km^2 and 329 km^2 respectively. The increase in swept area in 2010/11 compared with 2009/10 is entirely due to an increase in swept area in the 0–400 m depth band. The swept area in the 400–800 m depth band has increased from 20 835 km^2 in 2009/10 to 25 999 km^2 in 2010/11. This is considerably lower than the peak in swept area in this depth band of nearly 59 000 km^2 in 2002/03. The swept area in the other three depth bands has decreased (Figure 16).

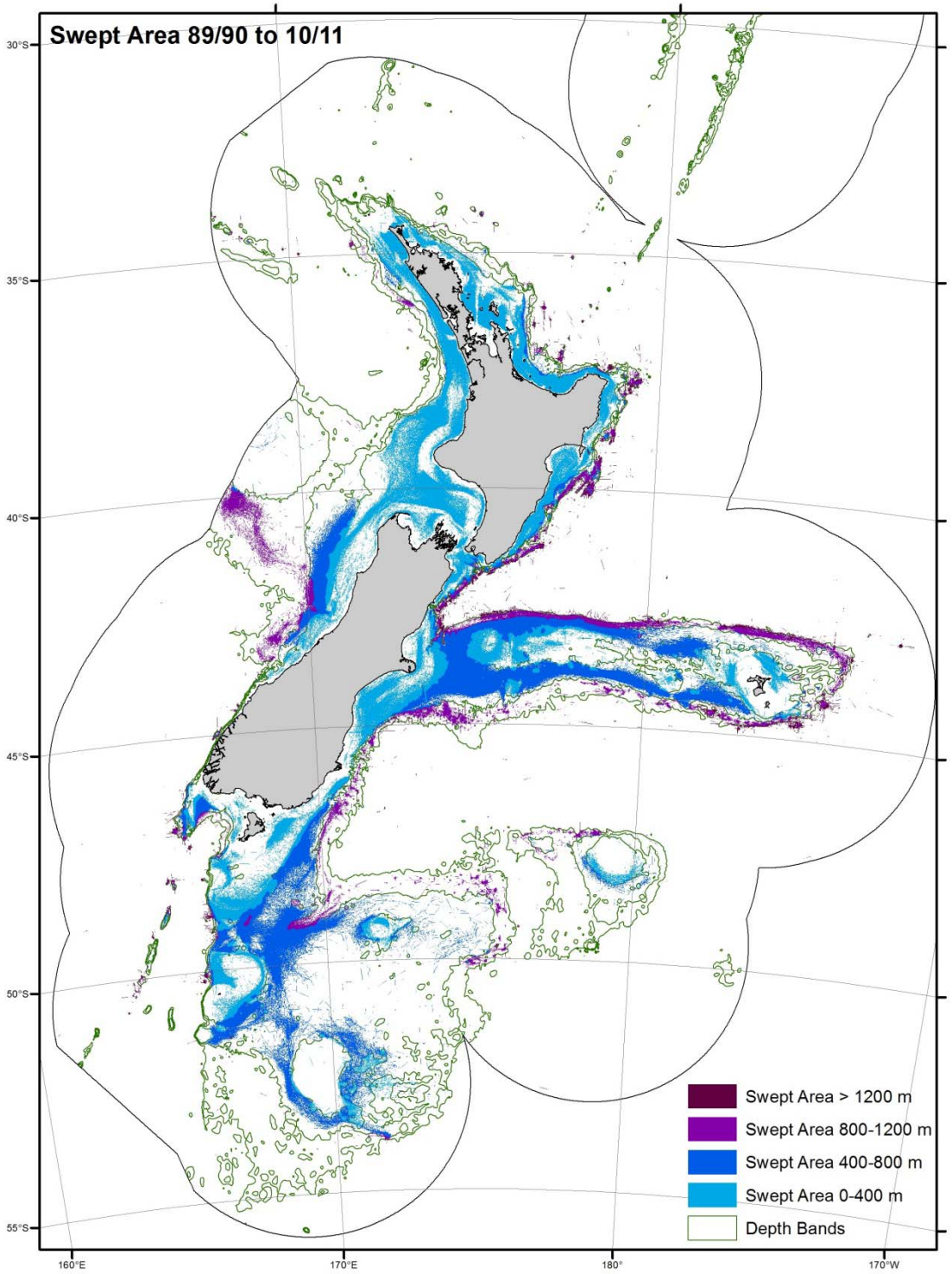

Figure 15: Swept area coloured by depth zone (400, 800 and 1200 m contours are shown).

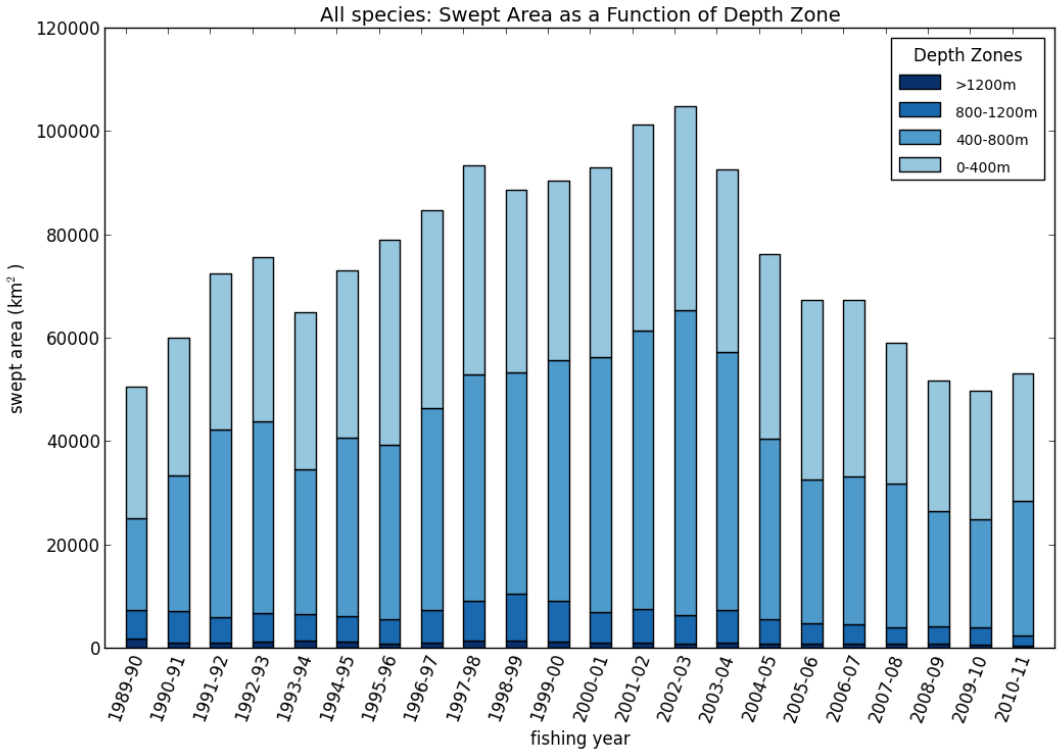

Figure 16: Swept area for each fishing year of the series, coloured by depth zone.

If we consider the cumulative swept area, the pattern is similar but not identical. In 2010/11 the cumulative swept area has increased in both the 0–400 m and 400–800 m depth bands (Figure 17). The 0–400 m increase is from 40 104 km^2 to 43 576 km^2 (9%); the 0–800 m increase is larger, from 34 701 km^2 to 48 140 km^2 (39%). The cumulative swept area in the 800–1 200 m and deeper than 1 200 m depth bands has decreased.

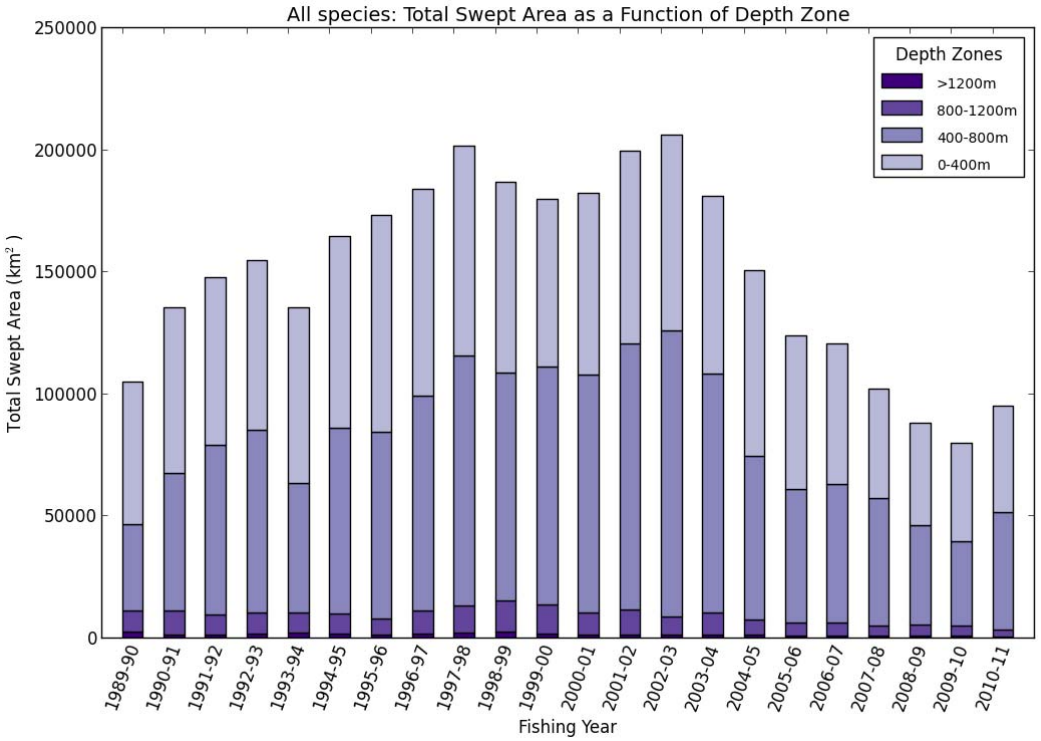

Figure 17: Cumulative swept area per year, coloured by depth band.

These trends vary for different species. For example, the swept area from trawls targeting hoki increased between 2009/10 and 2010/11 from 18 640 km^2 to 24 029 km^2, an increase of 29% (Figure 18, Table 5), which was reflected in each depth band. The largest increase is in the 400–800 m depth band, which has changed from 3.4% of the depth band to 4.4% in 2010/11.

Table 5: Swept area in each depth band for trawls targeting hoki and orange roughy in 2009/10 and 2010/11.

