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Extent of bottom contact by New Zealand commercial trawl fishing for deepwater Tier 1 and Tier 2 target fishstocks, 1989–90 to 2015–16

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S.J. Baird
B.A. Wood

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Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
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EXECUTIVE SUMMARY

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Trawl effort data from the 1990 to 2016 fishing years were used to map the extent of commercial trawl fishing conducted on or near the seafloor inside the New Zealand 200 n. mile Exclusive Economic Zone (EEZ) outer boundary. The analysis utilised the three Ministry for Primary Industries trawl data collection forms for fishing years 1990–2016. The analysis was restricted to the deepwater Tier 1 and Tier 2 fishstocks, and was two-part: at Statistical Area resolution and at tow-by-tow resolution as a footprint derived from an estimate of swept area of the gear. About 1.08 million trawl records were included in the footprint dataset for effort using bottom trawl and midwater trawl gear reportedly deployed within 1 m of the seafloor.

The Statistical Area analysis indicated that the areas with the greatest amount of bottom-contacting effort for 1990–2016 were 034 off the South Island west coast, 028 at the southern edge of the Stewart-Snares shelf, and 602 around the Auckland Islands. A number of deepwater fishstocks contributed to the effort in these fisheries: hake (*Merluccius australis*), hoki (*Macruronus novaezelandiae*), jack mackerels (*Trachurus* spp.), and ling (*Genypterus blacodes*) in all areas listed above; arrow squid (*Nototodarus* spp.) in 602 and 028; and scampi (*Metanephrops challengeri*) in 602. Other Statistical Areas with high numbers of tows included 035, 030 and 027 off the west and southern South Island; 020–022 off the east coast South Island; 401 in waters around the Mernoo Bank on the Chatham Rise; and 014 off the east coast North Island. Both Tier 1 and Tier 2 fishstocks contributed to these areas; Tier 2 targets were important in inshore east coast areas of the main islands.

The Tier 1 and Tier 2 target fishstock footprint for 1990–2016 was estimated at 335 812 km^2. This represents 8.2% of the seafloor between the coastline and the outer boundary of the EEZ and 24% of the seafloor down to 1600 m that is open to fishing. The Tier 1 target fisheries accounted for 93% of the total 1990–2016 deepwater footprint, with hoki effort contributing 50% to the total. Hoki trawls covered about 12% of the seafloor open to fishing. The total footprints for each of the other Tier 1 targets covered about 1% or less of the seafloor out to the outer EEZ boundary, and 1–3% of the area open to fishing. About 76 km^2 of seafloor contacted in 2016 had not been contacted during 1990–2015.

The footprint for the most recent fishing year (2016) covered 44 261 km^2, about 1% of the EEZ and Territorial Sea and 3% of the 'fishable' area. Hoki effort was the main contributor to the 2016 footprint. When the data are restricted to 2008–16, the relative increase in the Tier 2 contribution, compared with the 1990–2016 period is evident; the Tier 1 targets combined represented 88% of the 2008–16 footprint of 158 685 km^2 (compared to the 93% for the whole period), and hoki represented about 42% of this total (compared with 50% for the whole period). Overall, the 2008–16 footprint area was 47% of the 1990–2016 footprint.

About 28% of the seafloor in waters shallower than 200 m was covered by the 1990–2016 footprint, 40% of 200–400 m, 35% of 400–600 m, 26% of 600–800 m, 16% of 800–1000 m, and 9% of 1000–1200 m was covered by the total footprint. About 4% of the seafloor at depths of 1200–1600 m was contacted by the total footprint. The hoki footprint had the greatest overlap of the 200–400 m, 400–600 m, and 600–800 m depth zones (19%, 25% and 24% respectively). Jack mackerel and arrow squid footprints had the greatest overlap at depths less than 200 m (14% and 8% respectively). The orange roughy total footprint had the greatest overlap in deep water (8% of the seafloor at 800–1000 m and 6% at 1000–1200 m).

Two of the Benthic-optimised Marine Environment Classification (BOMEC) classes had at least 50% of their seafloor area contacted by the total footprint, three had 37–46%, and another three had 23–27% contact. Overall 13% of the seafloor area covered by the 15 BOMEC classes (to depths of 3000 m) was contacted by the total footprint. Hoki, jack mackerel, and arrow squid footprints were the main contributors to areas of greatest overlap.

The aggregated swept area for 1990–2016 totalled 3.07 million km^2, and 95% of this was from Tier 1 target fishstocks, in particular, hoki. The annual aggregated swept area peaked in 1998 at about 166 000 km^2, but since 2006 the bottom-contacting trawl effort has decreased and the annual aggregated swept area has been about 75 000–85 000 km^2. The aggregated swept area for 2016 was 78 372 km^2.

Summary statistics of the footprint overlap of areas where the Tier 1 targets are more likely to be found are also provided, as are statistics on intensity and frequency from the cell-based analysis. A DVD of relevant shapefiles and maps accompanies this report and is available on request from science.officer@mpi.govt.nz.

1. INTRODUCTION

The nature and extent of the area contacted by trawl gear within the New Zealand 200 n. mile EEZ, an area of approximately 4.1 million km^2, was initially determined for offshore target fisheries conducted by vessels over 28 m length (Baird et al. 2011). Following that work, the Ministry for Primary Industries (MPI) restricted this analysis to the extent of trawl bottom contact for the larger vessels that targeted the deepwater Tier 1 and Tier 2 target species (Black et al. 2013, Black & Tilney 2015, Black & Tilney 2017). Separate work also determined the extent of seafloor contact for inshore fisheries by smaller vessels (Baird et al. 2015). These results provide indicative, not absolute, measures of effort relative to the seafloor. They show the general patterns of intensity and frequency of fishing on or near the seafloor summarised over a 25-km^2 cell grid, but are based on best-practice assumptions about the gear used, the configuration of each tow, the precision and resolution of the data, and the choice of analysis cell size (see Baird et al. 2011, Black et al. 2013).

The above analyses used data provided by commercial trawl fishers on three different forms: Trawl Catch Effort Processing Returns (TCEPRs) used since October 1989, Trawl Catch Effort Returns (TCERs) used since October 2007, and Catch Effort Landing Returns (CELRs) used between October 1989 and September 2007. The first two form types collect tow-by-tow data from which the trawl swept area can be estimated and located in geographic space, with the provision of position data and tow speed and tow duration data for a measure of distance towed. The CELR form collected daily data at the scale of broad fishery areas used by the Ministry for Primary Industries, and thus the effort was summarised as the number of tows per Statistical Area.

Integral to a spatial analysis of the nature and extent of fishing effort data is the provision of accurate and precise location data and understanding of the gear used, including its dimensions and configuration under tow. A discussion on trawl gear components and gear configuration, with relevance to seafloor contact, and the availability of data to describe the bottom contact was provided by Baird et al. (2011). Some of the more pertinent points are repeated here. The resolution of the TCEPR and TCER start and finish positions are, at best, to one minute, which is equivalent to about 1.852 km, and these positions represent the location of the fishing vessel when the net reaches fishing depth, rather than the location of the net. For example, when trawling on underwater features such as hills, the gear used in the orange roughy (*Hoplostethus atlanticus*) fishery, which is likely to be the fishery with the greatest disparity between vessel and net location, could be 1200–1500 m behind the vessel.

Several important values for the trawl gear and rigging are either not collected or represent a best guess. For example, the only recorded measure of net spread (wingspread) is determined by the fisher from the net plans as the distance in metres between the wings of the net. Thus, there is no measure of the doorspread in the commercial data, which would provide a more realistic measure of trawl spread. Generic doorspread values, allocated by target fisheries, and agreed to by the MPI Aquatic Environment Working Group (AEWG) were used in the analyses referenced above, based on known industry data. Data that describe possible variations in gear configuration are now collected by MPI fisheries observers and were used in this work to provide context for some gear parameters explored in the analysis of bottom contact.

Under the overall DAE2016/05 objective that aims to monitor the 'footprint' of trawl fishing for deepwater species on or near the seabed, this report addresses specific objectives 1–2:

1. To estimate the trawl footprint and map the spatial and temporal distribution of trawling on or near the seabed throughout the EEZ between 1 October 1989 to 30 September 1990 (hereafter referred to as fishing year 1990) and the most recent completed fishing year (1 October 2015 to 30 September 2016), referred to in this report as the 2016 fishing year.

2. To produce summary statistics, for Tier 1 deepwater fisheries and the aggregate of all Tier 1 and Tier 2 deepwater fisheries, of the extent and frequency of fishing by year, by depth zone, by fishable area, by predicted BOMEC habitat class, and by preferred habitat of key target species; and to identify any trends or changes to meet management needs.

Consultation with MPI at the start of the project determined the following output requirements:

1. For each deepwater Tier 1 target species, and for Tier 1 and Tier 2 combined, summarise and map data for the CELR data form for the period of its use (1990–2007), by Statistical Areas.
2. For each deepwater Tier 1 target species, and Tier 1 and Tier 2 targets combined, summarise and map data from the three trawl forms in use during 1990–2016 (CELR, TCER, and TCEPR), for the full period, and for the most recent fishing year 2016, by Statistical Area.
3. For each deepwater Tier 1 target species, and Tier 1 and Tier 2 targets combined, summarise data and produce footprint maps and statistics from the TCER data, as well as TCER and TCEPR forms for 2008–16 and for 2016.
4. For each deepwater Tier 1 target species, and Tier 1 and Tier 2 targets combined, summarise data and produce footprint maps and statistics from the TCEPR forms for 1990–2016 and 2016.
5. For each deepwater Tier 1 target species, and the Tier 1 and Tier 2 target species combined, report on the overlap of the 1990–2016 and the 2016 trawl footprints (based on TCER and TCEPR) data with:
    a. 200-m depth zones down to 1600 m;
    b. the 15-class Benthic-optimised Marine Environment Classification (BOMEC) generated by Leathwick et al. (2012);
    c. the 'preferred habitat' of Tier 1 species where these layers actually represent the distribution of the probability of capture of each of the seven Tier 1 fish species (after Leathwick et al. 2006) and the annual distribution of arrow squid (*Nototodarus sloani*, *N. gouldi*) and scampi (*Metanephrops challengeri*) (www.nabis.govt.nz);
    d. the 'fishable area' – waters down to 1600 m that are open to fishing within the outer boundary of the New Zealand 200 n. mile Exclusive Economic Zone (EEZ), and including the 12 n. mile Territorial Sea.

As a consequence of the spatial analyses, a large number of Geographic Information Systems (GIS) shapefiles were produced using ArcGIS and submitted to MPI with this report. Each shapefile contains the data for each trawl footprint analysis. Thus, two different scales of resolution are required to summarise these data: at the level of Statistical Area and at the tow level (swept area footprint).

This report is divided into several sections, based on the different spatial analyses allowed by the data, the main emphasis being on the TCEPR and TCER trawl data. Each section has an associated appendix to present the underlying data and output. The following section (Section 2) describes the general methodology for dealing with the three fishery data form sources, with the underlying data summaries presented in appendices. Much of the methodology used here follows methodology accepted by the MPI Aquatic Environment Working Group, previously presented in reports by, for example, Baird et al. (2011), Black et al. (2013), Baird et al. (2015), and Black & Tilney (2015, 2017). These reports provide a full description and discussion of the methods. Section 2 also discusses the GIS layers used for the footprint overlays.

Section 3 provides the Statistical Area summaries required for points 1 and 2 above. Section 4 concentrates on the use of data with tow-by-tow position records collected on TCERs and TCEPRs to generate the required trawl footprints. It describes the methodology used to explore and analyse 27 years of trawl fishing effort on or near the seafloor and presents the results of these spatial analyses, including the aggregated trawl swept area and the footprint swept area (the amount of the seafloor that was contacted by trawl gear). This section satisfies the requirements of points 3 and 4 above. Section 5 provides summaries of the overlap of each data layer in point 5 above. Lastly, Section 6 discusses the management implications of the footprint analyses and gives recommendations for future work.

2. METHODS

The methods below briefly describe the database development, data exploration and grooming, and preparation for spatial analysis. These methods build on those developed and described by Baird et al. (2011) and Black et al. (2013) for TCEPR data and Baird et al. (2015) for TCER data. For the purposes of this study, the EEZ and the Territorial Sea form the full extent of the maritime area around New Zealand as the analysis area; and the two EEZ enclaves are also included as waters available for fishing (total area of analysis is 4 111 569 km^2). Much of this is deepwater that has not been exploited by fishing activity (see Baird et al. 2011). Fishing took place predominantly on the continental shelf waters in depths defined by the distribution of target species, generally in waters shallower than 1600 m.

2.1 Fishery data sources

The objectives of this project relate to trawl effort that has contact with the seafloor. All effort data with contact or within 1 m of the seafloor were provided by MPI as extracts from the *warehou* database for the three form types: TCEPR, TCER, and CELR. These data included effort that used bottom trawls and midwater trawls. A separate extract of vessels data was also provided by MPI.

Masters of trawl vessels are required to fill out TCEPRs if the vessel is over 28 m in overall length or if the vessel was required by the Director-General of Fisheries to furnish a TCEPR (as required by the Fisheries (Reporting) Regulations 1990). These returns usually relate to trawl operations undertaken at depths greater than 200 m. However, masters of smaller trawl vessels (less than 28 m in length that generally fish shallow, inshore waters) may also report effort on TCEPRs (see Baird et al. 2011), and since late 2007, on TCERs – the forms that replaced the CELR form previously used to report catch and effort from small inshore trawlers.

The data collected on TCEPRs provide information about each fishing operation, with tow-by-tow records of latitude, longitude, and date-time for the start and end of each tow, target species, tow duration, tow speed, and gear parameters, amongst others. The TCERs also provide similar tow-by-tow data, but have position information for the start of the tow only. Data collected on CELRs during each fishing year (1990 to 2007) summarise daily effort for a given Statistical Area, fishing method, and target species. Although there was provision on these CELR forms for latitude and longitude records to be entered, this was not common practice and would only provide one start position for all the daily effort recorded on a CELR form. These factors limited the spatial and temporal use of CELR data, and thus the CELR data were summarised separately, by general Statistical Area.

Data required for this work included variables that described each fishing event, such as position, depth, date and time, gear type, form type, target species, duration, tow speed, and the associated vessel specifications.

2.1.1 Fishery data grooming and treatment

The initial data exploration on all trawl effort data included broad queries to isolate duplicates or missing data, with particular attention to those variables identified by Baird et al. (2011) as important for this spatial analysis. We followed the methods outlined by Baird et al. (2011), with emphasis on the Tier 1 and Tier 2 deepwater target species fishstocks (Ministry for Primary Industries 2016a), listed below in Table 1. Note that there was no effort reported for the Tier 2 targets of deepwater crab species or for pale ghost shark, and these are not included in Table 1.

Table 1: Tier 1 and Tier 2 deepwater fishstocks for which there was trawl effort during 1990–2016 (see Ministry for Primary Industries (2016a), Ministry for Primary Industries (2016b) plenary for fishstock areas).

Code: Fishstock	Common name	Scientific name
Tier 1		
HAK: all	Hake	*Merluccius australis*
HOK: all	Hoki	*Macruronus novaezelandiae*
JMA: JMA 3, JMA 7	Jack mackerels	*Trachurus declivis*, *T. murphyi*, *T. novaezealandiae*
LIN: LIN 3–LIN 7	Ling	*Genypterus blacodes*
OEO: all	Oreo species	*Allocyttus niger*, *Neocyttus rhomboidalis*, *Pseudocyttus maculatus*
ORH: all	Orange roughy	*Hoplostethus atlanticus*
SBW: all	Southern blue whiting	*Micromesistius australis*
SCI: all	Scampi	*Metanephrops challengeri*
SQU: all	Arrow squid	*Nototodarus sloanii*, *N. gouldi*
Tier 2		
BAR: BAR 4, BAR 5, BAR7	Barracouta	*Thyrsites atun*
BYX: all	Alfonsino	*Beryx splendens*, *B. decadactylus*
CDL: all	Black cardinal fish	*Epigonus telescopus*
EMA: EMA 3, EMA 7	English mackerel	*Scomber australasicus*
FRO: FRO 3–FRO 9	Frostfish	*Lepidopus caudatus*
GSH: GSH 4–GSH 6	Dark ghost shark	*Hydrolagus novaezelandiae*
LDO: all	Lookdown dory	*Cyttus traversi*
PRK: all	Prawn killer	*Ibacus alticrenatus*
PTO: all	Patagonian toothfish	*Dissostichus eleginoides*
RBT: all	Redbait	*Emmelichthys nitidus*
RBY: all	Rubyfish	*Plagiogeneion rubiginosum*
RIB: RIB 3–RIB8	Ribaldo	*Mora moro*
SKI: SKI 3, SKI 7	Gemfish	*Rexea solandri*
SPD: SPD 4, SPD 5	Spiny dogfish	*Squalus acanthias*
SPE: SPE 3–SPE 7	Sea perch	*Helicolenus percoides*
SWA: all	Silver warehou	*Seriolella punctata*
WWA: all	White warehou	*Seriolella caerulea*

Data were treated separately by form type, and the primary grooming checks and numbers of changes are given in Appendix A. Particular attention in the effort checking and grooming was given to variables required to characterise the effort: location/area fished, date and time, gear type, target species, number of tows, fishing duration, towing speed, vessel characteristics (including size and nationality), effort width (wingspread), and depth. Vessels were categorised by length: under 28 m, 28–46 m, 46–80 m, and over 80 m; and by fleet nationality based on home port and crew nationality (see Baird et al. 2011).

In summary, underlying the data grooming, the following assumptions were made with respect to the database:

- All dates were accepted as reported.
- All gear type data were used as reported, except for a very small number of midwater tows wrongly coded as 'MPT' (non-existent code): thus 'BT' represented use of bottom trawl gear, 'BPT' for a bottom pair trawl, and 'MW' for midwater trawl net. The relatively small number of 'BPT' records were reassigned to 'BT'.
- All vessel keys were accepted as real.
- Targets were generally accepted as reported, except those considered to be typographical errors or those that showed obvious inconsistencies; for example, 'SNA' tows in waters south of 42°S where 'SWA' was the target in tows of the same trip.
- Tows with null values for the trip number were ignored.

Summaries of the final groomed datasets are presented in Appendix A.

2.2 GIS layers for estimating the overlap of the bottom-contacting trawl footprint

To determine the extent of coverage of the trawl footprint on 200-m depth zones, the potential 'fishable' area, and modelled environmental classification layers, as required in the project specifications, a series of Geographic Information Systems (GIS) layers were acquired from MPI or generated from NIWA data. These are described below. Note: all the spatial overlap and area calculations were made from data in the following projection: Albers Equal Area Projection (central meridian at 175° E, standard parallels at 30° S and 40° S, and the latitude of origin at 40° S). Appendix B provides maps of the spatial distributions of these layers.

2.2.1 Depth zone

This layer was created from the latest NIWA bathymetry data (Mackay et al. 2016) to yield 200-m depth zones down to 1600 m, the depth that is close to the depth limit of current trawling effort (see Figures A1–A3 in Appendix A). The distribution of these zones is shown in Figure B1 in Appendix B. The area (km^2) of each zone was calculated using tools in ArcGIS and provided in the footprint overlap analysis in Section 5.1.

2.2.2 Benthic-optimised Marine Environment Classification (BOMEC)

This layer was created by Leathwick et al. (2012) and contains 15 classes that represent different environments modelled from demersal fish distribution data and a number of modelled environmental variables for waters within the EEZ outer boundary, down to 3000 m (see Figure B1 in Appendix B). Thus, it extends beyond the depths where fishing normally occurs. The area (km^2) of each class was calculated, as above, and these areas are given in the footprint overlap analysis in Section 5.2.

2.2.3 Probability of capture/annual distribution for the Tier 1 target species

For the seven fish targets in the deepwater Tier 1 group of fishstocks, predicted fish distribution layers (Leathwick et al. 2006) were used to compare with the footprint coverage. Leathwick et al. (2006) predicted the distribution of the probability of capture during a standardised trawl in waters down to 1950 m within the outer EEZ boundary, based on presence/absence data and relevant modelled environmental variables (Figures B2a–B2d in Appendix B). For scampi and arrow squid, the annual distributions of the populations as mapped by MPI (www.nabis.govt.nz) are used as a proxy for the species distribution (see Figure B2e).

Where the footprint target species data are represented in groups, as for oreo species and jack mackerel species, a single predicted layer was generated by spatially combining the individual predicted layers in GIS; thus, for example, a jack mackerel layer was generated from the predicted layers for the three *Trachurus* species. The complete coverage of predicted area by fish species was the same for each species, and the areas (km^2) for each fish species probability group (e.g., 0%, 1–10%, 11–20%, etc.) were calculated as above and are given in Section 5.3. The arrow squid and scampi areas match the extent of the EEZ and the Territorial Sea; the areas of unknown presence, hotspot, 90% and 100% annual distribution for arrow squid and scampi were calculated, as above.

2.2.4 Fishable area

This area has an outer limit of 1600 m and reflects the waters included in the depth zone layer (defined above), but has a smaller coverage due to the exclusion of Benthic Protection Areas (BPAs) introduced in 2007, closed areas to protect underwater features including seamounts (the first of which were closed in 2001), and marine reserves, for example, around the Auckland Islands group (see Figure B3 in Appendix B). The area covered by the fishable area was calculated as 1 399 376 km^2, which is 34% of the area within the EEZ outer boundary (4 111 569 km^2).

3. STATISTICAL AREA ANALYSIS OF BOTTOM-CONTACTING TRAWLING EFFORT

The numbers of bottom-contacting tows reported were summarised to provide a total of effort by reported Statistical Area, using CELRs for fishing years 1990–2007 and the combination of all three forms for 1990–2016 and for 2016, for the Tier 1 species and the combined total of Tier 1 and Tier 2 species (see Appendix C).

3.1 CELR forms

Overall, the 6882 CELR tows for deepwater Tier 1 and Tier 2 fishstocks accounted for about 0.6% of the almost 1.09 million bottom-contacting tows (see Appendix A, Table A8). Annual totals of Tier 1 tows were greater than Tier 2 totals in each fishing year, especially after the mid-1990s (Figure 1). Most CELR effort included here was targeted at orange roughy (38%), hoki (22%), and barracouta (21%) (Table A2 in Appendix A). The Statistical Areas with the highest numbers of CELR tows were 034 and 033 off the South Island west coast, and 017 in Cook Strait (Figure 2, Table C1 in Appendix C).

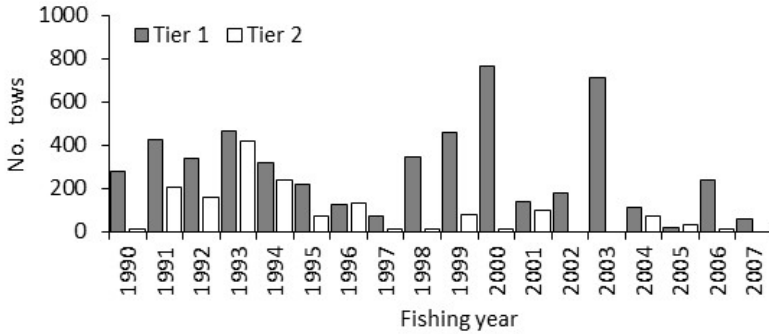

Figure 1: Number of CELR bottom tows reported for Tier 1 and Tier 2 species, by fishing year, 1990–2007.

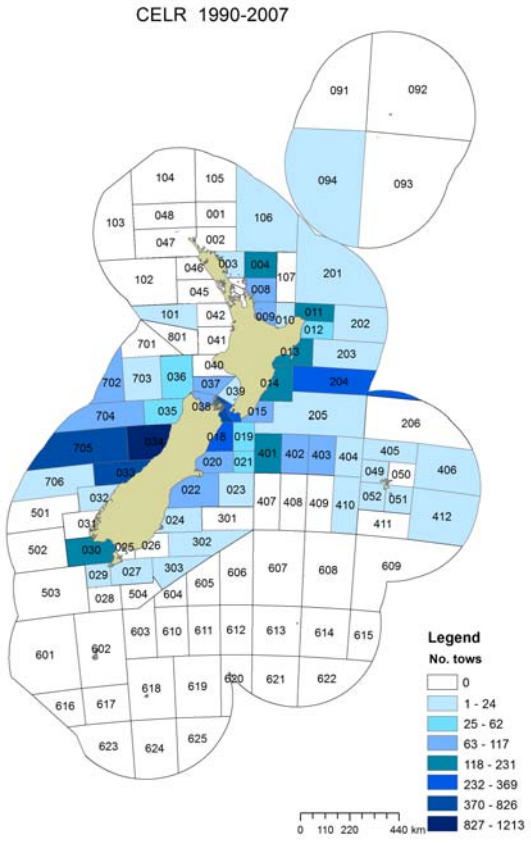

Figure 2: Number of CELR bottom tows reported for Tier 1 and Tier 2 species, by Statistical Area, 1990–2007.

3.2 CELR, TCER and TCEPR forms

Tier 1 and Tier 2 fishstock data from the combined CELR, TCER and TCEPR forms for fishing years 1990–2016 and for the most recent fishing year, 2016, are summarised in Figure 3, based on the final groomed data given in Appendix A. Appendix C gives the separate 1990–2016 and 2016 summary figures for each Tier 1 target species (Figures C1a–C1e) and tabulated summary of Tier 1 species, Tier 2 totals, and Tier 1 and Tier 2 overall totals for each contacted Statistical Area, for the 1990–2016 period (Tables C2 and C3). These data represent 99.3% of bottom-contacting 1990–2016 trawl effort for deepwater Tier 1 and Tier 2 species; the remainder had null Statistical Area records.

The Statistical Areas with most bottom-contacting effort during 1990–2016 were 034 off the South Island west coast, 028 at the southern edge of the Stewart-Snares shelf, and 602 around the Auckland Islands. The following deepwater fishstocks contributed to the effort in these fisheries: hake, hoki, jack mackerel, and ling in all areas listed above; arrow squid in 602 and 028; and scampi in 602 (see Figures C1a–C1e).

Other Statistical Areas with high numbers of tows included 035, 030, and 027 off the west and southern South Island; 020–022 off the east coast South Island; 401 around the Mernoo Bank on the Chatham Rise; and 014 off the east coast North Island. A variety of Tier 1 and Tier 2 fishstocks contributed to these areas, with Tier 2 targets important in inshore east coast areas of both main islands (Tables C2 and C3).

4. SPATIAL ANALYSIS OF TCER AND TCEPR DATA

Both these forms allow a finer resolution of spatial analysis and presentation, but require different treatment to generate swept area estimates: TCEPR data include both start and end positions, whereas TCER have tow start positions only. Thus, the groomed data are treated separately before being combined into a spatially-enabled database to develop the swept area statistics. The methods described below follow those used and fully described by Baird et al. (2011) and Black et al. (2013) for TCEPR data and Baird et al. (2015) for TCER data (see Appendix A).

The groomed dataset consisted of 1 082 996 TCER and TCEPR bottom-contacting tows (see Table A6). In accordance with previous work, the start and finish positions were randomly jittered using an offset of ± 0.5 minute, in an attempt to better represent the start and finish positions, given that the position data were truncated to the nearest minute of arc. These jittered values were stored as new fields in the dataset. Note that the reported position data represent where the vessel was at the time the net was deemed to have reached (and left) fishing depth rather than the position (location) of the net. However, the use of random jittering does limit the artificial patchiness of effort created by the data resolution.

4.1 Preparation for estimating swept area from TCER forms

The TCER data lack information that describes the finish location. Although a measure of swept area can be calculated, based on the duration of the tow and tow speed, the swept area cannot be spatially represented, other than as a circle centred on the start position. We followed the methods described by Baird et al. (2015) whereby, within a trip, a tow direction was generated from the bearing between the start position of a tow and the start of the following tow. A distance measure (km) was estimated from the tow speed and tow duration data and used with the estimated bearing to generate finish coordinates.

The data summary in Appendix A indicated the majority of TCER trips were of fewer than four tows, which means a substantial number of tows had no following tow (in a given trip). Thus, the last tows and only tows of a trip are identified, and for each of these tows, a bearing was estimated based on the median estimated bearing values from other tows by the same vessel for the same target species within $1/30^{th}$ of a degree north/south or east/west, using a minimum number of two tows. This was used to generate finish coordinates (as above). Where this failed, finish coordinates were generated by using the median estimated bearing values from tows of the same target species within $1/30^{th}$ of a degree north/south or east/west, using a minimum number of two tows. A bearing could not be estimated for 4% of TCER tows.

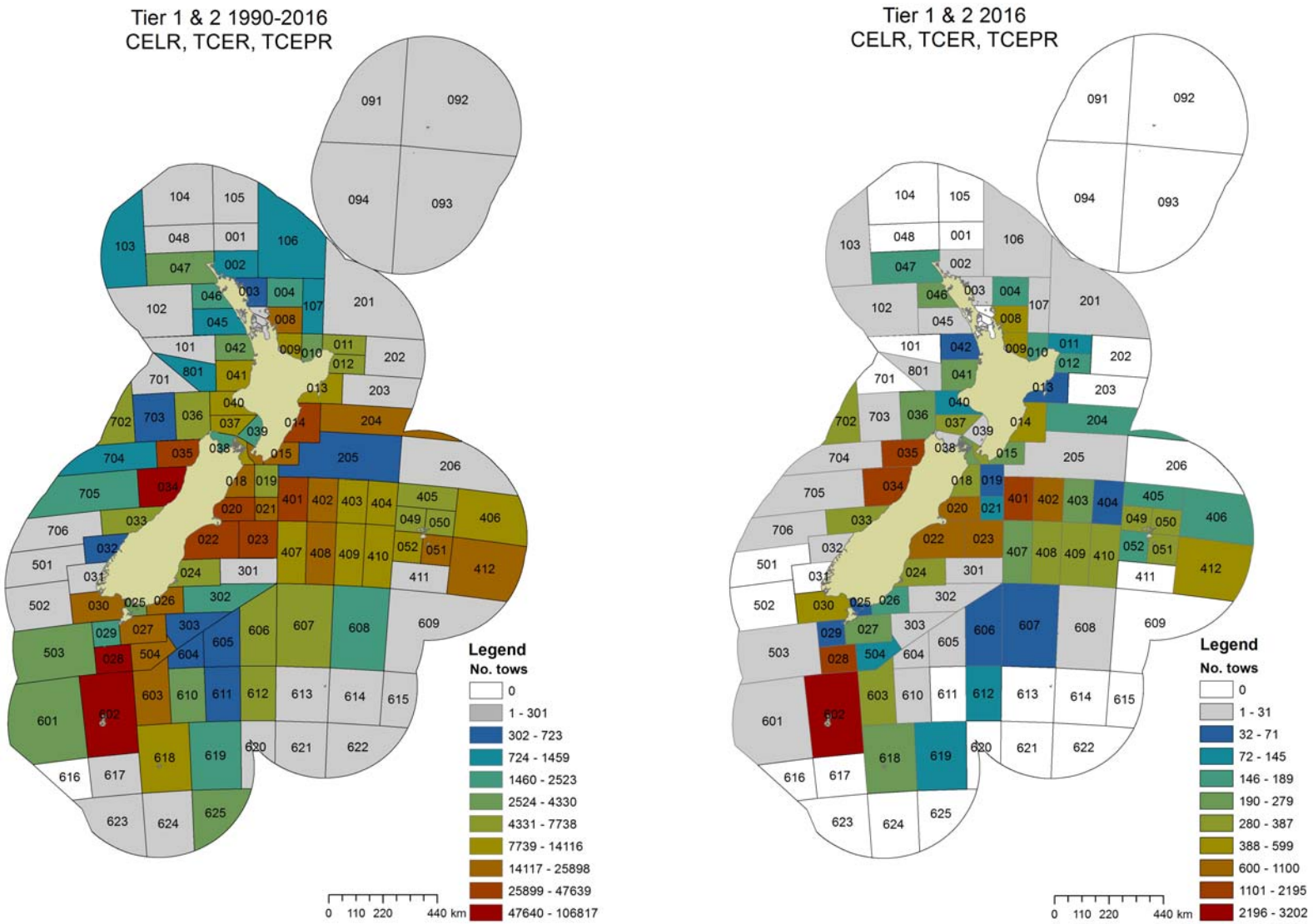

Figure 3: Combined all-form total for all deepwater Tier 1 and Tier 2 species, for fishing years 1990–2016 (left), and for 2016 (right), by Statistical Area.

4.2 Spatial allocation of TCEPR and TCER tows

Additional columns were created within the dataset to provide four columns of start and finish positions (*lons_fin*, *lats_fin*, *lonf_fin, latf_fin*) for use in the final spatial analysis. Thus, for TCEPR data, the jittered start and finish positions were used to populate these fields. For the TCER, the jittered start positions were used for all TCER tows; and the estimated end longitude and latitude values were used for the finish locations of all tows, except the last and only tows of a trip. For the latter group, the target derived latitude and longitudes were used for the finish positions.

For the calculation of swept area, the best measure of potential area of the seafloor contacted by the trawl gear is the distance between the doors (doorspread). Fishers are not required to report doorspread, so historically for this work, a generic doorspread value was assigned to each tow, based on vessel size, target species, and known gear parameters. Thus, to progress the swept area calculations, new fields for TCEPR records were added to the dataset.

1. A new field of generic doorspread values was created to provide a better estimate of the gear width for bottom trawls. The doorspread values assigned to the data are given in Table A9 in Appendix A. These are very similar to the values that were used in previous iterations of the trawl footprint and recognise that there may be differences in the spread of gear depending on the vessel size. A comparison with a small amount of available observer data indicated that these broad values were within normal ranges (MPI, pers. comm.). From 2008, the number of nets used was recorded on the TCER and TCEPR forms and this was used to identify tows that used twin trawls in hoki target fishing and twin-rig and triple-rig trawl gear in scampi fisheries.
2. A distance for each trawl track was calculated from the start and finish positions.
3. A second distance value was calculated for each tow; this was based on the reported speed and the tow duration (the difference between the reported tow start and finish times).

To populate these fields, each tow was converted into a trackline (distance between the reported start and finish locations). These values are summarised by the Tier 1 species and for the total dataset in Table A10 in Appendix A. Each trackline was buffered by the assigned doorspread to produce polygons to represent the trawl path. All tows were assumed to be in a straight line. Tows with a single valid position (or with identical start and finish positions) were assigned a point location and buffered by the doorspread. For some tows this may generate apparent higher effort in some localised areas (and an apparent lower effort in surrounding areas), but it may be appropriate for very short tows that may have identical start and finish positions (such as those on underwater hills). There were 371 tows for which only a start position could be used (0.03% of the total data).

Tows that were considered too long were identified by the rule used in the previous work by Black & Tilney (2017): ‘long’ tows were those that were longer than 70 km for scampi and arrow squid and longer than 55.56 km for all other species considered here. Using these criteria, it appears that for some species the upper limit may be too short, as indicated by the data for hake and a few other middle depths species (Figure A4 in Appendix A). Overall, the 27 867 ‘long’ tows represented 2.7% of the data, but for a target species such as hake, they represented 22.5% of hake tows in the dataset; whereas the ‘long’ tows in the hoki dataset accounted for 3.2% of the hoki data. For both these species, the data suggest that tows up to 70 km could be considered as part of the normal range. For the hake footprint dataset, if hake or hoki tows over 70 km instead of the 55.56 km were the upper limit, 10% of the hake data and 1% of the hoki data would be dropped.

Another 0.3% of the TCER and TCEPR data were identified as being on land. Most of these tows targeted barracouta (especially in Statistical Areas 036–038, where narrow landforms such as Farewell Spit created a problem because of the resolution of the position data). Other main contributing target species were fished in and around the top of the South Island, especially in the Cook Strait area; as well as scampi in Statistical Area 014, and scampi and arrow squid in 602 near the Auckland Islands.

Overall, the percentage of TCER and TCEPR data not included in the final footprint analysis due to 'long' tows and tows on land was about 2.8% of the 1990–2016 total tows; this gave a trawl footprint dataset of 1 052 868 tows (Table A1).

4.3 Assignment of TCEPR and TCER tow data to 25-km^2 cells

To aid in the categorisation and analysis of the data, a grid of approximately 25-km^2 cells was created as a database table and joined to the TCER and TCEPR effort table, after Baird et al. (2011). A 5x5 km cell size was chosen as a reasonably fine unit for an area the size of the EEZ. This grid was generated in the Albers Conic Equal Area Projection for the New Zealand EEZ (see Section 2.2) and re-projected to latitude and longitude degrees to overlay with effort data as a basis for spatial analysis. The resolution of tow position data was, at best, about 1.852 km. Each cell was assigned a depth derived from the NIWA regional bathymetry dataset that represented the depth at the cell midpoint.

The 25-km^2 cell grid table was joined to the TCEPR data to create a new database table to enable the spatial overlay of the grid with the estimated doorspread-based polygons of swept area (Figure 4). Thus, the effort could be analysed by grid cell to identify and quantify the amount of effort per cell over time and to generate an indicative 'footprint' of trawl effort on the seafloor. For area-based calculations, the data were re-projected to the Albers Conic Equal Area projection to minimise distortions caused by converging lines of longitude with increasing latitude using degrees as the coordinate units. For each cell, the sum of the area of all the portions of the estimated doorspread polygons that lie within that cell was calculated. Thus, a cell in any given fishing year may have an aggregate swept area of 0 (unfished) or 25 km^2 (swept area is similar to the cell size), or perhaps 100 km^2, suggesting that, on average, the cell area was swept four times.

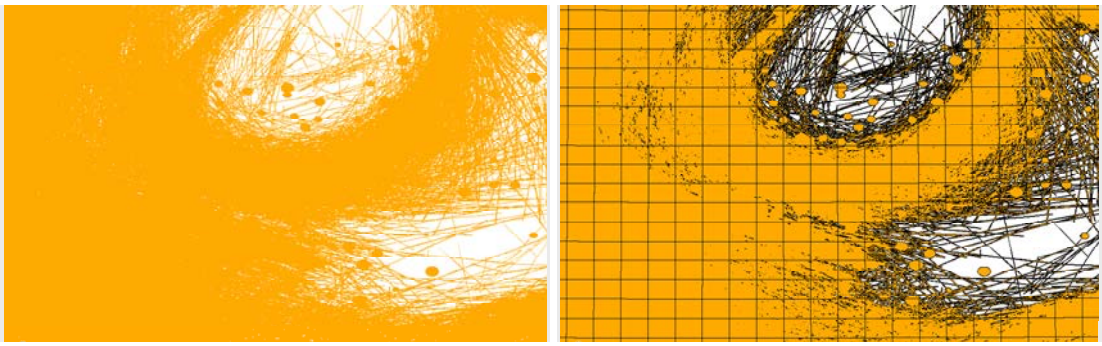

Figure 4: Spatial representation of trawl effort converted to polygons and overlaid with a 25-km^2 cell grid, in a heavily fished area surrounding shallow unfished areas.

4.4 Measures used to summarise swept area

This study used the reported number of tows for TCER and TCEPR data and the estimated swept area for each of these tows (measured in km^2), hereafter referred to as the *swept area*, as measures of the fishing intensity.

1. *Swept area* is the area (km^2) derived from the tow distance as measured between start and finish positions and the assigned doorspread. This measure was used to summarise the effort and the total for each fishing year, referred to as the *aggregate swept area*.
2. *Trawl footprint* is the area (km^2) that represents the seafloor area estimated to have been contacted by trawl gear.

4.5 TCER and TCEPR data representation and underlying assumptions

The effort data used here represent subsets of the total commercial trawl effort data reported during these years. First, data are for tows that used bottom trawl gear or midwater gear within 1 m of the seafloor, and second, the data are restricted to two data sources (the TCEPR form for 1990–2016 fishing years, and the TCER for the 2008–16 fishing years).

Some underlying assumptions need to be stated.

1. The time series has an artificial start and end. The study treats the first fishing year of data, 1990, as the start of fishing in each area, and thus any discussion of trends is relative to 1990.
2. It is assumed that the paths (trackline) of all tows follow a straight line between the reported start and end positions. In reality, tows may follow contours and may include turns, but the trackline data do not allow any determination of actual tow path. The duration-speed distance measure provides some measure of a tow path distance and where this differs from the trackline distance it could be assumed to be closer to the 'real' length of a tow.
3. It is assumed that the gear is in contact with the seafloor throughout the tow.
4. The resolution of the position data is to the nearest minute (about 1.852 km – assuming no allowance for latitudinal changes).
5. The measure of swept area will be indicative and may well be better estimated for certain target species where fishing effort is carried out by larger vessels with gear parameters that are better understood. It is likely that the effort in years may be underestimated for at least six large trawlers that used twin-trawl gear before 2008 when data collection on the number of nets started. A twin trawl is likely to have a doorspread twice that of a single trawl (for example, 400–450 m compared with 200 m) according to unpublished MPI observer data, industry sources, and gear manufacturers.
6. The irregular nature of the seafloor is ignored and it is assumed that, within each 25-km^2 cell, the seafloor is homogeneous.
7. The patchy distribution of fishing is in part due to avoidance of areas of the seafloor that are unfishable because of undersea formations or habitats such as sponge gardens that fishers may describe as 'foul ground'.

4.6 The nature and extent of TCER and TCEPR trawling on or near the seafloor

4.6.1 The total number of bottom-contacting trawls and the total spatial area affected ('footprint') each year

Appendix D provides additional data summaries for the footprint analysis. The annual numbers of TCER and TCEPR bottom-contacting tows targeted at Tier 1 deepwater species and the combined Tier 1 and Tier 2 targets retained for the footprint analysis are given in Table D1 in Appendix D, with the annual totals for Tier 1 and all deepwater fishstocks shown in Figure 5. Over all fishing years (1990–2016), effort for hoki accounted for 36.8% of the 1 052 868 tows, with arrow squid (16.0%), orange roughy (12.2%), and scampi (11.2%) the next most numerous.

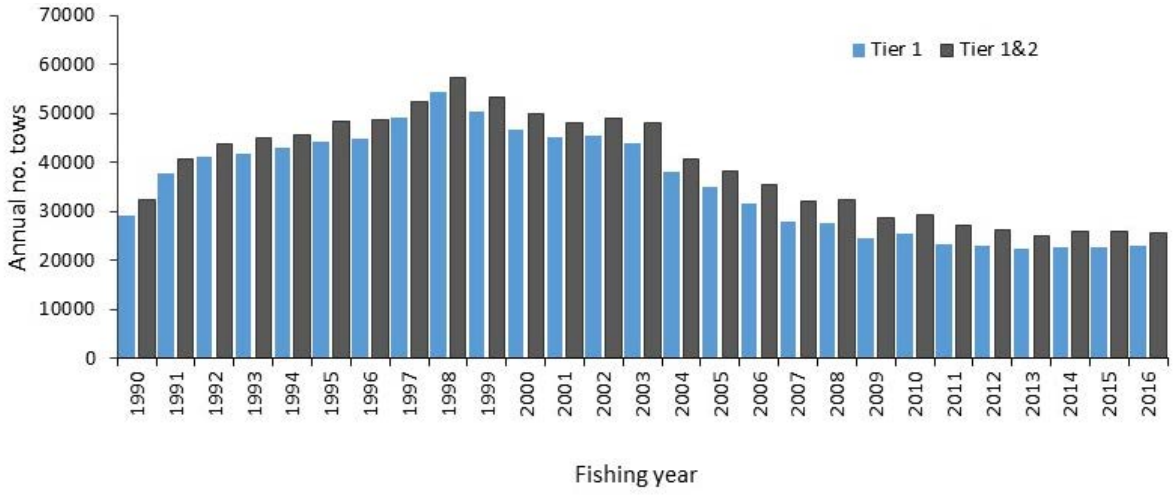

Figure 5: Annual totals of tows reported on TCERs and TCEPRs for Tier 1 and for Tiers 1 and 2 target species, for fishing years 1990–2016. The total number of tows that contributed to the footprint analysis, for all years and targets, was 1 052 868 tows.

Hoki consistently accounted for the highest percentage of tows, by fishing year, particularly during the mid-1990s to mid-2000s when over 20 000 hoki tows were reported annually and 2012–16 when annual number of hoki tows numbered 9000–10 000. This trend is mirrored by the amount of seafloor contacted by the annual hoki trawl footprint (Figure 6, Table D3); the footprint covered about 25 000 km^2 in recent years, about half that in the peak years of the early 2000s.

Squid tows peaked at 9000–10 000 in the mid–late 1990s, then dropped to 7000–9000 during 2001–06 and subsequently to 2000–3000 tows each year for 2013–16. The annual trawl footprint decreased steadily from the early 2000s to 3000–3500 km^2 each year during 2013–2016.

The annual number of scampi tows and the scampi footprint were reasonably consistent throughout the time series, at around 4000–5000 tows and 4000–5000 km^2. Annual numbers of tows for orange roughy decreased after the late 1990s, and dropped to 1500–2000 for the 2011–14 fishing years, then increased to about 3000 tows for 2016. The resulting effect on the estimated orange roughy footprint is evident, with between 660 and 2200 km^2 contacted annually during 2011–16.

Annual trends for the other Tier 1 species follow a similar pattern in that the relative number of tows and footprint areas are generally smaller and more stable towards the end of the 1990–2016 period (see Figure 6 and Tables D1–D4).

The total annual footprints for the Tier 2 targets showed a decrease for the years when the Tier 1 target footprints were at their greatest coverage (Figure 7). Barracouta consistently had the largest annual footprint, with the other main target being silver warehou in all years except 2003 and 2004 when there was an increase in the sea perch footprint.

Throughout the fishing years 1990–2016, the annual Tier 1 footprint generally decreased from the peak of about 76 500 km^2 in 2003 and 2004 to about 40 000–44 000 km^2 in the last 10 years. After a low in 2004 (less than 3000 km^2), the annual total Tier 2 footprint peaked in 2008 at about 7000 km^2, then decreased to about 4000–5000 km^2 in the last eight years and was about 10% of the Tier 1 annual totals.

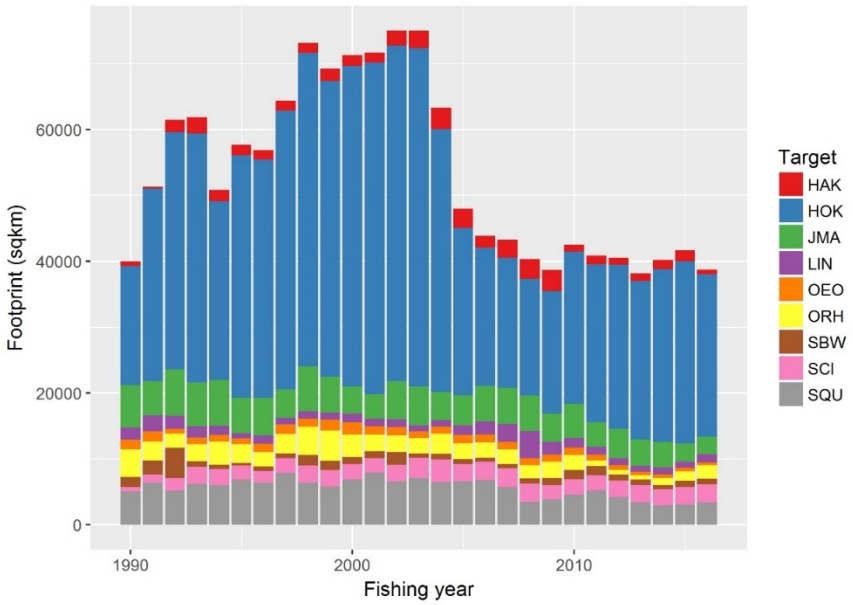

Figure 6: The annual footprint for Tier 1 deepwater fishstocks, based on TCER and TCEPR forms, for fishing years 1990–2016.

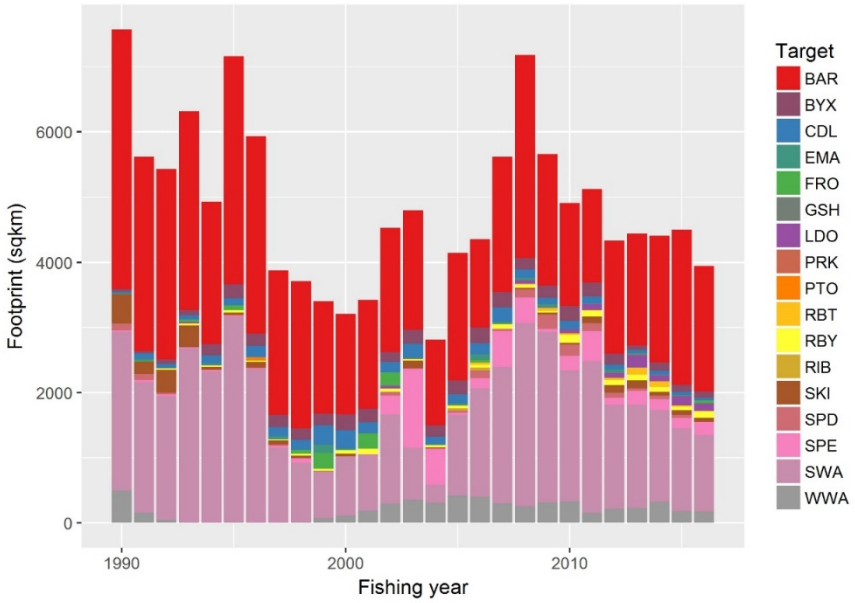

Figure 7: The annual footprint for Tier 2 deepwater fishstocks, based on TCER and TCEPR forms, for fishing years 1990–2016.

Tier 1 target species contacted 42 428 of the 44 918 cells contacted by the combined Tier 1 and Tier 2 targets (Table D2 in Appendix D), with hoki tows in at least half the cells, and squid and orange roughy tows in about 20–25% of cells.

Further data summaries of the swept areas (footprint and aggregated) and cell statistics of intensity and frequency are presented in Appendix D.

4.6.2 The total trawl footprint

The total trawl footprint for 1990–2016 (Figure 8) was estimated at 335 811.8 km^2 (Table 2). This represents 8.2% of the waters included in the Territorial Sea and the EEZ (4 111 569 km^2). The Tier 1 targets accounted for 93% of the total 1990–2016 deepwater footprint, with hoki effort contributing 50% to the total. The total footprints for each of the other Tier 1 targets covered about 1% or less of the combined Territorial Sea and EEZ waters.

The footprint for the most recent fishing year (2016) covered 44 261.5 km^2, about 1% of the EEZ and Territorial Sea (see Figure 8). Hoki effort was the main contributor to the 2016 footprint.

When the data were restricted to 2008–16, the years in which both TCER and TCEPR data were used (see Figure 8), the relative increase in the Tier 2 contribution is evident. The Tier 1 targets combined represented 88% of the 2008–16 footprint of 158 684.8 km^2, and hoki represented about 42% of this total (see Table 2). Overall, the 2008–16 footprint area was 47% of the 1990–2016 footprint.

The spatial coverages of these footprints are shown in Figures D1–D2 in Appendix D. The total trawl footprint for 2016 was compared with the 1990–2015 total footprint and there was about 76 km^2 of seafloor that was trawled in 2016, but not in the previous 26 years (Figure D3 in Appendix D). Most of this effort was directed towards orange roughy across the north-eastern Challenger Plateau in Statistical Area 701 (see Figure 2 for locations of Statistical Areas).

Table 2: Bottom-contacting trawl footprint statistics for deepwater Tier 1 and Tier 2 target fishstocks, for 1990–2016, 2016, and 2008–16. These footprints are from TCER data (from 2008) and TCEPR data (all years); and the TCER data represent about 2% of the total input data. Target species codes are defined in Table 1. The extent of the area of the EEZ waters and the Territorial Sea (EEZ&TS) is 4 111 569 km^2. The extent of the fishable area (see Section 2.2.4) is 1 399 376 km^2.

Analysis period	Target species	No. of tows	No. 25-km^2 cells	Trawl footprint (km^2)	Overlap EEZ&TS (%)	Overlap fishable area (%)
1990–2016	Tier 1 & Tier 2	1 052 868	44 918	335 811.8	8.2	23.5
1990–2016	Tier 1	962 606	42 428	313 652.8	7.6	22.0
1990–2016	HAK	16 949	4 341	19 551.0	0.5	1.4
1990–2016	HOK	387 653	23 429	167 101.3	4.1	11.8
1990–2016	JMA	50 112	5 986	44 429.2	1.1	3.2
1990–2016	LIN	18 495	6 361	24 293.9	0.6	1.7
1990–2016	OEO	59 128	5 668	15 961.5	0.4	1.1
1990–2016	ORH	128 095	10 551	34 725.2	0.8	2.4
1990–2016	SBW	15 468	3 940	21 013.7	0.5	1.5
1990–2016	SCI	117 855	7 404	22 536.7	0.5	1.6
1990–2016	SQU	168 851	9 020	40 131.5	1.0	2.8
2016	Tier 1 & Tier 2	25 572	11 547	44 261.5	1.1	3.2
2016	Tier 1	22 798	9 876	40 883.9	1.0	2.9
2016	HAK	313	410	731.9	<0.0	0.1
2016	HOK	8 644	4 179	24 756.9	0.6	1.8
2016	JMA	842	1 158	2 708.2	0.1	0.2
2016	LIN	931	850	1 241.3	<0.1	0.1
2016	OEO	793	472	378.3	<0.0	0.0
2016	ORH	3 085	1 740	2 207.9	0.1	0.2
2016	SBW	349	473	870.7	<0.0	0.1
2016	SCI	5 056	1 345	5 316.8	0.1	0.4
2016	SQU	2 785	1 058	3 414.6	0.1	0.2
2008–16	Tier 1 & Tier 2	245 548	24 176	158 684.8	3.9	11.3
2008–16	Tier 1	214 088	21 399	139 766.7	3.4	9.9
2008–16	HAK	5 654	1 804	8 040.8	0.2	0.6
2008–16	HOK	77 247	9 098	67 340.6	1.6	4.8
2008–16	JMA	11 888	2 720	19 408.7	0.5	1.4
2008–16	LIN	9 396	3 542	10 080.3	0.2	0.7
2008–16	OEO	15 253	2 111	4 817.6	0.1	0.3
2008–16	ORH	22 526	3 965	10 287.5	0.3	0.7
2008–16	SBW	4 257	1 647	7 629.3	0.2	0.5
2008–16	SCI	40 212	2 957	13 114.9	0.3	0.9
2008–16	SQU	27 655	2 907	12 295.3	0.3	0.9

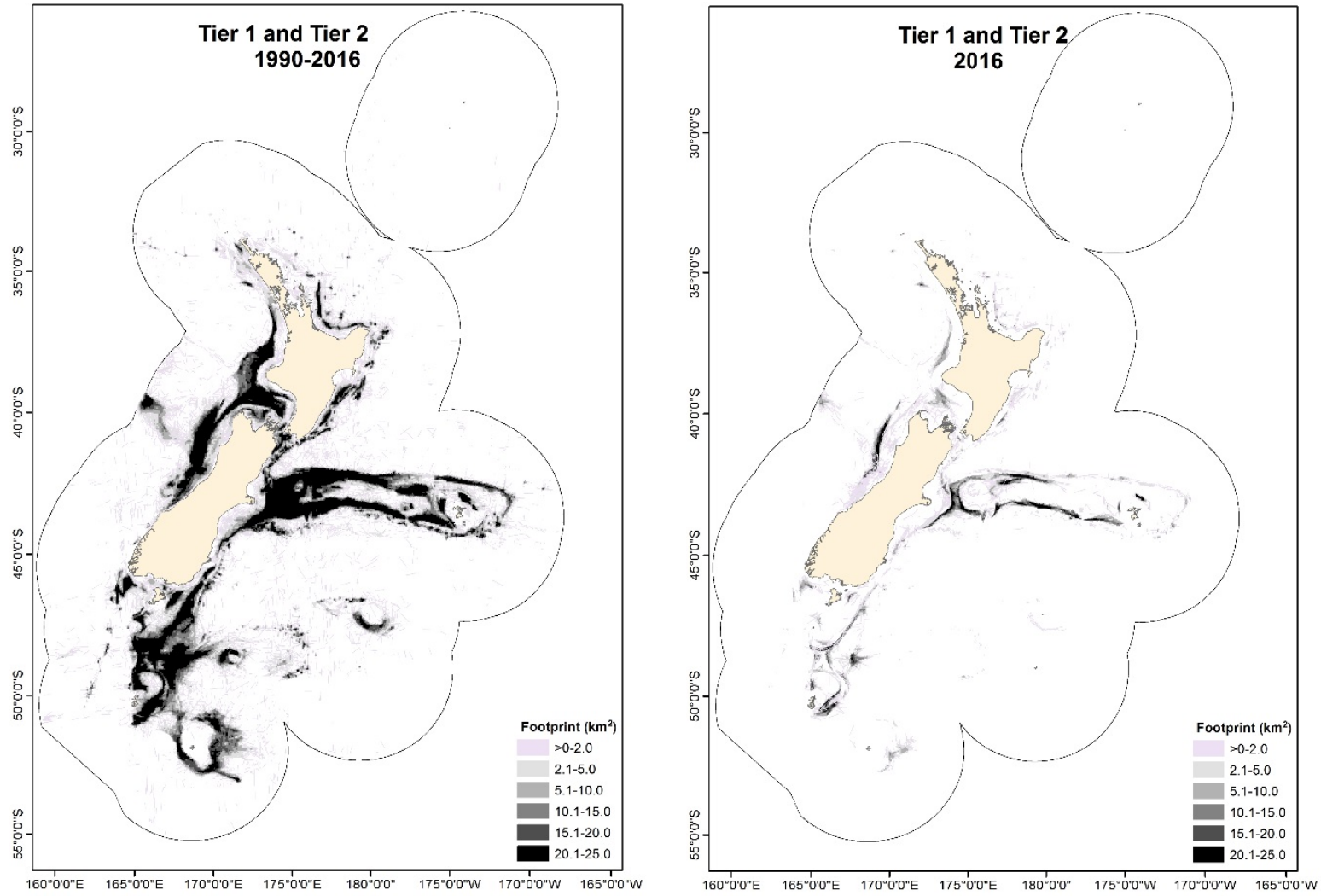

Figure 8: Bottom-contacting trawl footprint (km^2) from TCER and TCEPR data for Tier 1 and Tier 2 target species combined, within each 25-km^2 cell, for 1990–2016, 2016, and 2008–16.

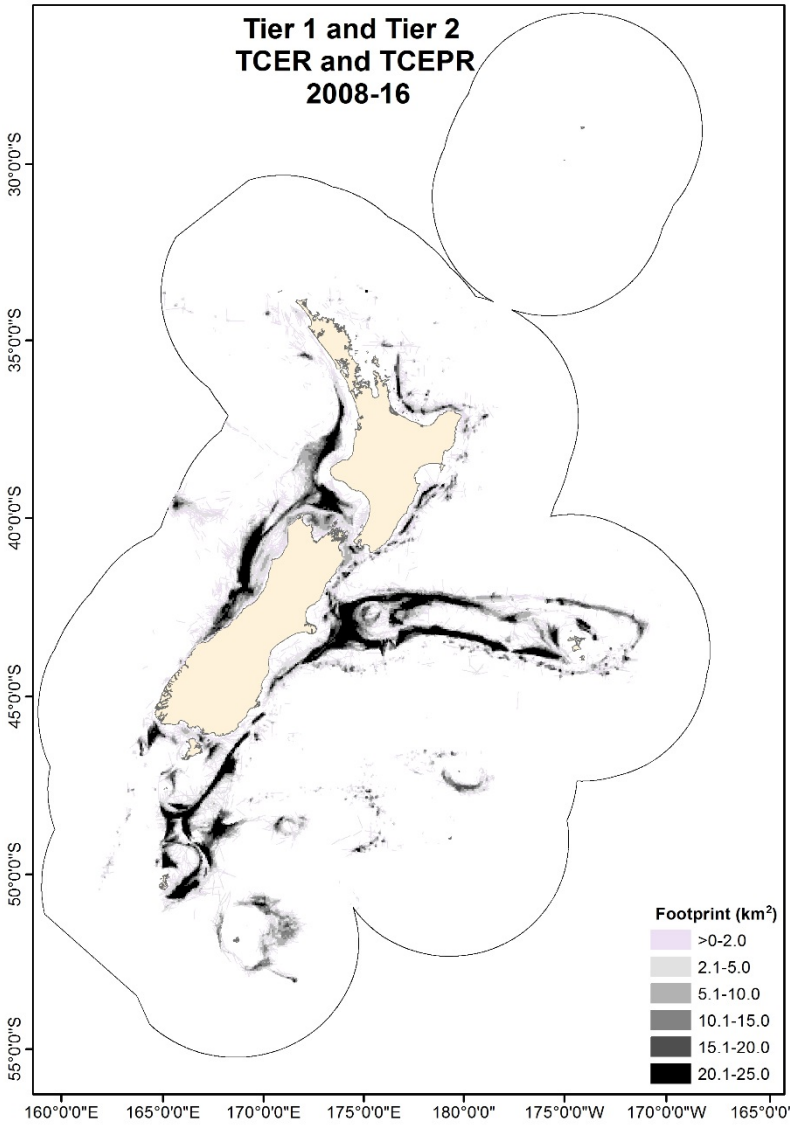

Figure 8 [Continued]

5. OVERLAP OF THE BOTTOM-CONTACTING TRAWL FOOTPRINT

GIS shapefiles of the footprint overlap data shown below are available on the DVD that accompanies this report. These files contain the underlying data and represent where the footprint overlaps the area of interest and thus may represent the full footprint, for example, where the area is within the EEZ and Territorial Sea, or a large proportion of it (for example, where the data are restricted to the 'fishable' area).

5.1 Overlap of the 200-m depth zones down to 1600 m

The 1990–2016 footprint overlap of each depth zone, expressed as the percentage contacted in each depth zone, is given for the Tier 1 targets for 1990–2016 and 2016 in Tables 3 and 4. The spatial distribution of the footprints relative to the depth zones are shown in Figures 9a–9e and Figure 10. The total hoki footprint has the greatest coverage of 200–800 m waters, contacting about 19% of the 200–400-m zone, 25% of the 400–600-m zone, and 24% of the 600–800-m zone.

In waters less than 200 m, the deepwater Tier 1 and Tier 2 targets with the greatest footprint overlap were jack mackerel species and arrow squid. Notably the inshore fleet also creates a 'footprint' which is likely greatest in the under-200-m depth zone (see Baird et al. 2015), but is not quantified here. Other deepwater targets with footprint overlap of at least 5% in the 200–400-m zone are jack mackerels, ling, scampi, and arrow squid. Hake, ling, southern blue whiting, and scampi footprints cover 3–6% of the 400–600-m zone.

In the deeper zones, orange roughy, oreo species, and hoki footprints have 4.2–7.6% overlap in 800–1000 m. The orange roughy footprint overlaps 6.3% of the 1000–1200-m zone, and oreo species have a 2.6% overlap in this zone. Orange roughy has the largest overlap in the two deepest zones, with 2% in 1200–1400 m and about 1% in 1400–1600 m.

The patterns seen for the 1990–2016 footprint for these species were similar in 2016, though the percentage overlap was substantially smaller, for only one year of footprint.

Table 3: The total area of each depth zone, all depth zones less than or equal to 1600 m combined, and the percentage of each depth zone covered by the 1990–2016 bottom-contacting trawl footprint for the Tier 1 deepwater target species.

Depth	Area	Footprint area overlap (%)									
zone (m)	(km^2)	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1
< 200	272 378	0.10	3.67	13.71	0.72	0.02	0.07	0.03	0.57	8.32	22.61
200–400	105 006	1.31	18.85	5.66	6.07	0.04	0.11	3.41	9.74	7.91	35.89
400–600	283 302	4.30	25.08	0.25	3.67	0.04	0.11	5.96	3.36	1.70	34.75
600–800	226 302	2.06	23.69	0.12	2.28	0.56	0.50	0.15	0.18	1.20	25.54
800–1000	182 709	0.52	4.49	0.03	0.13	4.22	7.64	0.02	0.10	0.22	15.35
1000–1200	186 205	0.02	0.99	0.02	0.03	2.58	6.27	0.01	0.08	0.15	9.14
1200–1400	210 881	<0.00	0.29	0.02	0.01	0.56	2.07	0.01	0.05	0.11	2.93
1400–1600	157 466	<0.00	0.21	0.01	0.01	0.23	0.98	<0.00	0.03	0.07	1.46
≤ 1600	1 624 249	1.20	10.19	2.73	1.49	0.96	2.05	1.29	1.37	2.43	19.03

Table 4: The total area of each depth zone, all depth zones less than or equal to 1600 m combined, and the percentage of each depth zone covered by the 2016 bottom-contacting trawl footprint for the Tier 1 deepwater target species.

Depth	Area	Footprint area overlap (%)									
zone (m)	(km^2)	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1
< 200	272 378	<0.01	0.05	0.95	0.04	–	<0.01	<0.01	0.01	0.79	1.83
200–400	105 006	0.01	1.29	0.09	0.26	–	<0.01	0.03	2.85	1.04	5.38
400–600	283 302	0.15	6.26	<0.01	0.24	–	<0.01	0.30	0.80	0.06	7.68
600–800	226 302	0.12	2.24	<0.01	0.07	<0.01	0.01	<0.01	<0.01	0.01	2.41
800–1000	182 709	0.01	0.19	<0.01	0.01	0.12	0.48	–	<0.01	<0.01	0.82
1000–1200	186 205	<0.01	0.03	<0.01	<0.01	0.07	0.47	–	<0.01	<0.01	0.57
1200–1400	210 881	<0.01	0.01	–	<0.01	0.01	0.16	–	<0.01	<0.01	0.17
1400–1600	157 466	–	0.01	–	<0.01	<0.01	0.04	–	<0.01	<0.01	0.05
≤ 1600	1 624 249	0.05	1.52	0.17	0.08	0.02	0.13	0.05	0.33	0.21	2.51

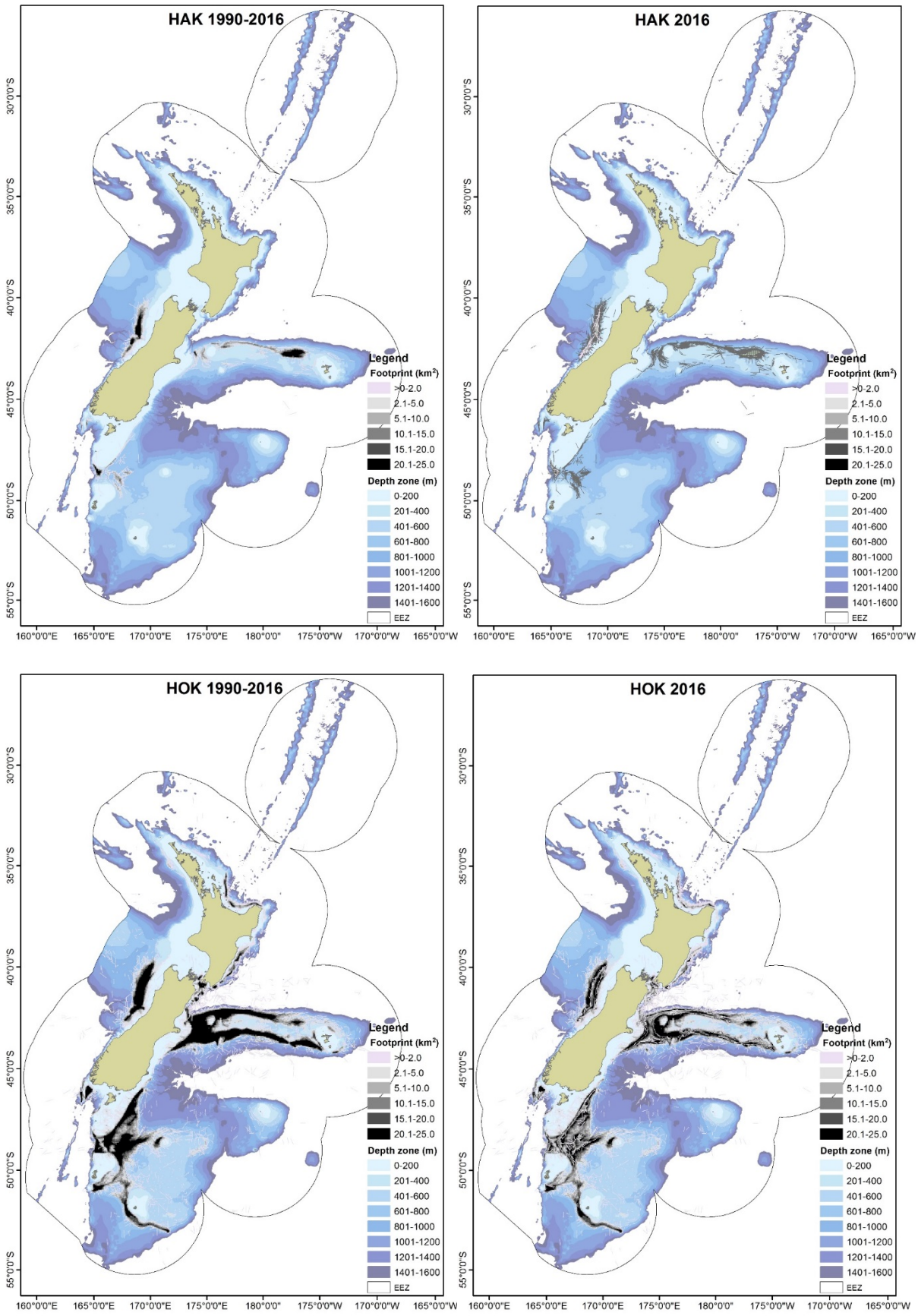

Figure 9a: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for hake (top) and hoki (bottom), relative to the 200-m depth zones.

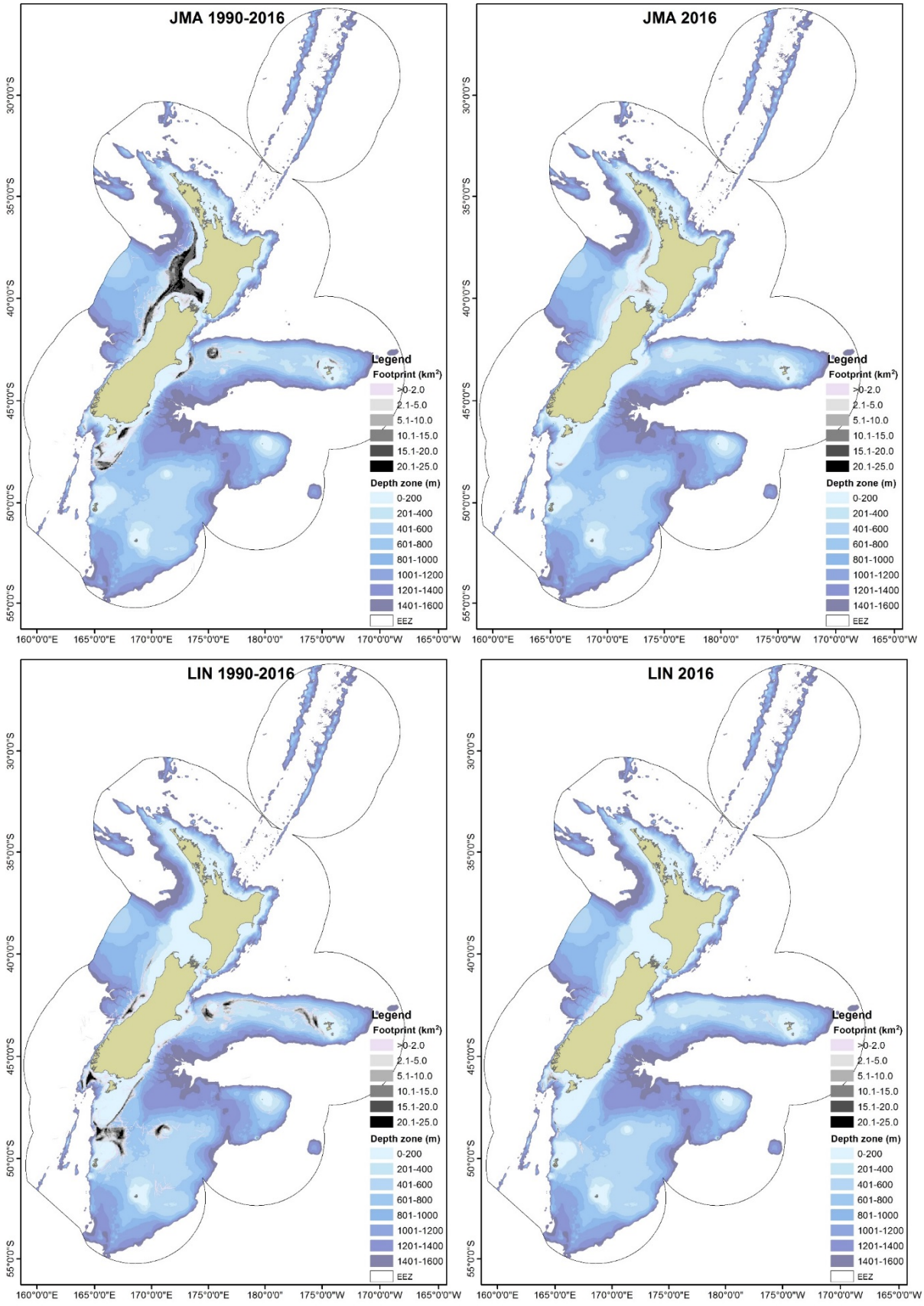

Figure 9b: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for jack mackerel species (top) and ling (bottom), relative to the 200-m depth zones.

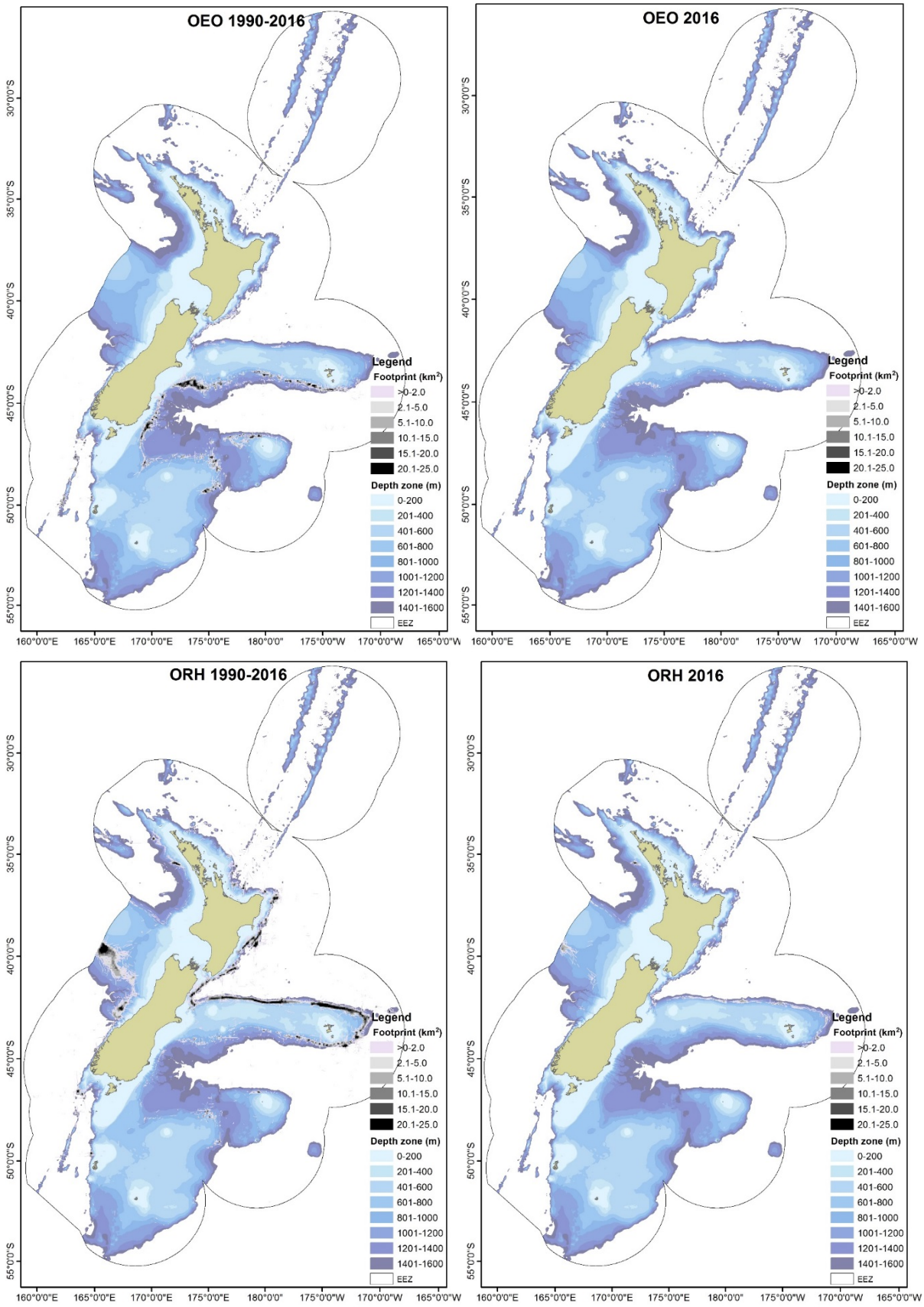

Figure 9c: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for oreo species (top) and orange roughy (bottom), relative to the 200-m depth zones.

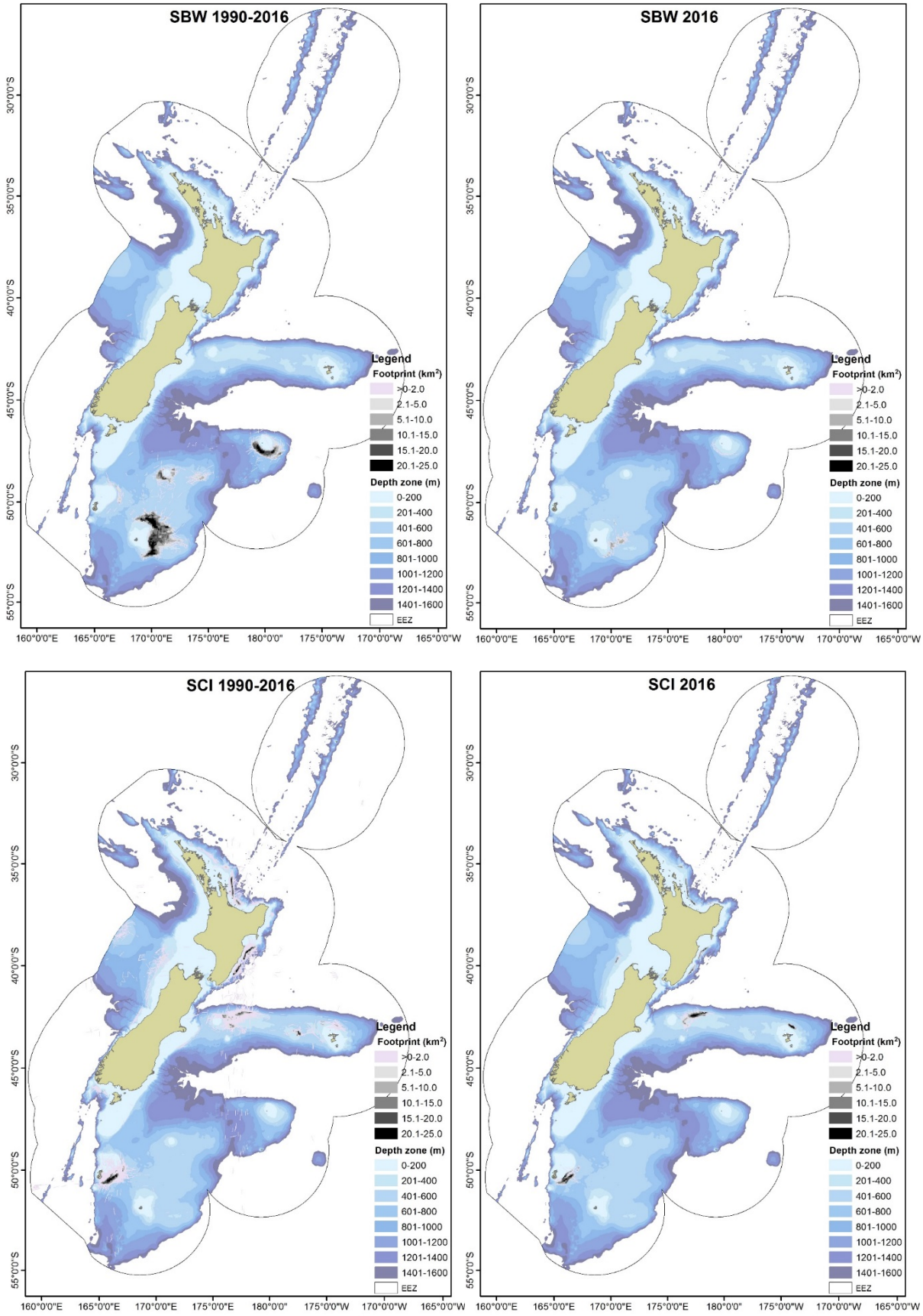

Figure 9d: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for southern blue whiting (top) and scampi (bottom), relative to the 200-m depth zones.

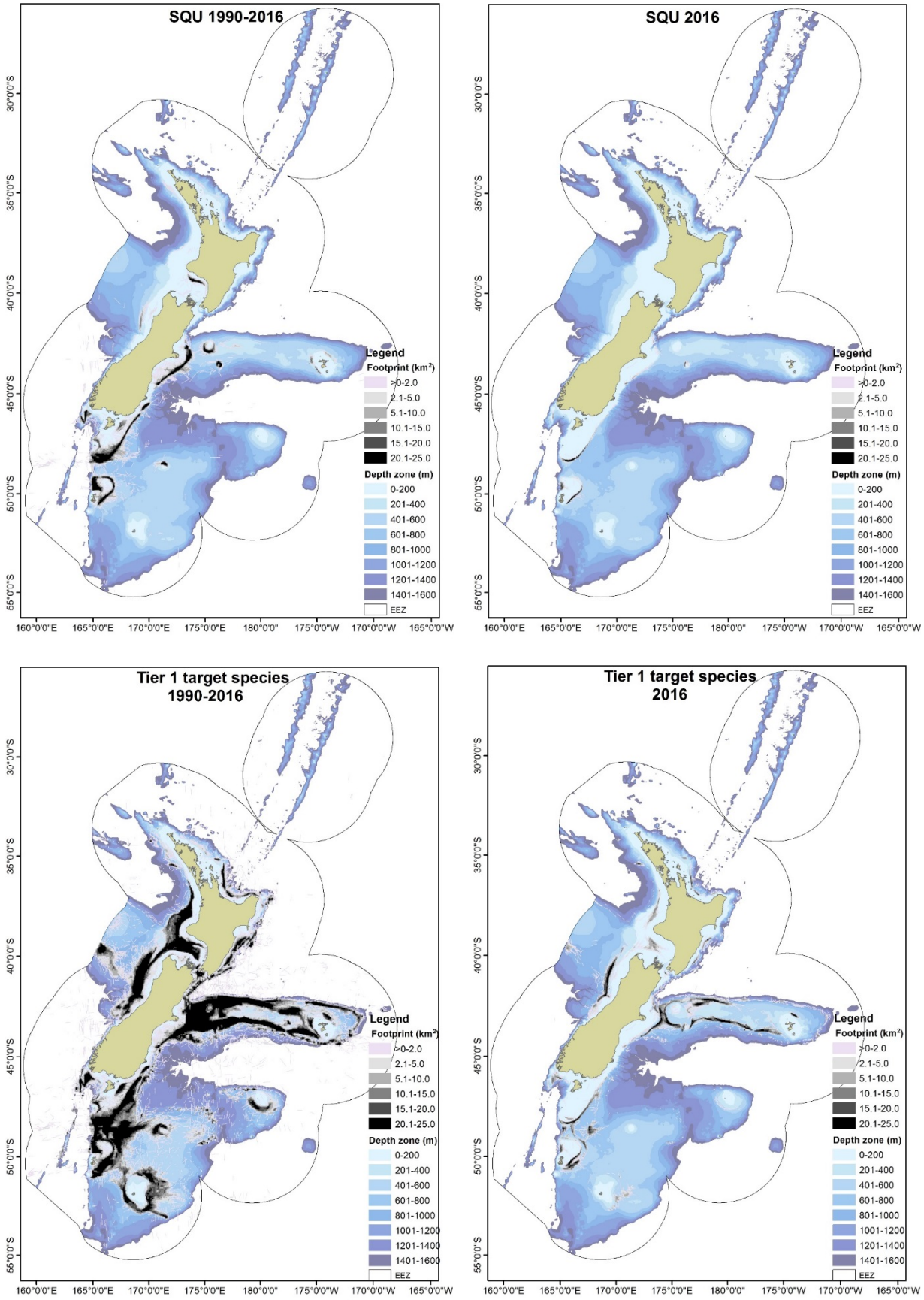

Figure 9e: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for arrow squid (top) and all Tier 1 species combined (bottom), relative to the 200-m depth zones.

For the all-year, combined Tier 1 and Tier 2 target species, the percentage overlap is over 25% in the waters shallower than or equal to 800 m, with the greatest percentage overlap in the zone with the smallest area (200–400 m) at about 39% (Table 5, Figure 10). The 2016 combined Tier 1 and Tier 2 target species overlap is also greatest in waters shallower than or equal to 800 m, with a maximum of about 8% overlap in the 400–600-m zone.

Table 5: The total area of each depth zone and the percentage of each depth zone covered by the 1990–2016 and 2016 bottom-contacting trawl footprints for the Tier 1 and Tier 2 deepwater target species combined.

Depth zone (m)	Area (km^2)	Footprint area overlap (%)	
		1990–2016	2016
< 200	272 378	28.05	2.54
200–400	105 006	39.19	5.99
400–600	283 302	35.24	7.88
600–800	226 302	26.00	2.47
800–1000	182 709	15.62	0.84
1000–1200	186 205	9.30	0.58
1200–1400	210 881	3.01	0.18
1400–1600	157 466	1.54	0.06
≤ 1600	1 624 249	20.37	2.72

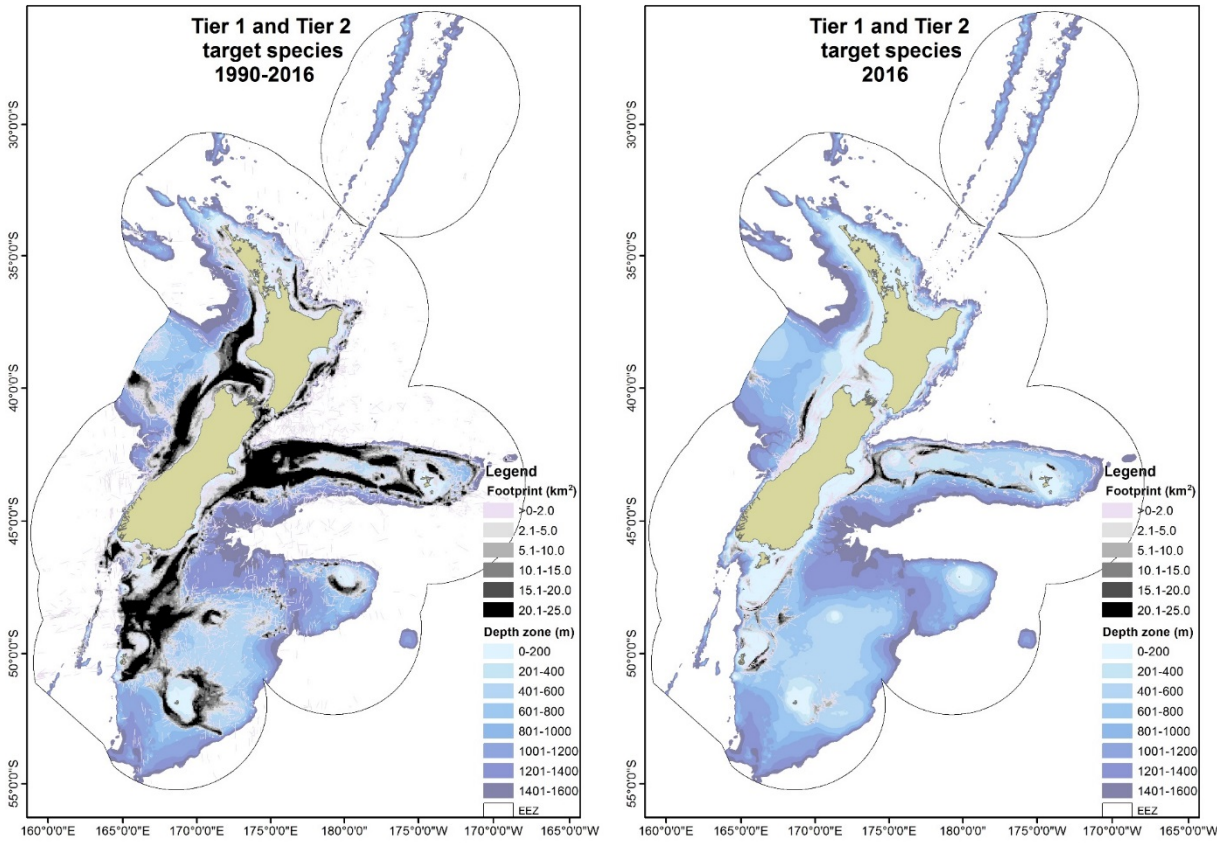

Figure 10: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for all Tier 1 and Tier 2 species combined (bottom), relative to the 200-m depth zones.