Depth band	Hoki Swept Area (km^2)		Orange Roughy Swept Area (km^2)	
	2009/10	2010/11	2009/10	2010/11
0–400 m	2 110	2 561	5	1
400–800 m	16 252	20 956	73	48
800–1200 m	273	487	1984	767
Deeper than 1200 m	5	25	519	215

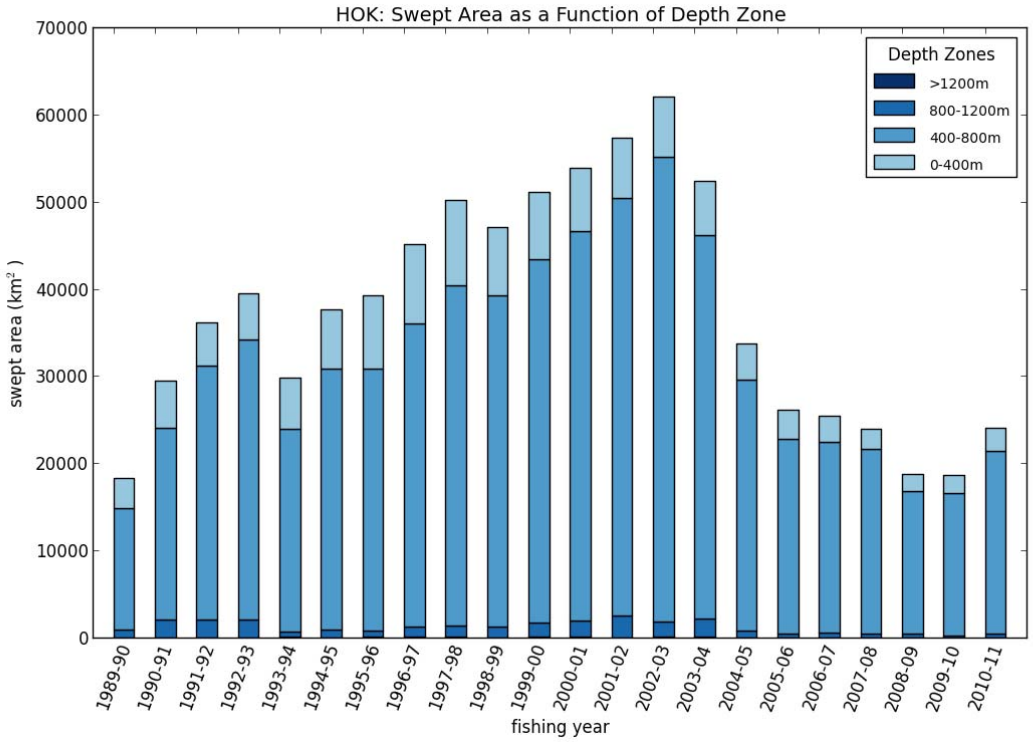

Figure 18: Swept area (km^2) for hoki targeted trawls as a function of depth (m) by fishing year.

The swept area for trawls targeting orange roughy has decreased markedly since 2009/10 (Figure 7, Table 5). This trend is present in each depth band, but is most noticeable in the 800–1200 m band, where the decrease is over 60%.

3.4 TCEPR Data and Fishable Area

For this analysis the fishable area is defined as that part of the TS and EEZ that is shallower than 1600 m and outside all Benthic Protection Areas (BPAs), Seamount Closure and Marine Reserve areas (Figure 19). The fishable area in the TS and EEZ is 1 408 210 km², which amounts to 34% of the total area of seabed in the TS and EEZ. The swept area within the fishable area is 383 085 km², or about 27% of the fishable area. Of this, 2902 km^2 was trawled for the first time in 2010/11. In 2010/11, the swept area is 3.8% of the fishable area and 1.3% of the EEZ and TS combined (Figure 20).

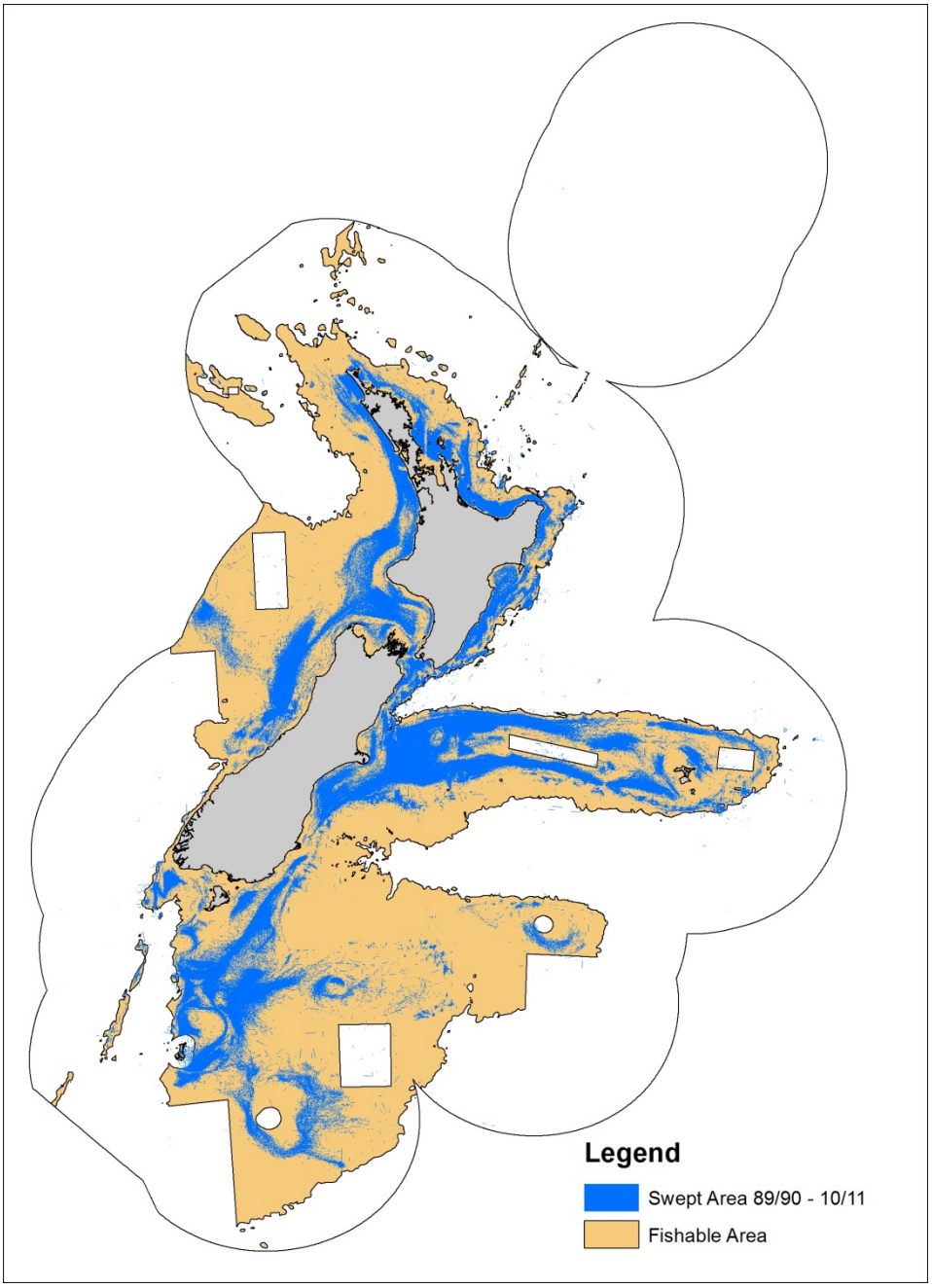

Figure 19: Trawl footprint for all species in relation to the fishable area for the period 1989/90 to 2010/11.

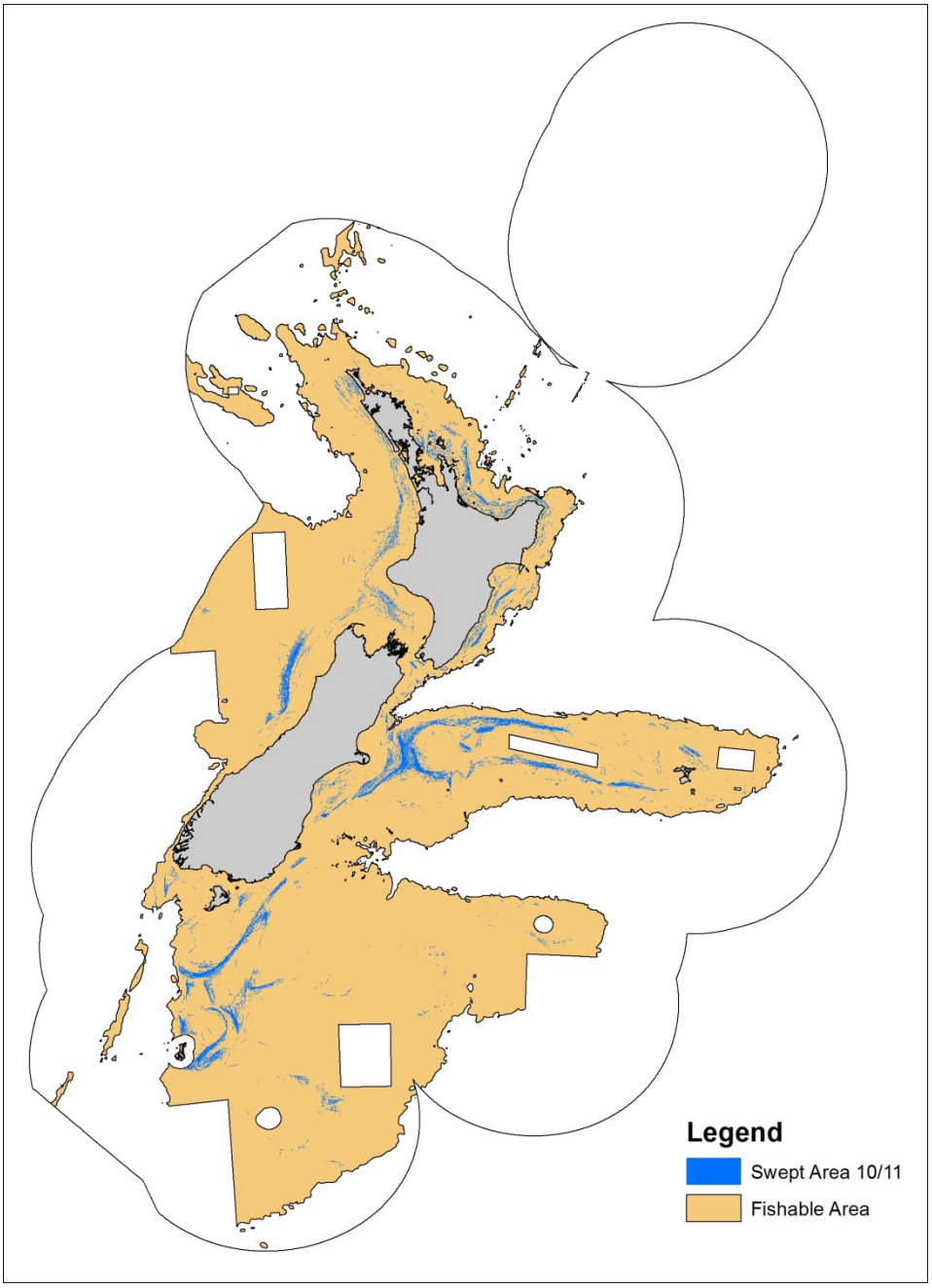

Figure 20: Estimated swept area in 2010/11 overlain on the fishable area. The swept area comprises 3.8% of the fishable area (i.e. Shallower than 1600 m) and 1.3% of the EEZ and TS combined.

The frequency-based analysis shows that 64% (35 957) of cells in the fishable area have been swept at some point between 1989/90 and 2010/11. Only 88 of these cells were swept for the first time in 2010/11. In total, 22% (12 443) of cells in the fishable area were swept in 2010/11, compared with 23% (12 705) of cells in 2009/10.