5.2 Overlap of the bottom-contacting trawl footprint and BOMEC

For the Tier 1 targets in 1990–2016, the greatest percent overlaps are evident in the BOMEC classes G, H, and I (see Figure B1 in Appendix B) when hoki was targeted, classes C and E when jack mackerel was targeted, and classes E and F from arrow squid effort (Table 6, Figures 11a–11e). The class with the highest species overlap is class I, which has an area of 52 000 km^2, and the hoki footprint covers 67% of the class, with the arrow squid footprint covering 9%. Similarly, the hoki overlap is equivalent to 30% of the area of class G, but this class is small in area relative to others. The patterns of overlap seen for the targets and BOMEC classes in 2016 (Table 7) are similar to those in 1990–2016.

Classes in predominantly deeper water, but not out to 3000 m, such as classes J, L, and M, cover the largest areas of seafloor within fishing depths and the percentage overlap is appreciably smaller: with 12% for hoki overlap and 8% for orange roughy in class J; 16% for hoki and 8% for southern blue whiting in class L; and 5% for hoki and 3% for oreo species in class M. Overlap statistics are very low (1 or less) where the classes are predominantly in waters too deep for trawling (class N and class O) or where classes are mainly in shallower depths infrequently fished by deepwater fleet vessels (class A and class K).

Table 6: The total area of each BOMEC class and the percentage of each area covered by the 1990–2016 bottom-contacting trawl footprint for the Tier 1 deepwater target species and for the Tier 1 species combined. Note there are some large differences in the areas of some classes. – indicates no overlap.

BOMEC		Footprint area overlap (%)									
class	Area (km^2)	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1
A	27 557.0	–	0.16	0.22	0.01	<0.01	0.09	<0.01	0.07	1.08	1.60
B	12 420.0	0.16	2.95	0.35	1.47	<0.01	0.04	0.05	0.02	0.24	5.05
C	89 710.2	0.08	2.06	26.71	0.32	<0.01	0.07	<0.01	0.55	1.32	30.51
D	27 267.9	0.05	1.99	1.55	0.40	0.04	0.10	0.01	0.01	3.26	6.00
E	60 989.8	0.39	8.95	14.17	1.79	0.09	0.03	<0.01	0.18	23.49	32.17
F	38 608.5	0.05	0.99	0.25	1.03	0.01	<0.01	5.09	0.87	11.82	18.33
G	6 341.9	0.78	29.85	0.28	10.01	0.04	0.94	–	2.02	0.08	39.49
H	138 551.4	5.49	28.24	7.18	6.25	0.03	0.12	0.02	8.92	4.97	43.10
I	52 223.9	3.80	66.65	0.58	7.65	0.37	0.21	4.03	0.10	8.93	73.75
J	311 360.4	2.60	12.03	0.25	0.65	2.20	7.82	<0.01	0.91	0.55	21.99
K	1 289.1	–	0.18	–	–	–	0.06	–	–	–	0.24
L	198 577.0	0.57	15.71	0.03	3.33	0.04	<0.01	8.15	2.83	2.13	27.19
M	233 825.5	0.09	4.64	<0.01	0.08	2.59	0.35	0.27	0.02	0.16	7.75
N	493 034.7	0.01	0.35	0.01	0.01	0.45	1.55	<0.01	0.04	0.08	2.29
O	935 315.2	<0.01	0.11	<0.01	<0.01	0.04	0.13	<0.01	0.02	0.02	0.33
All	2 627 072.6	0.74	6.35	1.69	0.92	0.61	1.32	0.80	0.85	1.51	11.90

Table 7: The total area of each BOMEC class and the percentage of each area covered by the 2016 bottom-contacting trawl footprint for the Tier 1 deepwater target species and for the Tier 1 species combined. – indicates no overlap.

BOMEC		Footprint area overlap (%)									
class	Area (km^2)	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1
A	27 557.0	–	<0.01	–	–	–	–	–	–	–	<0.00
B	12 420.0	<0.01	0.13	<0.01	0.09	–	–	–	<0.01	–	0.23
C	89 710.2	<0.01	0.06	2.38	0.03	–	<0.01	–	0.01	–	2.48
D	27 267.9	–	0.04	0.02	0.04	–	–	–	–	0.09	0.18
E	60 989.8	<0.01	0.17	0.44	0.10	–	–	–	–	2.16	2.80
F	38 608.5	–	<0.01	–	0.01	–	–	0.03	0.01	1.14	1.19
G	6 341.9	0.09	2.23	0.01	0.92	–	–	–	0.18	<0.01	3.39
H	138 551.4	0.04	4.23	0.21	0.31	–	<0.01	–	2.32	0.28	7.26
I	52 223.9	0.42	19.19	–	0.27	<0.01	<0.01	0.10	–	0.54	20.22
J	311 360.4	0.14	1.99	<0.01	0.12	0.05	0.52	–	0.14	<0.01	2.91
K	1 289.1	–	–	–	–	–	–	–	–	–	0.00
L	198 577.0	<0.01	0.92	–	0.06	<0.01	–	0.39	0.82	0.48	2.61
M	233 825.5	–	0.19	–	<0.01	0.08	<0.01	0.01	–	<0.01	0.29
N	493 034.7	–	0.01	–	<0.01	<0.01	0.11	–	<0.01	0.001	0.13
O	935 315.2	–	<0.01	–	–	<0.01	<0.01	–	<0.01	–	0.01
All	2 627 072.6	0.03	0.942	0.10	0.05	0.01	0.08	0.03	0.20	0.130	1.56

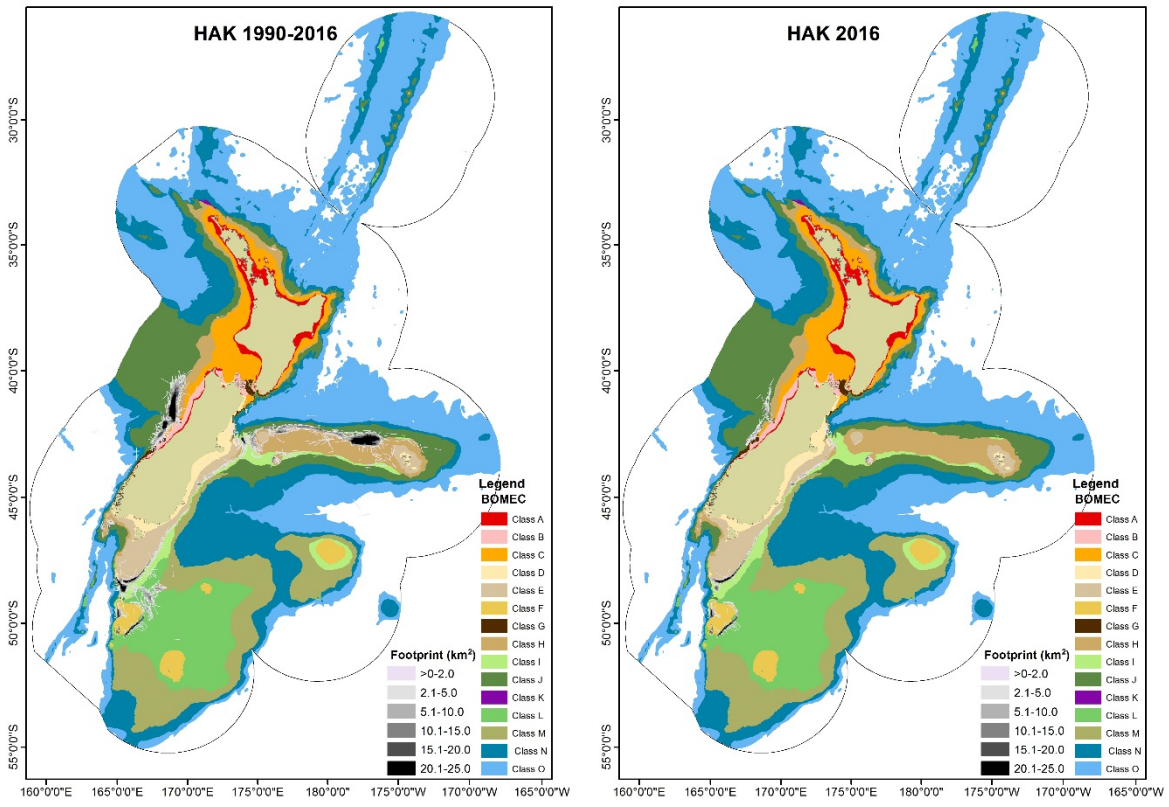

Figure 11a: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for hake, relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

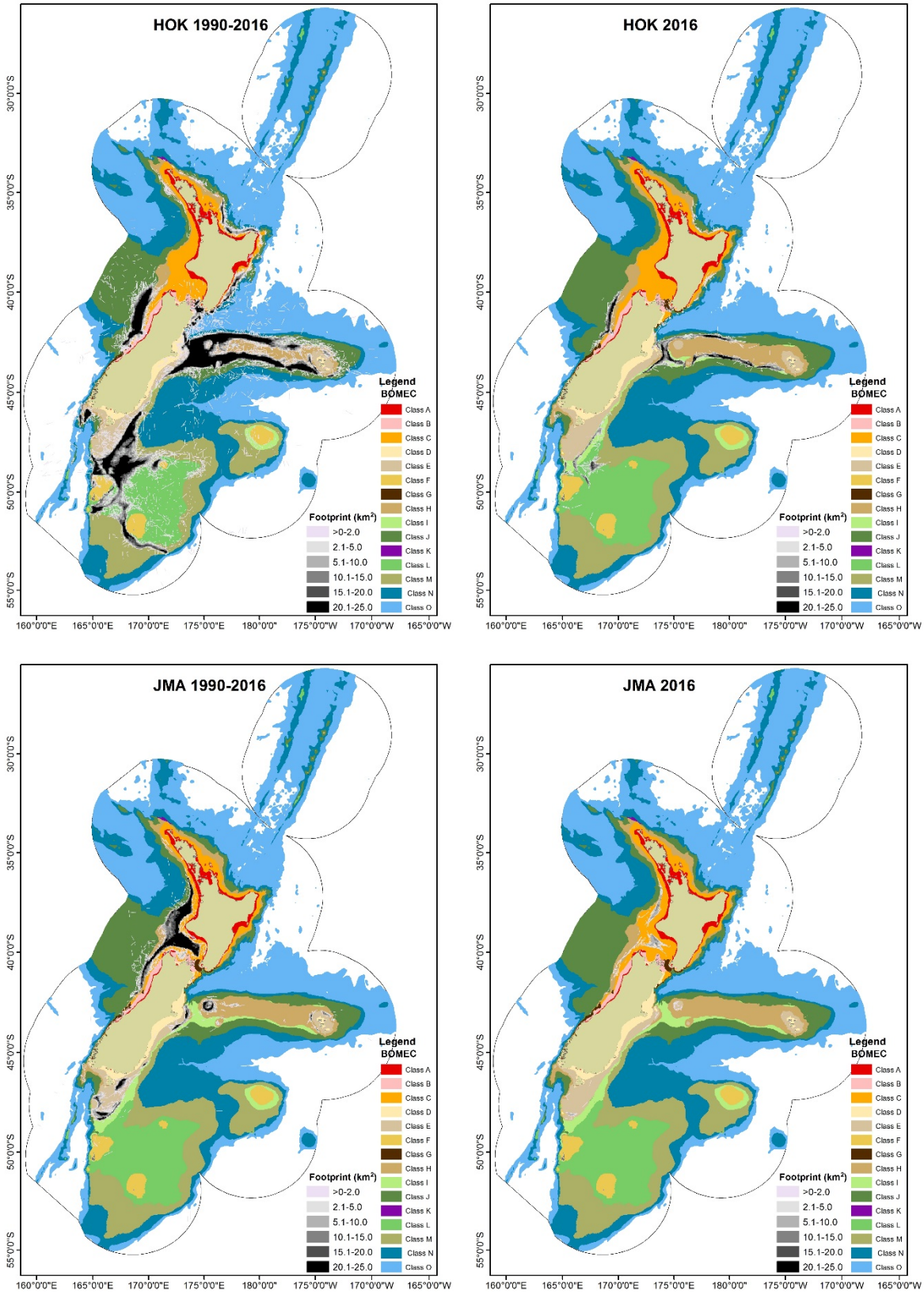

Figure 11b: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for hoki (top) and jack mackerel species (bottom), relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

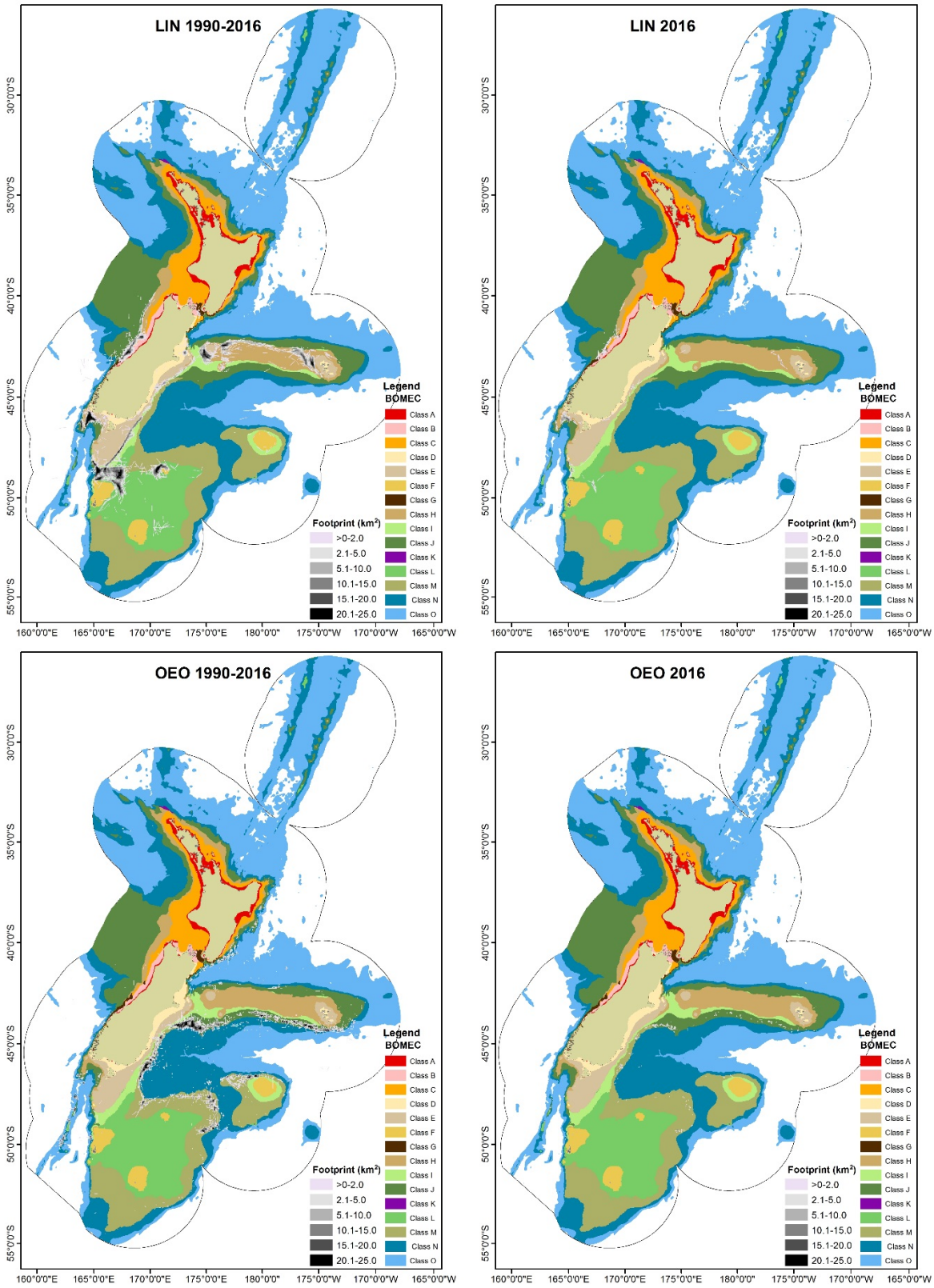

Figure 11c: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for ling (top) and oreo species (bottom), relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

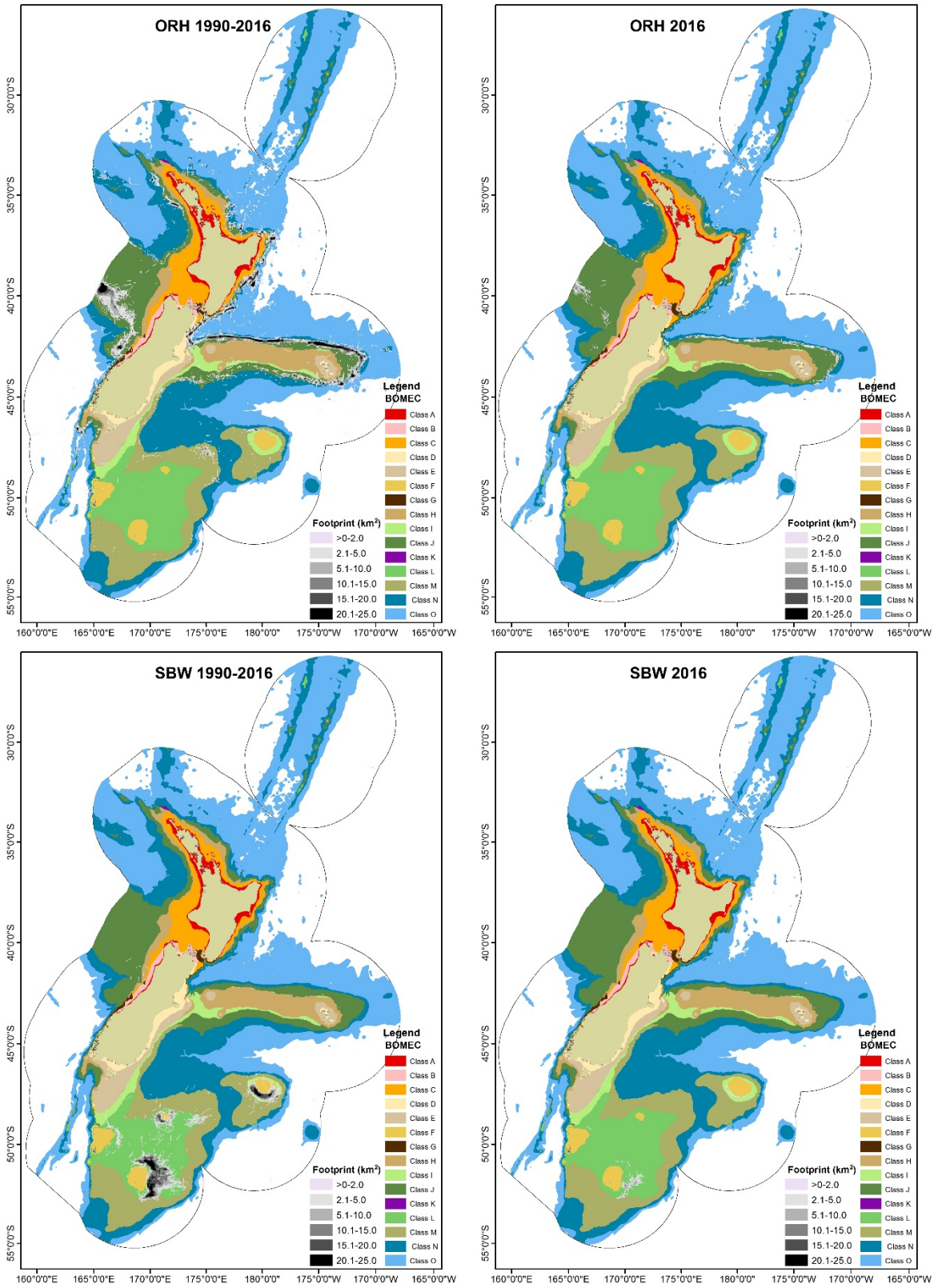

Figure 11d: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for orange roughy (top) and southern blue whiting (bottom), relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

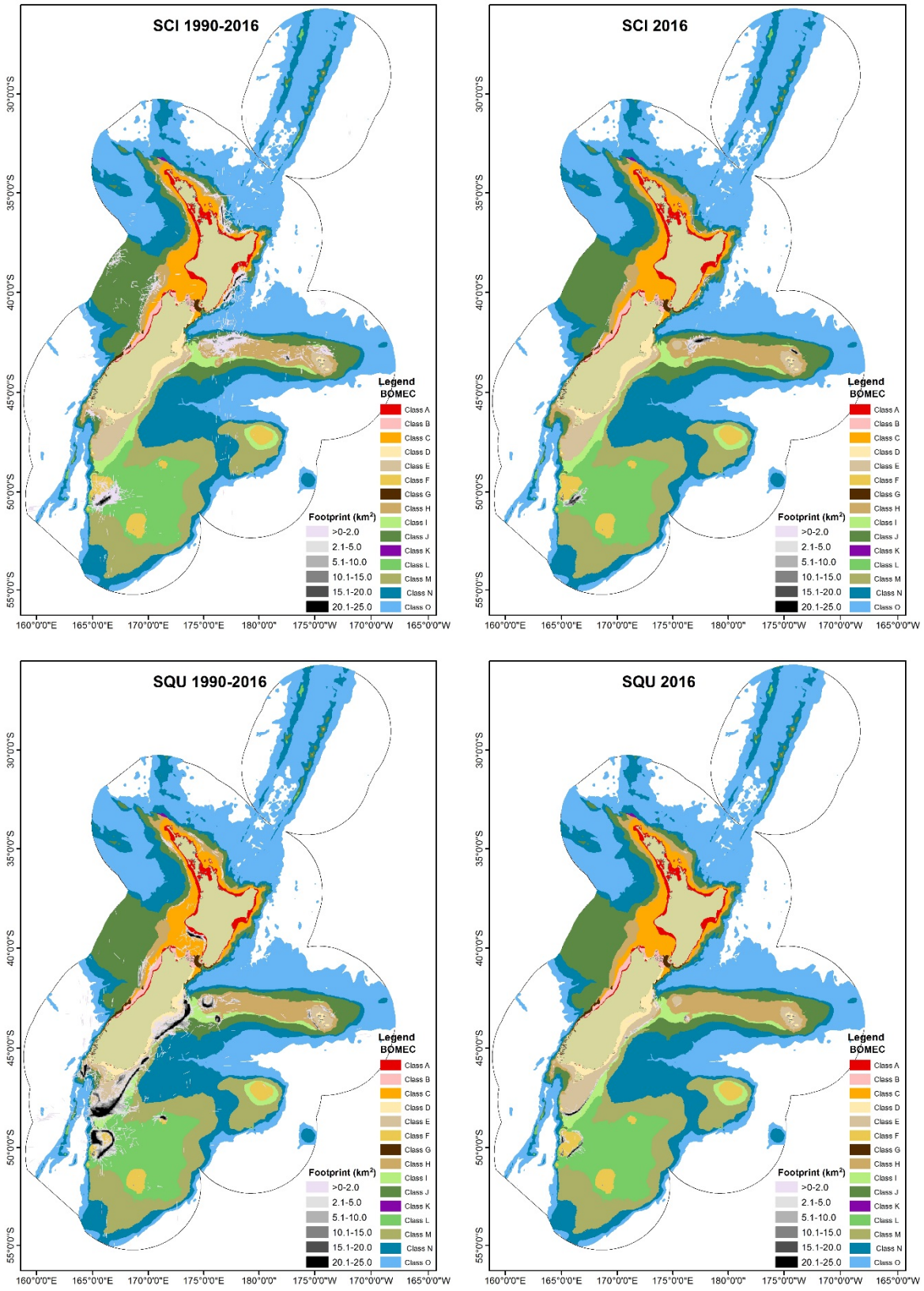

Figure 11e: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for scampi (top) and arrow squid (bottom), relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

The all-year, combined Tier 1 and Tier 2 species footprint was largely determined by the distribution of the Tier 1 species and had the greatest overlap in class I, at 74% as a combination of arrow squid and hoki effort (Table 8, Figure 12). About 52% of class G (small area in Cook Strait region) was covered by the total footprint, 46% of class H (across the Chatham Rise), 37% of class C by jack mackerel species effort off the west coast of the North Island and upper South Island, and 37% of class E by mainly jack mackerel and arrow squid effort on the shelf off the South Island east coast. Tier 2 targets contributed more than Tier 1 targets to the class B overlap of 23% in inshore waters off the South Island west coast.

The BOMEC classes with the smallest total footprint overlap were in areas where there was little fishing for the deepwater targets for the fishstocks being considered (see Figure 12).

Table 8: The total area of each BOMEC class and the percentage of each area covered by the 1990–2016 and the 2016-only bottom-contacting trawl footprints for the Tier 1 and Tier 2 deepwater target species.*

BOMEC class	Area (km^2)	1990–2016 (%)	2016 (%)
A	27 557.0	5.2	<0.1
B	12 420.0	23.3	1.9
C	89 710.2	37.4	3.0
D	27 267.9	9.8	0.4
E	60 989.8	37.4	4.8
F	38 608.5	18.4	1.2
G	6 341.9	51.5	5.6
H	138 551.4	46.1	8.1
I	52 223.9	74.1	21.2
J	311 360.4	22.7	3.1
K	1 289.1	0.2	0.0
L	198 577.0	27.3	2.7
M	233 825.5	7.8	0.3
N	493 034.7	2.4	0.1
O	935 315.2	0.4	<0.1
All	2 627 072.6	12.7	1.7

* A comparison with Table 9 of Black & Tilney (2017) shows a decrease in the latest report of the percentage footprint coverage from 1990–2016 of areas A, C, D, E. This appears due to the faulty inclusion of some inshore stocks in the Black and Tilney (2017) report where stocks of a species are shared between deepwater and inshore fisheries management, e.g., JMA, LIN, BAR and some other Tier 2 species.

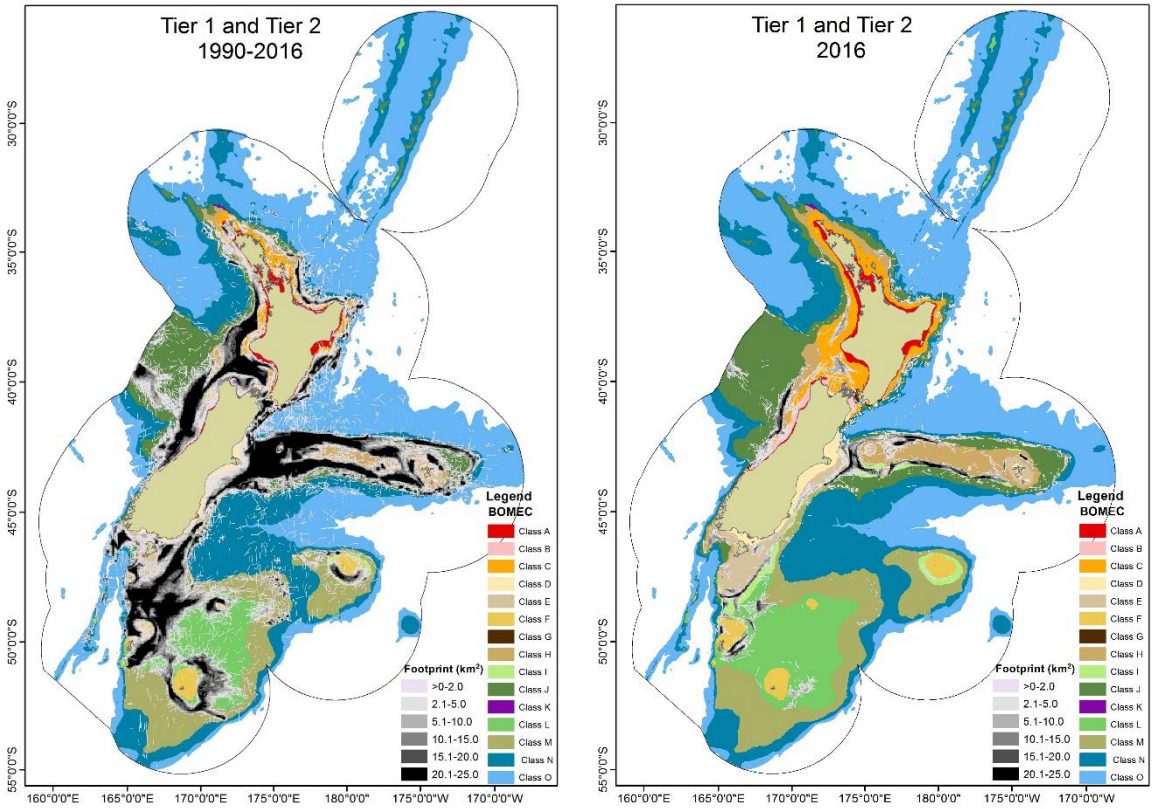

Figure 12: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for Tier 1 and Tier 2, relative to the 15 BOMEC classes (to depths of 3000 m) (after Leathwick et al. 2012).

5.3 Overlap of the bottom-contacting trawl footprint and preferred fish habitat/annual distribution for Tier 1 species

Overlap of each Tier 1 species footprint on their 'preferred habitat' distribution for the seven fish species (or annual distribution for scampi and arrow squid) is shown in Figures 13a–13d and the percentage overlap is given in Table 9. This overlap is presented as the percent overlap for the probability of capture of a fish from a standardised trawl, where 91–100% is the body of water in which a trawl is most likely to capture the species. The footprint overlaps of the annual distributions for scampi and arrow squid are given in Table 9 and Figure 14.

These fish distributions are considered to represent the likely availability of a species to bottom trawl gear, being based on research bottom trawl surveys optimised for a selection of fish species and undertaken in specific areas at specific times of the year. For most Tier 1 targets, the target-specific footprint has the greatest overlap in waters with the highest predicted probability; the exceptions being hake and jack mackerel which are targeted using bottom trawl and midwater trawls. These species have relatively small proportions of their predicted distribution in the 91–100% group, and the footprints show the highest overlap in waters of greater than 60% probability. The overlap plots for these species indicate that the footprints are very close to the areas of 91–100%, which are in deeper areas for hake, for example, and in shallower areas for jack mackerels. The jack mackerel distribution represents a combination of three species and any depth/area differences may be a result of individual species preferences for these schooling species, particularly given that one of the main drivers of the predicted distribution is depth (see Leathwick et al. 2006).

Another consideration when comparing the fish predicted distribution with the trawl footprint is that the footprints represent the deepwater target fishstocks (see Table 1), and for jack mackerels and ling this restricts the extent of the footprint within the EEZ; for example, jack mackerel to JMA 3 and JMA 7.

Table 9: The total area of each preferred habitat and the percentage of each species' 'preferred habitat' (probability of capture) area (for HAK, HOK, JMA, LIN, OEO, ORH and SBW) or annual distribution (for SCI and SQU) covered by the 1990–2016 and 2016 bottom-contacting trawl footprint for the Tier 1 deepwater target species.

Preferred habitat (%)	HAK Area (km^2)	HAK Footprint overlap (%)		HOK Area (km^2)	HOK Footprint overlap (%)		JMA Area (km^2)	JMA Footprint overlap (%)	
		1990–2016	2016		1990–2016	2016		1990–2016	2016
0	202 097	0.12	0.00	204 964	0.16	0.01	1 418 076	0.06	0.00
1–10	1 026 654	0.11	0.00	733 939	0.91	0.02	150 038	1.41	0.02
11–20	170 408	0.33	0.01	134 901	2.70	0.10	54 084	4.04	0.06
21–30	103 565	0.53	0.01	59 165	4.29	0.19	49 732	11.35	0.29
31–40	79 792	1.05	0.02	42 155	5.49	0.27	42 506	14.67	0.49
41–50	72 627	2.23	0.08	34 019	7.18	0.46	37 320	11.78	0.51
51–60	67 559	3.33	0.25	32 943	7.88	0.53	33 291	14.91	1.21
61–70	63 800	4.40	0.30	35 693	7.20	0.76	36 193	25.11	2.20
71–80	56 649	9.42	0.32	39 001	9.49	0.97	28 729	22.36	1.50
81–90	26 713	14.73	0.24	64 032	9.87	1.33	14 934	16.75	3.13
91–100	3 067	8.16	0.08	492 119	26.97	4.55	8 030	0.59	0.00
All	1 872 931	1.04	0.04	1 872 931	8.86	1.32	1 872 933	2.37	0.14

Table 9 [Continued]

Preferred habitat (%)	LIN Area (km^2)	LIN Footprint overlap (%) 1990–2016	LIN Footprint overlap (%) 2016	OEO Area (km^2)	OEO Footprint overlap (%) 1990–2016	OEO Footprint overlap (%) 2016	ORH Area (km^2)	ORH Footprint overlap (%) 1990–2016	ORH Footprint overlap (%) 2016
0	26 441	0.00	0.00	706 800	0.042	0.00	994 473	0.09	0.00
1–10	1 004 746	0.02	0.00	556 069	0.117	0.00	365 503	0.30	0.01
11–20	114 741	0.31	0.01	114 076	0.226	0.00	73 394	0.94	0.06
21–30	77 477	1.24	0.04	70 741	0.358	0.00	49 725	1.18	0.09
31–40	47 409	2.10	0.09	48 614	0.373	0.01	36 247	1.24	0.08
41–50	36 658	2.80	0.15	44 832	0.446	0.00	30 953	1.51	0.09
51–60	40 624	2.28	0.13	45 664	0.511	0.01	31 241	1.44	0.06
61–70	35 529	2.58	0.14	48 856	0.847	0.01	39 780	1.42	0.07
71–80	48 160	2.32	0.17	62 442	1.833	0.02	49 936	1.68	0.11
81–90	106 259	2.79	0.13	81 103	3.409	0.07	57 127	2.96	0.15
91–100	334 887	4.41	0.23	93 734	9.979	0.30	144 552	18.17	1.27
All	1 872 931	1.29	0.07	1 872 931	0.841	0.02	1 872 931	1.82	0.12

Table 9 [Continued]

Preferred habitat (%)	SBW Area (km^2)	SBW Footprint overlap (%) 1990–2016	SBW Footprint overlap (%) 2016	SCI Annual distribution*	SCI Area (km^2)	SCI Footprint overlap (%) 1990–2016	SCI Footprint overlap (%) 2016	SQU Area (km^2)	SQU Footprint overlap (%) 1990–2016	SQU Footprint overlap (%) 2016
0	1 197 845	0.01	0.00	None	3 615 226	0.04	<0.01	2 953 821	0.11	0.00
1–10	471 015	0.17	0.00	Hotspot	15 122	35.48	8.67	58 591	26.47	1.38
11–20	22 369	2.18	0.03	90% population	78 404	14.26	3.14	251 879	12.03	1.23
21–30	15 581	2.50	0.03	100% population	496 344	4.25	1.07	1 157 748	6.33	0.58
31–40	12 632	2.81	0.08							
41–50	11 644	2.68	0.03							
51–60	10 187	4.29	0.04							
61–70	9 455	5.97	0.06							
71–80	12 704	8.74	0.07							
81–90	26 675	12.32	0.18							
91–100	82 824	15.82	0.94							
All	1 872 931	1.12	0.05							

***** For SCI and SQU, the areas given here represent the areas shown for the annual distribution for scampi and arrow squid provided by MPI at www.nabis.govt.nz. The 'None' category is the area outside the 100% population area within the combined EEZ and Territorial Sea.

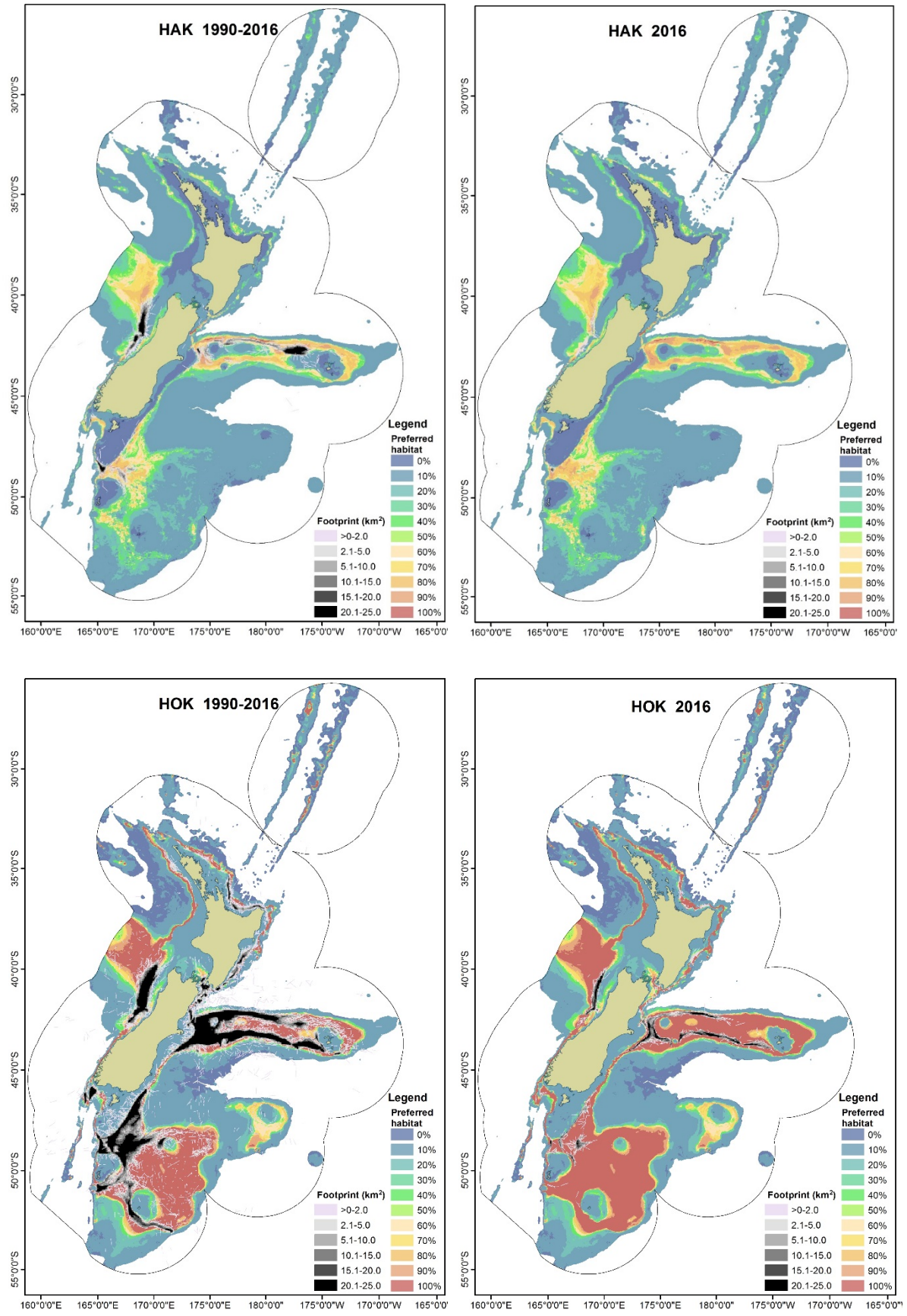

Figure 13a: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for hake (top) and hoki (bottom), relative to the predicted distribution of the preferred habitat for that species (after Leathwick et al. 2006).

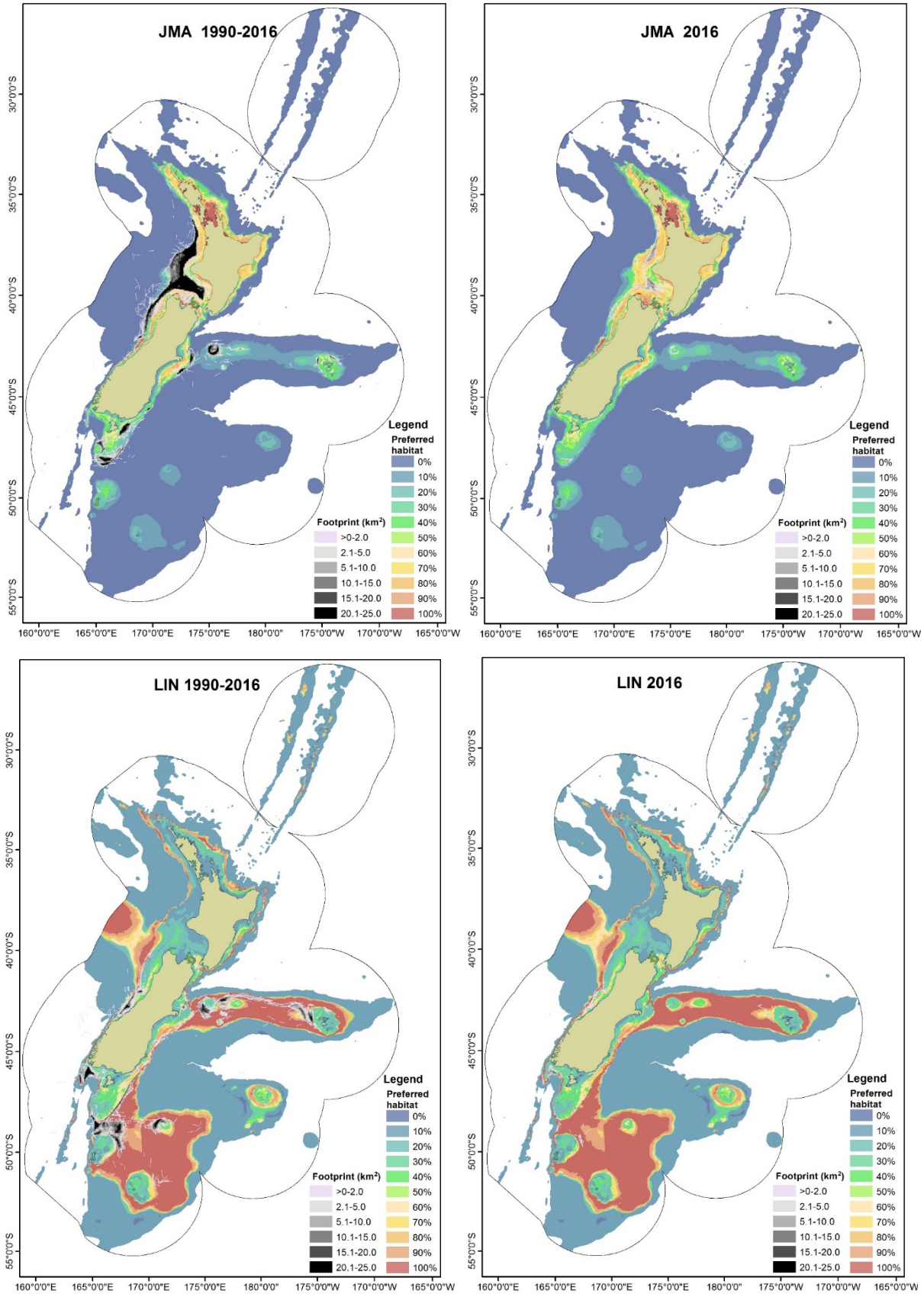

Figure 13b: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for jack mackerel species (top) and ling (bottom), relative to the predicted distribution of the preferred habitat for that species (after Leathwick et al. 2006).

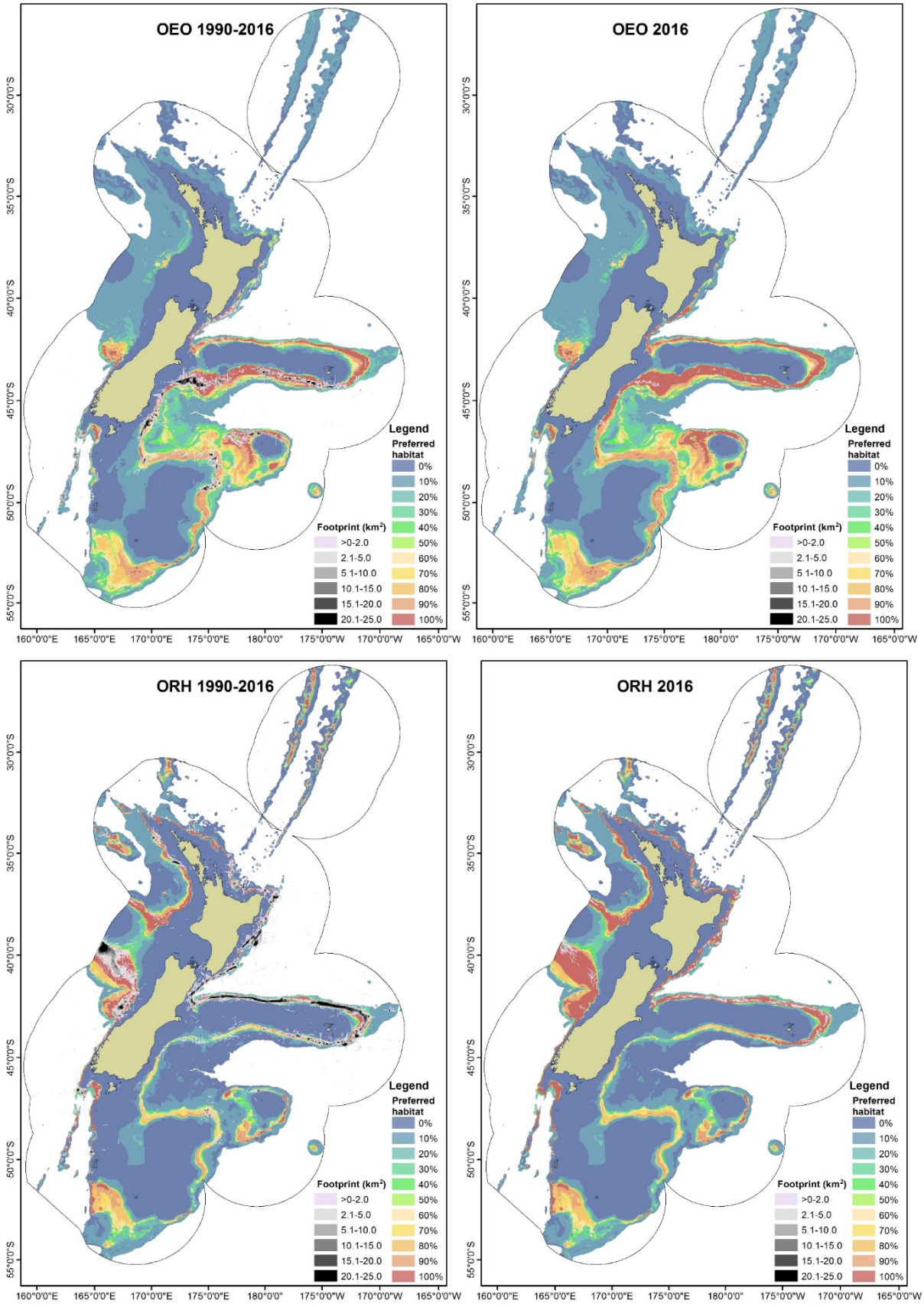

Figure 13c: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for oreo species (top) and orange roughy (bottom), relative to the predicted distribution of the preferred habitat for that species (after Leathwick et al. 2006).

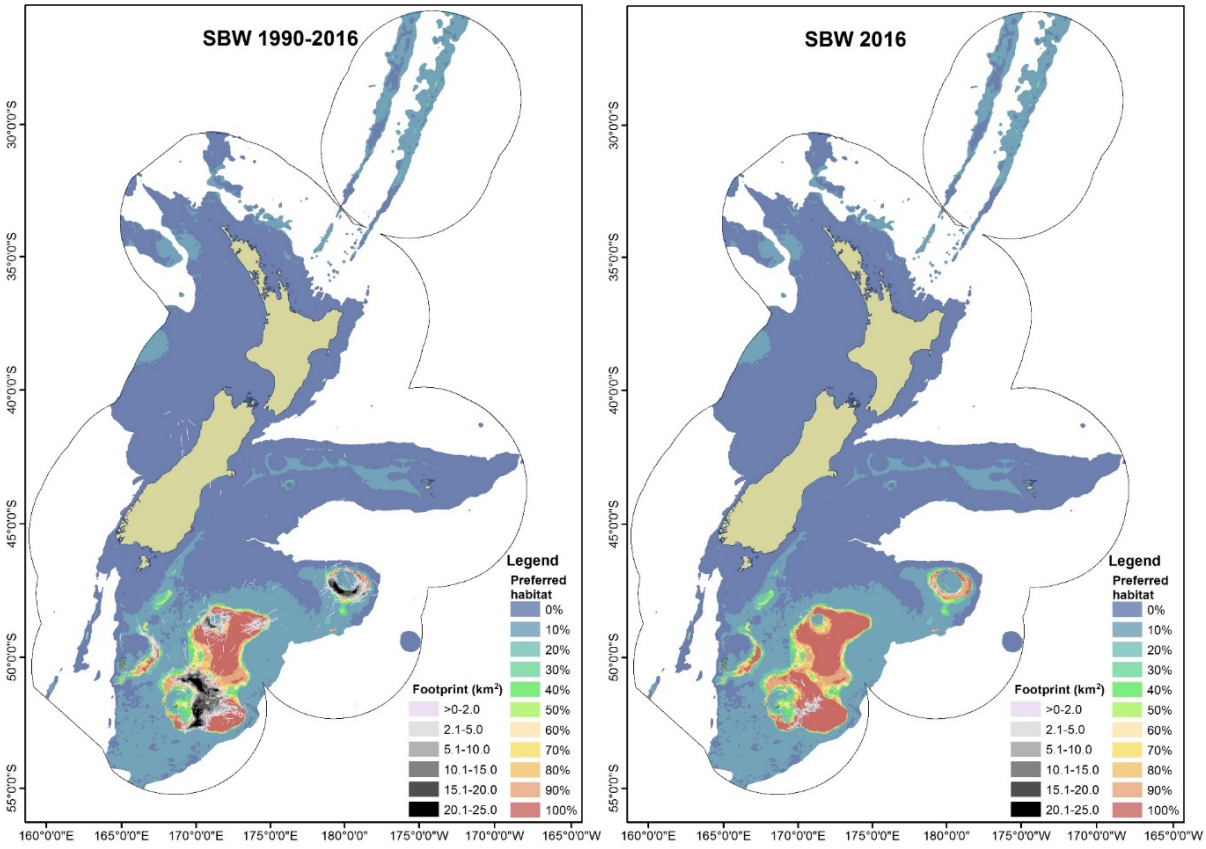

Figure 13d: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for southern blue whiting, relative to the predicted distribution of the preferred habitat for that species (after Leathwick et al. 2006).

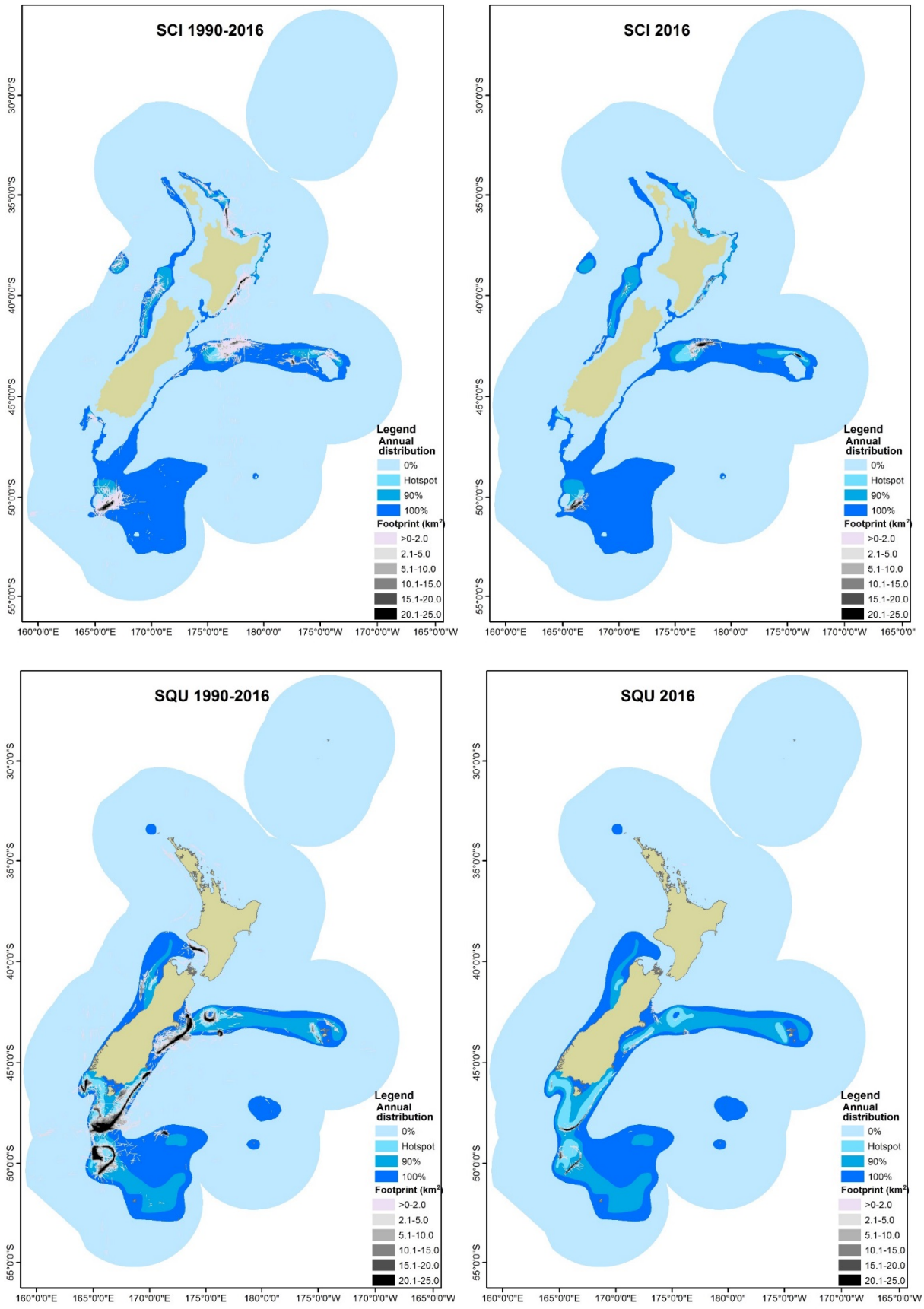

Figure 14: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for scampi (top) and arrow squid (bottom), relative to the annual distribution of the species population (see www.nabis.govt.nz).

5.4 Overlap of the bottom-contacting trawl footprint and 'fishable' area for Tier 1 and Tier 2 species

The overlap statistics of the trawl footprint on the 'fishable' area are given in Table 2 and the 1990–2016 and 2016 overlap is shown in Figure 15. About 23.5% of the fishable area was contacted by trawl gear, 22% by Tier 1 targets, with hoki covering the greatest area, at about 12%. The jack mackerel 1990–2016 and the arrow squid footprints both covered about 3%.

In the 2008–16 period, the Tier 1 and Tier 2 footprint covered 11.3% of the 'fishable' area, compared with the 10.0% covered by the Tier 1 target footprint. Again, hoki had the greatest overlap (4.8%), with jack mackerel next at 1.4%, and arrow squid and scampi at about 1%. A relative increase in the footprint and consequent overlap in 2016 for scampi is evident in Table 2. For 2016, 3.2% of the 'fishable' area was covered by the footprint of Tier 1 and Tier 2 targets, and 2.9% for Tier 1 species.

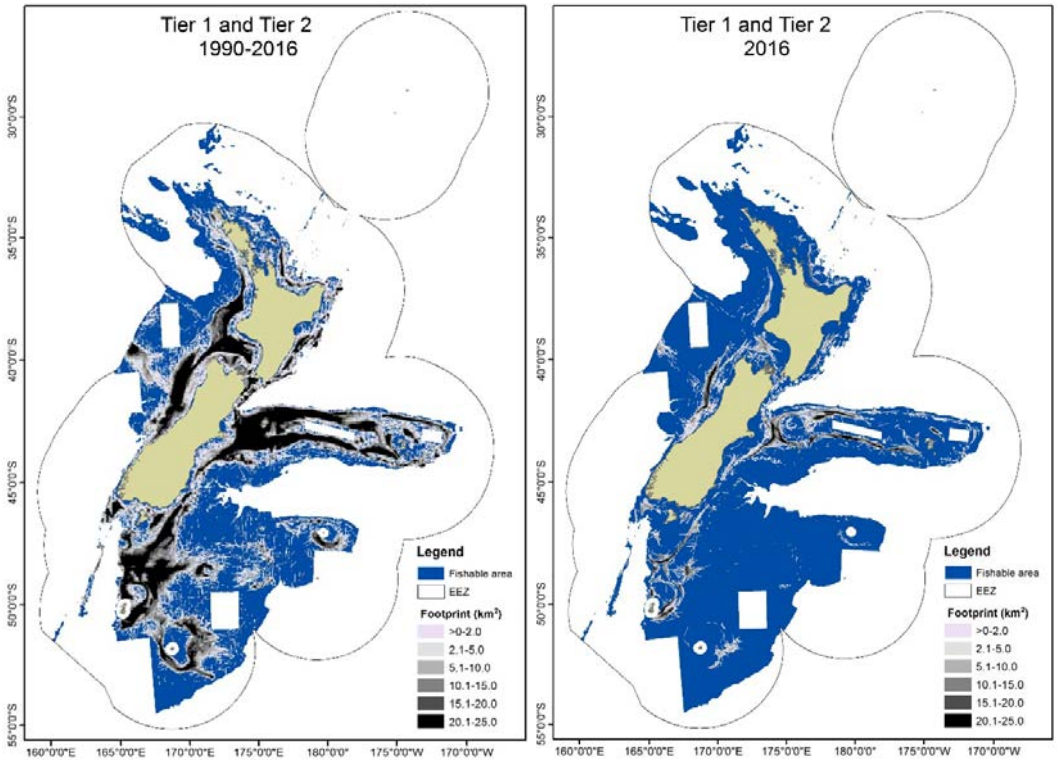

Figure 15: Distribution of the 1990–2016 (left) and the 2016 trawl footprints (right) for Tier 1 and Tier 2 targets combined, relative to the 'fishable' area.

6. MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

The deepwater bottom-contacting trawl footprint describes the proportion of the seafloor that has been contacted by trawl gear from vessels targeting deepwater target fisheries within the New Zealand EEZ. The annual monitoring of this trawl footprint meets several Management Objectives (MO) in the annual operational plans for the deepwater fisheries, in particular the Environmental Outcome MO 2.3 and MO 2.7 (see Ministry for Primary Industries 2015), which relate to protection of habitats of particular significance and the benthic habitat. This information is also used as part of the assessment requirements for a number of New Zealand deepwater fisheries under the Marine Stewardship Council certification process for sustainable fisheries (see www.msc.org).

The extent of the bottom-contacting trawl footprint and the intensity and frequency of trawling effort for deepwater Tier 1 and Tier 2 species can be monitored, singly or grouped, spatially and temporally, by

accessing the 1989–90 to 2015–16 data prepared under this project. However, it must be remembered that these data represent the bottom-contacting effort, thus, depending on the fishing method for the target species, it does not show the full distribution of fishing effort for each target. For some fisheries, the effort using midwater gear in the water column rather than near the seafloor may be greater in some areas, for example, for species such as hake and jack mackerels. Naturally this midwater effort is not included in the bottom-contacting trawl footprint. Other influences on the data that are not evident in any increases or decreases in the amount of effort or swept area are the changes in fisheries that relate to fisheries management, such as the change in quotas or fleet or areal changes in fishing distribution.

Data issues

The footprint analysis work is undertaken with an agreed set of assumptions (see Section 2.1.1), and these are yet to be tested to assess the impact they may have on the resulting footprints or the aggregated swept area totals. Baird et al. (2011) summarised the implications of the use of the effort data, particularly in relation to the resolution of the position data, tow path assumption as a straight line, tow duration, doorspread measurement, depth of trawling, and size of cell for final analysis of frequency and intensity. The final analysis provides a footprint that is our best current estimate of seafloor contact by trawl gear. The methods used, although consistent with international best practice, and included in assessing global footprints (see https://trawlingpractices.files.wordpress.com/2012/10/trawling-best-practices-fourth-meeting-report.pdf), could be tested to potentially improve the accuracy of this estimate.

Over the time series, there have been changes in some of the above parameters in terms of the data collection and the type of fleet operating in various fisheries. One of the inputs to the development of the swept areas for the footprint is the length of a tow. Currently, the straight-line distance (trackline) between the start and finish positions is used in the calculation of the swept area for a tow. It is accepted that vessels in certain fisheries and fleets follow contours when fishing or perform turns during a tow. The differences between the trackline distance and that calculated from the tow duration and tow speed can be quite large, as shown in Figure 16 for the Tier 1 middle depths species (hake, hoki, ling, jack mackerel, southern blue whiting and squid), as well as for scampi.

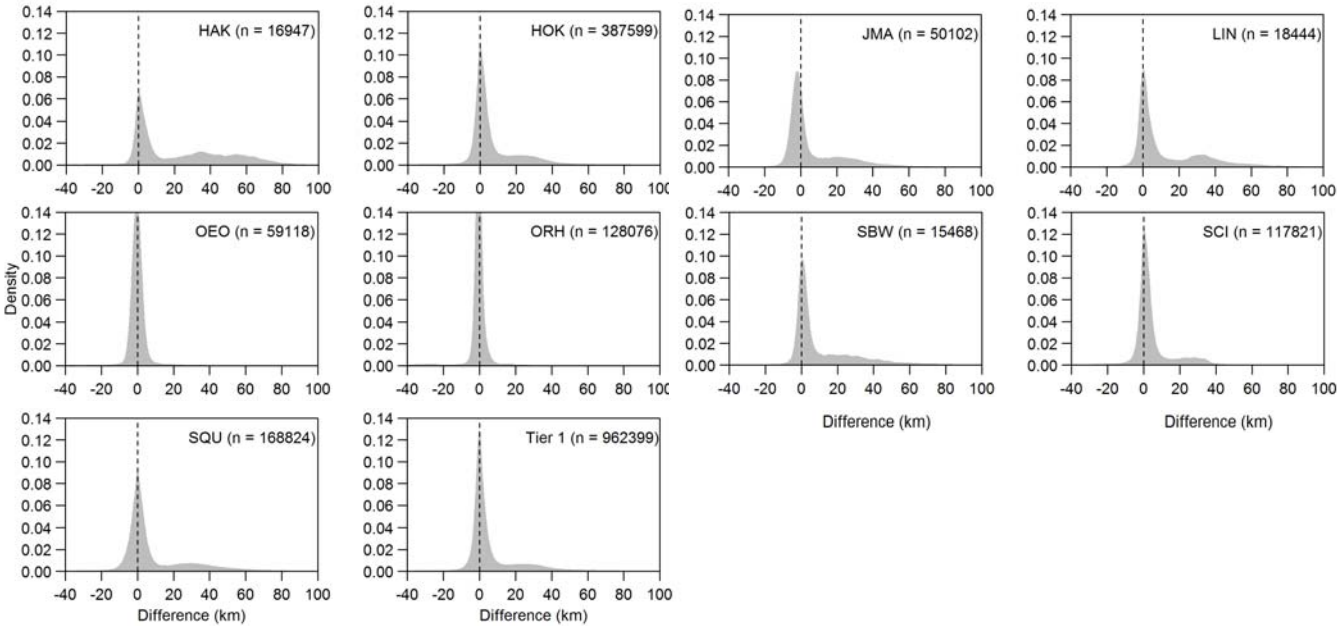

Figure 16: The difference (km) between the duration-speed distance and the trackline distance for all data where there were non-null records, by TCEPR Tier 1 species: hake, hoki, jack mackerel, ling, oreo species, orange roughy, southern blue whiting, scampi, arrow squid, and all Tier 1 species combined. This figure is based on data prepared ahead of the spatial analysis, thus, 'long' trackline distances are retained.

Deepwater targets show few differences, because most vessels target oreo species and orange roughy using short tows on underwater features. Where differences are negative, it appears that the duration-speed distance is shorter than the trackline distance; some differences may be related to errors in the underlying data, particularly tow duration or the resolution or accuracy of the start and finish positions.

A further assumption underlying the use of the trackline data is that most Tier 1 target tows should be no longer than 55.56 km (30 n. miles), other than for scampi and arrow squid where the accepted maximum trackline length is 70 km (e.g., Black et al. 2013). As is evident above, for some species this may be too restrictive – the data indicate that tows may be longer. In the following example, for hake, the effect of ignoring tows longer than the 55.56 km cut-off is a decreasing trend in trackline length, whereas it appears that the tows may be increasing in length, based on the duration-speed distances for the same tow data (Figure 17).

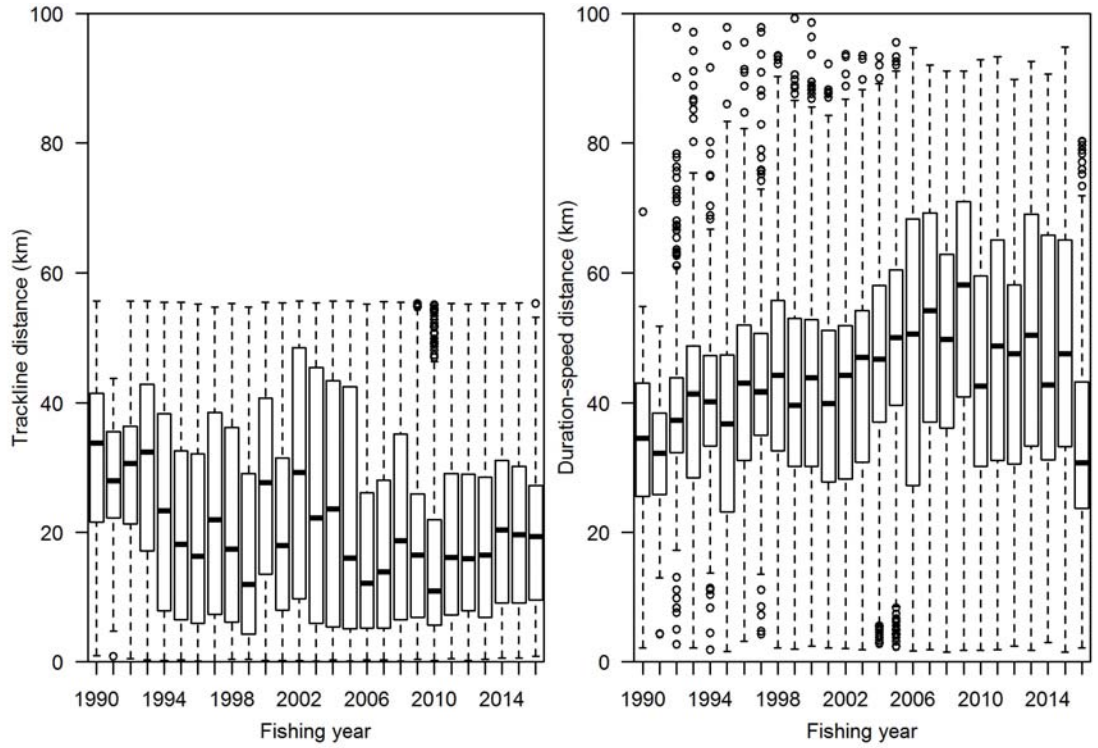

Figure 17: Comparison of the hake tow length data where the trackline records have been restricted to 55.56 km as maximum tow distance ('long' tow rule) (left) and the duration-speed distance for the same hake data.

Further, the effect of the cut-off at 55.56 km (following the 'long tow rule') for hake tracklines suggests that in some years, particularly more recent years when the targeted effort for hake has decreased, a high proportion of the hake effort would not be included in the footprint analysis. About 50% more 'long tow' data in most years would be included if the cut-off was at 70 km (Figure 18). A similar effect is seen in the tow swept area analyses, with an inflated effect because of the 'long tow' influence on the swept area calculation. Over 75% of the 'long tow' hake data presented below (all years combined) were from effort off the west coast South Island (HAK 7 fishstock) – the main area for hake catch from hake-targeted bottom trawl effort since 2009 (Ballara 2015, Ballara in press).

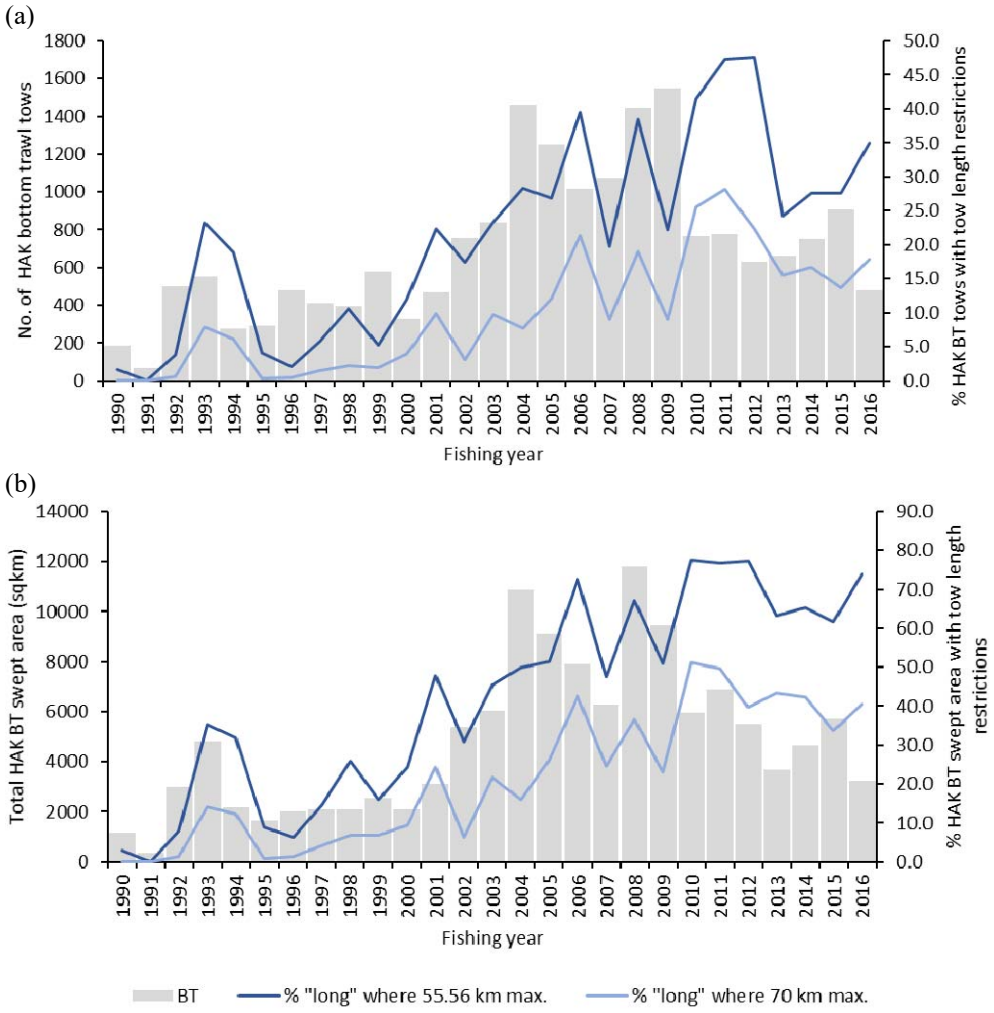

Figure 18: (a) The annual number of bottom tows (BT) for hake (bars) in the dataset before the spatial analysis was completed, and the percentage of tows designated 'long' for the maximum tow length values (55.56 km and 70 km), and (b) the total annual swept area for hake bottom tows (bars) and the percentage of annual swept area from 'long' tows.

Use of the trawl footprint project outputs

Within the current trawl footprint project, there are requirements to compare the various footprints of the deepwater Tier 1 target species and the combination of Tier 1 and Tier 2 target species with various predicted habitat layers, including the BOMEC and the 'preferred habitat' distributions of Tier 1 species. The 15-class BOMEC was generated as a further development of the original Marine Environment Classification (Snelder et al. 2003) with the addition of demersal fish and benthic invertebrate data layers based on trawl survey data to better inform the modelling of available and relevant environmental data (Leathwick et al. 2012). Currently, it is the 'best available' descriptor of the marine environment out to 3000 m, and its use (and usefulness) as a measure of the distribution and variation of habitat type, for comparison with the trawl footprint, is disputed (Ford et al. 2016). The overlap of the two data layers provides some information, at the scale of the EEZ, about intensity and extent of coverage of shelf, slope and deeper marine areas at different latitudes where bottom-contacting fishing occurs.

The use of data layers to represent the demersal fish distribution – as the probability of capture of a fish species in a standardised trawl (see Leathwick et al. 2006) – to develop statistics of the overlap with the trawl footprint, by Tier 1 fish species, should be done with caution. The underlying biological data for the fish probability distribution are from trawl surveys undertaken in specific waters at specific times (part seasons), with specific objectives that generally relate to a small number of species, and sometimes to

size-ranges of those targeted species. For example, two of the main trawl middle-depths surveys that contributed data to the fish probability layers are the Chatham Rise January survey, which is focused on adult and juvenile hoki, and hake and ling to a lesser extent, in 200–800 m (O'Driscoll et al. 2011), and the December sub-Antarctic trawl survey, which is optimised for the same species, in 300–800 m.

Table 9 indicated some potential anomalies in terms of the probability of capture demersal distribution for hake and jack mackerels where the species trawl footprints had relatively low overlap with the highest probabilities of capture. The area (km^2) of highest probabilities for these species was small and, in the case of hake, was in slightly deeper water than the fishing effort (on the northern slope of the Chatham Rise) and in the Kaikoura Canyon area off the east coast of the South Island where there was no reported bottom-contacting hake effort. The areas with highest probability of capture for jack mackerel species are in shallow waters within the Hauraki Gulf, in Tasman Bay and Golden Bay at the top of the South Island, and south of the main trawling grounds for jack mackerels off the west coast of the South Island. For the other fish species, the overlap percentage tended to be greater in areas where the probability of capture was higher. Ideally, input data to the prediction of preferred/suitable habitat for describing the spatial distribution of fish species would be provided by random trawl surveys that allowed unbiased sampling of fish species, rather than those optimised for certain species.

The footprint overlap with 200-m depth zones summarises the bottom-contacting trawl effort for each species as well as in total and indicates the depths at which there is likely more seafloor modification by trawl gear – albeit in defined geographical areas.

The trawl footprint work has also been used to provide GIS layers of extent and gradient of fishing pressure in a variety of biodiversity, benthic habitat, and ecological research projects undertaken primarily for the Ministry for Primary Industries and the Department of Conservation (e.g., Anderson et al. 2014, Baird et al. 2013, Baird et al. 2015, Bowden & Leduc 2017, Hewitt et al. 2011, Tuck et al. 2017). For these types of research, the coarse scale of the EEZ-wide footprint analysis (spatially and temporally), relative to the fine scale of biodiversity distributional data, has compromised the final analyses for some groups of organisms (e.g., particularly the infauna as shown by Bowden & Leduc 2017).

The footprint outputs can also be used to inform potential research planning, such as survey design for seafloor areas that have been fished or have never been fished.

Recommendations for refinements for the footprint analysis

1. Use the commercial effort data to better define tow length, supplemented with use of observer data that is currently collected to describe trawl gear and operation (including doorspread, number of turns, etc.) information, once the business rules for these observer data have been refined to provide a more useful dataset for analysis. This information could then be used to better inform the generation of each trawl footprint.
2. Explore the use of vessel data that may better describe the tow path and thus provide a better representation of the spatial footprint of a trawl.
3. Require that the TCER data have an added field that collects the finish position data for each tow, thus negating the estimation of the TCER tow direction and length. Currently the tow length of the TCER tow is described by the duration-speed, whereas the tow length of the TCEPR tow is determined by the straight-line length between the start and finish positions.
4. Explore the use of a métier-based effort description (e.g., ICES 2010, Ulrich et al. 2012) to better characterise and represent the complexity of the nationality-fleet-target-gear effort to better inform the inputs and outputs of the footprint analysis.
5. Generate a footprint analysis dataset/database that provides a continuous footprint throughout the Territorial Sea and the EEZ, including inshore coastal and offshore fisheries. Data for individual fisheries could be readily extracted, displayed and summarised. If combined with a métier-based approach, the discontinuity created between inshore and offshore trawling effort or between effort for different target species may be reduced, with fewer artefacts in the resulting footprints.

7. ACKNOWLEDGEMENTS

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APPENDIX A: Data grooming and dataset summaries for CELR, TCER and TCEPR data

Effort data from all three trawl forms were appended with the vessel data provided by MPI. The data were subjected to grooming routines using the *R* Statistical package following the methods used by Baird et al. (2011). In total, the initial dataset for all target species, all trawl gear types, and all forms numbered 1 975 076 records for fishing years 1990–2016.

For each form type, the grooming concentrated on the main variables considered necessary for the spatial analysis required here. These are treated separately, by form type, in the sections below. Previous work indicated that most amendments to data are due to transcription or typographical errors (see Baird et al. 2011). Data for each of the main variables were explored using the vessel/nation/vessel size/target species categories to isolate records with invalid codes or values and any obvious transcription or recording errors and to determine the distribution of variables used to characterise the effort. Where possible these errors were amended. No data were deleted, other than duplicated records, and new fields were created to accommodate changed and new (derived) values. The grooming process was iterative, with 'corrections' made to one field at a time. Data within a defined range of values for each variable were retained as reported and those outside the range were assigned a median value determined from the data. Where there were zero values, missing data, or mismatched data (such as gear methods and headline heights for a given target species) median imputation methods were used to generate new data, based on the reported non-null data for a trip or a vessel.

The grooming process and the effects on the dataset are described below, along with the final datasets for the CELR data and the combined TCER and TCEPR data (the latter dataset contains the data prior to the spatial analysis). Table A1 gives a summary of the tow numbers throughout the grooming process, from the original MPI dataset, through to the relevant Tier 1 and Tier 2 fishstock dataset used to generate the trawl footprint. Overall, 97% of the TCER and TCEPR tows were retained in the 1990–2016 footprint analysis for the relevant gear types and deepwater target fishstocks – 1 052 868 tows, of which 98% were from TCEPRs and 78% used bottom trawl gear.

1.0 CELR data

Each CELR record represents the daily effort reported by a fisher; thus, each record may describe data for a number of tows that targeted a certain target species in a particular Statistical Area. The primary variables for these data are: target species, number of tows, Statistical Area fished, gear method, and date. The original dataset from the Ministry for Primary Industries contained 13 533 records for a variety of target species. Table A1 gives a data summary for the CELR data retained for the deepwater Tier 1 and Tier 2 fishstocks.

Target species: The reported target codes were checked for mismatches with gear and area, with the emphasis on the Tier 1 and Tier 2 deepwater targets. The primary emphasis for the target species checks was to ensure that there were no codes that could affect the inclusion of a tow to the Tier 1 and Tier 2 final datasets. Records for the oreo species codes ('BOE', 'OEO', 'SSO') were assigned to the generic 'OEO' code because the data are not necessarily reported by species. Only data for the relevant target species were kept, to give a total of 3055 daily records.

Statistical Area: The reported Statistical Area represents the area where the daily effort took place. These records were considered correct because they were sensible for the target species reported on the daily forms. The Statistical Area data were used to define whether a daily record was in the Tier 1 or Tier 2 fishstock. Any that were outside the fishstock area (n = 303 daily records), or had null values for Statistical Area (n = 153 records), were not included. This gave a final dataset of the relevant target species fishstocks data of 2586 daily records (see Table A1). Note there was no CELR effort reported for ghost shark or spiny dogfish in this final CELR dataset.

Table A1: Deepwater Tier 1 and Tier 2 species data summary for CELR, TCER and TCEPR forms. The CELR data summary is presented in (a), TCER in (b), and TCEPR in (c). The data in (a), (b) and (c) are combined for the Statistical Area summary. The combined summary for TCER and TCEPR data prior to the spatial analysis is given in (d), and (e) summarises the TCER and TCEPR data retained for the spatial analysis (that is, were not 'long' tows or tows on the land).

(a)

CELR data (1990–2007)

Number of daily records in the original MPI CELR dataset for all targets = 13 533 records

Number of daily records for Tier 1 and Tier 2 targets = 3055 records

Number of daily records for Tier 1 and Tier 2 target fishstocks, 1990–2007 = 2586 records

Total number of trawl vessels that targeted Tier 1 and Tier 2 target fishstocks = 53 vessels

Total number of trawl trips that targeted Tier 1 and Tier 2 target fishstocks = 987 trips

Total number of tows for targeted Tier 1 and Tier 2 target fishstocks, 1990–2007 = 6882 tows

'Number of tows' field was amended for 1.4% of final dataset of 2586 daily records

'Gear type' field was amended for 0.15% of final dataset of 2586 daily records

(b)

TCER data (2008–16)

Number of tows in the original MPI TCER dataset for all targets = 429 831 tows

Number of TCER tows for Tier 1 and Tier 2 targets = 41 092 tows

Number of TCER tows for Tier 1 and Tier 2 target fishstocks = 28 583 tows

Final TCER dataset

Total TCER tows for Tier 1 and Tier 2 target fishstocks, where trip number is not null = 28 176 tows

Number of TCER trawl vessels that targeted Tier 1 and Tier 2 target fishstocks = 94 vessels

Number of TCER trips that targeted Tier 1 and Tier 2 target fishstocks = 7132 trips

(c)

TCEPR data (1990–2016)

Number of tows in the original MPI TCEPR dataset for all targets = 1 531 634 tows

Number of TCEPR tows for Tier 1 and Tier 2 targets = 1 262 376 tows

Number of TCEPR tows for Tier 1 and Tier 2 target fishstocks = 1 221 942 tows

Final TCEPR dataset

Total TCEPR tows for Tier 1 and Tier 2 target fishstocks where trip number is not null = 1 209 507 tows

Number of TCEPR trawl vessels that targeted Tier 1 and Tier 2 target fishstocks = 441 vessels

Number of TCEPR trips that targeted Tier 1 and Tier 2 target fishstocks = 33 672 trips

(d)

Total TCER & TCEPR Tier 1 and Tier 2 fishstock data prior to spatial analysis

Total TCER & TCEPR Tier 1 and Tier 2 fishstock data: bottom and midwater tows = 1 237 683 tows

Total TCER & TCEPR Tier 1 and Tier 2 fishstock data: bottom and midwater trawls within 1 m seafloor = 1 082 996 tows

Percent TCER & TCEPR tow-by-tow data changed

% gear code changes	0.05%
% effort depth changes	0.2%
% bottom depth changes	0.2%
% tow speed changes (includes null values)	37.0%
% tow duration changes (includes null values)	6.0%
% tow position changes	<0.01%

(e)

Final TCER & TCEPR spatial analysis dataset

% TCER & TCEPR tows that were 'long' tows and dropped	2.7%
% TCER & TCEPR tows that were on land and dropped	0.3%

Total Tier 1 and Tier 2 fishstock tows retained for the footprint analysis (97%) = 1 052 868 tows

98% from TCEPRs and 78% used bottom trawl gear

Number of daily tows: The maximum number of trawls for a daily record was set at six, based on the available data. Median values for daily effort, based on the target species, were used to amend 1.4% of the daily records that had null records or were considered outliers. The median number of tows per day in the final CELR data was 3 tows (range 1–6 tows).

Gear type: All fishing reported on the CELR data for Tier 1 and Tier 2 targets used bottom pair trawls, bottom trawls and midwater trawls.

Date: The CELR form was discontinued for trawl data collection when the TCER form was introduced in October 2007. However, there were 13 records (23 tows) for Tier 1 and Tier 2 fishstocks reported by one vessel in the 2009 fishing year; 11 of these records were duplicated in the TCER data and all were removed from the CELR dataset.

Final CELR deepwater Tier 1 and Tier 2 dataset: The final dataset consisted of 2586 daily records with 6882 tows made by 53 small vessels during 1990–2007 (Tables A1 and A2).

2.0 TCER and TCEPR data

Data from TCEPR forms covered fishing years 1990–2016, whereas the TCER forms spanned fishing years 2008–16, providing data on a tow-by-tow basis. The primary variables for the spatial analysis of these data were: target species, gear type, start position data, tow duration, tow speed, and trip number. The trip number was assigned to the data by MPI and is necessary for grooming procedures and in the development of the swept area estimation for the TCER data (see Baird et al. 2015). Depth data that describe the depth of the gear and the seafloor at the start of fishing were also groomed to aid in summarising the main depth ranges for each target species. Tables A3–A10 provide summary data for TCER and TCEPR data, including the groomed dataset finalised for the spatial analysis. Figures A2 and A3 provide depth data summaries of the final groomed TCER and TCEPR dataset and Figure A4 gives distance-related variable comparisons for the same dataset.

Target species: Target species codes were checked for validity by comparing the area fished and the gear type used by a vessel on a trip. Effort targeted at oreo species under the codes for black oreo and smooth oreo ('BOE', 'SSO') were reassigned to the generic code for oreo species ('OEO'). Similarly, the jack mackerel code 'JMA' may represent any of the three *Trachurus* species that were targeted.

Of the total 1 961 465 TCER and TCEPR tows in the MPI original extract, 0.02% had amendments made to the reported target species. These were made before the data were divided to exclude any non-deepwater Tier 1 and Tier 2 targets so that 'problem' target species, caused mainly by typographical or transcription errors, such as 'SNA' and 'SWA' could be amended. The position data and tow depth data were used to define whether the tow was a snapper tow ('SNA') or a silver warehou ('SWA') tow. Any 'SNA' tows south of 42°S were re-coded as 'SWA': this change was made to about 0.07% of the original 104 399 snapper tows. There was less clarity in the delineation of the northern extent of silver warehou tows and the target species records were left as reported. It could be assumed that northern tows recorded as 'SWA' in depths of less than 100 m were 'SNA' (see Figure A1 for a comparison of data distribution by depth and FMA for 'SNA' and 'SWA' tows): thus, potentially up to 9% of the 18 589 silver warehou tows reported on TCER and TCEPRs from FMAs 1, 2, 8, and 9 may have been for snapper.

Trip number: A total of 407 TCER tows had a null entry for trip number (Table A3). These tows represented 1.4% of the TCER Tier 1 and Tier 2 fishstock data and, because the trip number is necessary in the estimation of the end point of a TCER tow for a swept area analysis, these were dropped from the final dataset (see Table A1). The tows with no trip number were from 33 vessels during 2008–16; 43% were from one vessel.

Of the 1 221 942 TCEPR tows included in the 1990–2016 dataset of deepwater Tier 1 and Tier 2 target tows, reported from 33 672 trips and 441 individual vessels, 12 435 had null values for the trip number (1.1% TCEPR tows) (Table A4).

Table A2: The total numbers of tows reported for deepwater Tier 1 and Tier 2 target fishstocks on CELRs, by target species and fishing year. Target species codes are defined in Table 1. Tier 1 target species codes are in bold.