3.5 TCEPR Data and Preferred Habitat

TCEPR data were used to map fishing effort for key target species against preferred habitat. An example is shown in Figure 21 for hoki, which illustrates that the swept area for the period 1989/90 to 2010/11 comprises a little over 10% of the total preferred habitat (i.e. in the over 0% probability of capture area). As was the case with the 1989/90 to 2009/10 data, the

hoki fishing grounds occur in fairly well-established, discrete areas within the preferred habitat range. There is only a gradual increase in the percentage of the habitat range swept, from 10% to 32%, between the over 0% and over 95% probability of capture areas, but then a steep escalation to 71% in the 99% probability of capture area. Figure 22 shows how the swept area and percentage swept area in the preferred habitat range for hoki varies by probability of capture area.

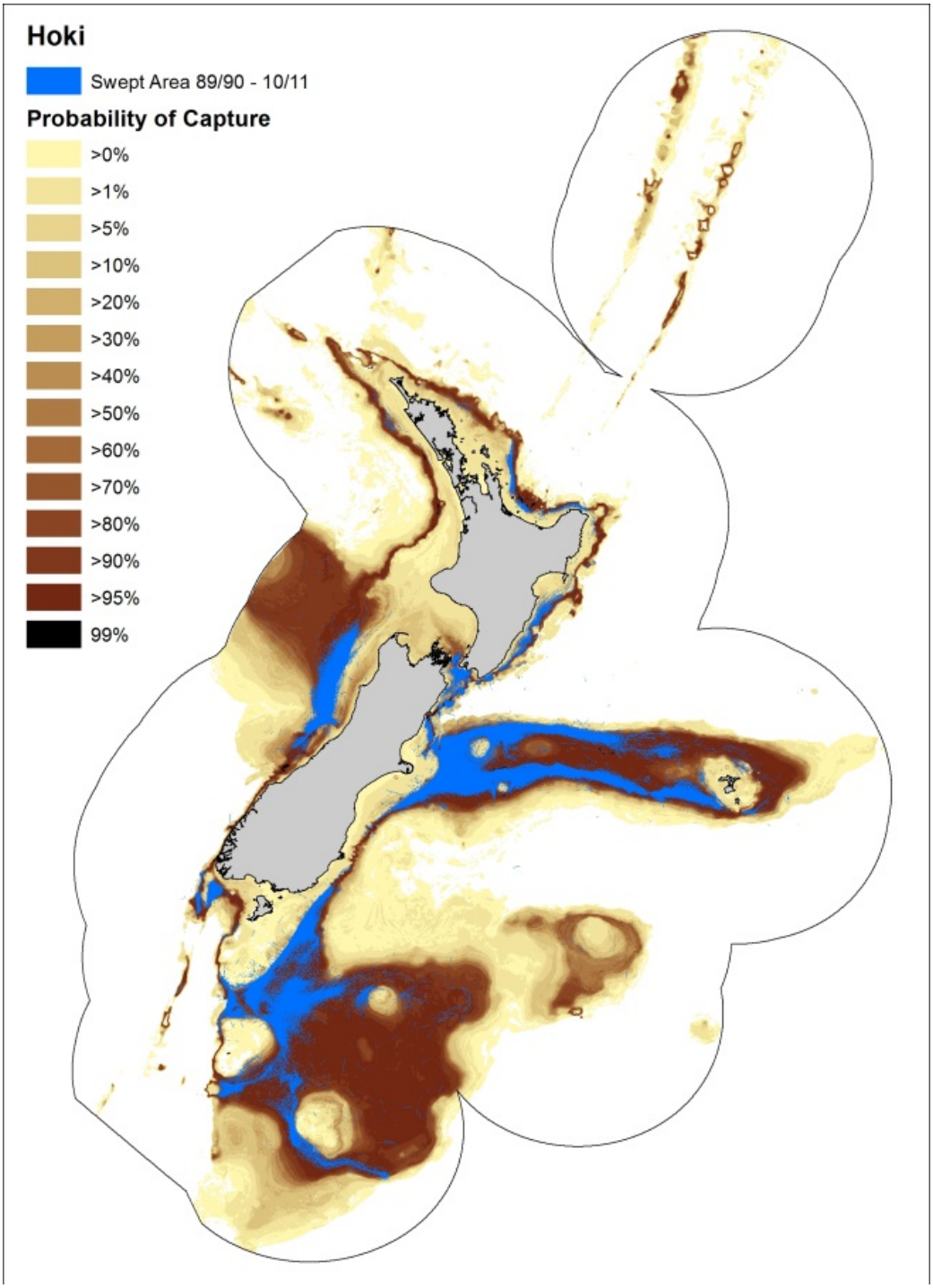

Figure 21: Preferred habitat (probability of capture) for hoki, overlain by the 1989/90 to 2010/11 swept area for hoki.

Orange roughy has a similar (but less pronounced) pattern (Figure 22, Figure 23). The swept area makes up 4% of the 0% probability of capture area for orange roughy. There is a gradual increase from 4% up to 25% in the more than 95% probability of capture areas, followed by a sharp increase to 45% in the 99% probability of capture area.

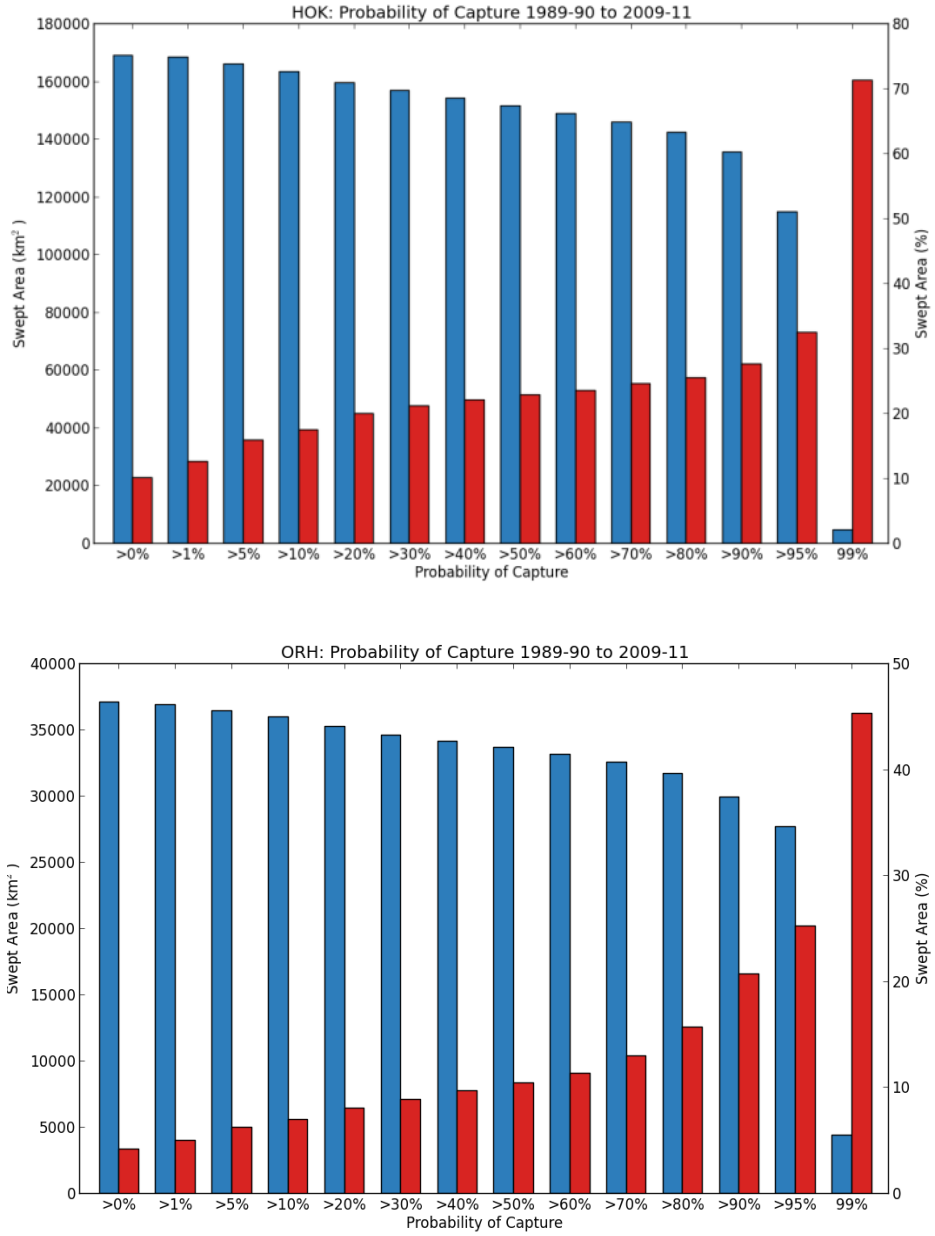

Figure 22: Swept area in square kilometres (blue) and as a percentage of each probability of capture area (red) for trawls targeting hoki (top) and orange roughy (bottom). Note that the two graphs have different ranges on their y-axis scales.

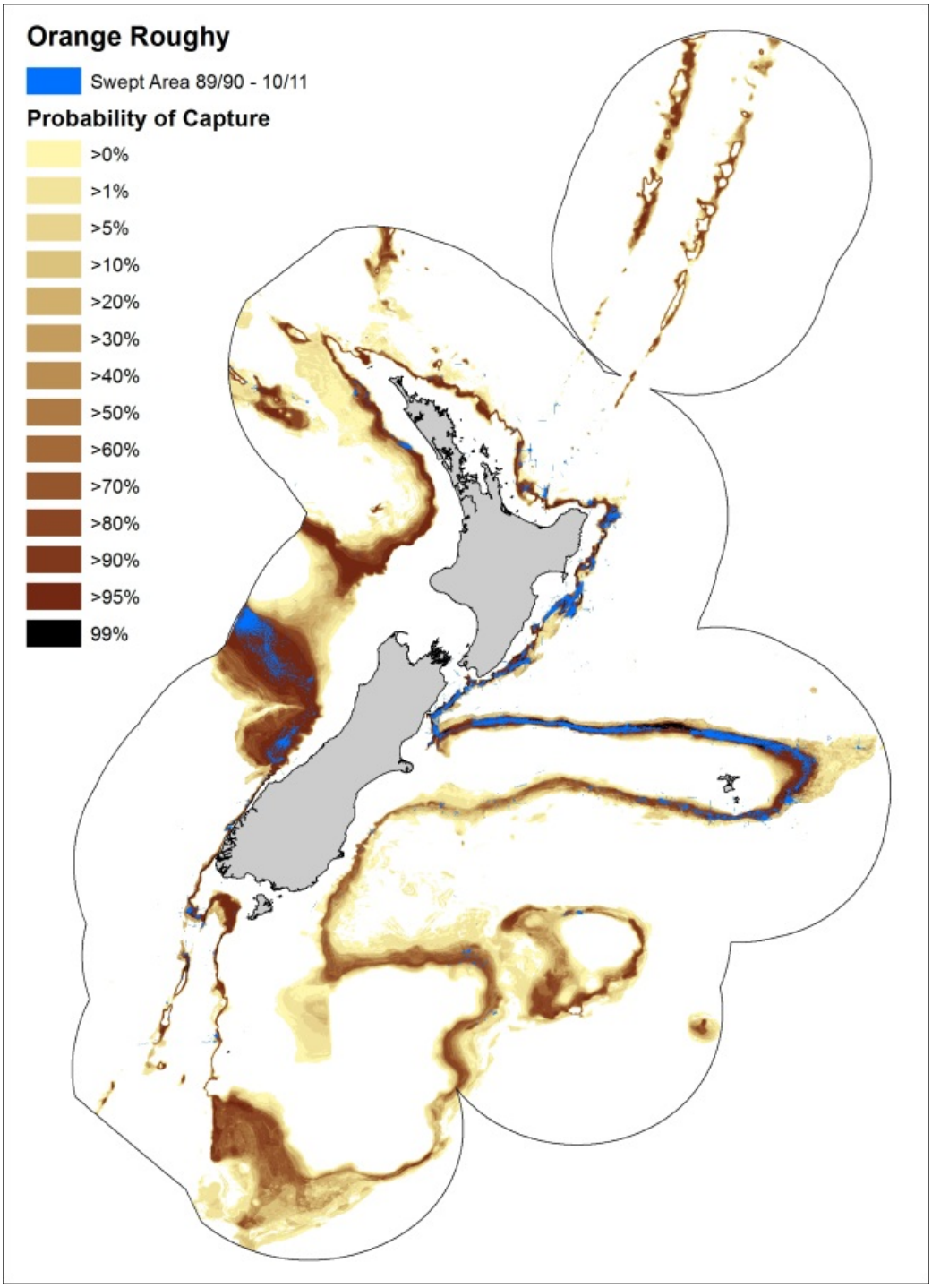

Figure 23: Preferred habitat (probability of capture) for orange roughy, overlain by the 1989/90 to 2010/11 swept area for orange roughy.

3.6 TCEPR Data and Benthic Habitats

In total, the 15 BOMEC classification areas cover 2 627 073 km², approximately 64% of the EEZ and TS. The swept area within the BOMEC for all species for the period 1989/90 to 2010/11 is estimated to be 387 325 km², about 15% of the total BOMEC classification area (Figure 24; Figure 25). The swept area for all species for the 2010/11 fishing year is 53 010 km², covering about 2.0% of all BOMEC zones. This is slightly greater than in the 2009/10 fishing year when the swept area was 49 695 km^2, or 1.9% of all BOMEC zones.

The frequency based analysis shows that approximately 37% of cells in the BOMEC have been swept since 1989/90. The cumulative swept area in the BOMEC region is 3 293 559 km^2.

Analysis of the estimated swept area within individual BOMEC zones could be used as an indication of the potential benthic effects by trawling. This analysis shows that, for the period 1989/90 to 2010/11, BOMEC 9 has the highest percentage swept area at over 70%, followed by BOMEC 3 at almost 65% (Table 6). More than 40% of BOMEC classes 1, 5, 7 and 8 are estimated to have been contacted by bottom trawling; less than 10% of BOMEC classes 11, 13, 14 and 15 are estimated to have been contacted by bottom trawling.

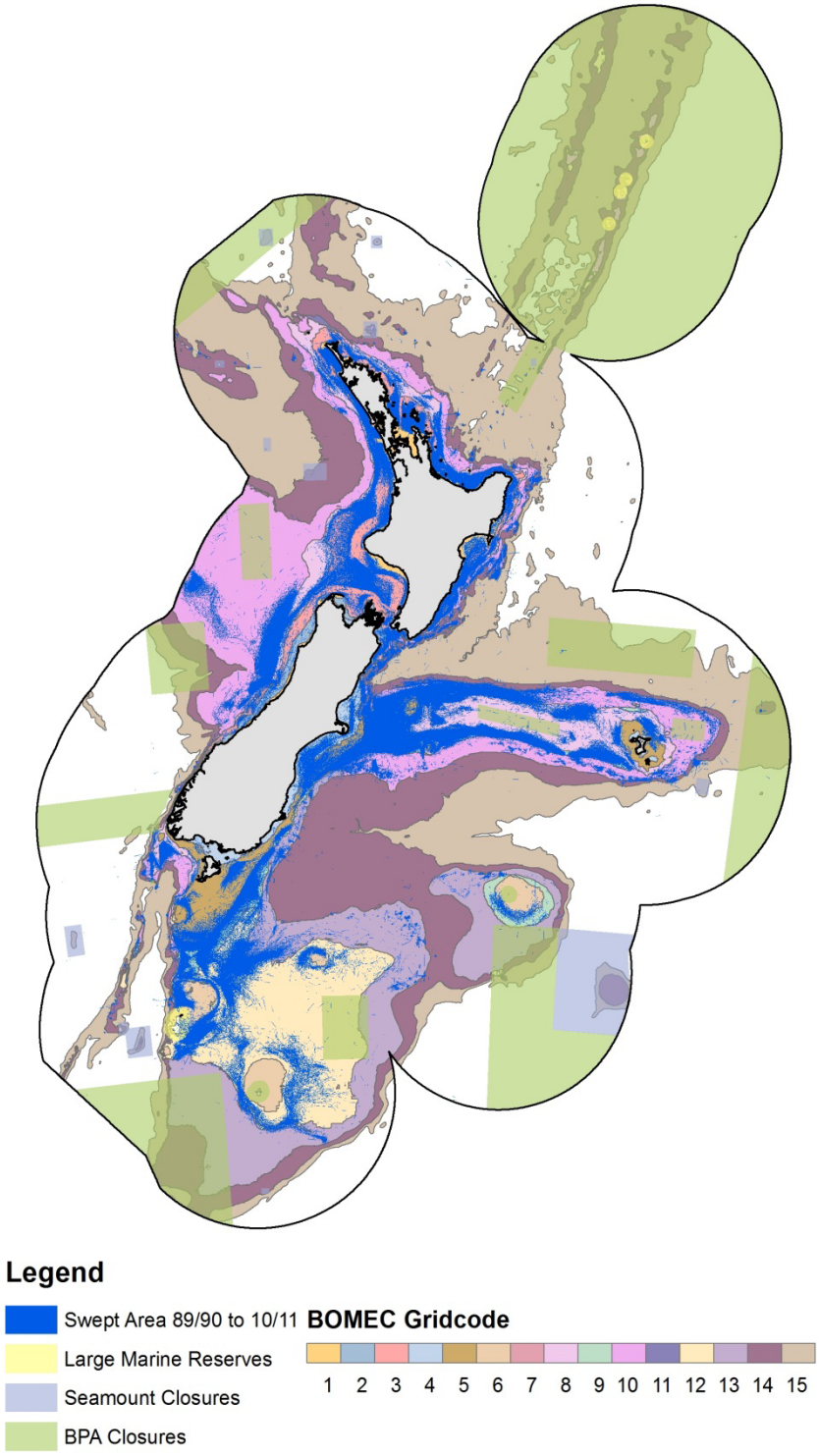

Figure 24: The BOMEC classification and trawl footprint for all species, 1989/90 to 2010/11.

Table 6: The area of each BOMEC zone and the corresponding swept area for trawls targeting all species 1989/90 to 2010/11.

BOMEC code	Area (km^2)	Swept Area (km^2)	Swept Area (%)
1	27 557	12 484	45%
2	12 420	3 331	27%
3	89 710	58 234	65%
4	27 268	9 675	35%
5	60 990	26 781	44%
6	38 609	6 787	18%
7	6 342	3 056	48%
8	138 551	68 922	50%
9	52 224	38 300	73%
10	311 361	71 912	23%
11	1 289	14	1%
12	198 577	55 181	28%
13	233 825	18 737	8%
14	493 034	11 453	2%
15	935 315	2 459	0.3%
TOTAL	2 627 073	387 323	15%

The frequency based analysis shows a similar pattern, the percentage of cells contaced is similar to the swept area, but the percentages are larger (Table 7). In the 1989/90 to 2010/11 period more than 90% of the cells in BOMEC classes 2, 3, 8 and 9 have been contacted by trawling; between 50% and 90% of cells in BOMEC classes 1, 4, 5, 7, 10 and 12 have been contacted by trawling, and less than 50% of cells in BOMEC 11, 13, 14 and 15 have been contacted by trawling (Table 8). The cell with the largest number of trawls between 1989/90 and 20010/11 is in BOMEC 5 which has seen 16 837 trawls. The BOMEC class with the largest trawl frequency is BOMEC 9 with a mean frequency of 468 trawls per cell.

Table 7: Trawl statistics for trawls targeting all species in 2009/10 and 2010/11 in the BOMEC zones.

BOMEC code	Swept Area (%)		Cells Contacted (%)		Mean Frequency of Trawled Cells	
	2009/10	2010/11	2009/10	2010/11	2009/10	2010/11
1	7%	6%	51%	49%	21	17
2	1%	1%	9%	11%	19	5
3	9%	8%	62%	62%	15	12
4	2%	2%	25%	28%	5	5
5	6%	7%	39%	38%	19	22
6	4%	2%	19%	19%	17	13
7	5%	5%	29%	36%	23	18
8	7%	8%	43%	45%	19	19
9	19%	22%	60%	57%	24	23
10	3%	3%	20%	16%	11	13
11	0%	0%	0%	0%	0	0
12	2%	3%	14%	17%	14	19
13	0%	1%	5%	6%	7	5
14	0%	0%	3%	2%	5	5
15	0%	0%	0%	0%	3	2
TOTAL	2%	2%	12%	12%	15	16

Table 8: Trawl statistics for trawls targeting all species in 1989/90 to 2010/11 in the BOMEC zones.

BOMEC code	Number of Cells	Cells Contacted (number)	Cells Contacted (%)
1	1 086	921	85%
2	502	461	92%
3	3 572	3 539	99%
4	1 091	892	82%
5	2 450	2 139	87%
6	1 542	882	57%
7	255	225	88%
8	5 559	5 102	92%
9	2 087	2 018	97%
10	12 431	8 290	67%
11	54	25	46%
12	7 926	5 692	72%
13	9 356	3 725	40%
14	19 758	3 078	16%
15	37 386	2 154	6%
TOTAL	105,055	39 143	37%

The fishing effort in the BOMEC areas has varied with time (Figure 25). For many of the areas (1, 2, 3, 6 and 7) the swept area has decreased between 2009/10 to 2010/11. However, the swept area in BOEMC areas 5, 8, 9 and 12 has increased. Although these four BOMEC zones all have a larger swept area in 2010/11 than 2009/10, all of them have seen a larger

swept area in previous years. For example, while the swept area in BOMEC 9 (dashed orange line in Figure 25) has increased from 19.0% in 2009/10 to 21.6% in 2010/11 it was maximal in 1998/99 at 37%. These changes in BOMEC 9 are primarily due to fluctuations in the number and location of trawls targeting hoki.

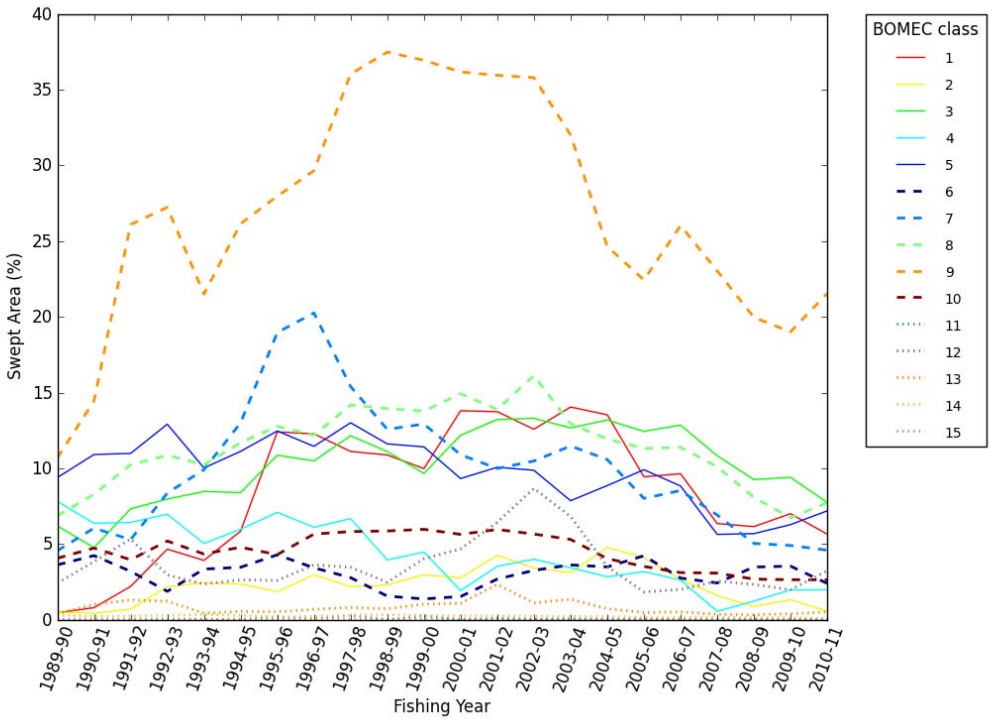

Figure 25: Swept area for all species (as a percentage of the BOMEC zone) as a function of time.