Fishing year	BAR	BYX	CDL	**HAK**	**HOK**	**JMA**	**LIN**	**OEO**	**ORH**	**SCI**	SKI	**SQU**	SWA	WWA	Total
1990	3	0	9	**3**	**50**	**0**	**0**	**0**	**227**	**0**	0	**0**	0	0	292
1991	180	14	11	**0**	**139**	**0**	**18**	**0**	**221**	**50**	0	**0**	0	0	633
1992	147	0	2	**0**	**57**	**0**	**45**	**11**	**225**	**4**	11	**0**	0	0	502
1993	412	0	0	**0**	**70**	**0**	**94**	**0**	**306**	**0**	6	**0**	1	0	889
1994	234	0	0	**0**	**137**	**0**	**20**	**1**	**159**	**0**	7	**0**	0	0	558
1995	74	0	0	**0**	**134**	**0**	**0**	**0**	**87**	**0**	0	**0**	0	0	295
1996	134	0	2	**0**	**111**	**0**	**0**	**0**	**14**	**0**	0	**0**	0	0	261
1997	8	0	0	**0**	**72**	**2**	**0**	**0**	**1**	**0**	0	**0**	2	0	85
1998	16	0	0	**0**	**178**	**0**	**0**	**0**	**171**	**0**	0	**0**	0	0	365
1999	77	0	0	**0**	**133**	**0**	**0**	**29**	**299**	**0**	0	**0**	0	0	538
2000	8	0	3	**0**	**215**	**0**	**0**	**79**	**453**	**13**	0	**4**	0	0	775
2001	100	0	0	**0**	**74**	**0**	**0**	**0**	**63**	**0**	0	**0**	0	0	237
2002	0	0	0	**0**	**35**	**0**	**0**	**0**	**12**	**130**	0	**0**	0	0	177
2003	0	0	0	**0**	**126**	**0**	**0**	**7**	**19**	**565**	0	**0**	0	0	717
2004	72	0	0	**0**	**0**	**2**	**0**	**0**	**52**	**56**	0	**0**	0	0	182
2005	4	31	0	**0**	**0**	**0**	**0**	**0**	**20**	**0**	0	**0**	0	0	55
2006	0	0	0	**0**	**13**	**0**	**10**	**2**	**218**	**0**	0	**0**	0	16	259
2007	0	0	0	**0**	**0**	**0**	**0**	**0**	**62**	**0**	0	**0**	0	0	62
All	1	45	27	**3**	**1 544**	**4**	**187**	**129**	**2 609**	**818**	24	**4**	3	16	6

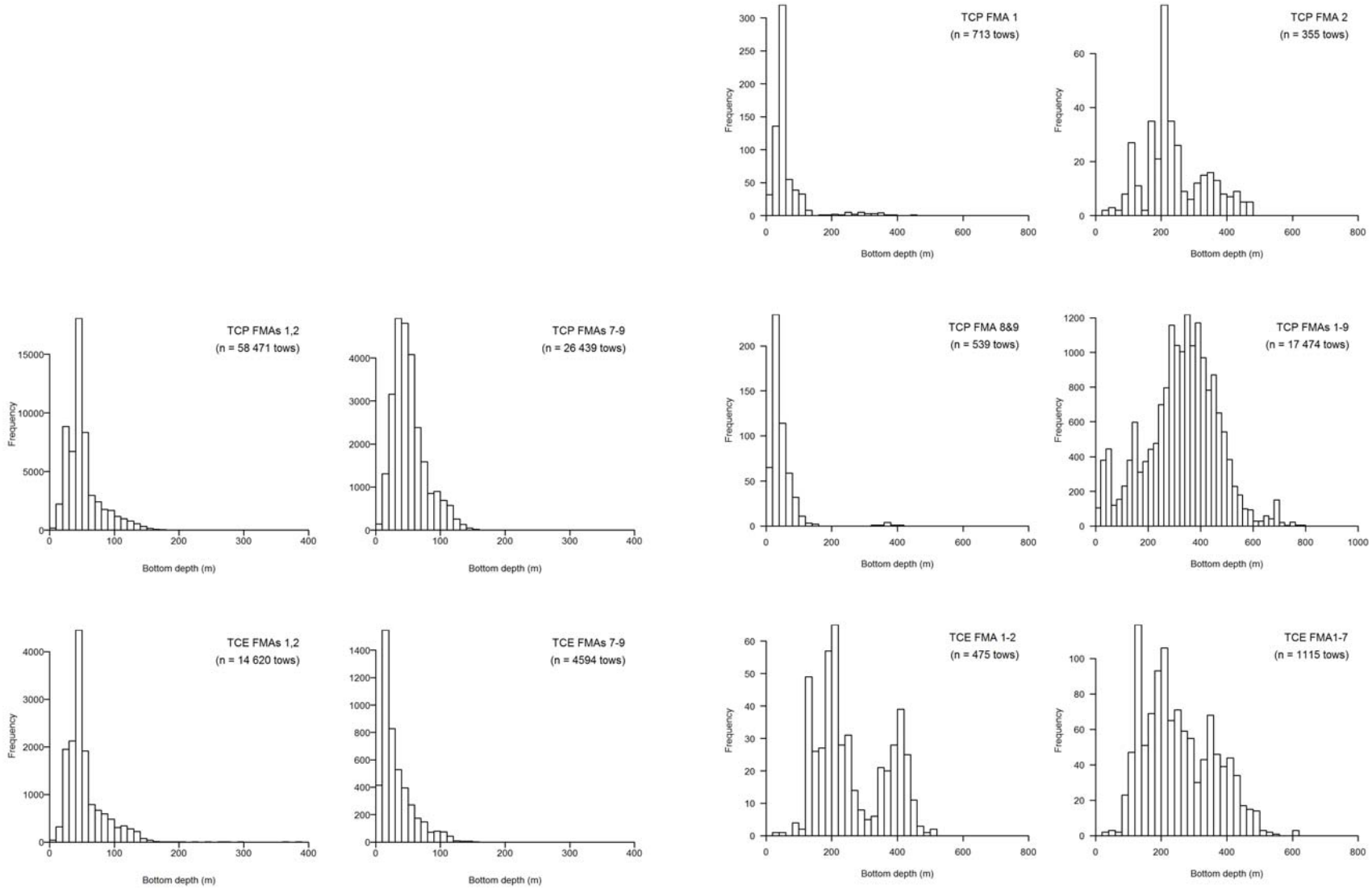

Figure A1: Frequency distribution of snapper reported effort (left) by depth and FMA for TCEPR forms (TCP, left upper) and for TCER (TCE, left lower) and frequency distribution of silver warehou effort (right) by depth and FMA, for TCEPR (right upper and central) and TCER (right lower).

Table A3: Number of TCER Tier 1 and Tier 2 tows with null trip values, by fishing year and target species.

Fishing year	BAR	HAK	HOK	LDO	LIN	RBY	SCI	SPD	SPE	SQU	SWA	Total
2008	2	1	4	0	0	0	0	14	0	0	0	21
2009	1	0	5	0	1	0	0	0	2	0	0	9
2010	7	0	4	0	50	0	0	26	9	0	0	96
2011	0	0	15	0	8	2	0	28	4	2	3	62
2012	7	0	14	0	2	0	0	12	0	0	0	35
2013	7	0	6	0	0	2	0	0	14	0	1	30
2014	15	5	3	1	1	0	4	16	8	0	0	53
2015	1	3	4	0	2	0	4	37	6	0	4	61
2016	0	0	5	0	17	0	0	0	17	1	0	40
All	40	9	60	1	81	4	8	133	60	3	8	407

Gear type: The majority of gear codes used on the TCER and TCEPR forms were for bottom trawl gear ('BT'), with the remainder reported as midwater trawl ('MW'), and a small number as bottom pair trawl ('BPT') and midwater pair trawl ('MPT'). All bottom pair trawl ('BPT') records were reassigned to 'BT' for this analysis; these tow records represented 0.05% of all TCER and TCEPR tows. The match between vessel keys, areas, target species, and date-time was not immediately obvious for those vessels with 'BPT' for the gear type and 'Y' for the *pair_trawl_yn* variable in the data. The TCER data included 97 'BPT' tows from 6 vessels, and the TCEPR data included 526 'BPT' tows from 12 vessels: to give a total of 17 vessels because one vessel used both TCERs and TCEPRs during the time period. These tows were in northern waters and targeted barracouta, ling, and silver warehou. It is likely the latter tows were snapper tows. Limited time in the project did not allow any further investigation of bottom pair trawl use.

It is interesting to note here that the TCEPR data included 'BT' and 'MW' tows reported as pair trawls (with 'Y'); these accounted for 0.02% of TCEPR bottom tows and 0.06% of midwater tows and the tows were treated as recorded, in terms of gear type.

The data included 62 hoki and southern blue whiting tows reported as 'MPT'. These tows used midwater gear with equal bottom and net depths at the tow start and reassigned to 'MW'. Midwater tows with net depths within 1 m of the bottom depths were retained in the dataset (n = 240 586 midwater trawl tows), along with 842 410 bottom trawl tows. In total, 12.5% of TCEPR and TCER midwater tows were dropped because the data indicated the gear was flown at least 1 m above the seafloor.

Statistical Area: The start positions of tows are assigned to Statistical Areas by MPI using the reported start latitude and longitude values. If one/either of these are invalid (for example, on land) or the given position falls on the boundary of two Statistical Areas, the record is null. Start position data were plotted to check for any inconsistencies and to identify the tows that match the target fishstocks given in Table 1. About 1.4% of the TCER and 1% of the TCEPR tows in the final dataset had null records for Statistical Area. However, 87% of the TCER data with no Statistical Area targeted hoki in Cook Strait, with start positions in Statistical Area 017.

Depths fished: Effort depth and bottom depth data were checked for inconsistencies. Bottom depth and net depth values reported at the start of each tow were used to describe depth ranges for each fishery and to determine which of the midwater tows were within 1 m of the seafloor, and thus would be included in the final dataset for the footprint analysis. Data summaries by vessel size and target species categories identified a small number of effort depth data changes (0.2% of the total TCER and TCEPR data); these changes were made by median imputation based on vessel trip and target species. For the bottom depth data, similar changes were made to 2% of the data. The distributions of effort depth at the tow start for bottom trawl and midwater trawl gear are shown in Figures A2 and A3.

Table A4: Number of TCEPR tows by target and fishing year where the trip number was null. Data in bold are for Tier 1 species.

Fishing year	BAR	BYX	CDL	FRO	**HAK**	**HOK**	**JMA**	**LIN**	**OEO**	**ORH**	RBT	RBY	**SBW**	**SCI**	SKI	SPE	**SQU**	SWA	WWA	Total
1990	34	7	0	0	**84**	**396**	**7**	**19**	**195**	**349**	0	2	**47**	**47**	9	1	**593**	7	0	1 797
1991	5	0	17	0	**0**	**396**	**6**	**19**	**61**	**499**	0	0	**74**	**152**	0	0	**206**	4	0	1 439
1992	38	25	2	0	**0**	**188**	**149**	**6**	**0**	**266**	0	0	**15**	**403**	0	0	**84**	0	0	1 176
1993	31	12	0	0	**0**	**483**	**1**	**0**	**152**	**56**	0	1	**14**	**118**	2	3	**140**	7	0	1 020
1994	16	6	2	0	**2**	**359**	**94**	**2**	**15**	**204**	0	0	**0**	**30**	0	0	**180**	1	0	911
1995	5	45	24	0	**0**	**201**	**0**	**0**	**83**	**178**	0	5	**1**	**73**	0	4	**126**	1	0	746
1996	13	21	15	0	**0**	**877**	**21**	**1**	**68**	**194**	0	6	**22**	**108**	0	5	**94**	5	0	1 450
1997	13	15	8	0	**0**	**382**	**63**	**0**	**94**	**217**	0	0	**55**	**85**	0	0	**128**	2	0	1 062
1998	3	11	10	0	**0**	**385**	**10**	**2**	**16**	**54**	0	0	**29**	**31**	1	0	**18**	10	0	580
1999	6	15	5	0	**1**	**73**	**6**	**0**	**31**	**97**	0	0	**0**	**24**	0	0	**290**	1	0	549
2000	1	3	0	1	**0**	**226**	**7**	**0**	**0**	**8**	0	0	**1**	**76**	0	0	**14**	0	0	337
2001	9	2	1	0	**0**	**18**	**5**	**0**	**2**	**0**	0	0	**0**	**25**	0	0	**6**	0	0	68
2002	3	18	6	0	**0**	**21**	**10**	**0**	**41**	**28**	0	0	**0**	**76**	0	0	**14**	0	16	233
2003	1	0	0	0	**0**	**166**	**1**	**0**	**10**	**19**	0	0	**0**	**0**	0	0	**4**	0	0	201
2004	0	1	1	0	**0**	**2**	**4**	**0**	**0**	**0**	0	0	**1**	**199**	0	0	**1**	0	0	209
2005	3	0	4	0	**0**	**0**	**1**	**0**	**0**	**9**	0	1	**0**	**61**	0	0	**7**	0	0	86
2006	0	0	2	0	**0**	**0**	**0**	**0**	**0**	**7**	0	0	**0**	**3**	0	0	**6**	0	0	18
2007	0	0	0	0	**0**	**5**	**4**	**0**	**0**	**0**	0	0	**0**	**49**	0	0	**10**	0	0	68
2008	1	0	0	0	**0**	**0**	**0**	**0**	**0**	**18**	0	1	**0**	**1**	0	0	**5**	0	0	26
2009	0	0	1	0	**0**	**0**	**1**	**1**	**0**	**3**	1	0	**0**	**0**	0	0	**10**	0	0	17
2010	0	0	0	0	**0**	**3**	**0**	**0**	**0**	**0**	0	3	**0**	**80**	0	0	**2**	0	0	88
2011	0	0	2	0	**0**	**0**	**3**	**0**	**0**	**3**	0	0	**0**	**2**	0	0	**0**	0	0	10
2012	28	0	0	0	**0**	**6**	**1**	**4**	**0**	**0**	0	0	**0**	**1**	0	0	**11**	4	0	55
2013	0	0	0	0	**0**	**4**	**1**	**0**	**0**	**0**	0	0	**2**	**3**	0	0	**0**	0	0	10
2014	0	0	0	0	**1**	**37**	**0**	**71**	**0**	**0**	0	0	**0**	**2**	0	0	**0**	0	0	111
2015	0	0	2	0	**0**	**1**	**0**	**0**	**0**	**0**	0	0	**0**	**0**	0	0	**0**	0	0	3
2016	0	0	0	0	**0**	**2**	**0**	**0**	**0**	**0**	0	0	**0**	**145**	0	0	**18**	0	0	165
Total	210	181	102	1	**88**	**4 231**	**395**	**125**	**768**	**2 209**	1	19	**261**	**1 794**	12	13	**1 967**	42	16	12 435

Tow speed: Tow speed variables were summarised by vessel size and target species. Reported values ranged from 0 to 2120 kn., with a median of 3.83 kn. and a mean of 4.4 kn. Median tow speed values were used to generate sensible towing speed for data outside the range of 2–6 kn., including 437 null values. Overall, 37% of tows had changes to reported speed values, and the minimum and maximum speeds of the amended dataset were 1.5 and 5.4 kn., respectively (median 4.0 kn., mean 3.7 kn.).

Tow duration: Where null records or outlying values existed for the duration of a tow, based on vessel-trip-target species data, the median value was used to amend 6% of TCER and TCEPR tow records. About 42% of the changes made were to the orange roughy data, 17% to oreo data, and 13% to hoki data.

The full range of tow duration data after this grooming was 0.01–12 h; and the amended data resulted in little difference to the overall range, with the first quartile at 1.6 h, median of 3.7 h, mean of 3.7 h, and third quartile at 5.2 h.

Tow position data: The TCEPR start and finish position data were plotted as an initial check for inconsistencies in location of effort. A very small percentage of tows (less than 0.01%) had obvious incorrect finish latitude values (north of 25° S) and incorrect longitude values (west of 160° E and east of 190° E) and these were readily identified as transcription or typographical errors and amended. All other position data problems were left unchanged before the final editing process for the spatial analysis that removed 'long' tows (see Section 4.2).

Tow distance: The tow distances between the TCEPR start and finish position data were calculated and plotted as an initial check for inconsistencies in location of effort. Long tows were identified, but no changes were made in these initial stages of grooming.

Number of tows per TCER trip: For the swept area analysis, it was necessary to look at the number of tows per trip. Of the 7132 trips, 23.4% had one tow, 22.8% had two tows, 17.3% had three tows, 10.8% had four tows, 6% had five tows, and 5% had six tows. Another 9% of trips had 7–11 tows per trip, and the remaining 10% of trips had more than 12 tows (maximum of 46 tows in 3 trips).

Summary data for the TCER and TCEPR dataset finalised and imported into the spatial analysis dataset are given in Tables A5–A10, including numbers of bottom-contacting tows by deepwater target species and fishing year (Table A5), by deepwater target species and 200-m depth zones (Table A6), and by target species and gear types (Table A7). Table A8 gives the total number of vessels and tows by form type, and Table A9 gives the doorspread values used to estimate the swept areas of TCER and TCEPR tows. Table A10 gives a summary of the trackline distance data for the TCER and TCEPR dataset.

Table A5: Number of bottom-contacting tows (from combined TCER and TCEPR data) by target species and fishing year, 1990–2016. Data in bold are Tier 1 target species. The total column includes an additional 82 tows targeted at GSH (n = 27), PRK (n = 4), PTO (n = 32), RIB (n = 19), which are not included as separate columns. This dataset represents the data imported into the spatially enabled database.

Fishing year	BAR	BYX	CDL	EMA	FRO	**HAK**	**HOK**	**JMA**	LDO	**LIN**	**OEO**	**ORH**	RBT	RBY	**SBW**	**SCI**	SKI	SPD	SPE	**SQU**	SWA	WWA	All
1990	1737	197	106	0	1	**187**	**8087**	**2228**	0	**676**	**1924**	**5619**	0	0	**933**	**2137**	147	31	13	**7713**	925	182	32844
1991	1505	246	368	11	3	**68**	**13080**	**1581**	0	**991**	**2534**	**4526**	0	6	**1310**	**3930**	68	28	14	**10095**	600	43	41007
1992	1186	319	169	1	2	**554**	**15503**	**2569**	0	**652**	**1284**	**6199**	1	39	**2245**	**5381**	112	7	34	**7405**	728	16	44406
1993	1486	356	188	1	7	**978**	**16377**	**2666**	9	**554**	**1868**	**7261**	0	72	**433**	**5205**	155	0	37	**7176**	1060	4	45897
1994	1044	486	303	7	1	**571**	**13210**	**2762**	2	**423**	**1611**	**10257**	0	51	**440**	**5152**	26	0	42	**9196**	867	0	46451
1995	1788	625	485	0	28	**761**	**17470**	**2059**	0	**241**	**1721**	**8806**	0	89	**173**	**3806**	27	0	38	**10089**	1247	3	49456
1996	1640	648	847	0	0	**531**	**21198**	**2001**	0	**385**	**2891**	**5271**	0	66	**332**	**3381**	31	1	12	**9442**	903	0	49612
1997	1241	708	844	10	0	**479**	**25095**	**1592**	0	**332**	**3360**	**5405**	0	33	**297**	**3502**	31	5	9	**9747**	522	1	53213
1998	1081	613	683	0	24	**461**	**27508**	**3262**	0	**330**	**3148**	**8695**	0	26	**786**	**3433**	23	0	46	**7873**	444	7	58443
1999	769	754	799	46	111	**707**	**24269**	**2515**	0	**362**	**3376**	**8090**	0	46	**777**	**4048**	7	0	2	**6947**	393	62	54080
2000	813	806	987	0	9	**421**	**25125**	**1686**	0	**467**	**3371**	**6357**	0	79	**506**	**4538**	21	0	0	**5307**	428	74	50995
2001	949	730	653	0	73	**562**	**24048**	**1586**	0	**308**	**3252**	**4330**	0	126	**455**	**4759**	2	0	2	**6833**	371	94	49133
2002	1030	555	758	0	75	**811**	**22178**	**2369**	27	**413**	**2674**	**4046**	0	84	**828**	**6472**	5	37	81	**7016**	626	218	50304
2003	965	917	1133	7	4	**914**	**21594**	**2570**	3	**387**	**2490**	**4586**	0	49	**360**	**4549**	25	0	302	**8049**	326	336	49566
2004	611	746	591	0	3	**1620**	**17212**	**1875**	0	**369**	**2271**	**4522**	0	66	**471**	**3498**	3	3	138	**7928**	133	307	42367
2005	773	986	801	9	4	**1414**	**11329**	**1893**	0	**665**	**2312**	**4353**	1	118	**395**	**4587**	0	8	9	**9485**	410	355	39914
2006	575	1294	995	35	11	**1255**	**9225**	**2247**	0	**1000**	**2019**	**4355**	13	152	**316**	**4864**	1	39	32	**7770**	618	247	37074
2007	956	829	1040	14	4	**1223**	**8475**	**2001**	0	**1344**	**2110**	**3808**	4	113	**328**	**5086**	0	12	161	**4788**	810	215	33322
2008	2197	652	540	15	0	**1532**	**7892**	**1971**	28	**2022**	**2476**	**3671**	6	97	**403**	**4803**	9	153	123	**3972**	1131	223	33916
2009	1318	776	416	24	0	**1700**	**7111**	**1585**	7	**1168**	**2165**	**3541**	18	65	**587**	**3974**	10	238	29	**3600**	1081	320	29733
2010	1019	935	541	1	0	**812**	**8553**	**1905**	39	**946**	**2535**	**2922**	9	198	**671**	**4168**	21	217	148	**3770**	763	199	30372
2011	924	878	386	4	0	**798**	**8353**	**1258**	59	**949**	**1893**	**1886**	3	172	**674**	**4444**	71	122	217	**4188**	863	115	28257
2012	1125	787	380	25	0	**644**	**8992**	**1523**	47	**828**	**1659**	**1589**	21	115	**445**	**4508**	83	102	46	**3461**	611	152	27147
2013	1113	257	228	6	0	**680**	**9398**	**1381**	106	**1002**	**1273**	**1592**	39	120	**389**	**4535**	74	52	178	**2625**	708	156	25923
2014	1167	522	312	0	3	**773**	**10338**	**1333**	45	**894**	**1259**	**2033**	34	111	**310**	**4415**	39	56	136	**2048**	738	242	26813
2015	1165	517	191	0	2	**930**	**10182**	**956**	73	**982**	**1260**	**2322**	17	104	**454**	**4419**	47	49	320	**1937**	635	101	26665
2016	1026	394	146	0	11	**480**	**8806**	**897**	64	**942**	**795**	**3094**	5	249	**351**	**5061**	40	0	227	**2809**	583	103	26086
Total	31203	17533	14890	216	376	**21866**	**400608**	**52271**	509	**19632**	**59531**	**129136**	171	2446	**15669**	**118655**	1078	1160	2396	**171269**	18524	3775	1082996

Table A6: Number of bottom-contacting tows (from combined TCER and TCEPR data) by target species and 200-m depth zone (based on reported depth data), for all fishing years combined (1990–2016), for deepwater Tier 1 fishstocks, and Tier 2 fishstocks separately. Target codes are defined in Table 1. The total number of tows by depth zone is given in the top table in the Tiers 1+2 column. Note: 30% of SWA tows in the 0–200-m depth range were in 0–100 m and may be misrecorded as 'SWA' instead of 'SNA' (snapper).

									Tier 1 fishstocks		Tiers 1+2
Depth zones (m)	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Total	total
0–200	23	13 452	49 218	623	53	173	21	151	119 038	182 752	215 097
200–400	312	55 914	2 898	5 109	23	53	3 380	78 200	51 196	197 085	227 949
400–600	13 472	247 276	128	9 580	198	602	12 172	40 236	950	324614	341 471
600–800	7734	78 617	20	4 314	5 771	27 193	92	33	68	123 842	135 783
800–1000	324	4 997	2	6	39 271	69 171	4	35	5	113 815	116 047
1000–1200	1	336	3	0	13 588	28 552	0	0	5	42 485	42 593
1200–1400	0	9	1	0	618	3 265	0	0	5	3 898	3 905
1400–1600+	0	7	1	0	9	127	0	0	2	146	151
All	21 866	400 608	52 271	19 632	59 531	129 136	15 669	118 655	171 269	988 637	1 082 996

																	Tier 2 fishstocks
Depth zones (m)	BAR	BYX	CDL	EMA	FRO	GSH	LDO	PRK	PTO	RBT	RBY	RIB	SKI	SPD	SPE	SWA	WWA	Total
0–200	25 257	65	24	194	141	10	4	0	0	130	265	0	147	1 032	1 463	3 593	20	32 345
200–400	5 856	10 020	84	20	233	15	19	4	0	41	2 066	0	833	104	499	10 271	799	30 864
400–600	67	5 707	2 797	1	2	2	378	0	9	0	104	9	89	21	432	4 464	2 775	16 857
600–800	10	1 641	9 769	1	0	0	108	0	7	0	11	10	9	3	0	192	180	11 941
800–1000	6	78	2 130	0	0	0	0	0	13	0	0	0	0	0	1	3	1	2 232
1000–1200	3	18	84	0	0	0	0	0	2	0	0	0	0	0	0	1	0	108
1200–1400	0	4	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	7
1400–1600	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
All	31 203	17 533	14 890	216	376	27	509	4	32	171	2 446	19	1 078	1 160	2 396	18 524	3 775	94 359

Table A7: Final combined TCER and TCEPR dataset before loading into the spatially-enabled database, by target and gear type, where target codes are defined in Table 1, 'BT' is bottom trawl, 'MW' is midwater trawl within 1 m of the seafloor, and 'TCP' is TCEPR form. The %kept column indicates the percentage of data, by target species, retained for the spatial analysis; where the percentage was less than 100%, data were removed because the tows were on land or considered too long (see Section 4.2).

Target code	BT	MW	All	%BT	%TCEPR	%kept
BAR	23 637	7 566	31 203	75.8	78.0	94.6
BYX	12 045	5 488	17 533	68.7	99.0	99.4
CDL	14 814	76	14 890	99.5	99.9	99.4
EMA	2	214	216	0.9	100.0	95.4
FRO	116	260	376	30.9	100.0	92.0
GSH	27	0	27	100.0	100.0	100.0
HAK	18 888	2 978	21 866	86.4	97.2	77.5
HOK	302 559	98 049	400 608	75.5	98.8	96.8
JMA	14 299	37 972	52 271	27.4	99.9	95.9
LDO	509	0	509	100.0	8.3	99.6
LIN	19 478	154	19 632	99.2	82.6	94.2
OEO	59 531	0	59 531	100.0	99.6	99.3
ORH	129 136	0	129 136	100.0	99.3	99.2
PRK	4	0	4	100.0	100.0	100.0
PTO	32	0	32	100.0	100.0	100.0
RBT	1	170	171	0.6	100.0	96.5
RBY	1 071	1 375	2 446	43.8	85.9	97.8
RIB	19	0	19	100.0	94.7	78.9
SBW	1 185	14 484	15 669	7.6	100.0	98.7
SCI	118 655	0	118 655	100.0	98.6	99.3
SKI	1 032	46	1 078	95.7	65.4	88.8
SPD	1 160	0	1 160	100.0	15.1	94.9
SPE	2 396	0	2 396	100.0	50.1	93.9
SQU	99 624	71 645	171 269	58.2	99.3	98.6
SWA	18 435	90	18 524	99.5	93.9	90.5
WWA	3 756	19	3 775	99.5	98.5	99.0
All	842 410	240 586	1 082 996	77.8	97.8	97.2

Table A8: Number of vessels and tows for each vessel size category, for all forms and fishing years 1990–2016.* CELR is Catch Effort Landing Return, TCER is Trawl Catch Effort Return, and TCEPR is Trawl Catch Effort Processing Return. The TCER and TCEPR data given here are the same data as given in the 'All' column in Table A7 and thus represent the final dataset before loading into the spatially-enabled database.

Vessel length	No. vessels				No. tows			
category	CELR	TCER	TCEPR	All	CELR	TCER	TCEPR	All
A < 28 m	50	94	84	166	6 640	24 360	138 206	169 206
B 28–46 m	3	0	46	48	242	0	217 064	217 064
C > 46–80 m	0	0	92	92	0	0	465 275	465 275
D > 80 m	0	0	155	155	0	0	238 091	238 091
All	53	94	377	461	6 882	24 360	1 058 636	1 089 878

***** Note: An error in the database script meant that tows on some vessels longer than 28 m were assigned a wider doorspread value when targeting scampi. This resulted in an overestimation of the overall aggregated swept area, but little difference to the overall scampi footprint because the effort with the wider doorspread values overlay the effort with correctly assigned doorspread estimates. The following years had between 10% and 20% (median of 15%) of records with 90 m instead of 70 m doorspread: 1993, 1994, 2002–13, and 2016. The remaining years had 0–7% records (median of 2.2%) at 90 m instead of 70 m doorspread. The 150 m doorspread value was incorrectly assigned to the effort of three vessels during 2002 (0.2% scampi tows in 2002), 2003 (5.1% scampi tows), and 2004 (10.9% scampi tows).

Table A9: Number of TCER and TCEPR tows in the footprint analysis dataset for fishing years 1990–2016, by target species and assigned doorspread values. Target species codes are defined in Table 1. Note: 400 m doorspreads represent gear where there was a record in the data that a twin rig trawl was used; this was recorded from 2008 onwards. Similarly, for scampi, the gear may be a twin rig (50 m spread) or a triple rig (70 m spread). Different sized doorspreads for a target such as BAR (barracouta) represent different vessel size. The TCER and TCEPR data presented here represent the final data used in the footprint analysis ('long' tows and tows on the land have been dropped, see Section 4.2).

Target	Generic doorspread values (m)					
code	50	70	90	150	200	400
BAR	0	9 072	2 692	17 764	0	1
BYX	0	2 702	14 231	493	0	0
CDL	0	1 759	13 039	0	0	0
EMA	0	0	0	206	0	0
FRO	0	0	7	339	0	0
GSH	0	1	25	1	0	0
HAK	0	611	192	0	16 118	28
HOK	0	12 633	58 702	0	299 415	16 903
JMA	0	47	298	49 767	0	0
LDO	0	506	1	0	0	0
LIN	0	3 880	1 383	12 436	0	796
OEO	0	1 513	26 092	31 523	0	0
ORH	0	11 073	78 529	38 493	0	0
PRK	0	4	0	0	0	0
PTO	0	0	0	32	0	0
RBT	0	0	0	165	0	0
RBY	0	885	1 507	0	0	0
RIB	0	1	0	14	0	0
SBW	0	0	0	15 467	0	1
SCI	10 790	94 386	11 929	750	0	0
SKI	0	507	23	427	0	0
SPD	0	936	37	128	0	0
SPE	0	1 362	34	855	0	0
SQU	0	5 508	4 822	158 521	0	0
SWA	0	1 981	1 411	13 170	0	207
WWA	0	57	78	3 602	0	0

Table A10: Summary statistics for the trackline distance (from start to finish position) based on the jittered and estimated positions in the finalised TCER and TCEPR dataset for fishing years 1990–2016. The TCER and TCEPR data presented here represent the footprint analysis data ('long' tows and tows on the land have been dropped, see Section 4.2).

Target code	Summary statistics for the trackline distance (km)						
	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum	Null records
HAK	0.01	2.00	3.51	6.75	7.58	55.62	19
HOK	0.08	6.89	19.19	22.10	35.58	55.64	2
JMA	0.04	13.08	22.55	23.34	32.37	55.58	10
LIN	0.04	8.95	18.56	20.37	29.35	55.61	51
OEO	0.02	1.87	3.10	4.96	5.38	55.52	10
ORH	0.01	2.00	3.51	6.75	7.58	55.62	19
SBW	0.14	7.55	13.30	15.29	20.82	55.60	0
SCI	0.04	20.15	28.33	25.94	33.15	70.09	34
SQU	0.05	12.98	22.43	23.48	32.27	70.13	27
Tier 1 + 2	0.01	5.91	17.83	19.02	29.69	70.13	371

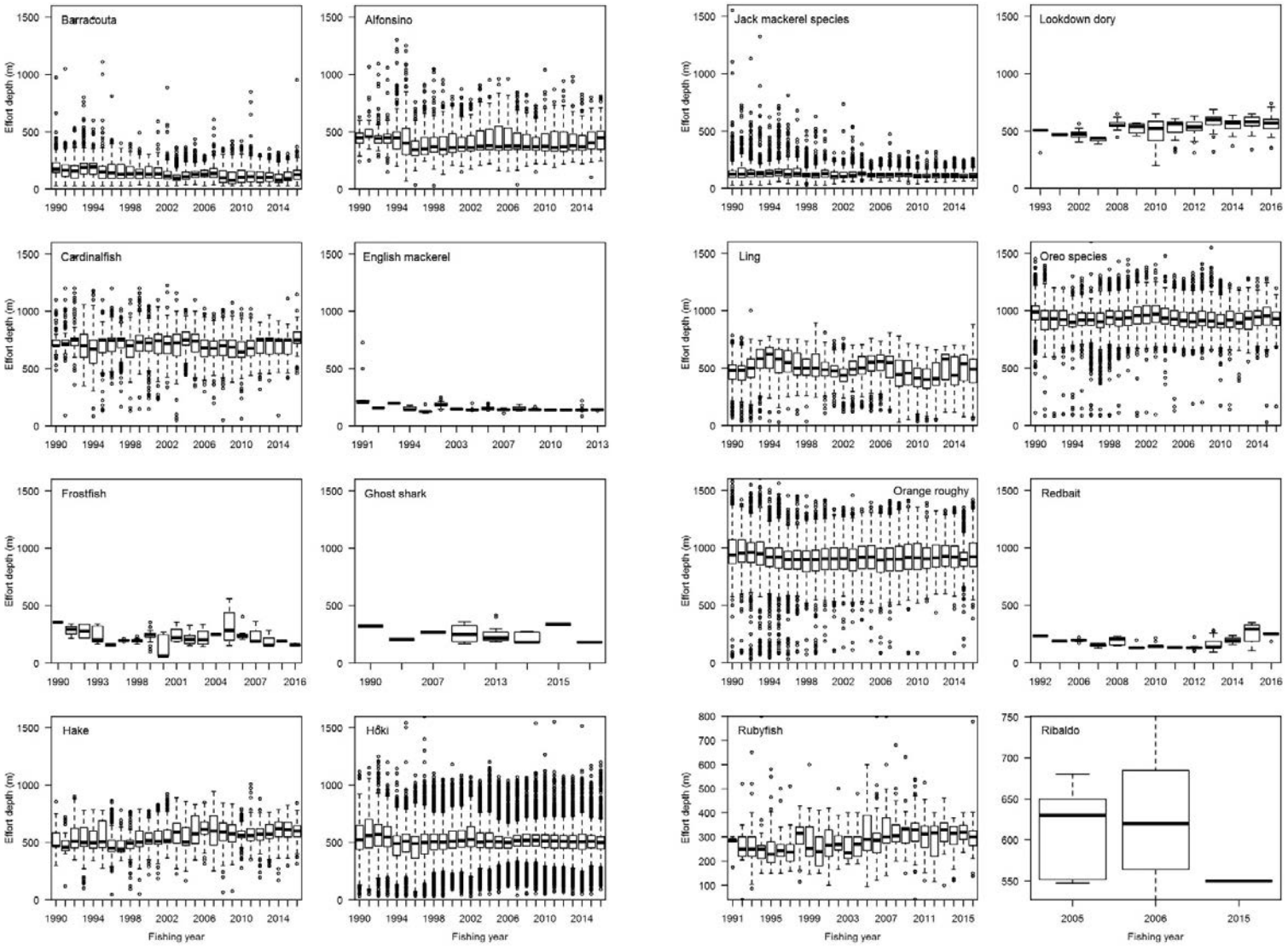

Figure A2: Distribution of effort depth values for the combined TCER and TCEPR dataset, by target species and fishing years 1990 to 2016. Plots show median values as the line inside the box (which represents the 25th and 75th percentiles), the whiskers indicate the upper and lower interquartile ranges, and the circles are outliers.

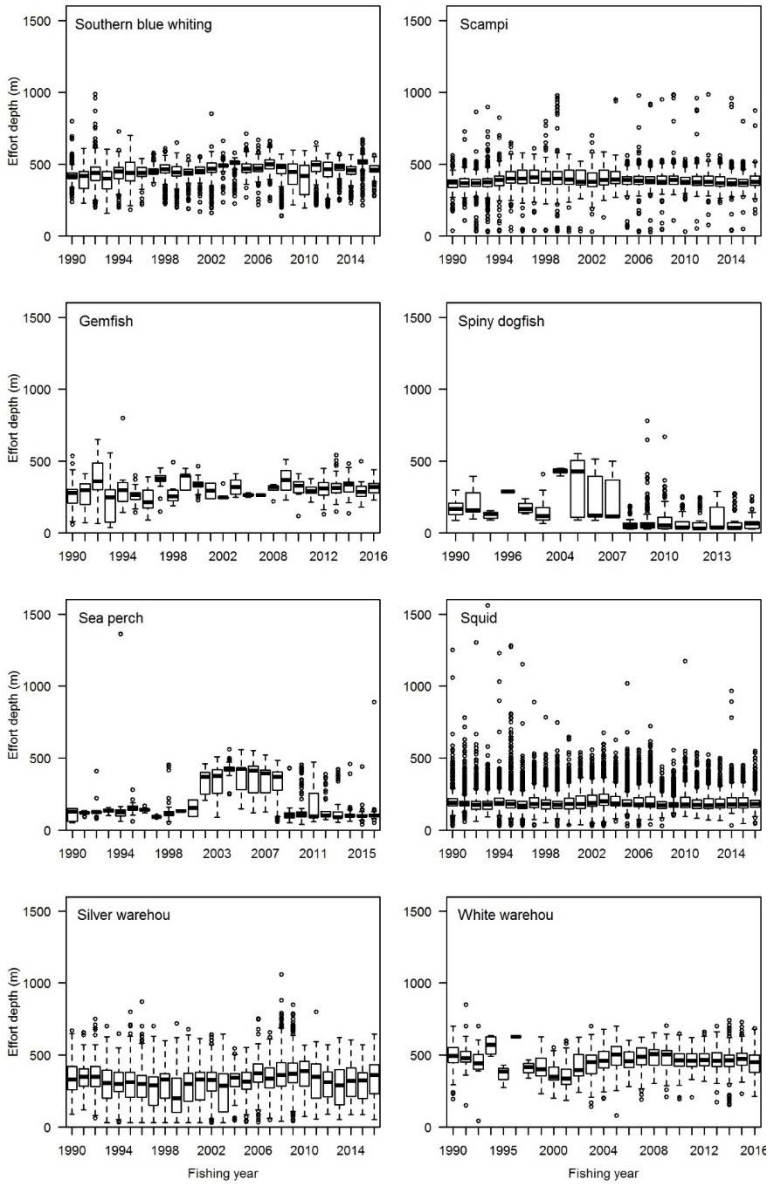

Figure A2 [Continued]

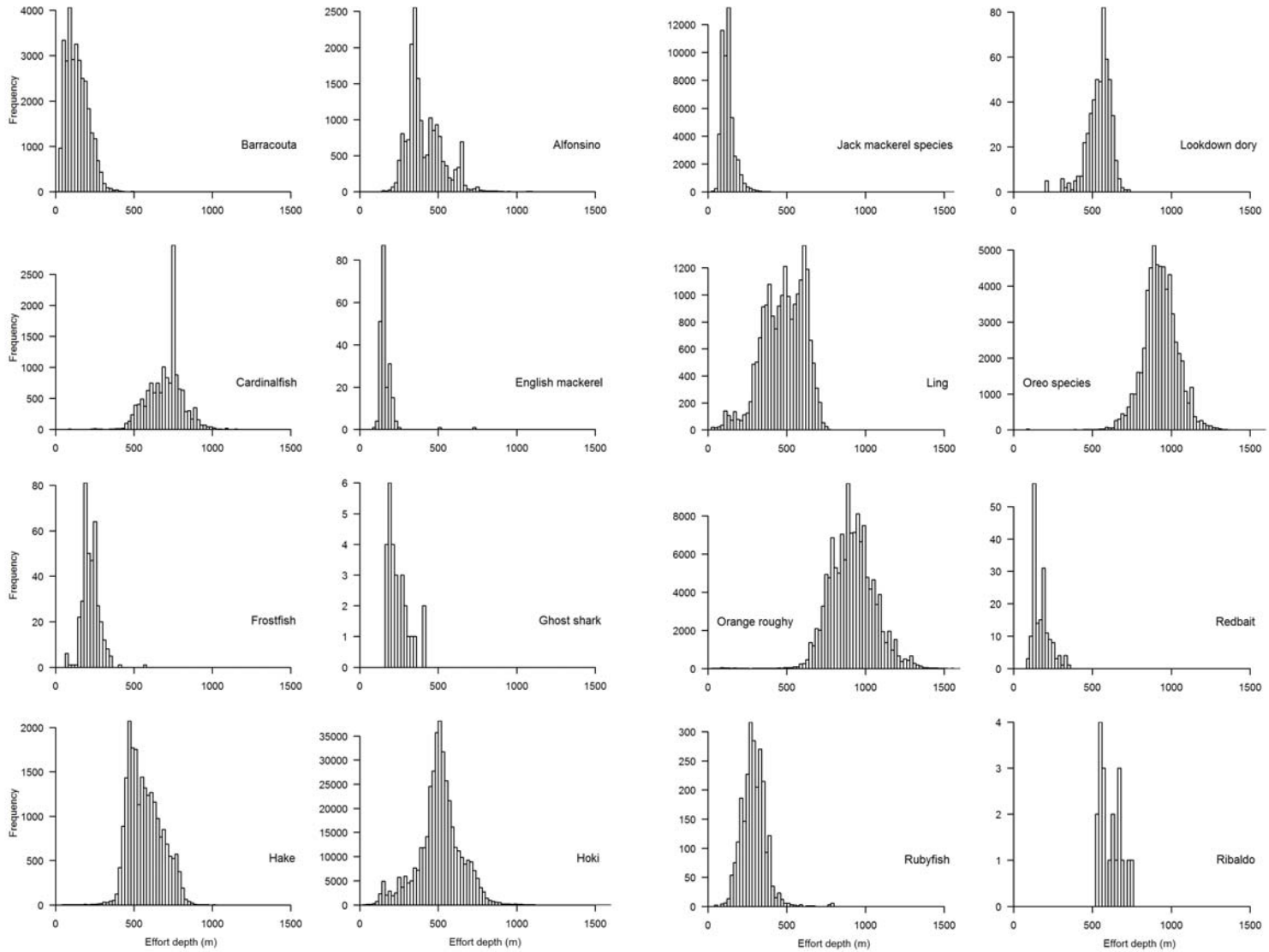

Figure A3: Frequency of effort (net) depth values for the combined TCER and TCEPR dataset, by target species and fishing years 1990 to 2016, at depths less than 1600 m.

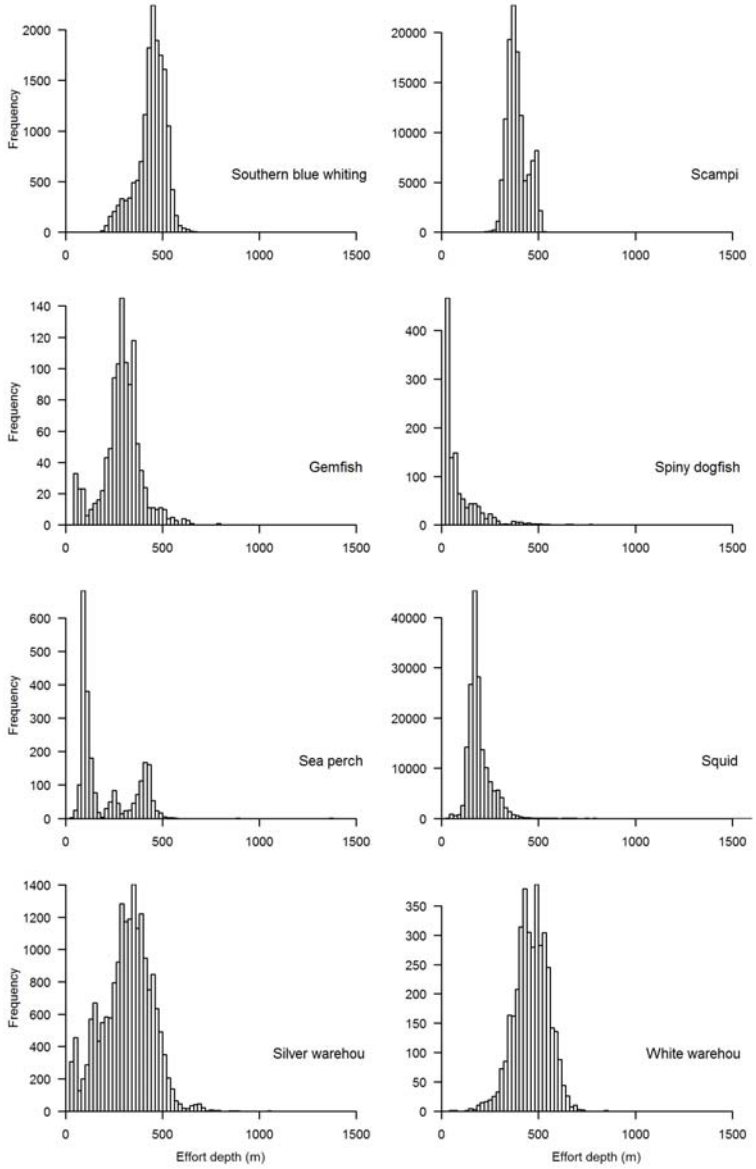

Figure A3 [Continued]

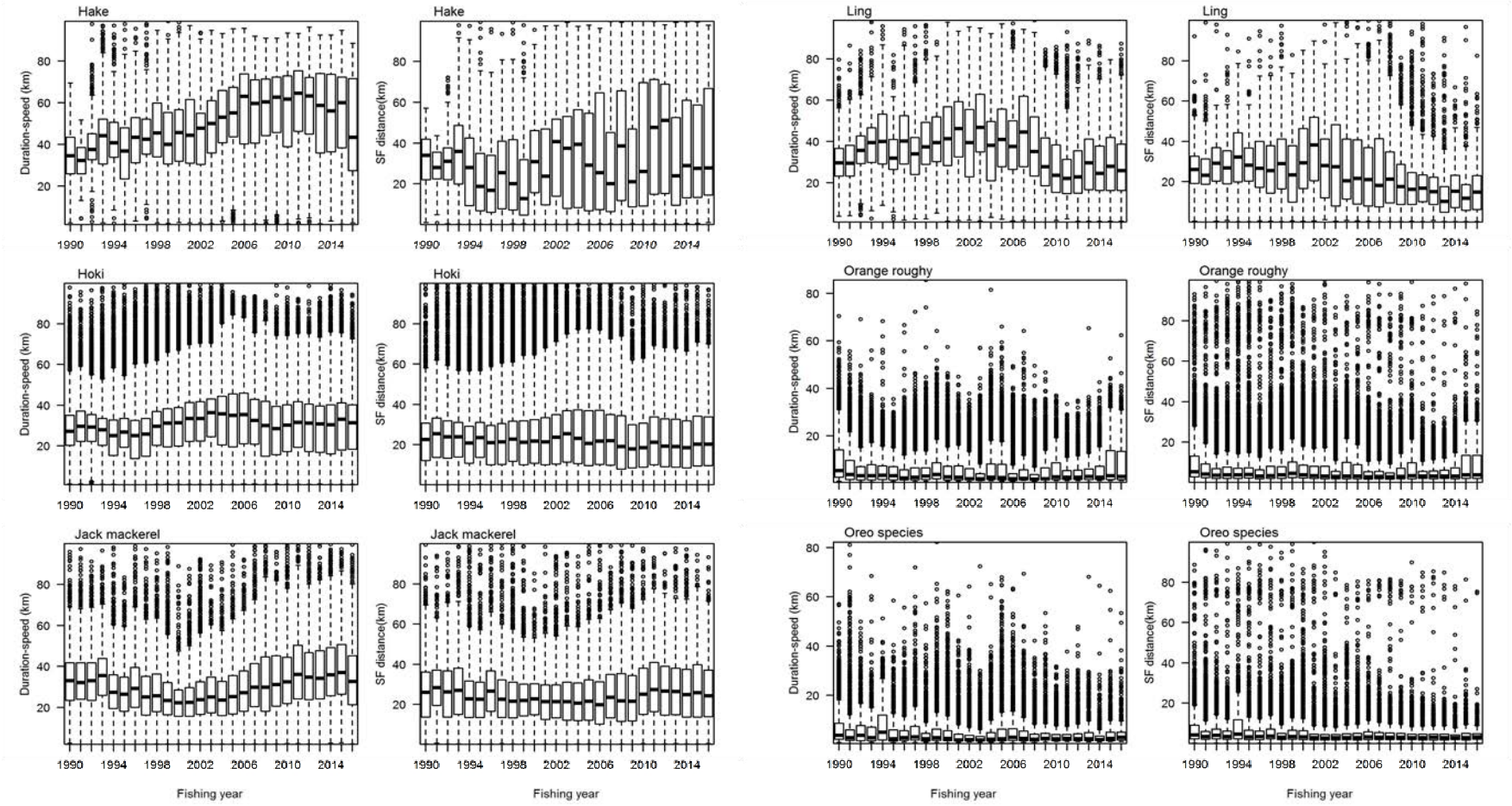

Figure A4: Comparison between distances based on reported data, where duration-speed is the groomed tow duration x speed length (km) and SF distance is the straight-line distance between the groomed reported start and finish data, for the TCEPR Tier 1 target species (bottom trawl and midwater trawl gear), 1989–90 to 2015–16. These data include all tows: that is, any 'long' tows remain in the dataset at this stage.