3.7 Trawl Footprint Analysis - Trends

The edited database has been used to estimate the area of sea floor trawled annually and to estimate what proportion of the most recent year's trawl footprint had previously been trawled (Figure 6). This shows that there has been a gradual decrease in the area of seafloor trawled that had not previously been trawled. In 2010/11 only 2958 km^2 of seafloor was trawled that had previously been untouched.

Much of the 2958 km^2 of sea floor that was swept for the first time in 2010/11 comprises many small patches of sea floor across much of the existing trawl footprint (for example, Figure 26). Many of these are infilling areas surrounded by grounds that have already seen much trawl effort, and the newly swept area is 'filling in the gaps' and may represent very little actual new area due to the inaccuracies in knowing the exact position of the trawl gear (see Methods section).

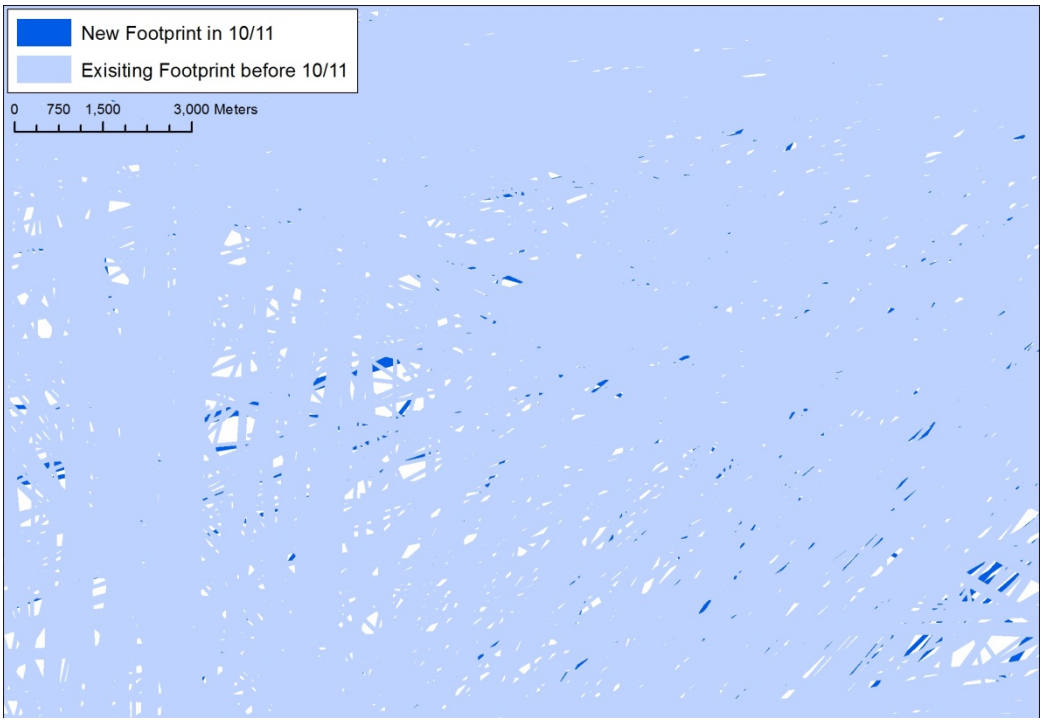

Figure 26: The south-western Chatham Rise showing the common spatial distribution of seafloor trawled for the first time in 2010/11.

There are a few regions where newly swept area represents an extension of the fishing grounds and more than just the filling in of small spaces between trawls. An example is in the region to the east of Campbell Island (Figure 27), where in 2010/11 there was a concentration of trawl activity, targeted at southern blue whiting, in an area that previously had been only sparsely trawled. A second example is a cluster of trawls targeting oreo on the southern flank of the Chatham Rise (Figure 28). This location has not previously been trawled during the study period. The nature of this trawl cluster suggests that it has occurred on a newly discovered undersea topographic feature (UTF) or on a fished UTF that has been contacted by bottom trawling for the first time since 1989/90.

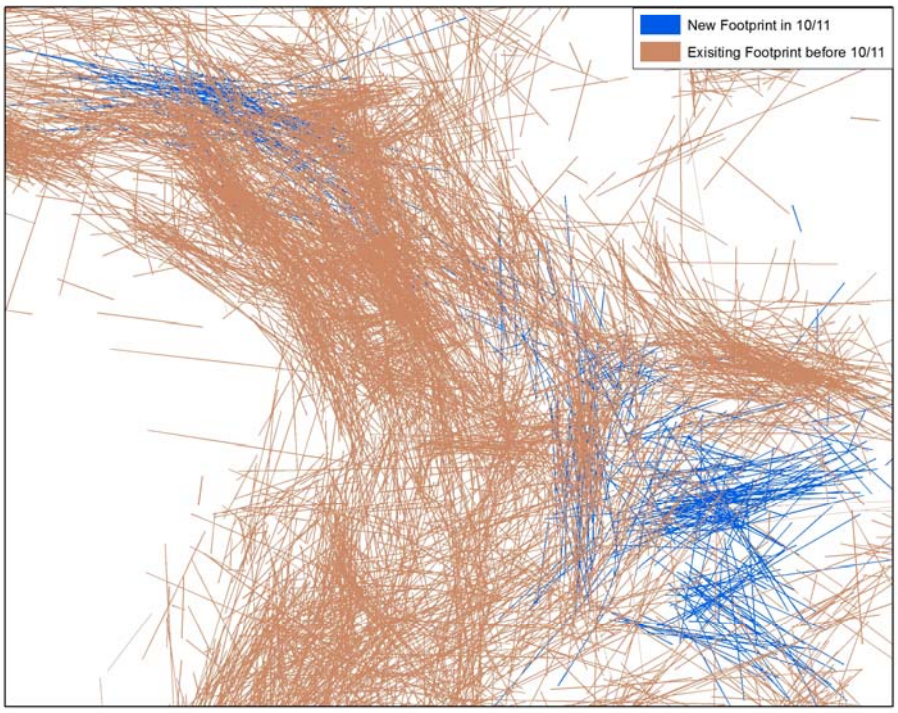

Figure 27: A region to the east of Campbell Island showing a shift in trawl effort during 2010/11 into an area that was previously only sparsely trawled.

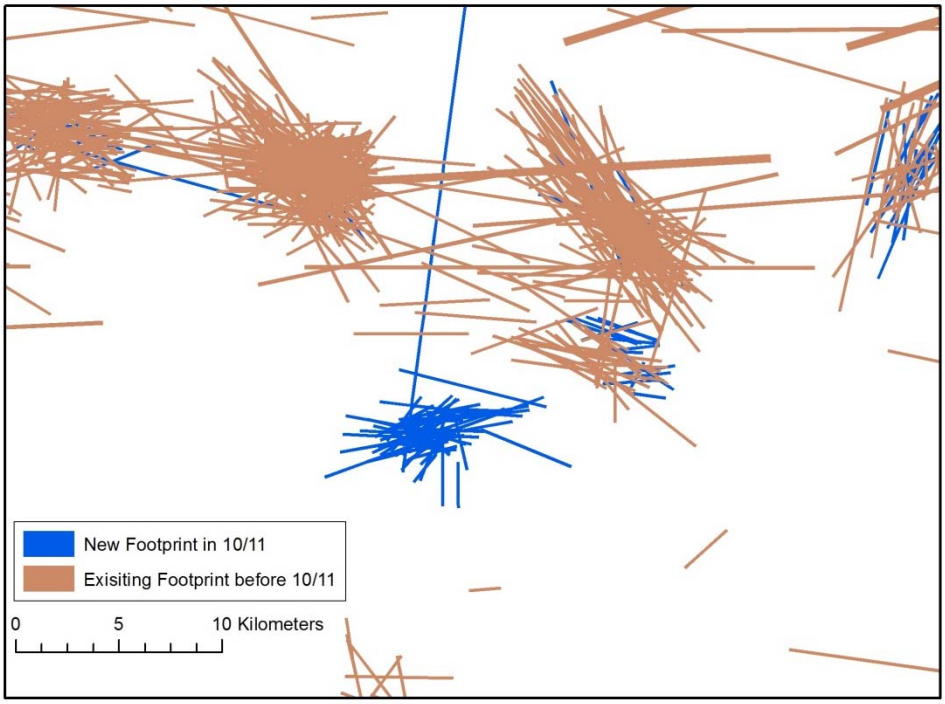

Figure 28: A region on the southern flank of the Chatham Rise showing a cluster of trawls in 2010/11 in an area previously unswept during the period 1989/90 to 2009/10.

Seafloor trawled for the first time in 2010/11 can be further analysed to examine the breakdown by target species (Table 9). These statistics need to be interpreted with caution as some of the area will be filling in of small spaces (as seen for example in, Figure 26) and may not actually represent newly trawled seafloor. Of the newly trawled area, approximately 25% was by trawls targeting the minor species, and a similar proportion by trawls targetting southern blue whiting. With the exception of trawls targeting hoki (which comprise 12% of the newly swept area) the remaining species contribute less than 10% each.

Table 9: The breakdown of area that has been trawled for the first time in 2010/11 by target species.

Target species	Newly swept area 2010/11 (km^2)	Newly swept area 2010/11 as a % of newly swept area for all species	Newly swept area 2010/11as a% of swept area for that species	Swept area for species (km^2)
BAR	90	3%	4%	2 046
HAK	15	1%	1%	1 223
HOK	357	12%	1%	24 029
JMA	236	8%	6%	3 700
LIN	44	1%	9%	492
minor	743	25%	9%	8 237
OEO	279	9%	35%	801
ORH	121	4%	12%	1 031
SBW	715	24%	50%	1 422
SCI	165	6%	3%	5 030
SQU	145	5%	3%	5 246
SWA	59	2%	3%	2 272

The newly trawled area can also be compared against the swept area (new or otherwise) for each target species in this year. This analysis shows that 50% of the swept area in 2010/11 for trawls targeting southern blue whiting was in areas of sea floor that had not previously seen trawling for any species. 35% of the swept area for trawls targetting oreo in 2010/11 was in new areas of sea floor. For trawls targeting orange roughy, 12% of the swept area was in new areas. For the remaining species the percentages are all less than ten.

The frequency-based analysis can be used to determine how many years it has been since each cell was last trawled. If all species are considered, it is evident that many (40%) of the trawled cells were last trawled within the last two years (Figure 29, Figure 30). However, there are some regions where no recorded trawls have occurred in the last 10 years (e.g. on Challenger Plateau). Some regions to the east of Pukaki Rise have not been trawled in the last 19 years.

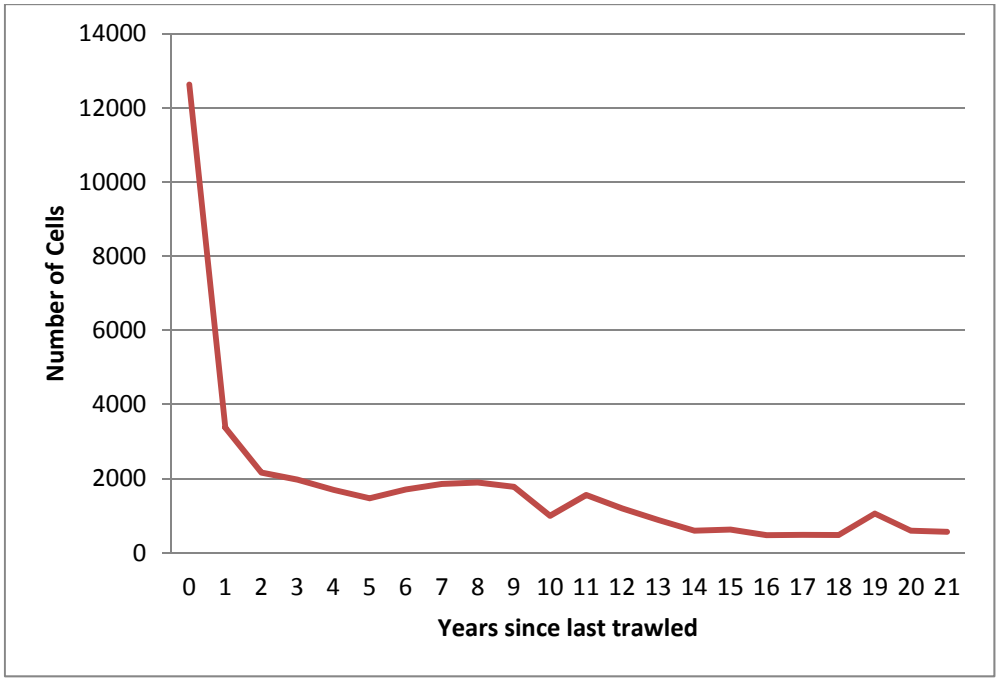

Figure 29: Number of years since each cell was last trawled (for all species).

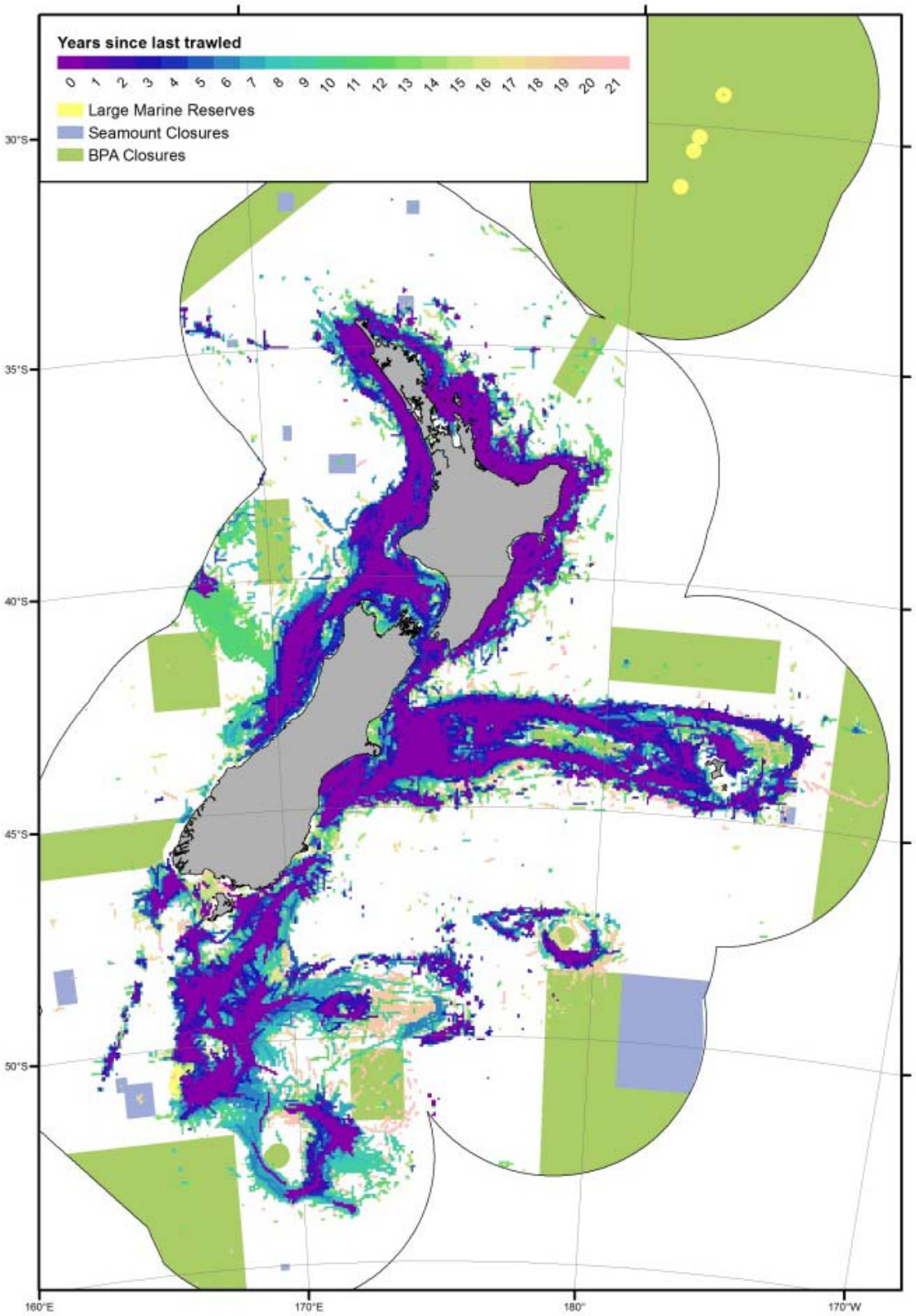

Figure 30: The number of years since each cell was last trawled (for all species). Areas closed to trawling are also shown.

This analysis can also be carried out on the individual target species to investigate how many years since each cell was last trawled for that species. For example, for trawls targeting silver warehou, there are areas round the northern North Island that appear not to have been fished

for more than ten years (Figure 31). Small areas around the Chatham Rise and to the east of Stewart Island have remained unswept for even longer periods. This may not be a real trend, but an example of data entry errors. Dave Foster 2014 (pers. comm.) suggests that some of the older records in the TCEPR database for SWA, were really trawls targeting SNA that were mis-entered as SWA. Plots of this nature may be a useful tool for identifying such errors.

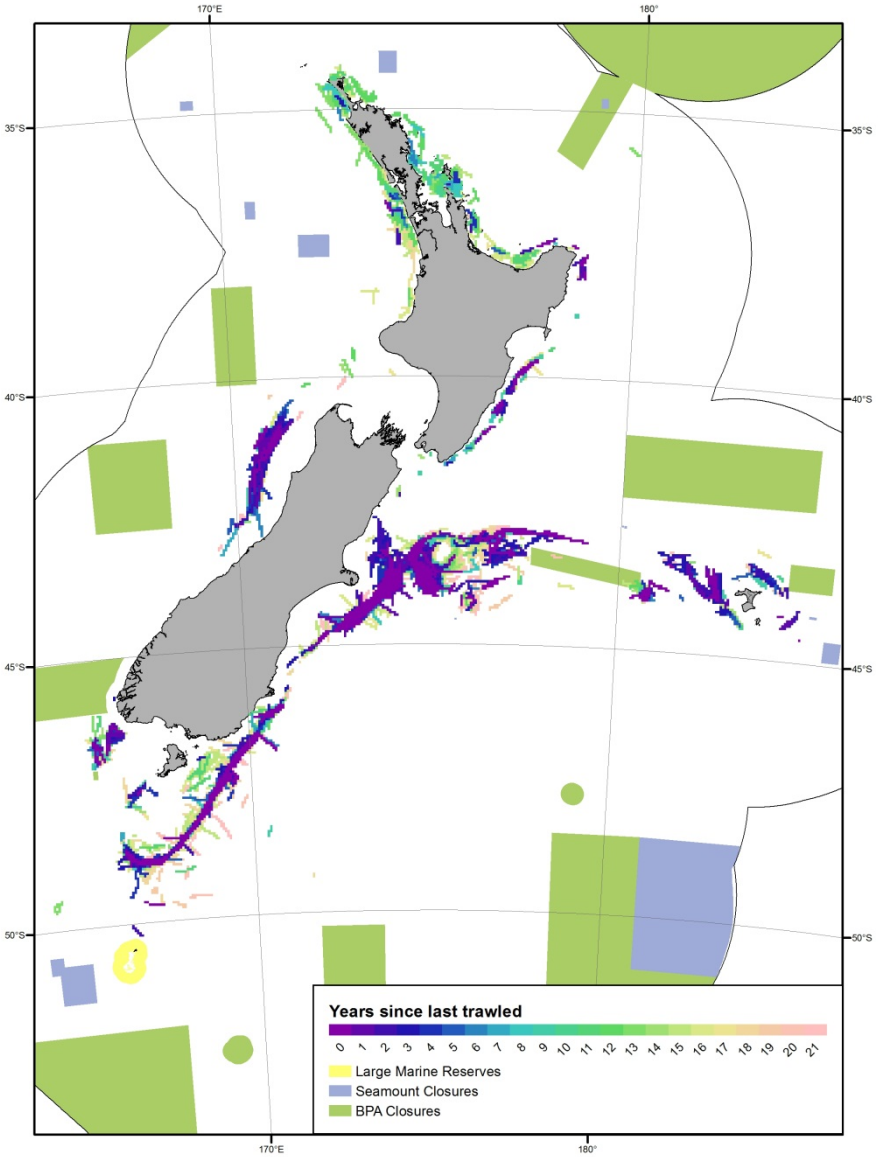

Figure 31: Number of years since each cell has last been trawled for silver warehou.

Plots showing the number of years since cells were last trawled by trawls targetting each species are in Appendix 3:

- Plots are in files <species id>2011_yearssince_fig.pdf, e.g. BAR2011_yearssince_fig.pdf.
- See file README.doc in Appendix 3 for more information.

Results are provided for the entire period (1989/90 to 2010/11).

4 DISCUSSION

This work updates Project DAE2010-04A (Black et al. 2013), with the inclusion of TCEPR data from the 2010/11 fishing year (i.e. an additional 31 453 records).

While the analyses were conducted for 11 key deepwater species/species groups (BAR, HAK, HOK, JMA, LIN, OEO, ORH, SBW, SCI, SQU and SWA) and for the aggregate of 89 minor deepwater species (resulting in 208 spreadsheets and figures, provided separately on DVD), only a few examples of these are provided in the report, to illustrate the nature of the information generated and provide insights into some of the observed trends.