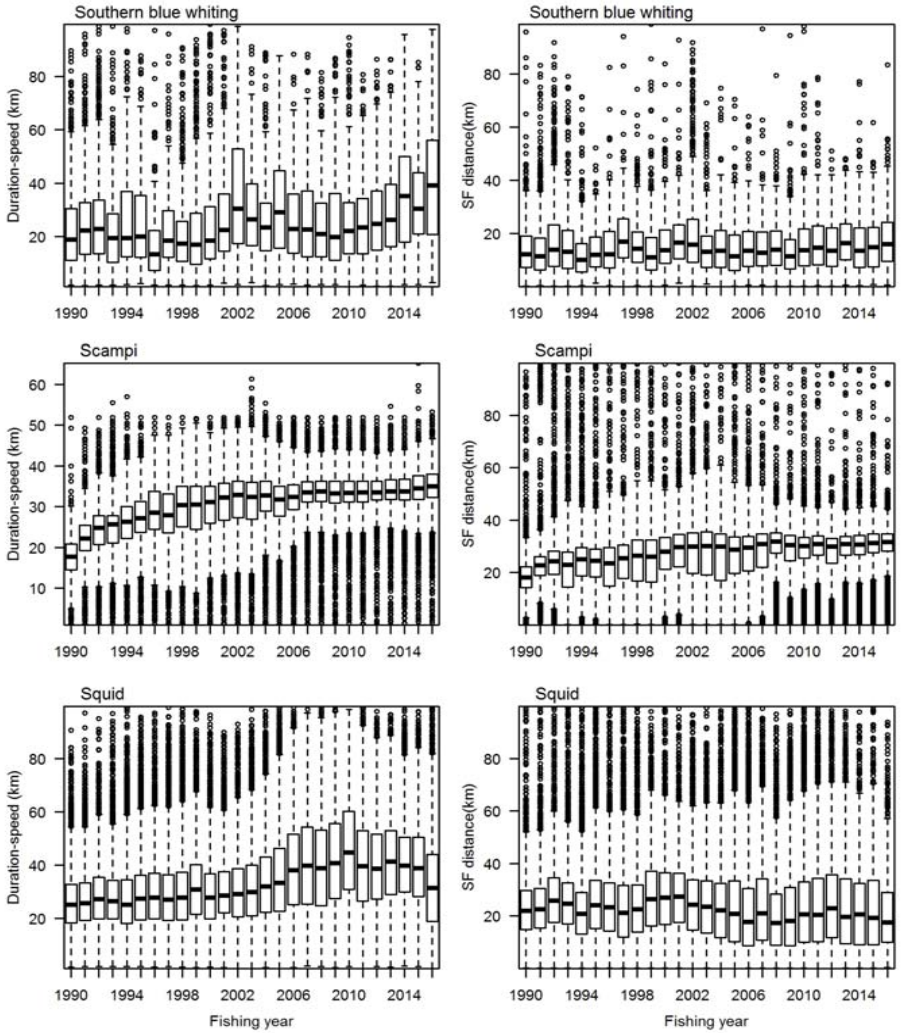

Figure A4 [Continued]

APPENDIX B: Depth zone, BOMEC, probability of species capture/annual distribution, and fishable area maps

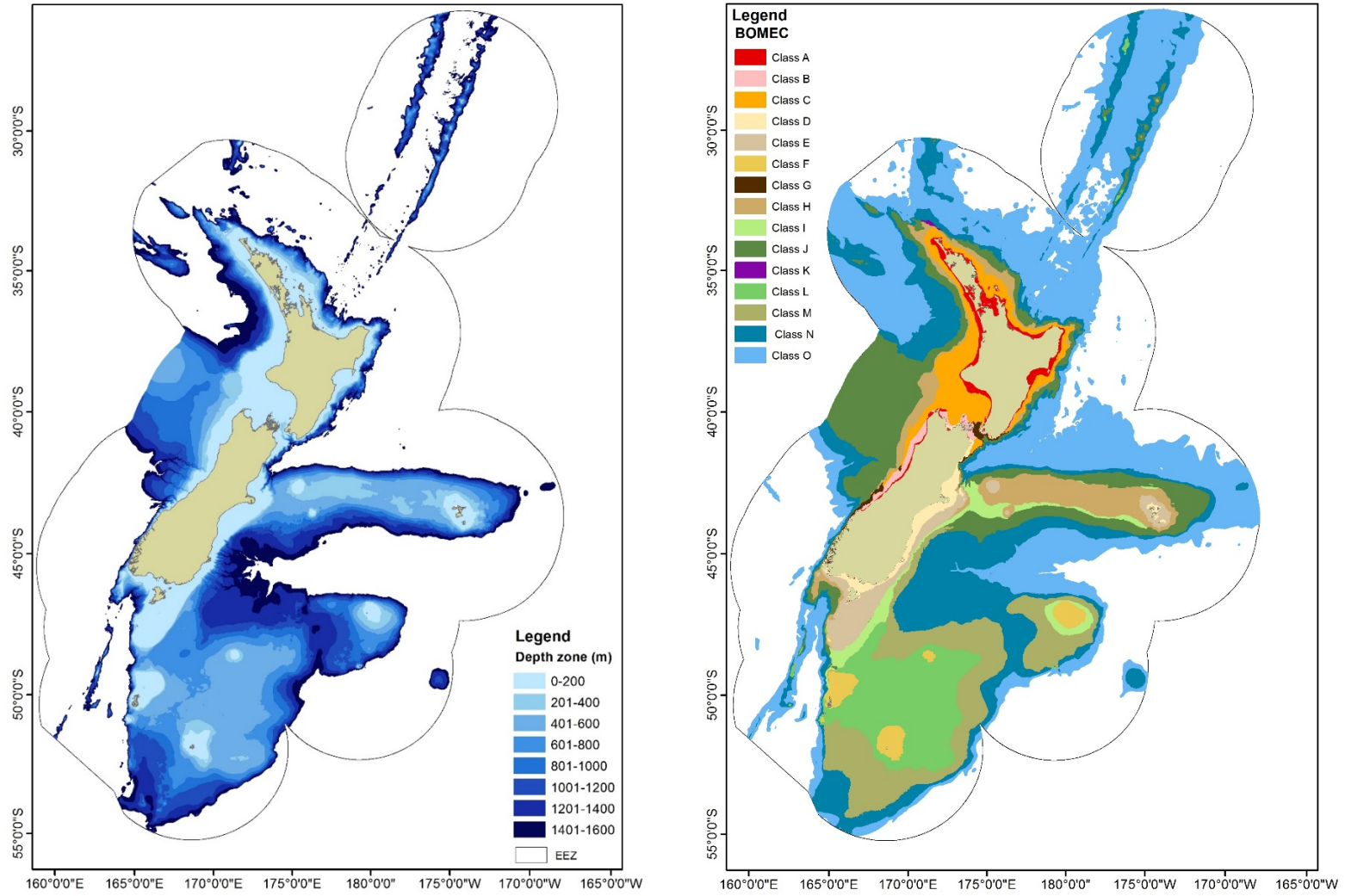

Figure B1: The extent of waters within the combined EEZ and Territorial Sea down to 1600 m depth, delineated by 200-m depth zones (left), and in waters delineated by the Benthic-optimised Marine Environment Classification (BOMEC) distribution (right), down to 3000 m (see Leathwick et al. 2012).

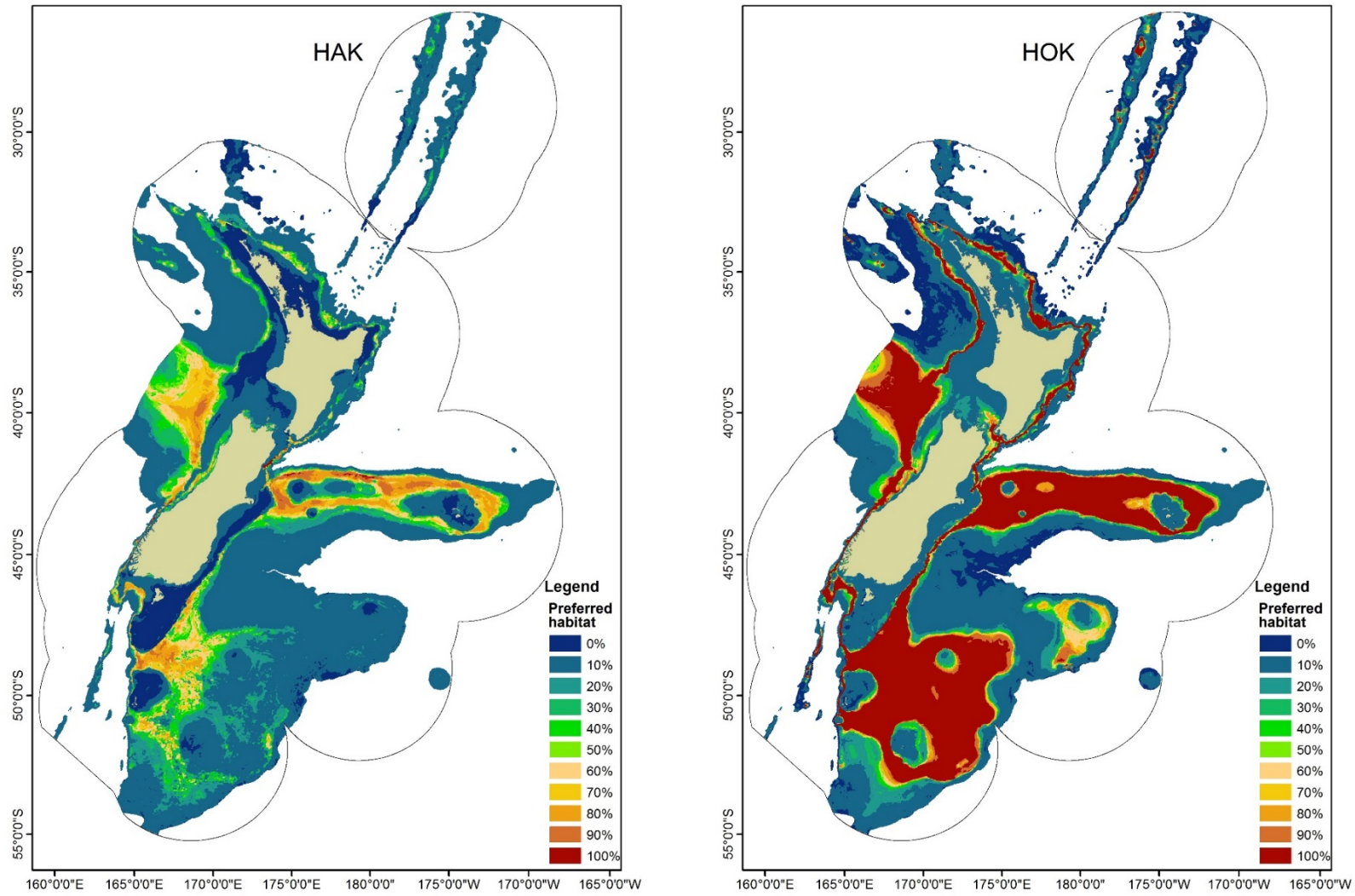

Figure B2a: The extent of waters within the combined EEZ and Territorial Sea down to 1950 m, delineated by predicted distribution of the preferred habitat for hake (left) and hoki (right) (after Leathwick et al. 2006), where the preferred habitat represents the probability of capture of that species in a standardised trawl.

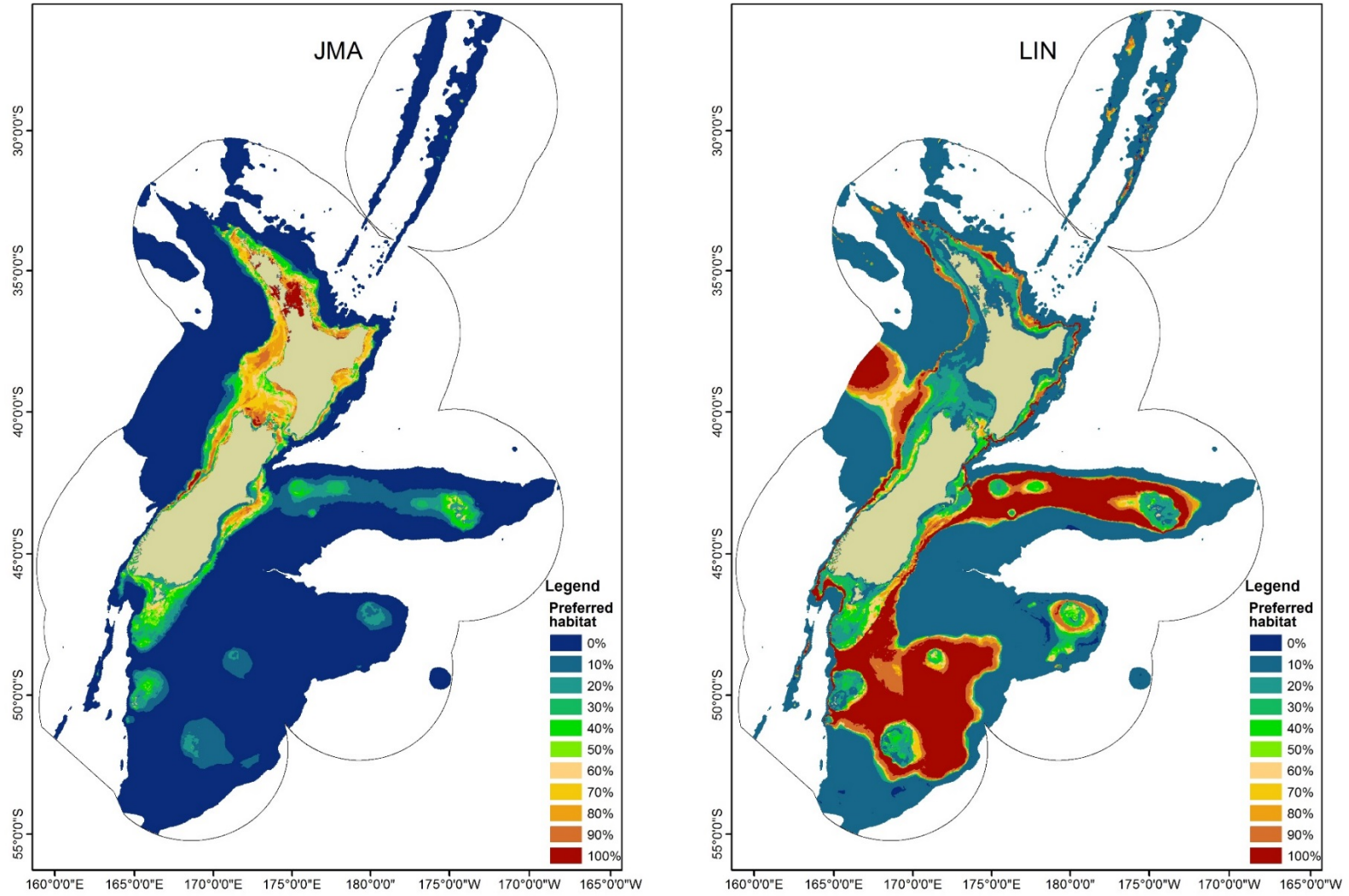

Figure B2b: The extent of waters within the combined EEZ and Territorial Sea down to 1950 m, delineated by predicted distribution of the preferred habitat for jack mackerel species (left) and ling (right) (after Leathwick et al. 2006), where the preferred habitat represents the probability of capture of that species in a standardised trawl.

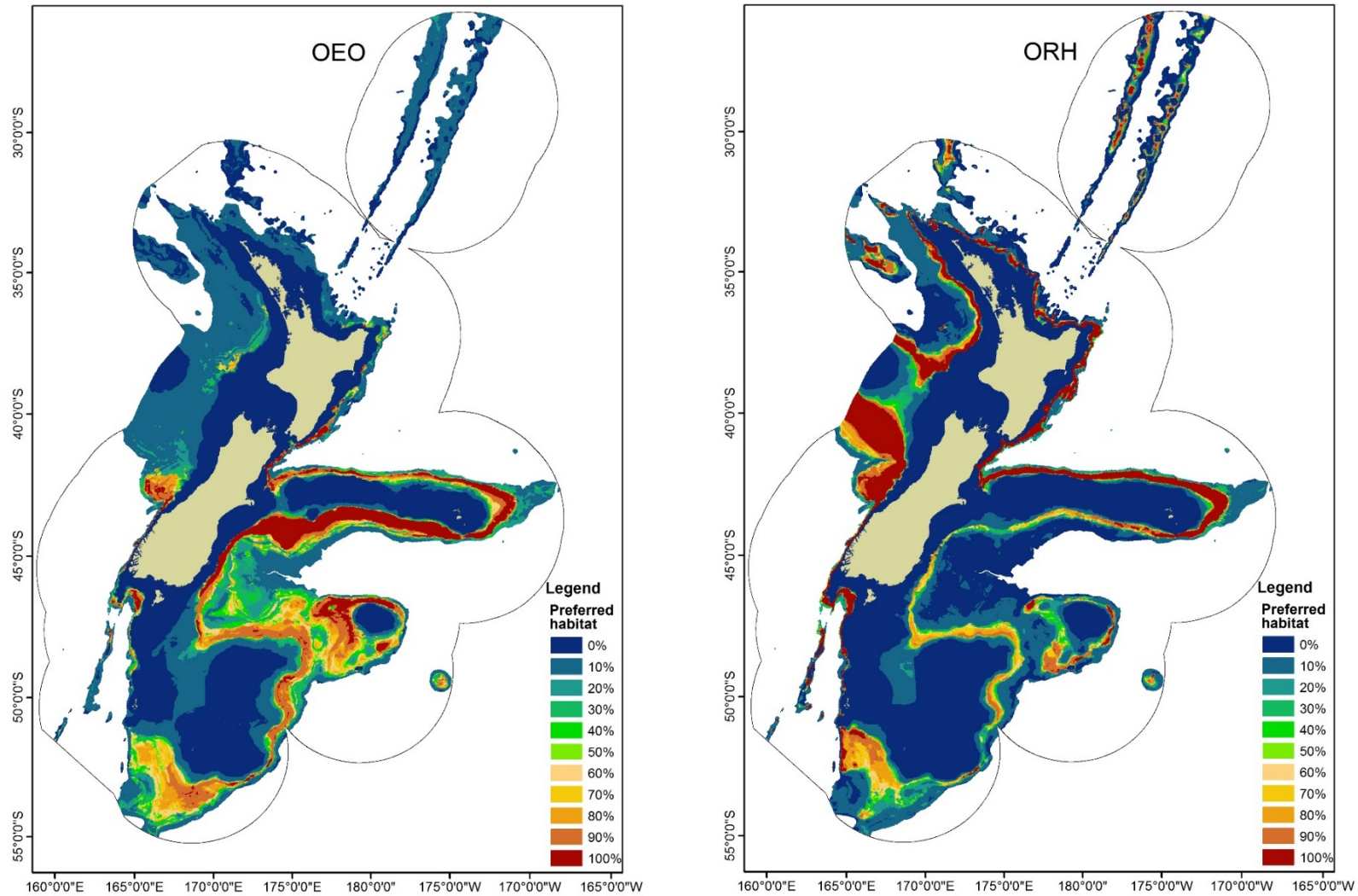

Figure B2c: The extent of waters within the combined EEZ and Territorial Sea down to 1950 m, delineated by predicted distribution of the preferred habitat for oreo species (left) and orange roughy (right) (after Leathwick et al. 2006), where the preferred habitat represents the probability of capture of that species in a standardised trawl.

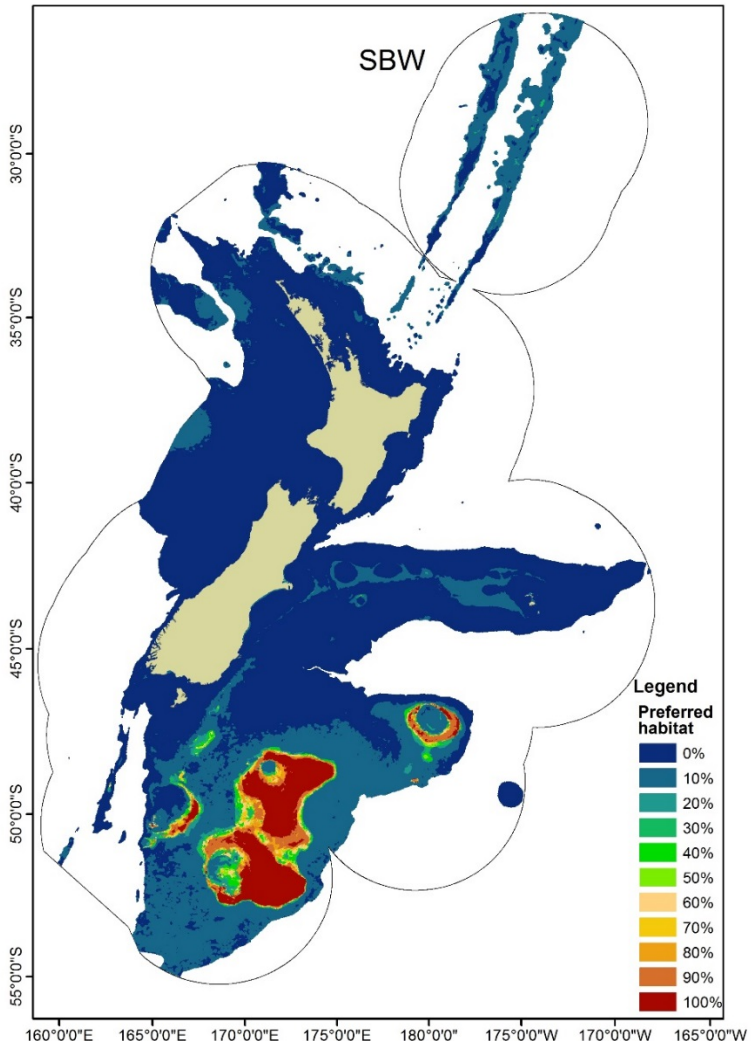

Figure B2d: The extent of waters within the combined EEZ and Territorial Sea down to 1950 m, delineated by predicted distribution of the preferred habitat for southern blue whiting (after Leathwick et al. 2006), where the preferred habitat represents the probability of capture of that species in a standardised trawl.

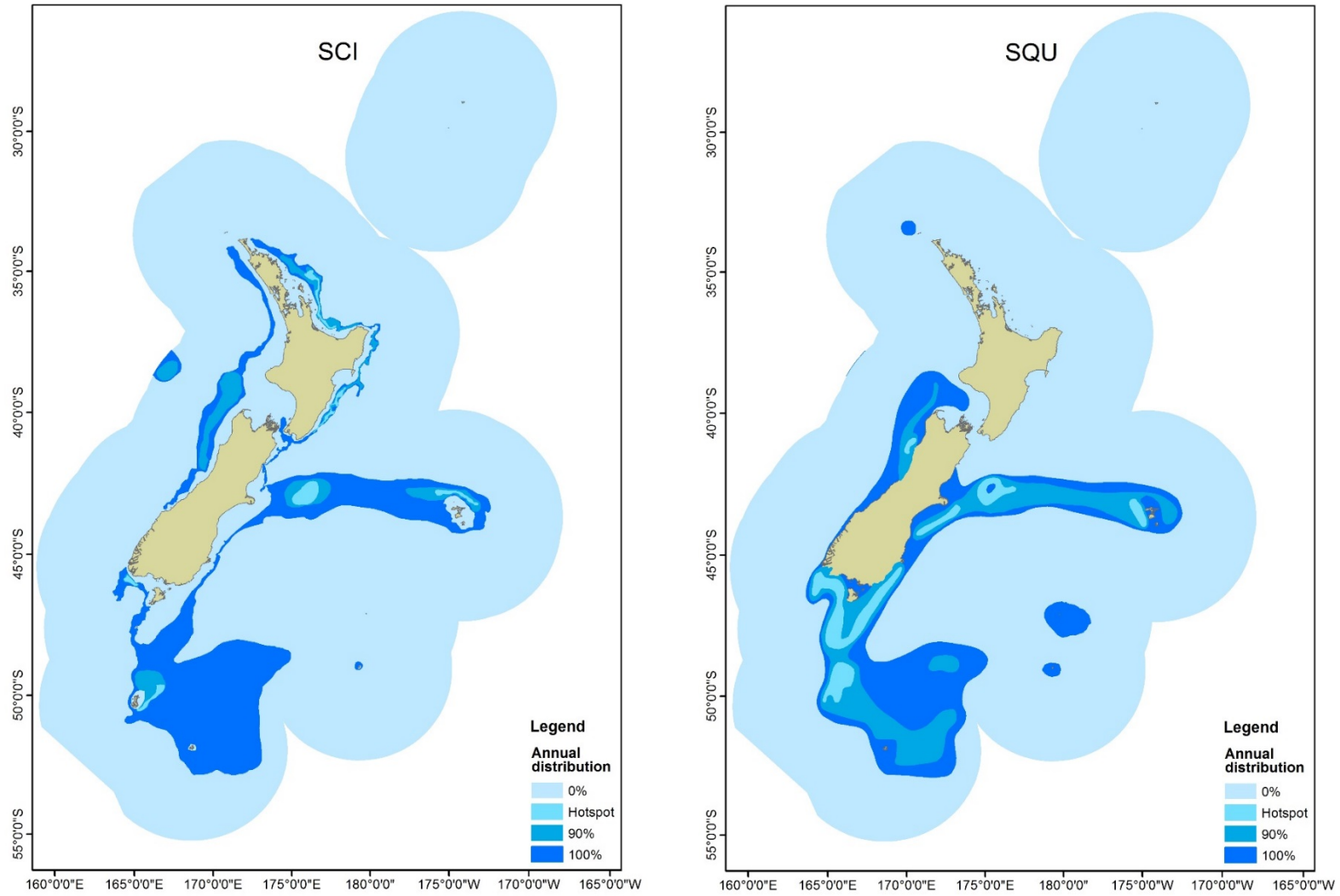

Figure B2e: The extent of waters within the combined EEZ and Territorial Sea, delineated by the annual distribution of scampi (left) and arrow squid (right) (from www.nabis.govt.nz).

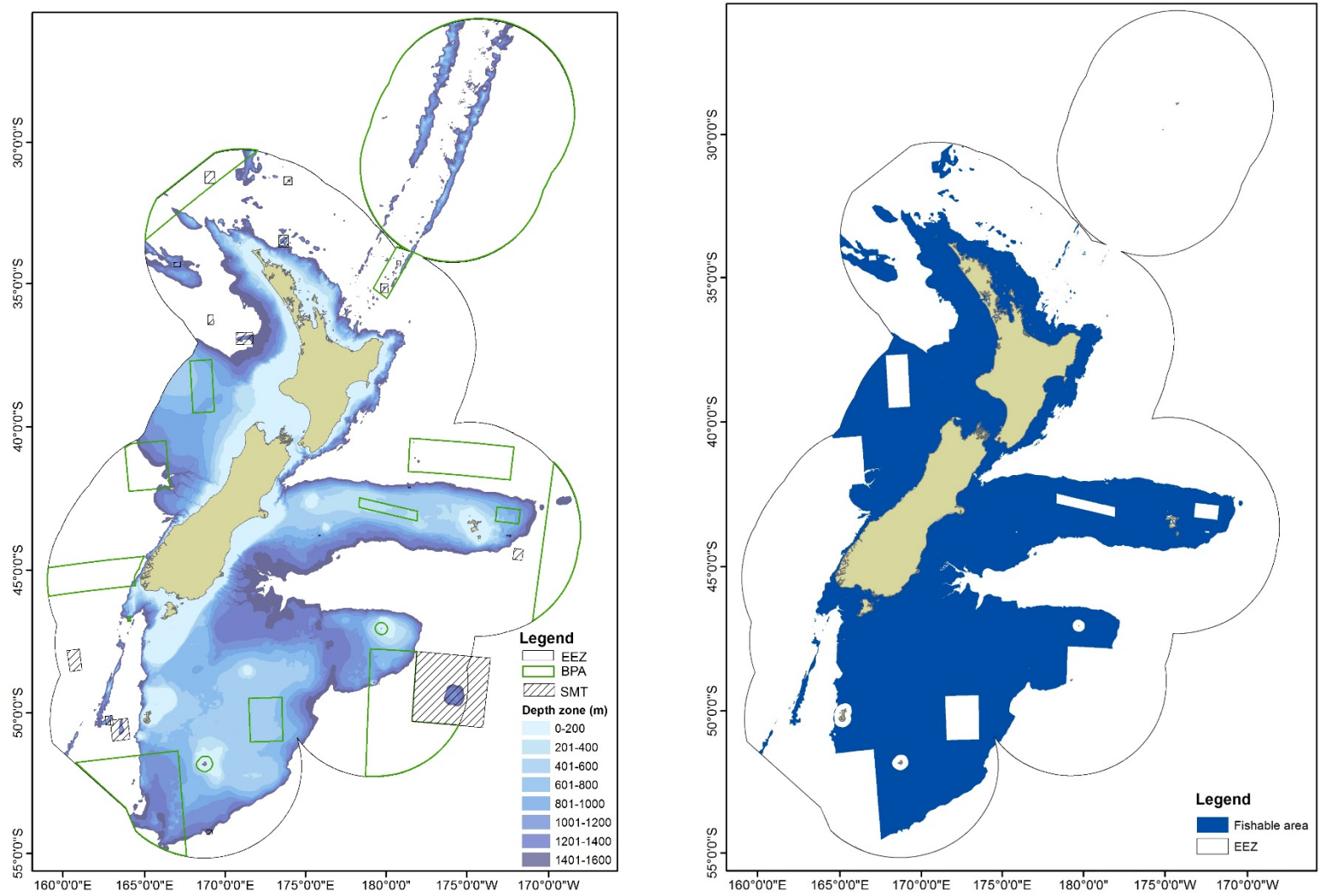

Figure B3: The extent of the waters down to 1600 m with the overlap of Benthic Protection Areas (BPA) and seamount closed areas (SMT) (left), and the fishable area with closed areas removed (right).

APPENDIX C: Statistical Area summaries

Table C1: Number of CELR tows by Statistical Area, all fishing years combined 1990–2007. A total of 270 tows with null Statistical Area records were not included in the total. Statistical Areas are shown in Figure 2. A total of 10 tows are included in the Tier 1 and Tier 2 totals, but not in the table (for HAK, SQU, and SWA).

Area	BAR	BYX	CDL	**HOK**	**JMA**	**LIN**	**OEO**	**ORH**	**SCI**	SKI	WWA	**Tier 1**	Tier 1,2
003	0	0	0	**0**	**0**	**0**	**0**	**0**	**5**	0	0	**5**	5
004	0	0	0	**0**	**0**	**0**	**0**	**0**	**152**	0	0	**152**	152
008	0	0	0	**0**	**0**	**0**	**0**	**0**	**81**	0	0	**81**	81
009	0	0	0	**8**	**0**	**0**	**0**	**11**	**77**	0	0	**96**	96
010	0	0	0	**9**	**0**	**0**	**0**	**0**	**0**	0	0	**9**	9
011	0	0	2	**21**	**0**	**0**	**0**	**208**	**0**	0	0	**229**	231
012	0	0	0	**10**	**0**	**0**	**0**	**19**	**0**	0	0	**29**	29
013	0	0	11	**16**	**0**	**0**	**0**	**144**	**0**	0	0	**160**	171
014	0	0	1	**26**	**0**	**0**	**0**	**19**	**157**	0	0	**202**	203
015	0	1	0	**14**	**0**	**0**	**0**	**29**	**26**	0	0	**69**	70
016	0	0	0	**368**	**0**	**0**	**0**	**1**	**0**	0	0	**369**	369
017	43	0	0	**455**	**0**	**0**	**0**	**0**	**0**	0	0	**455**	498
018	88	7	0	**87**	**0**	**4**	**0**	**85**	**0**	11	0	**179**	285
019	0	0	0	**0**	**0**	**0**	**1**	**38**	**0**	0	0	**39**	39
020	0	0	0	**26**	**0**	**6**	**0**	**38**	**2**	0	0	**72**	72
021	0	0	0	**0**	**0**	**0**	**0**	**4**	**58**	0	0	**62**	62
022	0	0	0	**0**	**0**	**0**	**73**	**0**	**0**	0	0	**77**	77
023	0	0	0	**0**	**0**	**0**	**1**	**0**	**0**	0	0	**1**	1
024	0	0	0	**0**	**0**	**0**	**24**	**0**	**0**	0	0	**24**	24
027	2	0	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	2
029	0	0	0	**0**	**0**	**3**	**0**	**0**	**0**	0	0	**3**	3
030	7	0	0	**0**	**0**	**35**	**0**	**0**	**185**	0	0	**220**	227
032	3	0	0	**0**	**0**	**3**	**0**	**0**	**2**	0	0	**5**	10
033	519	0	0	**42**	**0**	**57**	**0**	**208**	**0**	0	0	**307**	826
034	534	0	0	**289**	**0**	**75**	**2**	**300**	**0**	13	0	**666**	1 213
035	41	0	0	**0**	**0**	**0**	**0**	**6**	**0**	0	0	**6**	47
036	36	0	0	**0**	**2**	**0**	**0**	**0**	**0**	0	0	**2**	38
037	92	0	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	92
038	101	0	0	**0**	**2**	**0**	**0**	**0**	**0**	0	0	**2**	103
039	0	0	0	**14**	**0**	**0**	**0**	**0**	**0**	0	0	**14**	14
049	0	14	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	14
051	0	2	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	2
052	0	0	0	**0**	**0**	**0**	**4**	**0**	**0**	0	0	**4**	4
094	0	0	0	**2**	**0**	**0**	**0**	**0**	**0**	0	0	**2**	2
101	0	0	0	**0**	**0**	**0**	**0**	**8**	**0**	0	0	**8**	8
106	0	0	0	**0**	**0**	**0**	**0**	**0**	**6**	0	0	**6**	6
201	0	0	0	**0**	**0**	**0**	**0**	**0**	**1**	0	0	**1**	1
202	0	0	0	**0**	**0**	**0**	**0**	**3**	**0**	0	0	**3**	3
203	0	0	0	**0**	**0**	**0**	**0**	**16**	**0**	0	0	**16**	16
204	0	14	11	**1**	**0**	**0**	**0**	**238**	**0**	0	0	**239**	264
205	0	0	0	**1**	**0**	**0**	**0**	**0**	**0**	0	0	**1**	1
302	0	0	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	1
303	0	0	0	**0**	**0**	**0**	**2**	**0**	**0**	0	0	**2**	2
401	0	0	0	**2**	**0**	**4**	**0**	**126**	**64**	0	16	**196**	212
402	3	3	0	**0**	**0**	**0**	**0**	**75**	**0**	0	0	**75**	81
403	0	0	0	**0**	**0**	**0**	**0**	**117**	**0**	0	0	**117**	117
404	0	0	0	**0**	**0**	**0**	**0**	**10**	**0**	0	0	**10**	10
405	0	0	0	**0**	**0**	**0**	**0**	**18**	**0**	0	0	**18**	18
406	0	0	0	**0**	**0**	**0**	**0**	**3**	**0**	0	0	**3**	3
410	0	0	0	**0**	**0**	**0**	**2**	**0**	**0**	0	0	**2**	2
412	0	4	0	**0**	**0**	**0**	**0**	**0**	**0**	0	0	**0**	4
702	0	0	0	**0**	**0**	**0**	**0**	**104**	**0**	0	0	**104**	104
703	0	0	0	**8**	**0**	**0**	**0**	**4**	**0**	0	0	**12**	12
704	0	0	0	**0**	**0**	**0**	**15**	**97**	**0**	0	0	**112**	112
705	0	0	0	**0**	**0**	**0**	**0**	**557**	**0**	0	0	**557**	557
706	0	0	0	**0**	**0**	**0**	**0**	**5**	**2**	0	0	**7**	7
UNK	0	0	2	**145**	**0**	**0**	**5**	**118**	**0**	0	0	**268**	270
All	1 469	45	27	**1 544**	**4**	**187**	**129**	**2 609**	**818**	24	16	**5 298**	6 882

Table C2: Number of CELR, TCER, and TCEPR tows by Statistical Area, all fishing years combined, for Tier 1 species, total Tier 2 species, and Tier 1 and Tier 2 combined from 1990–2016. Another 7439 tows with null Statistical Area records are not included in the total. Statistical Areas are shown in Figure 2.

Area	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1	Tier 1&2
1	0	1	0	0	0	9	0	0	0	10	14
2	0	28	0	0	0	761	0	14	19	822	913
3	0	31	0	0	1	5	0	155	18	210	407
4	0	111	0	0	0	144	0	1078	10	1343	1606
5	0	0	0	0	0	13	0	4	0	17	96
6	0	1	0	0	0	3	0	4	0	8	132
7	0	2	0	0	0	0	0	0	0	2	2
8	0	1617	0	0	0	2439	0	11511	12	15579	19118
9	3	1212	0	0	0	569	0	7680	3	9467	9720
10	0	575	0	0	0	1784	0	248	1	2608	4116
11	0	885	0	0	4	5443	0	57	0	6389	7738
12	0	101	0	0	10	3290	0	126	0	3527	5804
13	0	268	0	0	98	4708	0	90	0	5164	9158
14	0	2135	1	1	88	2814	0	24763	0	29802	32367
15	1	4587	0	0	674	5298	0	3735	2	14297	18056
16	5	17373	0	0	5	91	0	1	1	17476	17617
17	0	12190	14	69	0	15	0	1	3	12292	13131
18	15	12220	70	40	74	5675	0	25	19	18138	20021
19	8	3217	2	1	170	2645	0	6	0	6049	6084
20	323	37414	366	567	18	1855	0	39	2565	43147	45125
21	101	8153	2319	424	7	15	0	4016	798	15833	16791
22	8	14213	2113	249	7872	174	2	39	20291	44961	47639
23	44	34459	20	154	10672	440	0	26	708	46523	46971
24	0	89	0	173	1670	76	0	1	2398	4407	5587
25	0	13	431	4	1	4	0	0	64	517	3027
26	4	3657	260	173	2924	35	0	1	6888	13942	16180
27	21	13334	1379	338	84	4	0	3	5235	20398	25898
28	1173	10464	3261	3205	227	94	0	1	61456	79881	86503
29	0	224	408	14	161	91	0	2	439	1339	2523
30	75	6526	53	3748	283	2935	0	544	4085	18249	20584
31	0	47	5	8	6	185	0	2	14	267	278
32	1	7	0	15	41	501	0	2	9	576	655
33	256	360	14	1126	7	920	0	20	7	2710	5463
34	9060	54987	885	1088	7	1085	11	41	83	67247	72339
35	2078	32524	2712	98	2	27	3	33	94	37571	42059
36	10	2123	3390	16	0	4	0	307	2	5852	6928
37	1	13	10877	0	1	0	0	1	898	11791	14116
38	0	2	127	0	1	0	0	1	11	142	1916
39	0	78	1564	1	2	5	0	1	162	1813	2117
40	0	0	8006	0	0	1	0	2	273	8282	8708
41	1	1	9944	0	0	12	0	0	20	9978	10405
42	0	4	2348	0	0	5	0	10	6	2373	3040
43	0	0	0	0	0	5	0	0	0	5	6
44	0	0	0	0	0	0	0	0	0	0	1
45	0	24	165	0	0	189	0	20	4	402	984
46	0	104	11	0	0	1237	0	20	35	1407	1628
47	0	35	13	0	10	1829	0	14	14	1915	2811
48	0	4	0	0	0	19	0	0	0	23	41
49	38	231	189	490	1	7	0	1300	116	2372	4884
50	6	165	93	11	0	48	0	3074	73	3470	5295
51	0	477	1	0	1130	9777	0	1	0	11386	15961
52	9	3573	42	200	3917	3241	0	15	143	11140	11495
91	0	0	0	0	0	6	0	0	0	6	7
92	0	0	0	0	0	1	0	0	0	1	1
93	0	0	0	0	0	1	0	4	0	5	5
94	0	4	0	0	2	21	0	4	0	31	38
101	0	3	3	0	0	33	0	1	0	40	42
102	0	1	0	0	1	25	0	4	0	31	33
103	0	0	0	0	21	1019	0	0	0	1040	1459

Table C2 [Continued]

Area	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier 1	Tier 1&2
104	0	0	1	0	0	2	1	0	0	4	5
105	0	3	0	0	0	2	0	0	2	7	8
106	0	4	0	0	0	303	0	17	1	325	1209
107	0	1	0	0	0	590	0	9	0	600	1013
201	0	5	0	0	1	178	0	4	0	188	301
202	0	0	0	0	0	8	0	0	0	8	10
203	0	0	0	0	0	35	0	0	0	35	47
204	0	33	0	0	36	9294	0	12	1	9376	15205
205	0	74	0	0	257	69	1	43	0	444	461
206	0	6	0	0	2	30	0	7	0	45	51
301	0	17	1	0	95	9	0	1	2	125	126
302	0	12	0	0	1589	4	0	0	8	1613	1622
303	0	14	0	0	472	2	1	0	4	493	494
401	195	10886	34	492	19	2118	2	25275	45	39066	40070
402	187	15354	3	141	4	1440	2	2585	6	19722	20048
403	671	2422	0	44	42	6869	0	17	0	10065	10137
404	5590	872	1	363	5	241	0	220	0	7292	8585
405	2	38	0	1	5	7497	0	5	0	7548	7553
406	2	28	0	0	17	8706	0	0	0	8753	9313
407	23	9512	10	35	524	216	0	35	571	10926	11357
408	2	13752	0	0	1351	185	0	2	2	15294	15309
409	2	8298	0	2	1257	285	0	11	1	9856	9869
410	24	7848	3	7	1834	1582	0	829	2	12129	12341
411	0	0	0	0	0	11	0	0	0	11	11
412	3	76	1	0	189	13657	0	0	4	13930	14671
501	0	0	0	0	1	7	0	0	0	8	8
502	0	4	1	1	0	19	0	1	0	26	26
503	0	41	4	0	2788	1187	0	0	54	4074	4330
504	29	6090	194	233	25	2	1	3	10775	17352	18561
601	0	9	0	2	2715	470	0	20	9	3225	3232
602	1664	17193	9	3843	838	1612	61	30053	51413	106686	106817
603	173	16405	0	1371	14	6	64	480	43	18556	18585
604	0	206	0	5	482	16	5	0	1	715	723
605	0	40	0	0	557	4	4	0	2	607	609
606	0	36	0	0	5966	1501	6	5	0	7514	7515
607	0	50	1	9	3398	717	1759	25	6	5965	5971
608	4	29	0	11	65	24	1857	2	4	1996	1999
609	0	3	0	0	4	9	1	0	0	17	18
610	0	1069	0	893	2	0	788	6	631	3389	3596
611	0	75	0	23	1	0	231	1	228	559	564
612	0	79	0	3	4246	1067	83	1	0	5479	5491
613	0	2	0	0	210	24	2	14	1	253	255
614	0	5	0	0	3	3	0	0	0	11	11
615	0	0	0	0	0	0	0	1	0	1	1
617	0	12	0	0	5	5	0	4	2	28	28
618	2	2648	0	26	0	0	8547	21	6	11250	11254
619	0	126	0	30	13	12	2136	3	4	2324	2333
620	0	4	0	0	31	3	2	0	0	40	41
621	0	6	0	0	0	0	0	3	0	9	9
622	0	0	0	0	0	1	1	0	0	2	2
623	0	2	0	0	3	5	0	7	8	25	25
624	0	120	0	0	4	4	13	0	0	141	141
625	0	2906	2	0	11	6	1	0	2	2928	2930
701	0	10	2	0	0	5	0	49	1	67	69
702	0	21	0	0	0	6473	0	37	3	6534	6539
703	19	502	13	2	0	115	0	19	1	671	682
704	0	21	1	1	17	998	1	16	3	1058	1071
705	6	36	0	1	2	1473	0	0	16	1534	1537
706	0	6	1	5	1	18	0	5	17	53	57
801	0	3	727	0	0	46	0	1	7	784	862
UNK	30	5271	180	62	367	948	83	577	408	7926	8527
Total	21869	402152	52275	19819	59660	131745	15669	119473	171273	993935	1089878

Table C3: Number of CELR, TCER, and TCEPR tows by Statistical Area, for Tier 1 species, total Tier 1 species, and Tier 1 and Tier 2 combined for 2016. Statistical Areas are shown in Figure 2. Only Statistical Areas with trawl effort in 2016 are included in this table.