The swept area estimate for the period 1989/90 to 2010/11, of 387 990 km^2, is approximately 3000 km^2 greater than for the period 1989/90 to 2009/10 (an increase of 1%). This increase in swept area in 2010/11 may be a reflection of the aggregate increase in catches of the 11 key deepwater species/species groups (Tier 1 species), from 301 666 t in 2009/10 to 309 572 t in 2010/11 (an increase of 3%). The largest fishery, hoki, has been the main driver in the overall trawl footprint trend (Black et al. 2013), and the hoki catch increase in 2010/11 over 2009/10, of 11 596 t (i.e. 11%), may therefore have been influential. This is supported by the observation that in 2010/11, hoki-targeted tows contributed 81% of the swept area in the 400–800 m depth zone, this being the depth zone that had the largest increase in swept area from 2009/10 to 2010/11, of 25%.

In the 0–400 m, 800–1200 m and deeper than 1200 m depth zones the swept area for all species combined remained much unchanged between 2009/10 and 2010/11, However, in the 0–400 m depth zone the cumulative swept area increased by 9%, suggesting an increased amount of fishing effort within this depth zone of the existing trawl footprint during 2010/11.

The number of 5 × 5 km cells contacted by trawls between 2009/10 and 2010/11 remained steady, with only a very slight reduction of 0.2% (266 cells). The mean frequency of tows per fished 5 × 5 km cell also remained steady at 15.3 tows and 16 tows, in 2009/10 and 2010/11, respectively. The mean frequency of trawled cells in the 400–800 m depth zone increased from 16.8 to 17.1 between 2009/10 and 2010/11, probably as a result of the increased hoki effort. The mean frequency of trawled cells decreased in the other three depth zones. The areas with the highest trawl frequencies per cell occur south-east of Stewart Island and on the western Chatham Rise.

While approximately 2 700 km^2 of the 2010/11 swept area estimate (i.e. approximately 5%), comprised ground not previously traversed, it is noteworthy that the extent of virgin ground trawled each year continues a downwards trend and comprises, at least partly, ‘infilling’ of untrawled spaces within existing trawl grounds, rather than new trawl grounds.

Analysis of swept area by BOMEC class revealed slight increases in proportional swept area for BOMEC 5, 8, 9 and 12 in 2010/11. These are areas closely associated with the hoki-targeted fishery, for which there was a 11 596 t catch increase from 2009/10 to 2010/11, for the western stock. The mean frequency of trawls within trawled cells increased by between 2 and 4 % in 11 of the 15 BOMEC classes. The increase in BOMEC 1 would suggest that there was greater effort in the shallow inshore bays in 2010/11. The western hoki fishery is likely to have driven much of the increase in BOMEC classes 3, 5, 6, 7, 8, 9, 10, 12 and 13. The slight increase in BOMEC class 14 may be a result of some exploration of deeper waters by the orange roughy fishery.

5 MANAGEMENT IMPLICATIONS

The 22-year database now available for interrogation by scientists and fisheries managers provides a powerful tool for monitoring trawl fishing trends in terms of both the scale of the trawl footprint (swept area), and the intensity of trawling (cumulative swept area).

The database could potentially be used to predict fishery behaviour consequent to fishery management decisions (e.g. relating to TACC/catch limit adjustments, vessel and gear parameters, area closures etc.).

Monitoring areal changes in the trawl footprint for individual species over time can also be used, by proxy, to reveal trends in the distribution behaviour of fish stocks, and offers the potential to establish links between distribution shifts and environmental phenomena such as El Niño/La Niña cycles and climate change.

The database is a source of information for use in studies aimed at investigating and evaluating the effects of varying levels of trawling intensity on benthic ecosystem structure and function (see for example Thrush et al. 2005). The cumulative swept area and frequency of trawling information, at a scale of 5 × 5 km, also provides opportunities for studies aimed at ground-truthing the effects of trawling on deepwater benthic communities. This kind of information is becoming increasingly sought after in light of the stringent requirements for sustainable fishery certification (e.g. Marine Stewardship Council certification).

6 ACKNOWLEDGEMENTS

This project was funded by The Ministry for Primary Industries (MPI) under code DAE2010-04. The Deepwater Group Ltd, MPI and Clement & Associates Ltd staff offered help and advice on the processing, presentation and interpretation of these data.

7 REFERENCES

Baird, S.J.; Wood, B.A. (2009). Extent of coverage of 15 environmental classes within the New Zealand EEZ by commercial trawling with seafloor contact. Final Research Report, for Ministry of Fisheries project BEN2006-01, Objective 5. (Unpublished report held by Ministry for Primary Industries, Wellington). 39 p.

Baird, S.J.; Wood, B.A.; Bagley, N.W. (2011). Nature and extent of commercial fishing effort on or near the seafloor within the New Zealand 200 n. mile Exclusive Economic Zone, 1989–90 to 2004–05. *New Zealand Aquatic Environment and Biodiversity Report* No. 73. 144 p.

Black, J.; Wood, R. (2009). Analysis of New Zealand's Trawl Footprint, GNS Science Consultancy Report 2009/123. 11p. (Unpublished report held by GNS Science, Wellington).

Black, J.; Wood, R. (2014). Analysis of New Zealand's trawl grounds for key middle depths and deepwater Tier 1 fisheries. *New Zealand Aquatic Environment and Biodiversity Report.* No. 122. 35 p.

Black, J.; Wood, R.; Berthelsen, T; Tilney, R. (2013). Monitoring New Zealand's trawl footprint for deepwater fisheries: 1989–1990 to 2009–2010. *New Zealand Aquatic Environment and Biodiversity Report 110*. 57 p.

Francis, M.P.; Dunn, A.; Mackay, K.A.; Anderson, O.F. (2003). NABIS marine finfish species distributions. Final Research Report for Ministry of Fisheries Research Project ZBD2002/20 Objectives 1 and 2. (Unpublished report held by Ministry for Primary Industries, Wellington). 28 p.

GEBCO (2010). General Bathymetric Chart of the Oceans: The GEBCO_08 global 30 arc-second grid. http://www.gebco.net/data_and_products/gridded_bathymetry_data/

Leathwick, J.; Francis, M.; Julian, K. (2006). Development of a demersal fish community map for New Zealand's Exclusive Economic Zone. NIWA client report for project HAM2006-062. (Unpublished report held by NIWA, Wellington). 21 p.

Leathwick, J.; Rowden, A.; Nodder, S.; Gorman, R.; Bardsley, S.; Pinkerton; M., Baird, S.; Hadfield, M.; Currie, K.; Goh, A. (2012). A Benthic-optimised Marine Environment Classification (BOMEC) for New Zealand waters, *New Zealand Aquatic Environment and Biodiversity Report No 88.* 54 p.

Thrush, S.F., Lundquist, C.J., Hewitt, J.E. (2005). Spatial and temporal scales of disturbance to the seafloor: a generalized framework for active habitat management. *American Fisheries Society Symposium* 41**:** 639–649.

APPENDIX 1 - MINOR TARGET SPECIES INCLUDED IN THE ANALYSIS

Some errors in data entry are expected with the large number of records analysed. The data corrections used in this report focused on the main sources of error that can be corrected without intensive, time consuming effort. A small number of records that remain in the analysis but appear to have an incorrect target secies are identified in Appendix 1 (and therefore use of these data in isolation may require further checking). These are **bolded** as they are either species outside the QMS, or unlikely to be targeted in deep water. These are unlikely to be the only errors that may (upon detailed investigation) be data entry errors. But given the large number of records utilised it is believed the effect of these errors on the overall findings is likely to be negligible.

Count	Reporting Code	Common Name	Target Tows	Percentage of Total Target Tows
1	SNA	Snapper	75 766	6.64%
2	TAR	Tarakihi	52 635	4.61%
3	TRE	Trevally	40 020	3.51%
4	GUR	Gurnard	18 179	1.59%
5	RCO	Red cod	17 538	1.54%
6	JDO	John dory	16 380	1.44%
7	BYX	Alfonsino	13 581	1.19%
8	SKI	Gemfish	13 311	1.17%
9	CDL	Black cardinal fish	11 454	1.00%
10	WAR	Blue warehou	3 795	0.33%
11	WWA	White warehou	3 056	0.27%
12	BNS	Bluenose	1 969	0.17%
13	STA	Stargazer	1 752	0.15%
14	RBY	Ruby fish	1 357	0.12%
15	SPE	Sea perch	1 043	0.09%
16	SPD	Spiny dogfish	911	0.08%
17	FLA	Flatfish	895	0.08%
18	ELE	Elephant fish	333	0.03%
19	FRO	Frostfish	329	0.03%
20	LEA	Leatherjacket	264	0.02%
21	SCH	School shark	243	0.02%
22	EMA	Blue mackerel	198	0.02%
23	GSH	Ghost shark, dark	148	0.01%
24	**SPI**	**Spider crab**	**142**	**0.01%**
25	MOK	Blue moki	103	0.01%
26	SSK	Smooth skate	95	0.01%
27	RBT	Red bait	73	0.01%
28	**CAR**	**Carpet shark**	**56**	**<0.01%**
29	BCO	Blue cod	55	<0.01%
30	RSK	Rough skate	43	<0.01%
31	LDO	Lookdown dory	41	<0.01%

Count	Reporting Code	Common Name	Target Tows	Percentage of Total Target Tows
32	**MDO**	**Mirror dory**	**39**	**<0.01%**
33	**SQX**	**Squid**	**37**	**<0.01%**
34	**PRA**	**Prawn**	**35**	**<0.01%**
35	**SBO**	**Southern boarfish**	**33**	**<0.01%**
36	**SOR**	**Spiky Oreo**	**32**	**<0.01%**
37	TRU	Trumpeter	32	<0.01%
38	**SKA**	**Skate**	**31**	**<0.01%**
39	**PTO**	**Patagonian toothfish**	**30**	**<0.01%**
40	**SFL**	**Sand flounder**	**29**	**<0.01%**
41	SPO	Rig	22	<0.01%
42	**SDO**	**Silver dory**	**21**	**<0.01%**
43	**SCO**	**Swollenhead conger**	**20**	**<0.01%**
44	**OPE**	**Orange perch**	**19**	**<0.01%**
45	HPB	Hapuku and bass	18	<0.01%
46	**MIX**	**Mixed fish**	**17**	**<0.01%**
47	**HOR**	**Horse mussel**	**15**	**<0.01%**
48	RIB	Ribaldo	15	<0.01%
49	**THR**	**Thresher shark**	**14**	**<0.01%**
50	KAH	Kahawai	11	<0.01%
51	**BOA**	**Sowfish**	**9**	**<0.01%**
52	RSN	Red snapper	9	<0.01%
53	**OFH**	**Oilfish**	**7**	**<0.01%**
54	**JAV**	**Javelin fish**	**6**	**<0.01%**
55	**ASP**	**Tam 'O Shanter urchin**	**5**	**<0.01%**
56	**HAP**	**Hapuku**	**5**	**<0.01%**
57	**RAT**	**Rattail**	**5**	**<0.01%**
58	**RBM**	**Rays bream**	**5**	**<0.01%**
59	**SSP**	**Scallop spat**	**5**	**<0.01%**
60	**TRA**	**Roughies**	**5**	**<0.01%**
61	BWS	Blue shark	4	<0.01%
62	**ESO**	**New Zealand sole**	**4**	**<0.01%**
63	**LSO**	**Lemon sole**	**4**	**<0.01%**
64	**BAS**	**Bass groper**	**3**	**<0.01%**
65	**BAT**	**Large headed slickhead**	**3**	**<0.01%**
66	**FIS**	**Unknown**	**3**	**<0.01%**
67	**GFL**	**Greenback flounder**	**3**	**<0.01%**
68	PRK	Prawn killer	3	<0.01%
69	**SND**	**Shovelnose spiny dogfish**	**3**	**<0.01%**
70	**BRA**	**Short-tailed black ray**	**2**	**<0.01%**
71	MAK	Mako shark	2	<0.01%
72	**ROC**	**Rock cod**	**2**	**<0.01%**
73	**SAU**	**Saury**	**2**	**<0.01%**

Count	Reporting Code	Common Name	Target Tows	Percentage of Total Target Tows
74	**SCA**	**Scallop**	**2**	**<0.01%**
75	SKJ	Skipjack	2	<0.01%
76	**SNS**	**Sunset**	**2**	**<0.01%**
77	**SSI**	**Silverside**	**2**	**<0.01%**
78	**BFL**	**Black flounder**	**1**	**<0.01%**
79	**HOL**	**Tubeshoulder**	**1**	**<0.01%**
80	**JGU**	**Japanese gurnard**	**1**	**<0.01%**
81	**MTP**	**Myctophum spp.**	**1**	**<0.01%**
82	**OSD**	**Smooth dog shark**	**1**	**<0.01%**
83	**SCC**	**Sea cucumber**	**1**	**<0.01%**
84	**SCL**	**Scales**	**1**	**<0.01%**
85	**SPF**	**Scarlet wrasse**	**1**	**<0.01%**
86	**SQI**	**Squirrelfish**	**1**	**<0.01%**
87	SWO	Swordfish	1	<0.01%
88	**TRG**	**Triggerfish**	**1**	**<0.01%**
89	**YEM**	**Yellow-eyed mullet**	**1**	**<0.01%**
		Total "minor" target trawls	**276 354**	**24.21%**
		Total all target trawls	**1 141 377**	**100.00%**

APPENDIX 2 – Catch by reporting form type as provided by Dave Foster (MPI)

A2 Proportion of estimated catch of Tier 1 species (plus SWA and BAR) by return type

Table 1. Types of return

Return abbreviation	Description	Completed by
TCEPR	Trawl catch, effort, and processing returns	Trawlers >28m in overall length or trawlers that the chief executive has advised to complete this return
TCER	Trawl catch effort return	Trawlers 6–28m in overall length or trawlers that the chief executive has advised to complete this return
CELR	Catch, effort, and landing returns	Vessels using methods not covered by other returns
LCER	Lining catch effort return	Bottom longliners >28m in overall length or longliners that the chief executive has advised to complete this return
LTCER	Lining trip catch effort return	Bottom longliners 6–28m in overall length or longliners that the chief executive has advised to complete this return
NCER	Netting catch effort returns	Set netters >6m in overall length.

A2.1 Hoki

Table 1A Estimated catch of hoki (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others	Total
2010/11	107 443	8 351	14	14	115 822
2009/10	97 905	7 253	8	19	105 185
2008/09	81 247	6 317	16	17	87 598
2007/08	80 083	7 376	1	15	87 475
2006/07	90 452	-	7 328	10	97 790
2005/06	96 431	-	5 553	0	101 984
Total	***553 561***	***29 297***	***12 920***	***76***	***595 854***

Table 1B. Proportion of estimated catch of hoki by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others
2010/11	93%	7%	<0.1%	<0.1%
2009/10	93%	7%	<0.1%	<0.1%
2008/09	93%	7%	<0.1%	<0.1%
2007/08	92%	8%	<0.1%	<0.1%
2006/07	92%	-	7%	<0.1%
2005/06	95%	-	5%	<0.1%
Total	***93%***	***5%***	***2%***	***<0.1%***

A2.2 Hake

Table 2A. Estimated catch of hake (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	Others	Total
2010/11	4 892	46	38	4 977
2009/10	3 885	32	29	3 946
2008/09	9 134	19	21	9 175
2007/08	5 129	18	20	5 166
2006/07	9 697	-	32	9 730
2005/06	8 887	-	29	8 916
Total	***41 625***	***115***	***170***	***41 910***

Table 2B. Proportion of estimated catch of hake by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	Others
2010/11	98%	1%	1%
2009/10	98%	1%	1%
2008/09	100%	<1%	<1%
2007/08	99%	<1%	<1%
2006/07	100%	-	<1%
2005/06	100%	-	<1%
Total	***99%***	***<1%***	***<1%***

A2.3 Ling

Table 3A. Estimated catch of ling (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	LCER	LTCER	CELR	TCER	NCER	Total
2010/11	6 047	1 877	2 088	75	917	82	11 095
2009/10	6 055	2 857	1 745	131	699	109	11 595
2008/09	6 728	2 593	1 462	188	563	101	11 636
2007/08	9 614	2 857	2 045	206	510	99	15 331
2006/07	10 153	2 566	-	1 818	-	133	14 670
2005/06	8 605	2 512	-	1 701	-	-	12 819
Total	***47 202***	***15 272***	***7 340***	***4 119***	***2 688***	***524***	***77 146***

Table 3B. Proportion of estimated catch of ling by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	LCER	LTCER	CELR	TCER	NCER
2010/11	55%	17%	19%	1%	8%	1%
2009/10	52%	25%	15%	1%	6%	1%
2008/09	58%	22%	13%	2%	5%	1%
2007/08	63%	19%	13%	1%	3%	1%
2006/07	69%	17%	-	12%	-	1%
2005/06	67%	20%	-	13%	-	-
Total	***61%***	***20%***	***10%***	***5%***	***3%***	***1%***

A2.4 Southern blue whiting

All estimated catch information for the last six years is reported on TCEPRs.

A2.5 Jack mackerel (all stocks)

Table 4A Estimated catch of jack mackerel (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	CELR	TCER	Others	Total
2010/11	29 825	8 296	159	4	38 285
2009/10	31 860	9 030	153	4	41 048
2008/09	28 921	9 781	129	6	38 837
2007/08	34 933	11 368	103	3	46 407
2006/07	32 519	5 168	-	6	37 693
2005/06	31 520	9 641	-	-	41 161
Total	***189 580***	***53 282***	***544***	***23***	***243 430***

Table 4B Proportion of estimated catch of jack mackerel by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	CELR	TCER	Others
2010/11	78%	22%	<1%	<0.1%
2009/10	78%	22%	<1%	<0.1%
2008/09	74%	25%	<1%	<0.1%
2007/08	75%	24%	<1%	<0.1%
2006/07	86%	14%	-	<0.1%
2005/06	77%	23%	-	-
Total	***78%***	***22%***	***<1%***	***<0.1%***

A2.6 Orange roughy

Table 5A Estimated catch of orange roughy (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Total
2010/11	5 931	15	-	5 946
2009/10	8 735	66	-	8 802
2008/09	10 576	86	-	10 661
2007/08	12 077	27	-	12 105
2006/07	12 777	-	312	13 089
2005/06	14 152	-	497	14 649
Total	***64 249***	***195***	***808***	***65 252***

Table 5B Proportion of estimated catch of orange roughy by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR
2010/11	100%	<1%	-
2009/10	99%	1%	-
2008/09	99%	1%	-
2007/08	100%	<1%	-
2006/07	98%	-	2%
2005/06	97%	-	3%
Total	***98%***	***0***	***1%***

A2.7 Oreos

Table 6A Estimated catch of oreos (all species, tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others	Total
2010/11	13 737	2	1	<1	13 740
2009/10	16 418	50	<0.1	<0.1	16 468
2008/09	14 622	649	-	<0.1	15 271
2007/08	15 217	525	134	<1	15 875
2006/07	15 129	-	704	-	15 833
2005/06	15 253	-	972	<0.1	16 225
Total	***90 376***	***1 225***	***1 810***	***<1***	***93 411***

Table 6B Proportion of estimated catch of oreos (all species, tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others
2010/11	100%	<0.1%	<0.1%	<0.1%
2009/10	100%	<0.1%	<0.1%	<0.1%
2008/09	96%	4%	-	<0.1%
2007/08	96%	3%	1%	<0.1%
2006/07	96%	-	4%	<0.1%
2005/06	94%	-	6%	<0.1%
Total	***97%***	***1%***	***2%***	***<0.1%***

A2.8 Scampi

All estimated catch information for the last six years is reported on TCEPRs.

A2.9 Squid

Table 7A Estimated catch of squid (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	SJCER5	TCER	CELR	Others	Total
2010/11	33 703	1 414	226	1	<0.1	35 344
2009/10	29 574	891	367	2	<0.1	30 834
2008/09	43 489	1 032	189	2	<0.1	44 712
2007/08	51 922	1 371	736	<1	<0.1	54 028
2006/07	63 261	2 278	-	1 221	-	66 760
2005/06	62 915	5 844	-	918	-	69 677
Total	***284 863***	***12 830***	***1 518***	***2 145***		***301 356***

Table 7B Proportion of estimated catch of squid by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	SJCER	TCER	CELR	Others
2010/11	95%	4%	1%	<0.1%	<0.1%
2009/10	96%	3%	1%	<0.1%	<0.1%
2008/09	97%	2%	<1%	<0.1%	<0.1%
2007/08	96%	3%	1%	<0.1%	<0.1%
2006/07	95%	3%	-	2%	-
2005/06	90%	8%	-	1%	-
Total	***95%***	***4%***	***1%***	***1%***	***<0.1%***

[5] Squid jig catch, effort return

A2.10 Barracouta

Table 8A Estimated catch of barracouta (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others	Total
2010/11	20 576	4 206	57	3	24 841
2009/10	22 452	3 801	100	1	26 354
2008/09	20 094	4 381	202	2	24 679
2007/08	21 512	4 234	63	6	25 815
2006/07	24 424	-	3 045	3	27 472
2005/06	21 771	-	3 998	-	25 769
Total	***130 829***	***16 621***	***7 464***	***16***	***154 929***

Table 8B Proportion of estimated catch of barracouta (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others
2010/11	83%	17%	<1%	<0.1%
2009/10	85%	14%	<1%	<0.1%
2008/09	81%	18%	1%	<0.1%
2007/08	83%	16%	<1%	<0.1%
2006/07	89%	-	11%	-
2005/06	84%	-	16%	-
Total	***84%***	***11%***	***5%***	***<0.1%***

A2.11 Silver warehou

Table 9A Estimated catch of silver warehou (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others	Total
2010/11	6 828	258	1	2	7 090
2009/10	6 140	333	2	2	6 478
2008/09	7 635	303	4	2	7 945
2007/08	7 079	221	<1	3	7 303
2006/07	13 037	-	107	1	13 144
2005/06	9 902	-	130	-	10 031
Total	***50 621***	***1 116***	***243***	***11***	***51 991***

Table 9B Proportion of estimated catch of silver warehou (tonnes) by form type for the period 2005/06 – 2010/11

Fishing year	TCEPR	TCER	CELR	Others
2010/11	96%	4%	<0.1%	<0.1%
2009/10	95%	5%	<0.1%	<0.1%
2008/09	96%	4%	<0.1%	<0.1%
2007/08	97%	3%	<0.1%	<0.1%
2006/07	99%	-	1%	<0.1%
2005/06	99%	-	1%	-
Total	***97%***	***2%***	***<1%***	***<0.1%***

APPENDIX 3 COMPILATION OF SPREADSHEETS AND FIGURES

Disk available upon request from Science Officer, Ministry for Primary Industries (Science.Officer@mpi.govt.nz).