Area	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier1	Tier1&2
002	0	0	0	0	0	17	0	0	0	17	18
003	0	0	0	0	0	1	0	0	0	1	1
004	0	6	0	0	0	4	0	86	6	102	179
008	0	44	0	0	0	8	0	347	0	399	484
009	0	46	0	0	0	32	0	385	0	463	465
010	0	28	0	0	0	60	0	42	0	130	179
011	0	10	0	0	0	94	0	3	0	107	145
012	0	0	0	0	0	16	0	0	0	16	158
013	0	0	0	0	0	49	0	0	0	49	65
014	0	56	0	0	0	27	0	430	0	513	574
015	0	43	0	0	0	47	0	63	0	153	206
016	0	281	0	0	0	0	0	0	0	281	297
017	0	153	0	9	0	0	0	0	0	162	209
018	0	219	0	3	0	97	0	0	15	334	378
019	0	34	0	0	0	20	0	0	0	54	54
020	2	811	1	5	0	48	0	0	110	977	1 100
021	0	79	27	0	0	2	0	2	2	112	137
022	0	339	9	13	113	0	0	0	167	641	816
023	0	747	0	0	97	1	0	0	87	932	966
024	0	1	0	47	61	0	0	0	68	177	366
025	0	0	1	0	0	0	0	0	0	1	56
026	0	13	1	17	93	0	0	0	17	141	169
027	0	106	1	0	0	0	0	0	37	144	211
028	19	156	60	195	7	0	0	0	824	1 261	1 502
029	0	1	5	0	1	0	0	0	0	7	71
030	0	42	0	332	0	0	0	0	63	437	465
032	0	0	0	0	0	0	0	0	0	0	1
033	44	14	2	63	0	4	0	10	0	137	327
034	210	1 675	10	65	0	11	0	15	0	1 986	2 195
035	88	1 190	53	4	0	4	0	1	0	1 340	1 423
036	0	73	43	0	0	0	0	68	0	184	223
037	0	0	261	0	0	0	0	0	0	261	346
038	0	0	0	0	0	0	0	0	0	0	14
039	0	2	4	0	0	0	0	0	0	6	18
040	0	0	107	0	0	0	0	0	0	107	129
041	0	0	237	0	0	3	0	0	0	240	240
042	0	0	56	0	0	3	0	0	0	59	59
045	0	0	4	0	0	9	0	0	0	13	13
046	0	0	0	0	0	252	0	0	0	252	253
047	0	0	0	0	0	188	0	0	0	188	189
049	0	1	5	28	0	0	0	147	0	181	304
050	0	0	0	0	0	0	0	340	0	340	357
051	0	0	0	0	17	205	0	0	0	222	387
052	1	89	0	2	56	8	0	0	0	156	159

Table C3 [Continued]

Area	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	Tier1	Tier1&2
102	0	0	0	0	0	0	0	0	0	0	1
103	0	0	0	0	0	0	0	0	0	0	7
106	0	0	0	0	0	0	0	0	0	0	21
107	0	0	0	0	0	9	0	1	0	10	12
201	0	0	0	0	0	0	0	0	0	0	1
204	0	0	0	0	0	59	0	0	0	59	161
205	0	0	0	0	0	0	0	1	0	1	1
301	0	0	0	0	2	0	0	0	0	2	2
302	0	0	0	0	22	0	0	0	0	22	22
303	0	0	0	0	8	0	0	0	0	8	8
401	0	250	0	0	0	69	0	1 453	0	1 772	1 776
402	0	406	0	0	0	66	0	261	0	733	734
403	1	33	0	0	0	238	0	0	0	272	272
404	2	3	0	18	0	13	0	0	0	36	62
405	0	0	0	0	0	155	0	0	0	155	155
406	0	0	0	0	0	176	0	0	0	176	180
407	0	246	0	0	6	0	0	0	17	269	279
408	0	365	0	0	22	0	0	0	0	387	387
409	0	323	0	0	12	1	0	0	0	336	336
410	0	266	0	0	58	9	0	2	0	335	356
412	0	1	0	0	0	596	0	0	0	597	599
503	0	0	0	0	13	0	0	0	0	13	17
504	0	61	0	1	0	0	0	0	69	131	144
601	0	0	0	0	5	2	0	0	0	7	7
602	113	235	0	116	11	54	3	1 351	1 319	3 202	3 202
603	0	254	0	22	0	0	0	15	0	291	291
604	0	0	0	0	5	0	0	0	0	5	5
605	0	0	0	0	2	0	0	0	0	2	2
606	0	0	0	0	38	0	0	0	0	38	38
607	0	0	0	0	22	0	25	0	0	47	47
608	0	0	0	0	0	0	8	0	0	8	8
610	0	2	0	0	0	0	0	0	2	4	5
612	0	0	0	0	119	0	0	0	0	119	119
618	0	3	0	0	0	0	199	0	0	202	202
619	0	0	0	0	0	0	111	0	0	111	111
702	0	0	0	0	0	374	0	0	0	374	374
703	0	3	0	0	0	2	0	0	0	5	5
704	0	0	0	0	0	13	0	0	0	13	14
705	0	0	0	0	0	10	0	0	0	10	10
706	0	0	0	1	0	0	0	0	0	1	1
801	0	0	6	0	0	25	0	0	0	31	31
UNK	0	96	4	1	5	12	5	38	6	167	173
Total	480	8 806	897	942	795	3 094	351	5 061	2 809	23 235	26 086

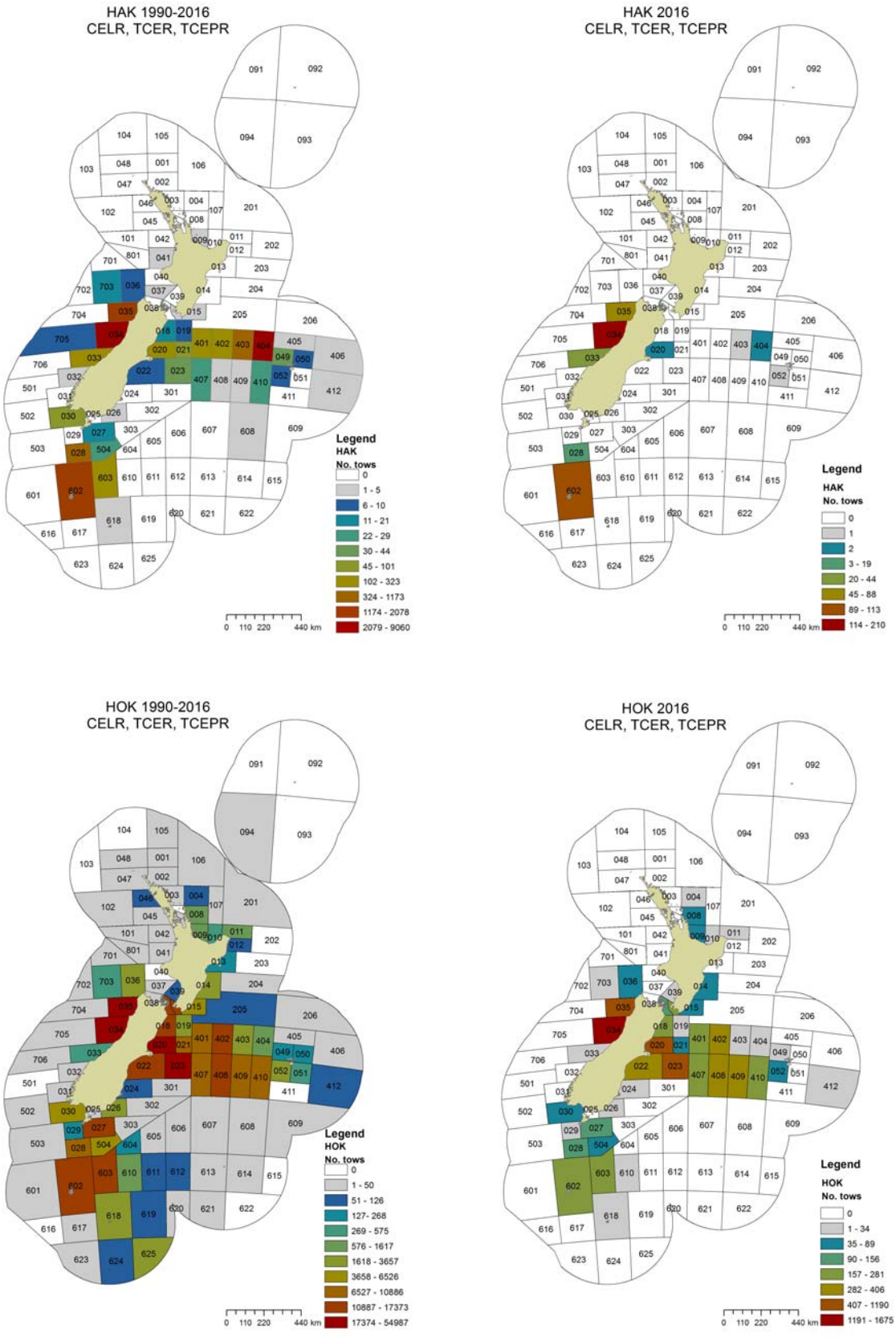

Figure C1a: Number of CELR, TCER, and TCEPR bottom-contacting tows by Statistical Area, all fishing years combined (left) and for 2016 (right) for hake fishstocks (top) and hoki fishstocks (bottom). In each plot in Figure C1, the data were classed using Jenks natural break classification in ArcGIS.

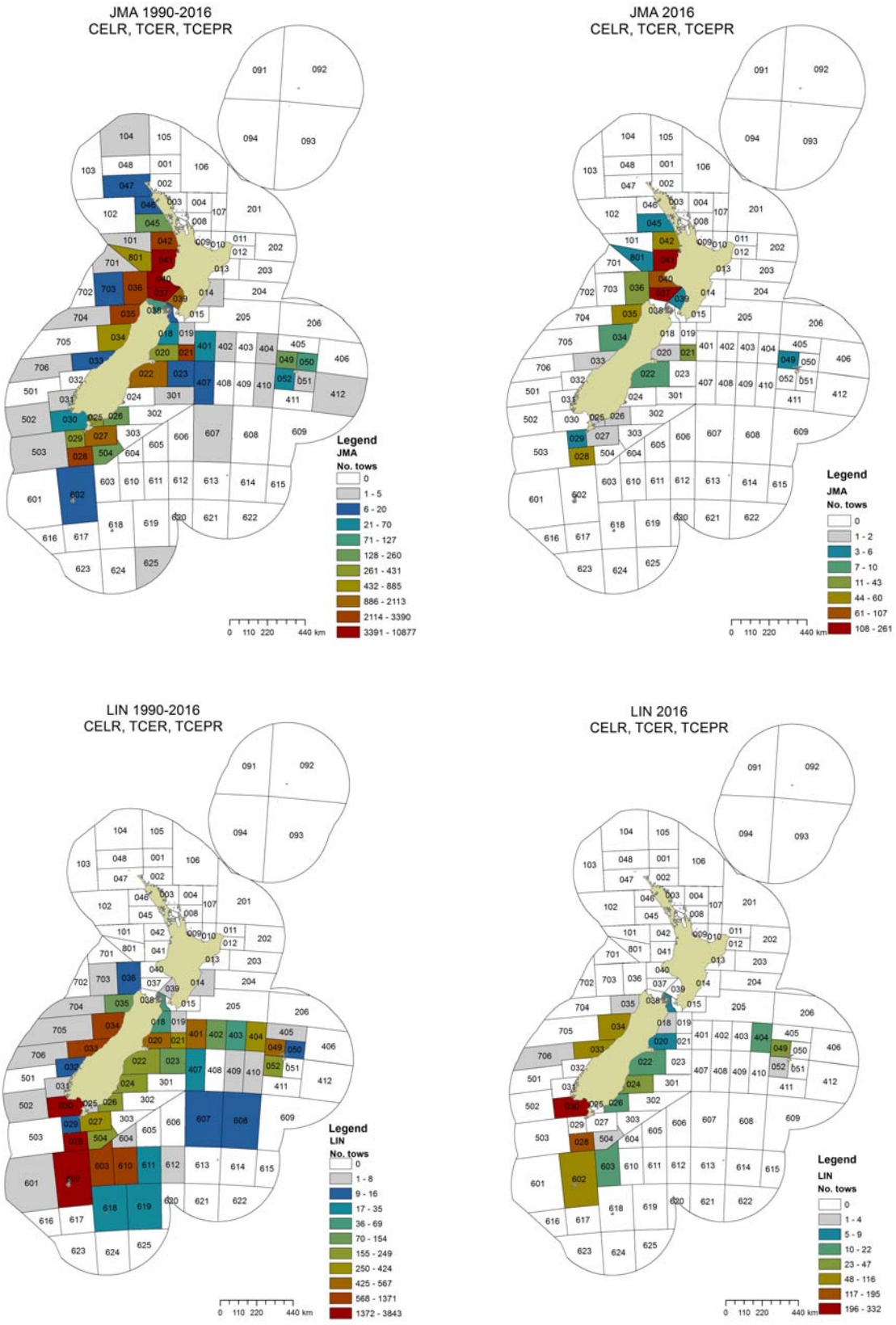

Figure C1b: Number of CELR, TCER, and TCEPR bottom-contacting tows by Statistical Area, all fishing years combined (left) and for 2016 (right) for jack mackerel fishstocks (top) and ling fishstocks (bottom).

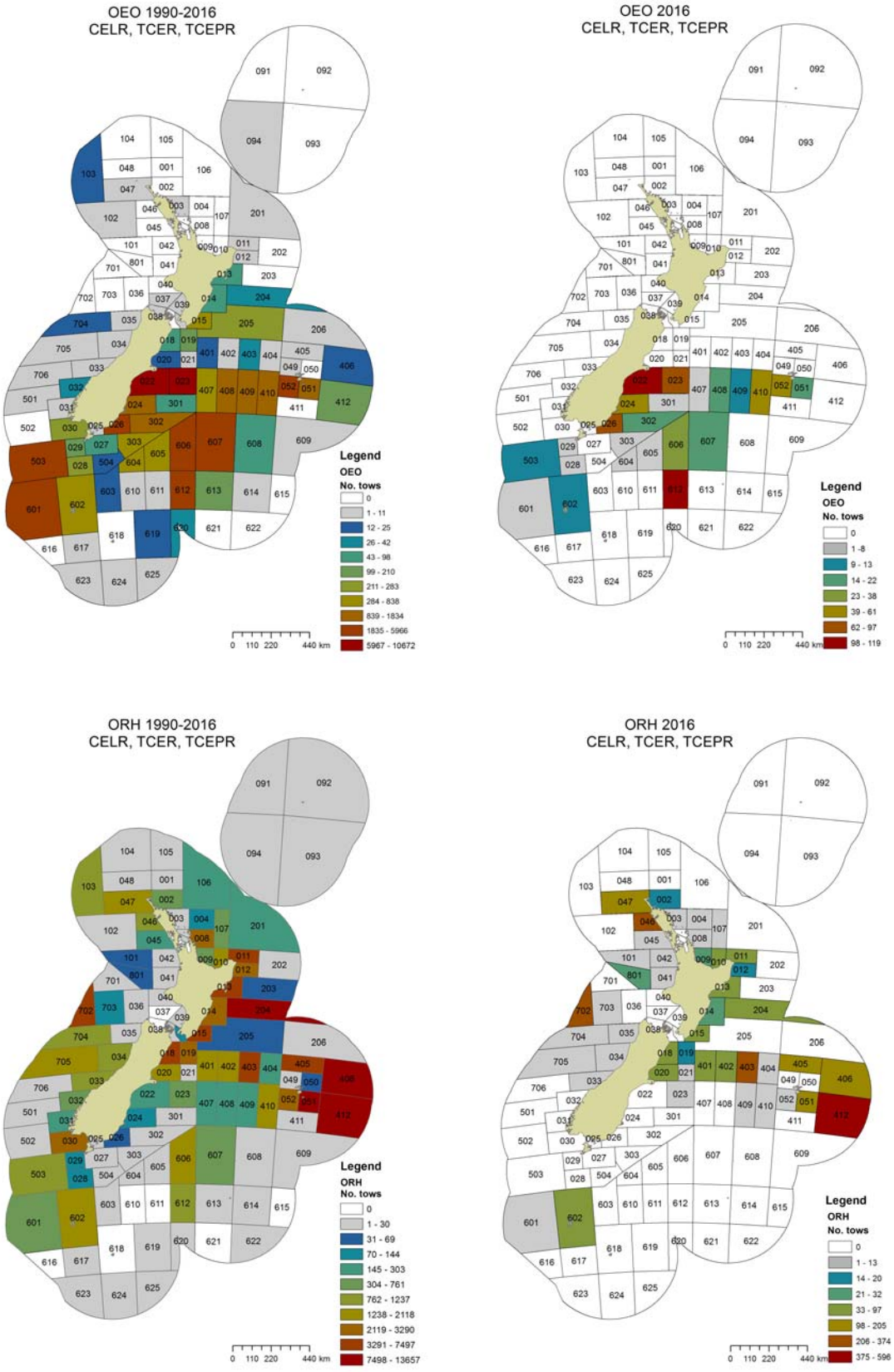

Figure C1c: Number of CELR, TCER, and TCEPR bottom-contacting tows by Statistical Area, all fishing years combined (left) and for 2016 (right) for oreo fishstocks (top) and orange roughy fishstocks (bottom).

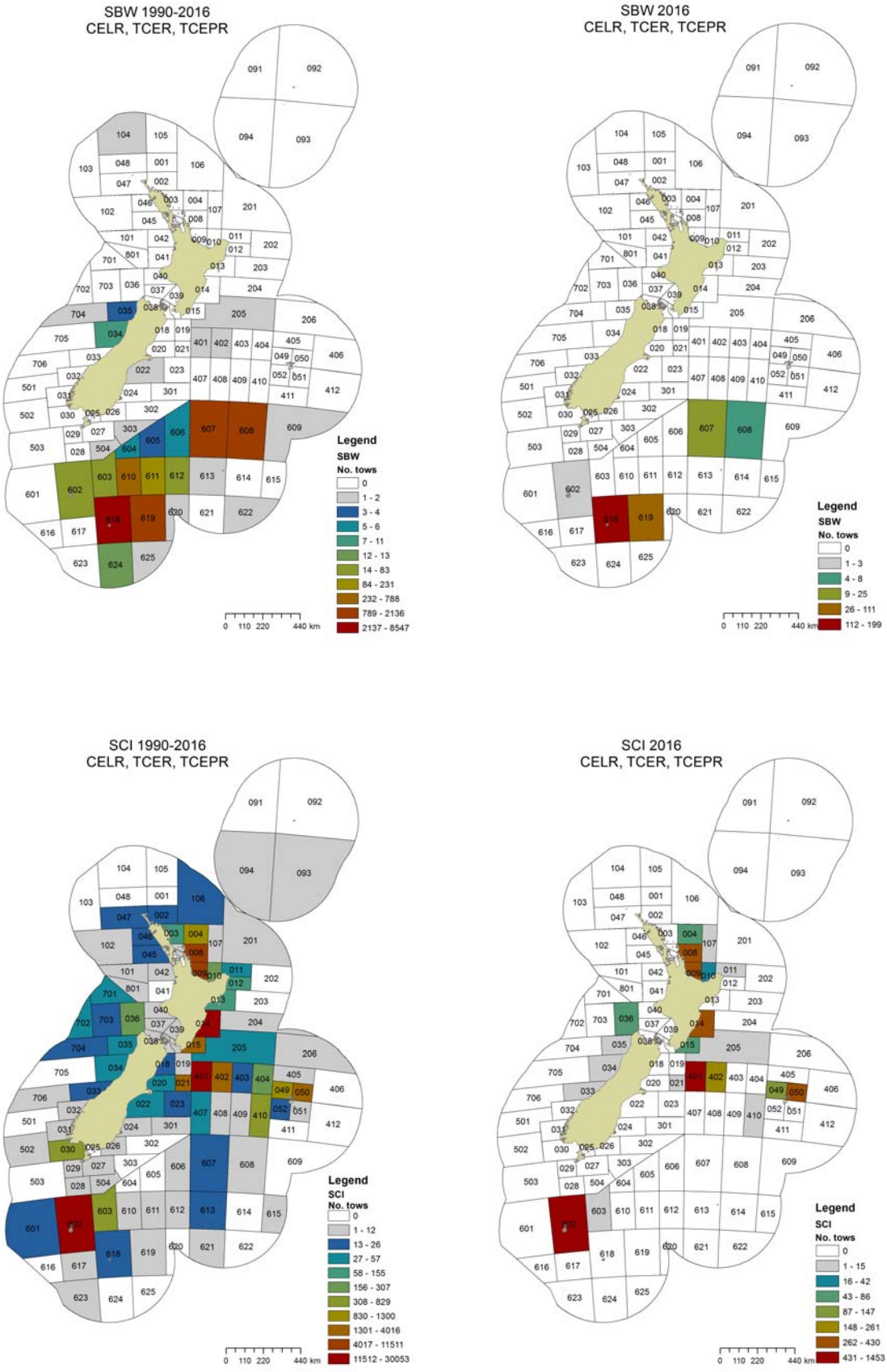

Figure C1d: Number of CELR, TCER, and TCEPR bottom-contacting tows by Statistical Area, all fishing years combined (left) and for 2016 (right) for southern blue whiting fishstocks (top) and scampi fishstocks (bottom).

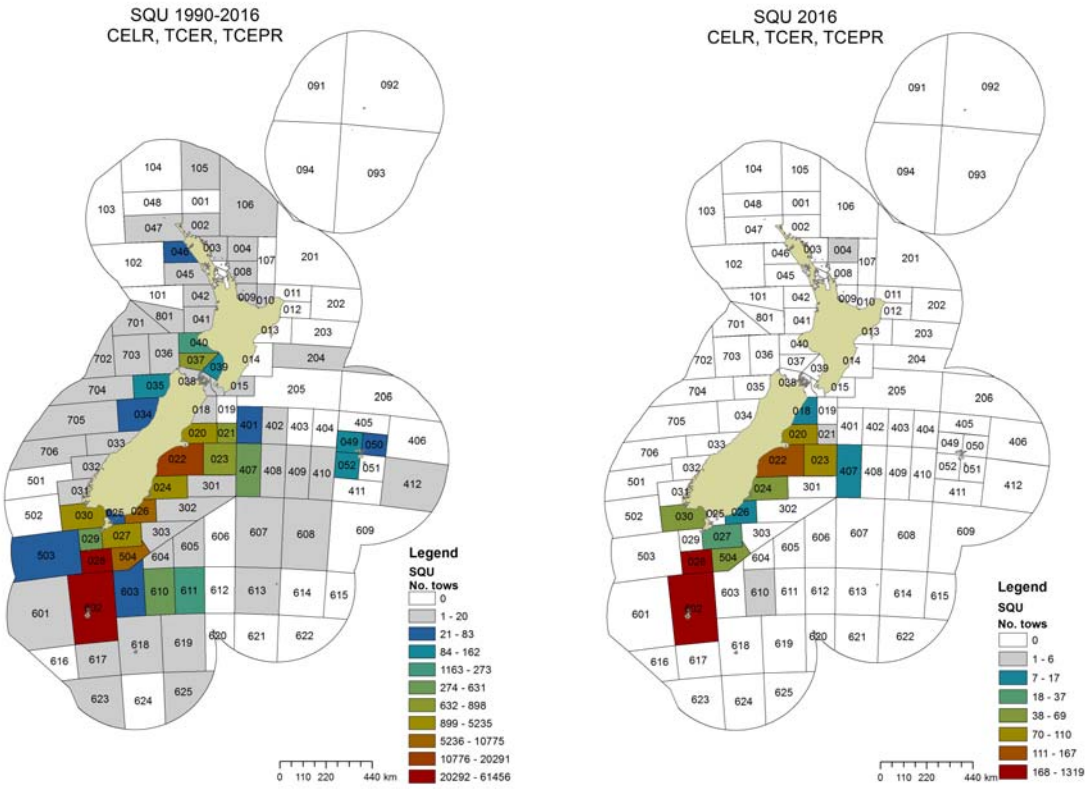

Figure C1e: Number of CELR, TCER, and TCEPR bottom-contacting tows by Statistical Area, all fishing years combined (left) and for 2016 (right) for arrow squid fishstocks.

APPENDIX D: Trawl footprint and aggregated swept area summaries

1.0 Spatial analysis data summaries

The total number of tows used in the footprint analysis is shown in Table D1. Between 1990 and 2005, the Tier 2 targets accounted for about 6–9% of the annual numbers of tows. From 2006–16, 11–15% of annual tows were from Tier 2 targets. For the 1990–2016 period, the Tier 2 targets accounted for almost 9% of the total tows.

The Tier 2 targets contacted about 5–9% of the total cells contacted each year for fishing years 1990–2007, but from 2008 onwards, Tier 2 targets covered 13–16% of the annual cells contacted (Table D2). Over all years, the Tier 2 target trawls covered about 6% of all the contacted cells.

The Tier 1 annual trawl footprints shown in Figure 6 are given in Table D3, as well as the totals for the Tier 1 and Tier 2 targets combined. Table D4 gives the total aggregated swept area by Tier 1 targets and for all targets combined.

2.0 Spatial distribution of TCER and TCEPR footprints

The distributions of TCER and TCEPR Tier 1 target trawl footprint data are shown in Figure D1 to provide a comparison of the data from the two forms. The TCER accounted for only about 2% of the tows over the 1990–2016 time period.

Figures D2a–D2c give the distributions and overlaps of the 1990–2016 data and the 2016 data, for each of the Tier 1 targets and for the combined Tier 1 and Tier 2 targets.

For the 2016 total footprint, a comparison with the 1990–2015 footprint indicated that about 0.2% of the 2016 footprint was outside the larger footprint. This 'new' area was equivalent to 76 km^2 and was based on 212 tows, 57% of which targeted orange roughy in Statistical Area 701. It is likely that a small proportion of the other tows that made up this 76 km^2 may be from trawls that are incorrectly located because of wrong position data.

3.0 Comparison of distance measures

The distributions of the distance measured between start and finish positions (trackline) and the distance calculated from the reported tow duration and tow speed (speed-duration) are shown in Figure D4 as a comparison of the possible tow lengths (distance). It is known that many fishers utilise turns whilst towing or follow a contour and thus rarely follow a straight line, as is assumed in the analysis presented in this report. The trackline distances have been truncated by the 'long' tow rule discussed earlier in Section 4.2.

4.0 Number of years a 25-km^2 cell has been contacted by trawl gear, 1990–2016

The numbers of years that the 25-km^2 cells were contacted are summarised in Figures D5 and D6. Of the 44 918 cells contacted during 1990–2016, 28% were contacted in one year only, 28% had contact in 2–5 years, and 14% in 6–10 years. 915 cells (2%) were contacted in 26 years, and 2235 were contacted in all 27 years.

Figure D7 shows the percentage of the 44 918 cells contacted in any one year – generally about 25–40% – and for years from 1995 shows the percentage of the cells contacted in that year that had had no trawling in the previous five years. This latter percentage dropped in the years post the effort peaks shown by the tow and footprint data, and increased slightly towards the end of the time series as the effort declined further.

5.0 Number of tows per 25-km^2 cell, 1990–2016 and 2016

The distribution of the numbers of tows per 25-km^2 cell are shown in Figure D8 for 1990–2016 and in 2106. In 1990–2016, the greatest numbers of tows were off the southern edge of the Stewart-Snares shelf in Statistical Area 028 where arrow squid and middle depths fish species are targeted.

In 2016, the cells with the most tows were to the north-east of the Chatham Islands (049, 050, 405) and to the east of Mernoo Bank in Statistical Area 401 — tows in both areas targeted scampi. Scampi was

the main target in the area of higher numbers of tows off the south-eastern edge of the Auckland Islands in Statistical Area 602. Hoki was the main target species that contributed to the high tow count in cells near the Hokitika Canyon off the west coast South Island in Statistical Area 034.

6.0 Aggregated swept area, 1990–2016 and 2016

The aggregated area swept for 1990–2016 was 3.07 million km^2 (Table D4 and Figure D9), with 95% from Tier 1 targets – most of which was from hoki targeting. The annual aggregated swept area ranged from about 125 000 and 166 000 km^2 (peak in 1998) and remained at these levels through the early to mid-2000s. Since 2006 the aggregated swept area has been less than 100 000 km^2 a year, at about 75 000–85 000 km^2. The total for 2016 was 78 372 km^2.

Table D1: Number of bottom-contacting tows for each Tier 1 species, total for Tier 1, and total Tier 1 and Tier 2 combined, by fishing year, 1990–2016.

Fishing year	Tier 1 targets										Tier 1 & Tier 2
	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	All	
1990	184	7 981	2 131	662	1 898	5 543	926	2 080	7 682	29 087	32 281
1991	68	12 898	1 518	977	2 508	4 481	1 294	3 872	10 061	37 677	40 504
1992	534	15 246	2 467	646	1 265	6 141	2 207	5 301	7 353	41 160	43 673
1993	841	15 990	2 523	538	1 851	7 177	417	5 149	7 105	41 591	44 817
1994	517	12 864	2 676	401	1 584	10 121	432	5 102	9 119	42 816	45 441
1995	740	16 960	2 018	227	1 687	8 709	172	3 768	9 886	44 167	48 267
1996	519	20 746	1 905	361	2 863	5 232	329	3 349	9 368	44 672	48 698
1997	453	24 574	1 541	311	3 336	5 361	293	3 472	9 647	48 988	52 289
1998	418	26 710	3 175	302	3 130	8 640	781	3 394	7 776	54 326	57 195
1999	677	23 723	2 456	336	3 355	8 014	769	4 005	6 876	50 211	53 128
2000	373	24 343	1 667	399	3 345	6 320	503	4 516	5 231	46 697	49 831
2001	453	23 320	1 559	258	3 231	4 302	450	4 743	6 784	45 100	48 044
2002	678	21 326	2 310	377	2 663	4 018	792	6 435	6 937	45 536	48 917
2003	710	20 537	2 516	321	2 484	4 570	354	4 519	7 981	43 992	47 980
2004	1 195	16 103	1 836	327	2 262	4 502	465	3 479	7 853	38 022	40 547
2005	1 075	10 596	1 835	577	2 303	4 330	392	4 548	9 264	34 920	38 299
2006	851	8 524	2 175	903	2 010	4 323	311	4 843	7 603	31 543	35 443
2007	1 009	7 965	1 916	1 176	2 100	3 785	324	5 068	4 670	28 013	31 966
2008	971	7 595	1 850	1 889	2 458	3 642	402	4 784	3 929	27 520	32 347
2009	1 349	6 937	1 488	1 108	2 154	3 513	584	3 958	3 486	24 577	28 580
2010	492	8 322	1 759	894	2 527	2 905	660	4 150	3 590	25 299	29 164
2011	428	7 968	1 139	919	1 886	1 876	668	4 426	4 063	23 373	26 969
2012	344	8 740	1 416	809	1 653	1 582	445	4 503	3 344	22 836	26 186
2013	518	9 080	1 278	984	1 268	1 587	389	4 522	2 549	22 175	25 000
2014	561	10 087	1 238	888	1 256	2 025	307	4 409	2 005	22 776	25 948
2015	678	9 874	878	974	1 258	2 311	453	4 404	1 904	22 734	25 782
2016	313	8 644	842	931	793	3 085	349	5 056	2 785	22 798	25 572
All years	16 949	387 653	50 112	18 495	59 128	128 095	15 468	117 855	168 851	962 606	1 052 868

Table D2: Number of 25-km^2 cells crossed by bottom-contacting tows for each Tier 1 species separately and in total, and for the total of Tier 1 and Tier 2 targets, by fishing year, 1990–2016.

Fishing	Tier 1 targets										Tier 1 &
year	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	All	Tier 2
1990	393	4 505	2 197	1 024	895	2 016	581	774	1 892	11 398	12 239
1991	194	5 825	1 812	1 212	1 065	1 694	844	958	2 243	12 543	13 274
1992	756	6 099	2 118	1 254	577	1 559	1 994	1 449	1 841	14 005	14 709
1993	883	6 780	2 020	939	674	1 937	656	1 969	1 807	13 713	14 811
1994	499	5 703	2 039	759	786	2 497	544	1 493	2 363	13 044	14 019
1995	545	7 114	2 009	636	698	2 206	419	1 403	2 780	13 367	14 733
1996	524	6 793	2 003	761	968	1 778	543	1 117	2 167	12 624	13 932
1997	548	8 011	1 741	688	1 275	1 972	480	1 114	2 341	13 960	14 714
1998	711	8 338	2 156	817	1 177	2 763	637	1 346	2 184	15 444	16 318
1999	808	7 227	1 625	661	1 290	3 008	821	1 578	2 015	14 791	15 803
2000	643	8 167	1 566	951	1 222	2 608	523	1 264	2 505	15 079	16 062
2001	624	8 845	1 264	711	1 111	1 715	591	1 013	2 370	14 480	15 565
2002	735	8 631	1 842	712	1 164	1 746	1 154	1 381	2 047	15 757	17 195
2003	773	8 655	1 962	679	950	1 664	394	1 178	2 263	15 085	16 368
2004	718	7 667	1 352	589	1 022	1 759	433	903	1 788	13 343	14 220
2005	805	5 519	1 417	821	1 202	1 715	485	1 263	1 868	12 301	13 098
2006	569	4 240	1 736	1 150	1 102	1 573	413	1 252	2 108	11 560	12 404
2007	899	3 956	1 691	1 413	1 132	1 331	393	1 155	1 668	10 996	12 077
2008	885	4 132	1 636	2 006	980	1 429	355	1 086	1 153	11 004	13 071
2009	906	3 798	1 516	1 288	907	1 606	632	1 013	1 048	10 430	12 232
2010	399	3 927	1 464	1 254	900	1 612	693	1 010	1 332	10 595	12 321
2011	478	4 279	1 313	1 115	801	891	609	1 041	1 301	9 862	11 817
2012	427	4 246	1 387	840	703	878	604	1 074	1 136	9 657	11 430
2013	460	4 261	1 410	700	528	787	344	1 268	833	9 085	10 778
2014	606	4 679	1 473	880	544	1 204	323	1 283	770	9 966	11 810
2015	574	4 679	1 141	676	515	1 383	393	1 265	877	9 864	11 335
2016	410	4 179	1 158	850	472	1 740	473	1 345	1 058	9 876	11 547
All years	4 341	23 429	5 986	6 361	5 668	10 551	3 940	7 404	9 020	42 428	44 918

Table D3: Trawl footprint (km^2) for each Tier 1 species by fishing year, for the Tier 1 total, and the Tier 1 and Tier 2 total, 1990–2016.

Fishing year	Tier 1 targets										Tier 1 & Tier 2
	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	All Tier 1	
1990	717.7	18 158.8	6 433.3	1 866.8	1 458.2	4 412.0	1 485.9	1 372.5	6 396.1	40 682.3	45 499.8
1991	318.2	29 381.9	5 134.7	2 482.6	1 518.9	3 001.0	2 146.6	2 578.2	7 976.2	52 200.2	55 488.9
1992	1 839.1	36 122.7	7 144.4	2 052.8	765.3	2 588.6	4 549.2	4 199.5	6 832.5	63 026.1	66 312.5
1993	2 413.1	38 021.7	7 206.0	1 723.5	963.3	3 047.5	846.3	4 493.4	7 015.4	63 055.4	66 898.2
1994	1 713.5	27 423.4	7 133.6	1 376.4	1 053.0	4 091.2	713.4	4 559.9	7 561.4	52 859.2	55 558.8
1995	1 575.2	37 004.3	5 378.9	795.7	907.9	3 424.8	372.2	3 664.3	9 089.7	58 373.3	62 273.2
1996	1 481.5	36 927.4	5 697.7	1 250.1	1 308.2	2 338.6	658.3	3 133.2	8 434.3	57 915.1	61 342.7
1997	1 529.3	43 157.1	4 318.8	1 002.2	1 575.3	3 104.2	734.4	3 458.4	9 460.0	65 025.4	67 405.3
1998	1 508.3	48 154.0	6 888.3	1 081.9	1 236.1	4 656.8	1 611.5	3 483.3	7 949.3	73 135.5	75 218.9
1999	1 863.4	45 390.2	5 422.9	1 051.5	1 700.0	4 994.1	1 367.0	3 932.8	7 127.8	69 263.1	71 055.3
2000	1 680.7	49 083.2	4 093.7	1 357.8	1 876.9	3 628.4	1 074.4	4 351.9	7 541.7	71 041.3	73 084.0
2001	1 476.9	50 908.5	3 752.8	1 065.0	1 276.5	2 550.8	1 069.0	4 416.4	9 029.3	72 853.1	75 307.1
2002	2 300.5	51 230.7	5 749.3	1 223.1	1 258.7	2 540.7	1 963.1	5 254.4	7 674.7	76 564.3	79 710.9
2003	2 677.9	51 700.2	5 973.5	941.6	1 002.7	2 460.0	633.3	5 049.9	8 413.6	76 336.1	80 012.9
2004	3 227.0	40 407.9	4 274.9	936.8	1 124.0	3 131.4	833.9	4 334.4	7 551.1	63 498.6	65 717.6
2005	2 897.5	25 734.8	4 598.3	1 437.5	1 289.4	2 489.5	720.4	4 523.9	8 120.5	49 812.8	52 666.2
2006	1 814.8	21 213.2	5 382.7	2 025.0	1 190.9	2 407.7	630.2	5 074.2	7 747.0	45 734.9	48 626.7
2007	2 709.9	19 829.2	5 530.7	2 699.5	1 129.2	2 312.3	655.9	5 313.7	6 253.1	44 812.6	48 863.2
2008	2 979.4	17 980.1	5 365.7	4 122.5	1 050.3	2 012.5	816.9	5 151.3	4 114.0	42 224.7	48 365.9
2009	3 189.9	18 708.5	4 288.3	1 986.4	1 022.3	2 465.6	1 052.1	4 095.5	4 340.9	39 442.0	44 314.1
2010	1 083.5	23 282.5	5 154.4	1 477.0	1 123.6	2 316.1	1 347.7	4 128.3	4 788.3	43 700.0	47 706.0
2011	1 299.8	24 064.5	3 720.0	1 250.9	875.8	844.8	1 406.5	4 589.8	5 518.0	42 249.1	46 495.8
2012	1 061.3	25 016.0	4 398.5	1 131.4	709.9	663.4	955.1	4 607.1	4 395.8	41 718.9	45 277.1
2013	1 094.6	24 282.9	4 079.4	880.2	532.2	675.2	853.2	4 788.5	3 516.5	39 727.4	43 413.9
2014	1 369.0	26 563.8	3 816.5	1 136.3	504.0	1 062.7	654.3	4 584.2	3 046.4	41 798.7	45 344.6
2015	1 677.4	27 777.4	2 800.1	992.4	556.7	1 603.4	957.3	4 520.1	3 070.7	42 796.5	46 431.9
2016	732.0	24 756.9	2 708.2	1 241.3	378.3	2 207.9	870.8	5 316.9	3 414.6	40 883.9	44 261.5
All years	19 551.0	167 101.3	44 429.2	24 293.9	15 961.5	34 725.2	21 013.7	7 834.7	40 131.5	313 652.8	335 811.8

Table D4: Aggregated swept area (km^2) for Tier 1 target species and the Tier 1 and Tier 2 target species combined, for fishing years 1990 to 2016, based on TCER and TCEPR data.

Fishing										Tier 1 targets	Tier 1 &
year	HAK	HOK	JMA	LIN	OEO	ORH	SBW	SCI	SQU	All Tier 1	Tier 2
1990	1 132.1	34 477.6	7 905.8	2 367.3	1 732.6	6 452.8	1 927.2	2 672.0	25 823.5	84 491.1	93 845.4
1991	373.1	59 896.5	6 227.9	3 436.2	1 862.3	3 992.0	2 614.9	6 072.8	34 919.6	119 395.4	126 553.3
1992	3 024.0	67 866.9	9 215.9	2 509.5	935.9	3 620.3	5 394.4	8 745.3	28 851.2	130 163.5	137 060.6
1993	5 046.4	70 209.0	9 777.8	1 997.4	1 204.0	4 244.0	906.1	7 910.9	26 448.8	127 744.4	136 205.1
1994	2 434.4	49 423.4	9 100.7	1 627.3	1 259.5	6 051.9	781.3	8 819.5	28 862.7	108 360.6	115 169.6
1995	3 052.1	72 983.2	6 815.1	883.4	1 051.4	4 843.2	383.0	6 148.0	36 209.7	132 368.9	142 628.0
1996	2 071.7	76 414.0	7 361.0	1 424.1	1 598.3	2 897.2	704.9	5 190.2	33 151.1	130 812.6	138 877.2
1997	2 151.8	90 608.0	5 220.8	1 112.4	1 978.1	3 791.7	810.2	5 856.2	32 061.0	143 590.2	148 493.9
1998	1 755.6	106 647.5	10 443.3	1 186.9	1 445.8	5 808.8	1 845.6	5 719.7	26 514.0	161 367.1	166 091.9
1999	2 392.0	93 151.3	8 020.5	1 149.8	2 100.0	6 099.9	1 542.8	6 745.4	27 020.4	148 222.2	152 326.5
2000	2 034.9	97 707.0	5 655.2	1 488.8	2 324.4	4 307.6	1 206.2	8 291.8	20 157.3	143 173.2	147 345.4
2001	1 872.9	95 177.4	4 986.0	1 191.0	1 482.5	2 990.3	1 172.4	9 162.9	24 896.7	142 932.2	147 101.4
2002	3 936.0	91 690.3	7 483.6	1 393.0	1 443.2	2 933.3	2 120.2	12 732.6	23 801.6	147 533.7	152 800.8
2003	3 535.6	91 962.3	8 232.2	1 089.9	1 150.2	3 006.9	753.3	9 736.6	27 408.3	146 875.2	152 939.4
2004	5 867.8	68 472.2	5 883.4	1 057.5	1 273.9	3 836.8	1 035.4	7 690.5	26 480.1	121 597.6	124 887.8
2005	4 769.4	43 022.1	6 170.8	1 772.6	1 424.6	3 122.4	811.8	8 586.0	30 081.2	99 761.0	104 804.8
2006	3 012.0	35 519.2	6 807.8	2 689.0	1 417.2	2 909.6	691.8	9 373.5	22 483.9	84 904.0	90 167.4
2007	3 713.2	33 034.0	6 806.4	3 410.8	1 315.7	2 741.9	740.1	10 096.3	15 648.1	77 506.5	84 158.4
2008	4 234.7	29 135.5	6 215.5	5 217.9	1 323.7	2 363.8	939.2	10 326.6	11 203.4	70 960.3	79 370.8
2009	5 109.1	32 485.4	4 966.4	2 381.9	1 220.9	2 813.0	1 151.2	7 205.7	10 530.5	67 864.1	74 534.6
2010	1 501.0	42 078.2	6 500.3	1 648.5	1 373.7	2 629.7	1 481.5	7 669.0	11 575.8	76 457.7	81 893.6
2011	1 642.6	42 593.9	4 433.5	1 474.0	1 007.2	930.2	1 660.3	8 514.9	13 423.0	75 679.6	81 329.4
2012	1 276.9	45 621.6	5 404.1	1 289.7	827.2	738.7	1 035.7	8 137.6	11 828.4	76 159.9	80 987.4
2013	1 413.8	44 338.1	4 827.8	1 330.0	597.0	761.4	1 020.2	8 378.3	8 328.0	70 994.5	75 922.4
2014	1 683.9	47 678.7	4 479.0	1 409.0	554.6	1 163.3	736.0	8 011.1	6 521.1	72 236.8	77 122.2
2015	2 270.3	50 865.3	3 277.3	1 410.0	625.9	1 865.5	1 093.7	8 278.9	6 029.6	75 716.5	81 235.3
2016	849.7	46 485.8	3 083.6	1 545.8	424.1	2 576.6	952.2	10 066.6	7 935.0	73 919.4	78 391.6
All years	72 156.8	1 659 544.3	175 301.7	49 493.9	34 954.1	89 492.8	35 511.9	216 138.9	578 193.8	2 910 788.2	3 072 244.3

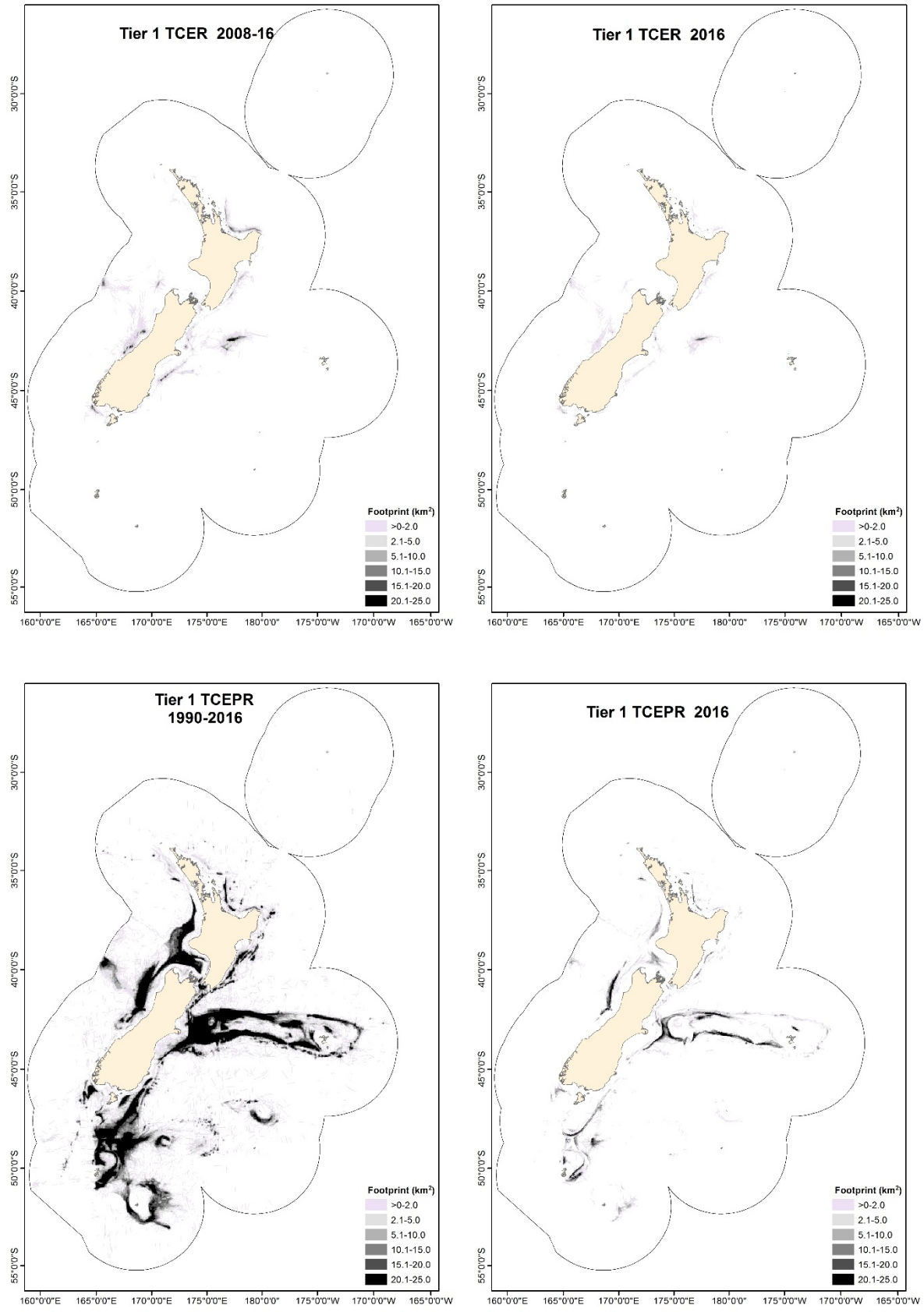

Figure D1: Bottom-contacting footprint (km^2) for TCER 2008–16 data (top) and TCEPR 1990–2016 data (bottom) Tier 1 target species combined.

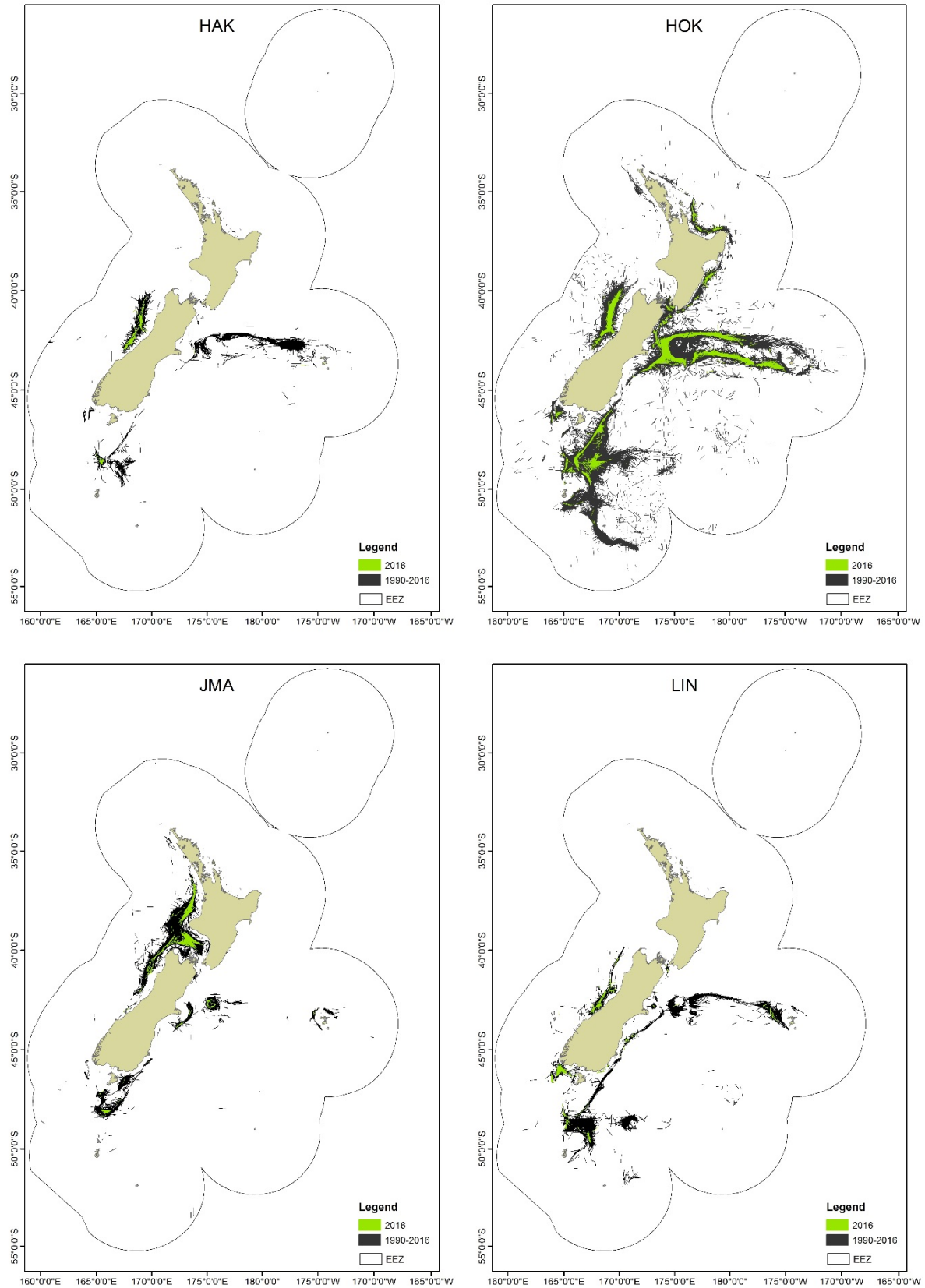

Figure D2a: Bottom-contacting footprint for TCER and TCEPR Tier 1 target species (hake, hoki, jack mackerel, and ling), for all fishing years 1990–2016 and for 2016. The outer boundary of the 200 n. mile EEZ, indicated here as 'EEZ', represents the combination of the EEZ and the 12 n. mile Territorial Sea.

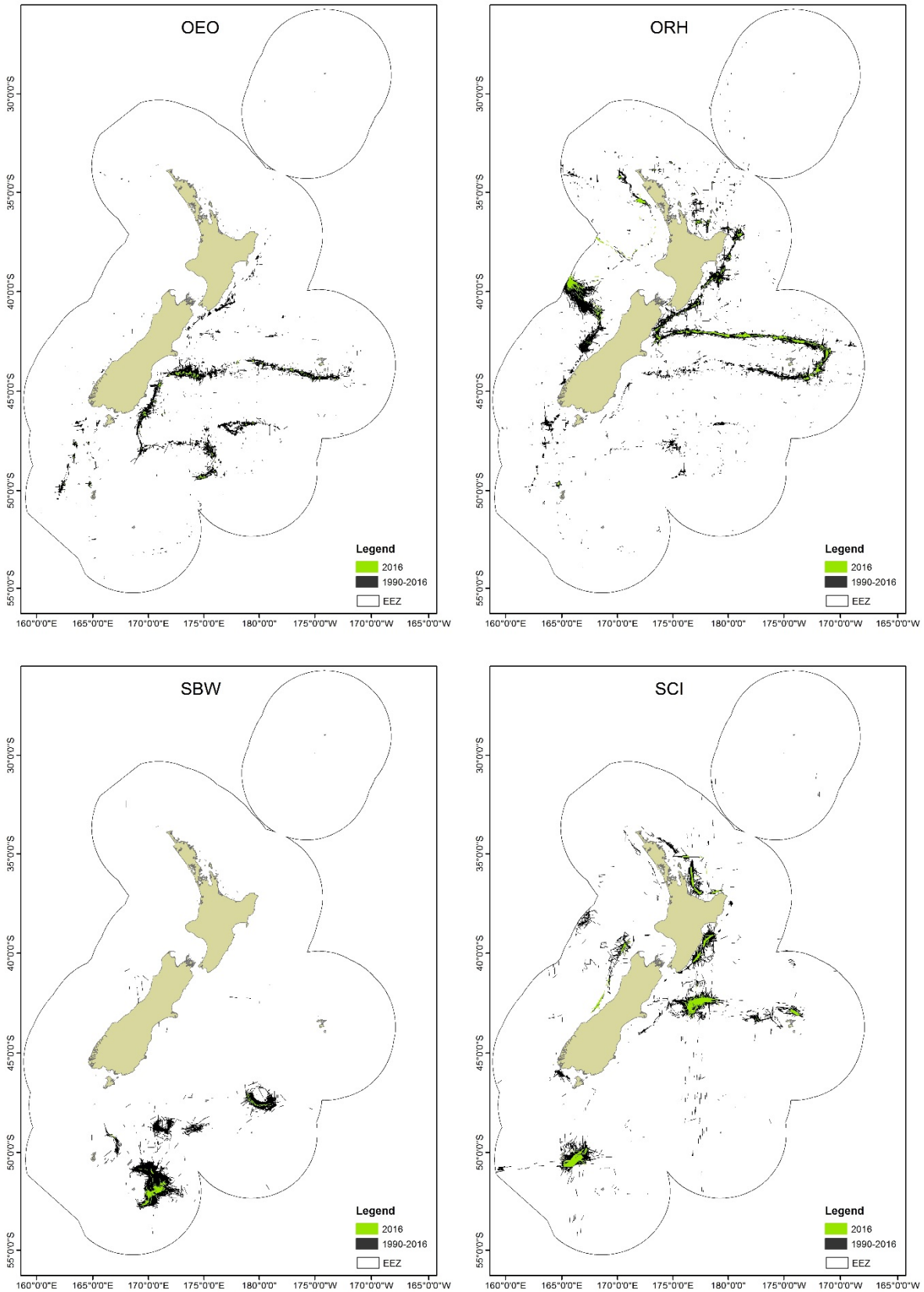

Figure D2b: Bottom-contacting footprint for TCER and TCEPR Tier 1 target species (oreo species, orange roughy, southern blue whiting, and scampi), for all fishing years 1990–2016 and for 2016.

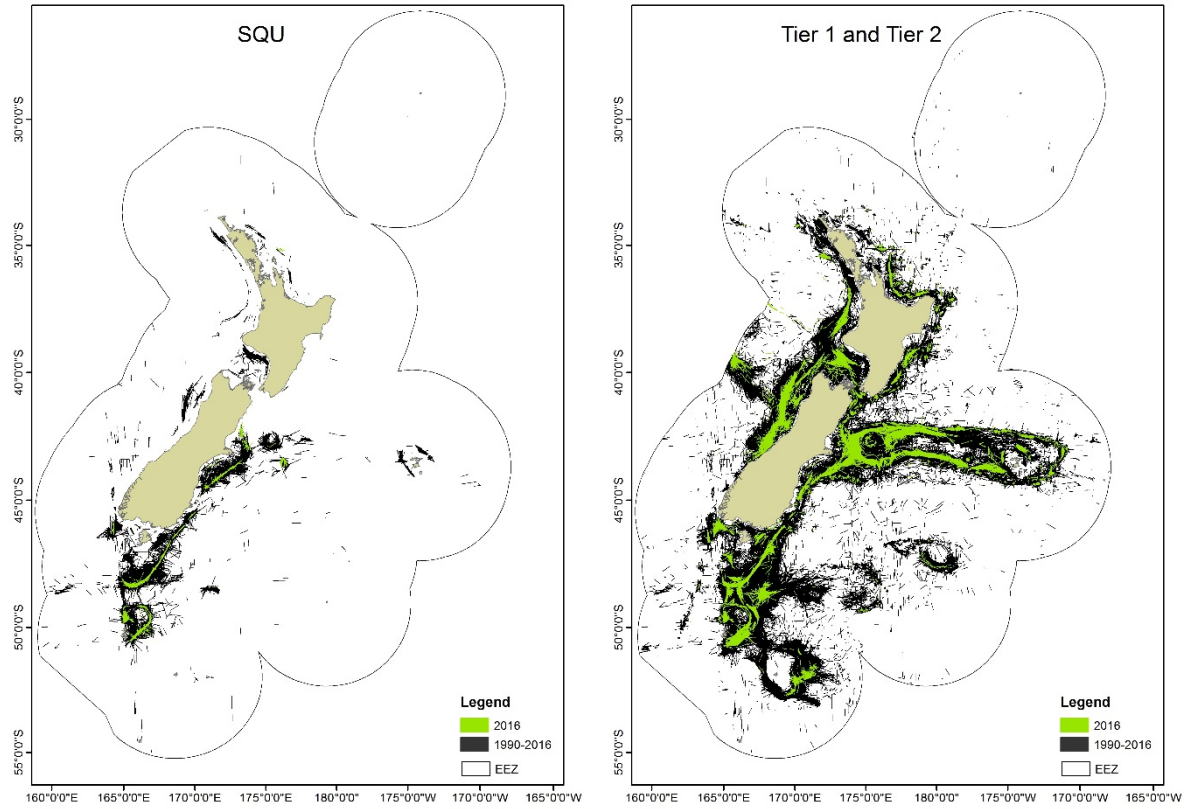

Figure D2c: Bottom-contacting footprint for TCER and TCEPR arrow squid (left) and for the combination of Tier 1 and Tier 2 species, for all fishing years 1990–2016 and for 2016.

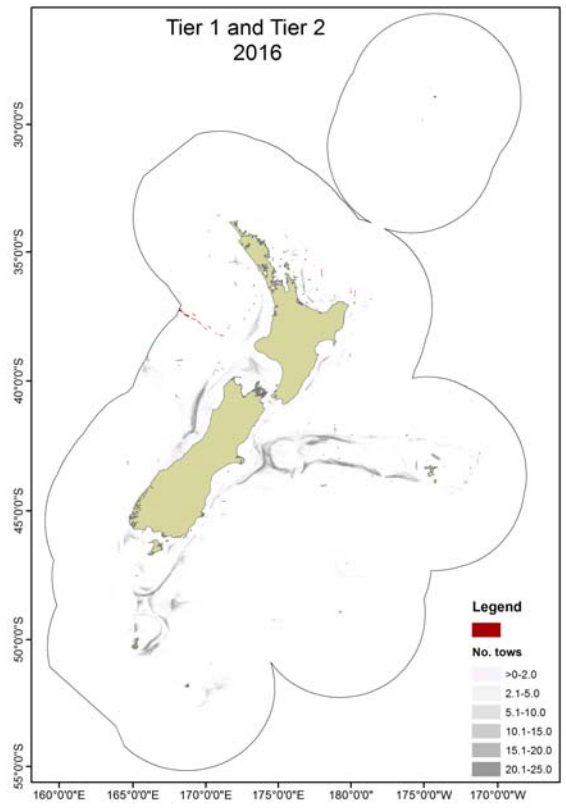

Figure D3: Number of tows per 25-km^2 cell for TCER and TCEPR Tier 1 and Tier 2 target species for 2016. Red indicates trawling outside the 1990–2015 footprint.

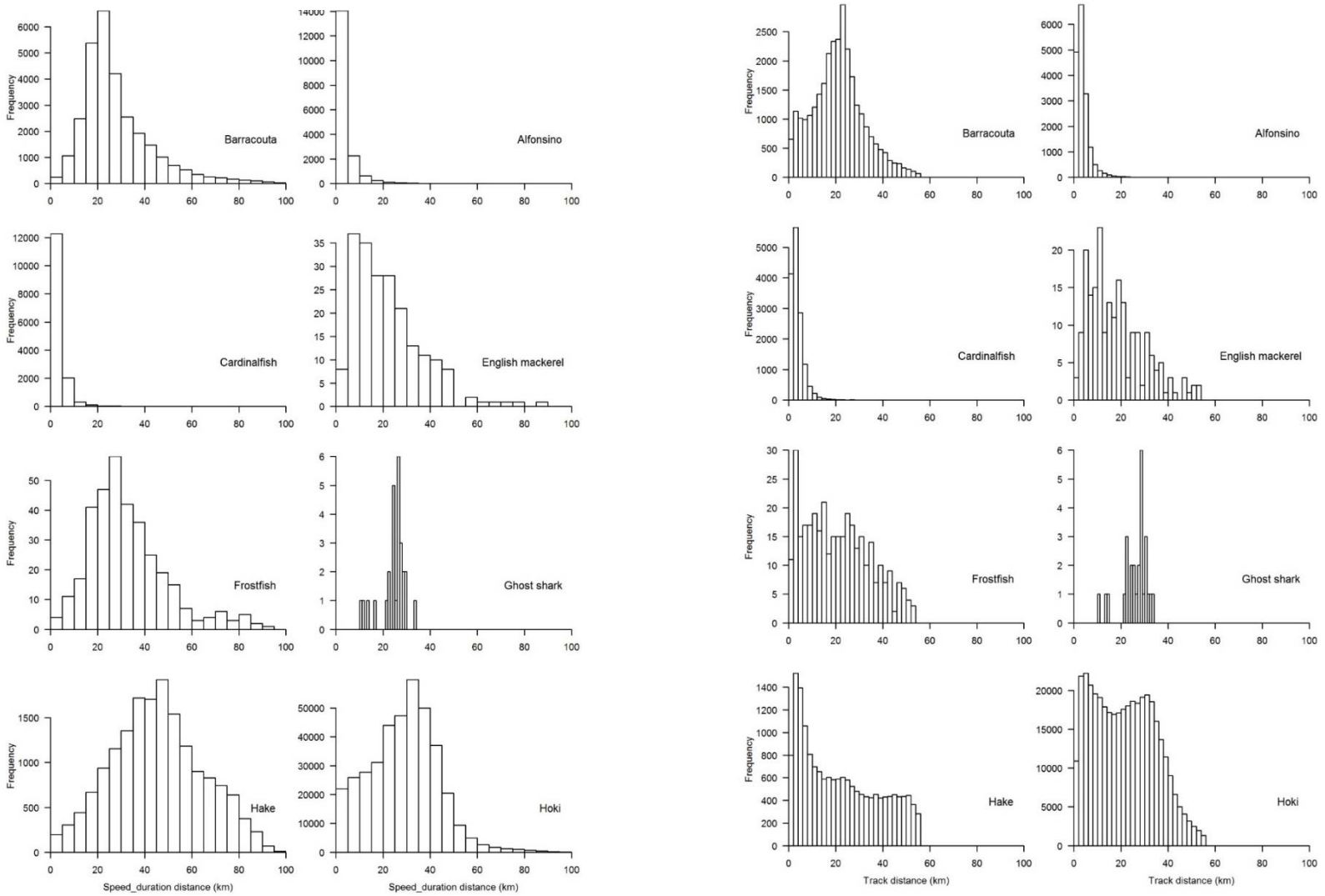

Figure D4: Frequency of distance (km) derived from speed and tow duration values (left) and distance between start and finish positions for the combined TCER and TCEPR dataset (right), by target species and fishing years 1990 to 2016.

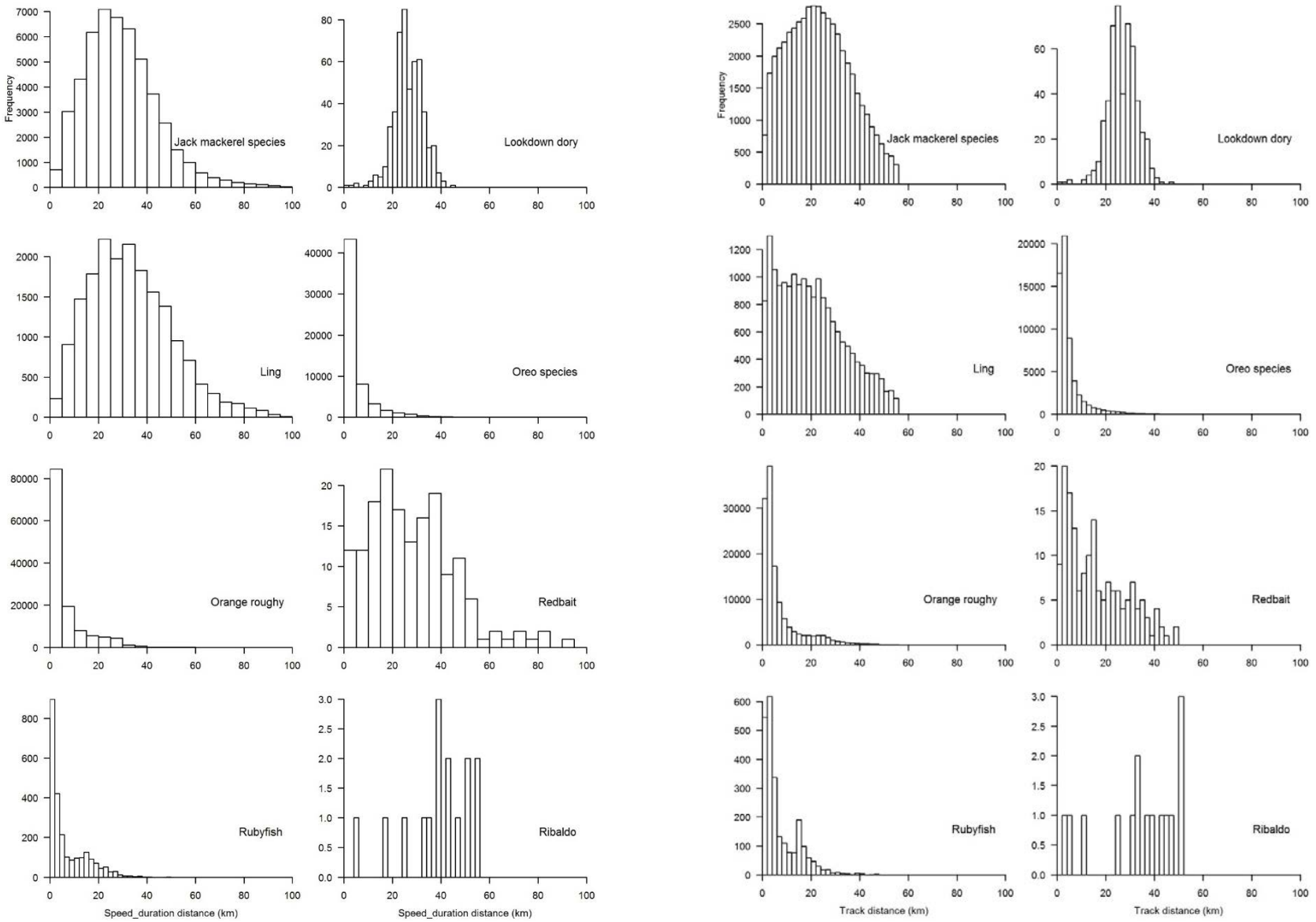

Figure D4 [Continued]

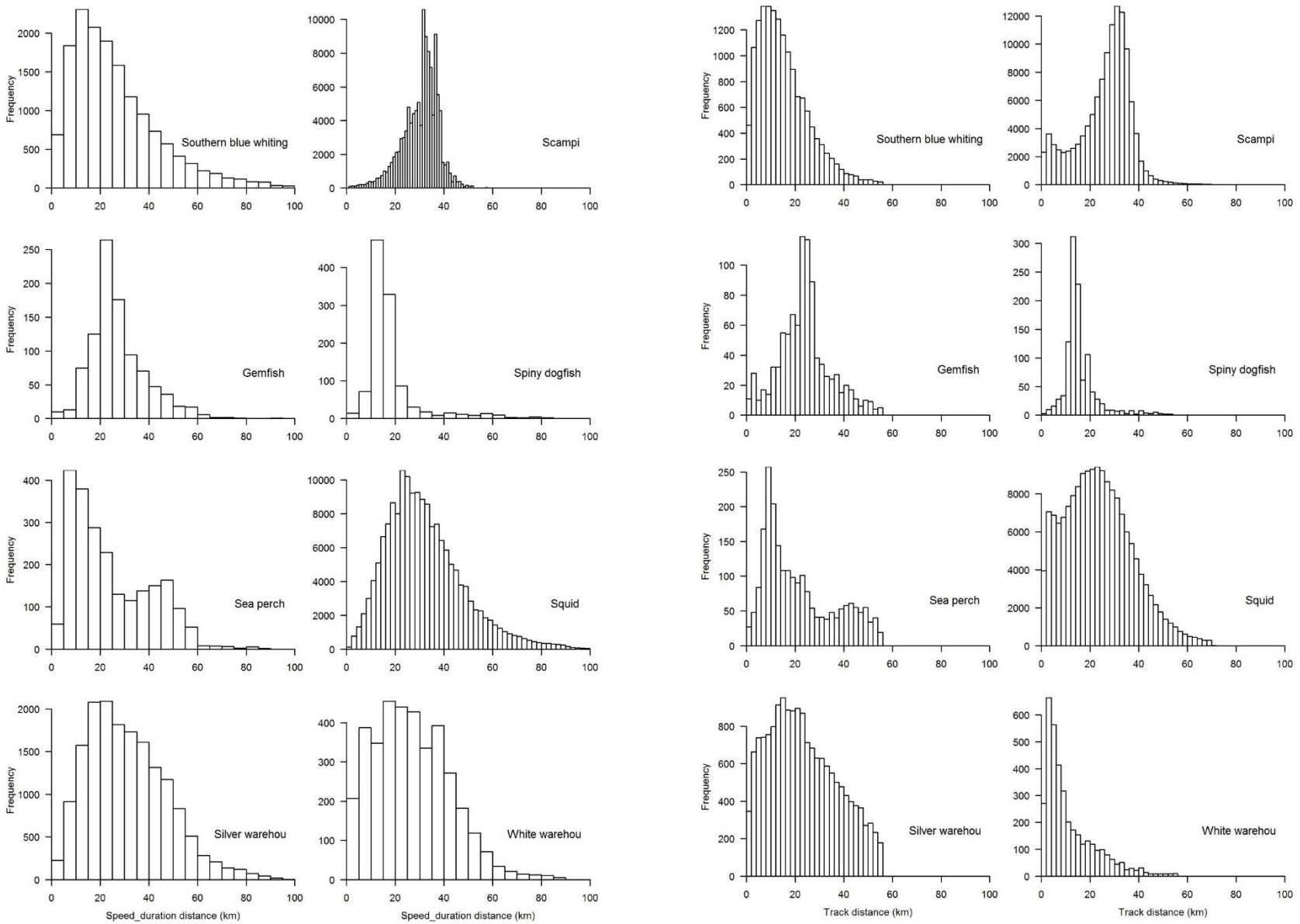

Figure D4 [Continued]

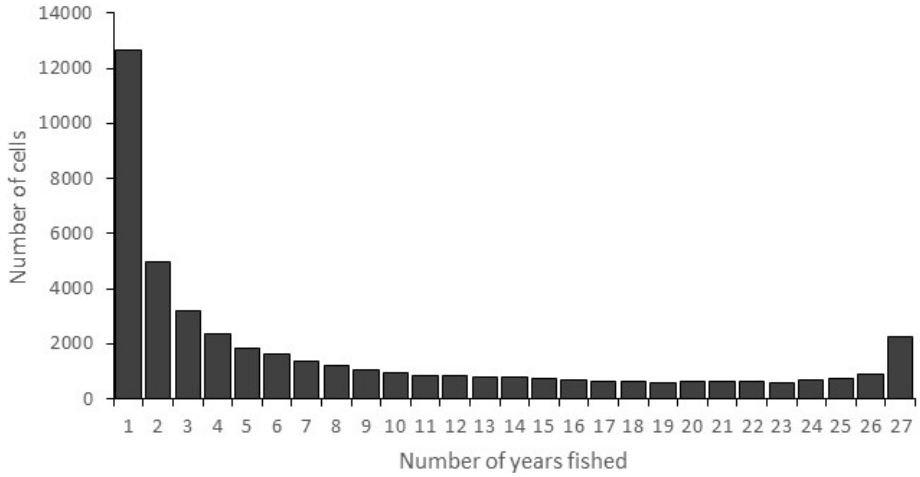

Figure D5: Number of years that 25-km^2 cells were contacted by trawl gear, 1990–2016, for those cells that were contacted.

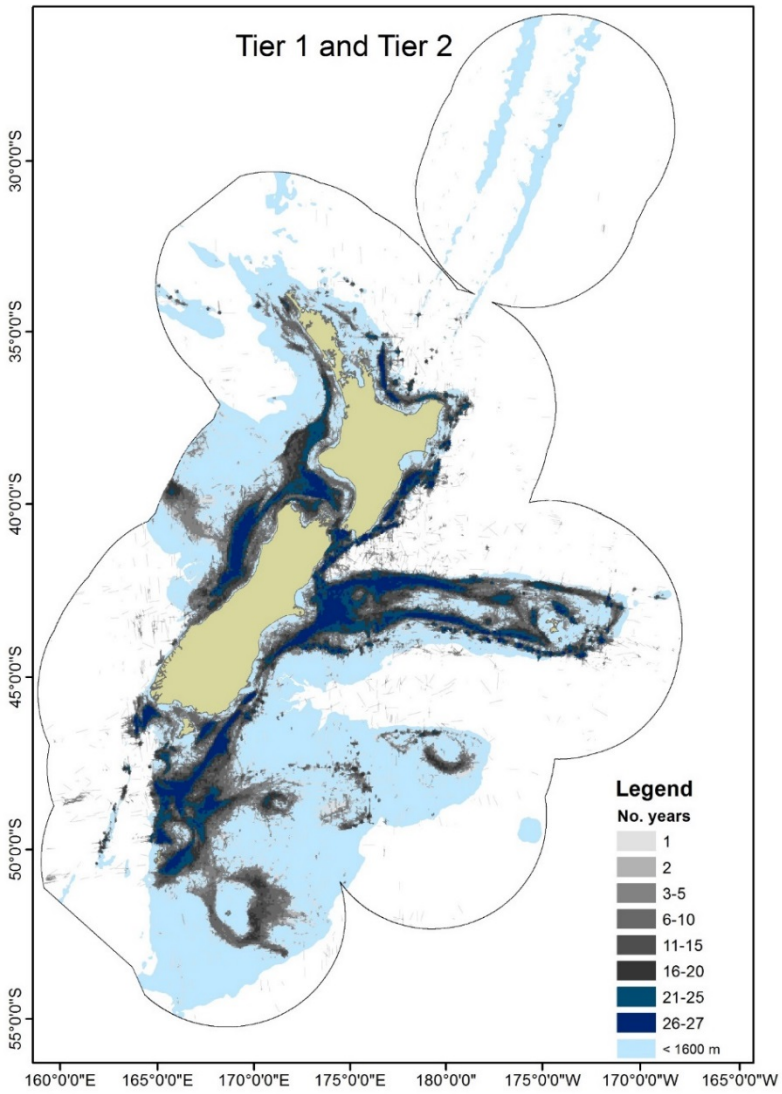

Figure D6: Number of years each 25-km^2 cell was contacted by trawl gear during 1990–2016.The 'fishable' area is represented by waters no deeper than 1600 m

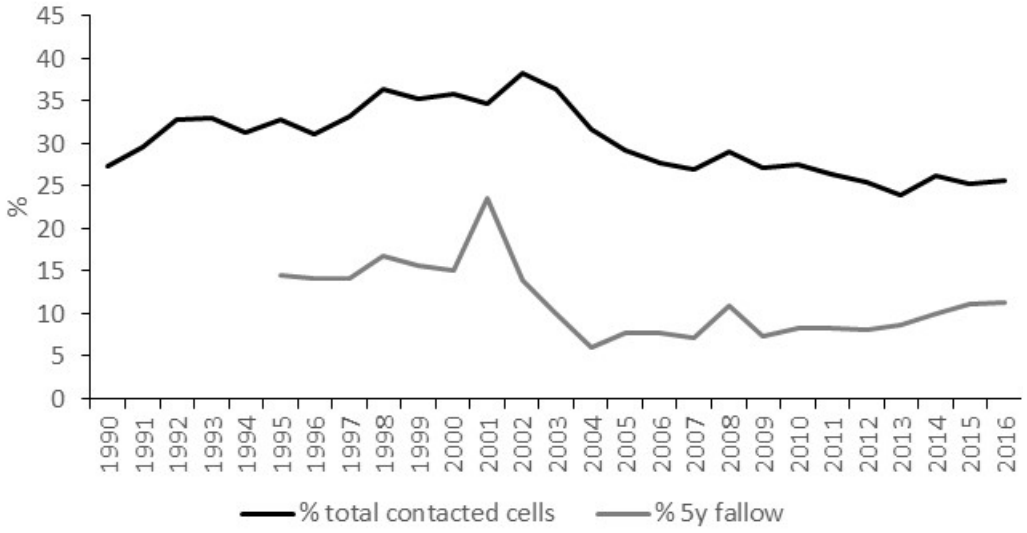

Figure D7: Percentage of the total number of contacted cells (44 918 cells during 1990–2016) with at least 1 trawl in each year (black line), and the percentage of the contacted cells in each year that was fallow (not contacted) for the previous five years (grey line).

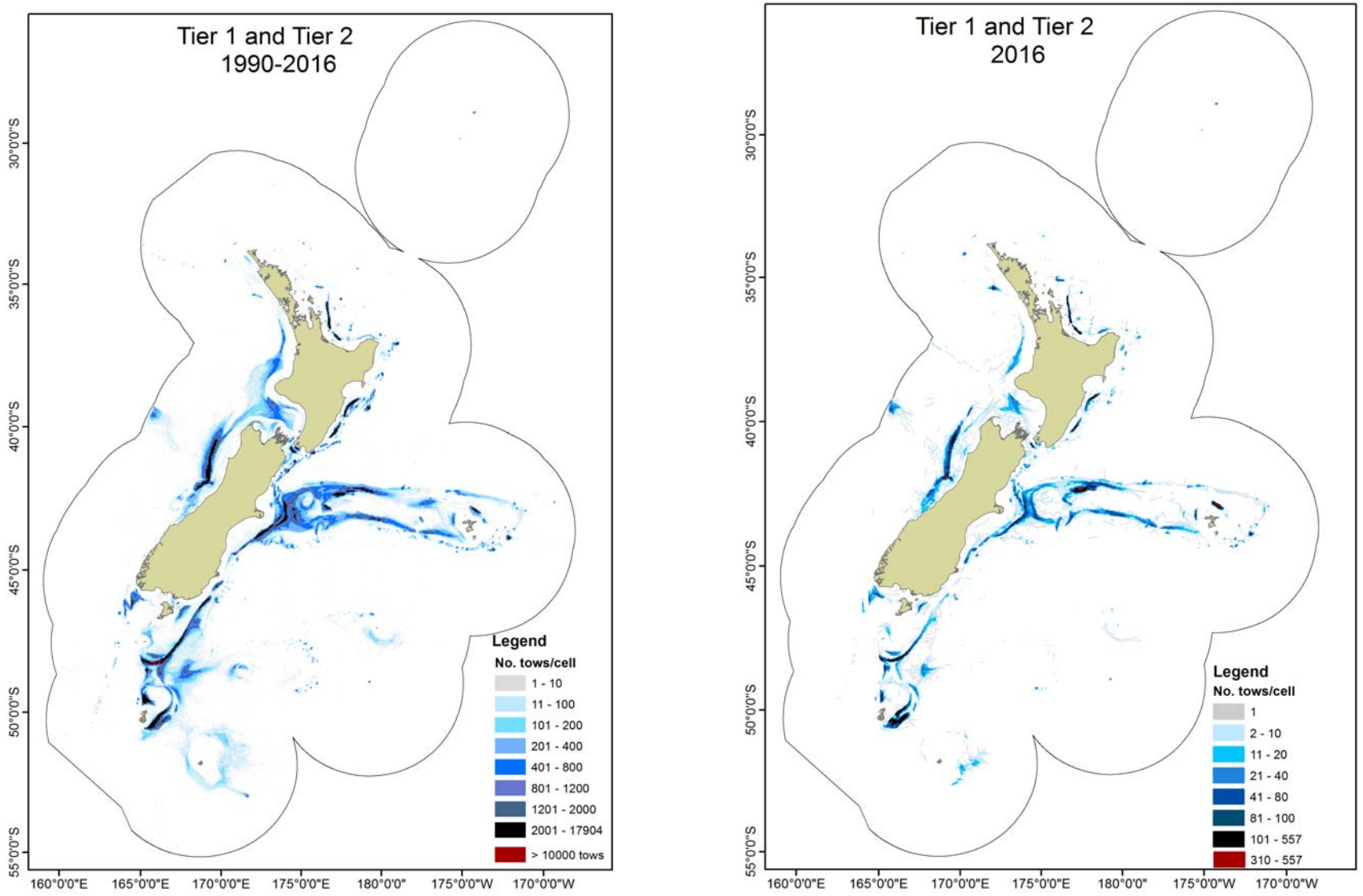

Figure D8: Number of tows per 25-km^2 cell for Tier 1 and Tier 2 targets, 1990–2016 (left) and for 2016 (right).

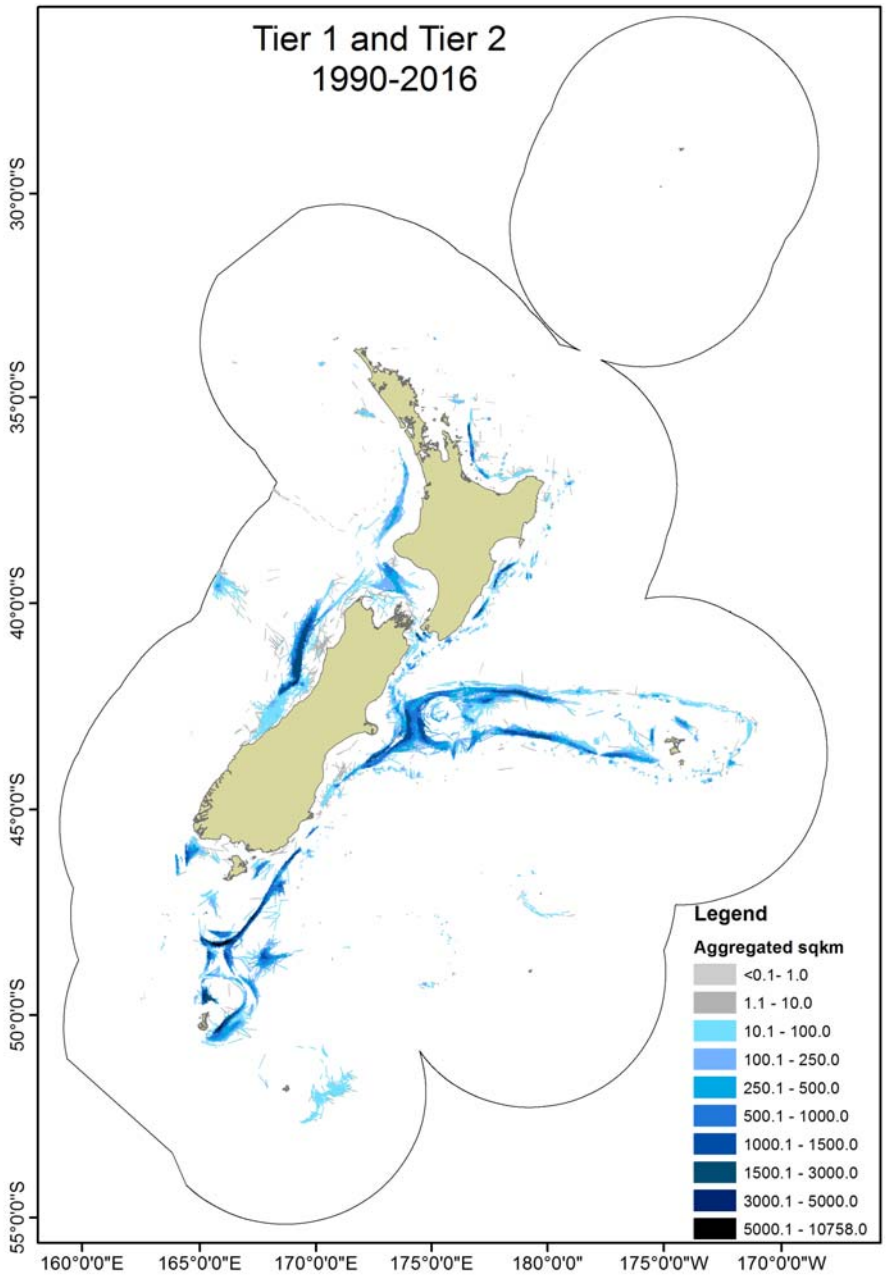

Figure D9: The aggregated swept area for Tier 1 and Tier 2 targets during 1990–2016.