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**Spatial analysis of Australian and New Zealand historical bottom trawl fishing effort in the
Convention Area of the SPRFMO**

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ABARES

Spatial analysis of Australian and New Zealand historical bottom trawl fishing effort in the Convention Area of the South Pacific Regional Fisheries Management Organisation

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Research by the Australian Bureau of Agricultural
and Resource Economics and Sciences

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1 Summary

The Bottom Fishing Interim Measures adopted by participants at the third international consultation to establish the South Pacific Regional Fisheries Management Organisation (SPRFMO) required participants to “Not expand bottom fishing activities into new regions of the Area where such fishing is not currently occurring.” At the time, no definitions was provided of areas where fishing is not currently occurring. The interim scientific working group subsequently recommended that areas being currently fished be expressed as grid blocks of 20 minute resolution that had been fished over the period 2002 to 2006, this being the reference period chosen for limiting bottom fishing effort or catch to ‘existing levels’. Both the 20-minute mapping resolution and the 2002–2006 reference period have since been questioned or criticised, indicating a need for further scientific advice on the effects of using different mapping resolutions and historical reference periods when mapping bottom fishing effort.

Combined Australian and New Zealand high seas bottom trawl tow data for the period 1990 to 2006 were used to compare estimates of ‘previously fished areas’ using estimated swept area (based on individual trawl tracks), 6-minute blocks and 20-minute blocks over different time periods, extending back in time from the SPRFMO 2002–2006 reference period to the period 1990–2006. Alternative time periods and mapping resolutions both have a substantial effect on effort maps and fished area estimates for bottom trawl fisheries in the western SPRFMO Convention Area.

Use of longer historical reference periods extending back in time from the current SPRFMO reference period of 2002–2006 results in a fairly steady increase in estimates of ‘fished area’. Compared to 2002–2006, extending the analysis back in time using 6-minute blocks adds about - 5% to the estimated ‘fished area’ with each additional year, with the 1990–2006 estimated ‘fished area’ being about 60% larger than over 2002–2006. Using 20-minute blocks adds about - 4% to the estimated ‘fished area’ with each additional year, with the 1990–2006 estimated ‘fished area’ being about 48% larger than over 2002–2006.

Estimates of ‘fished area’ generated using any mapping resolution other than actual trawl tracks substantially exaggerate the areas within the footprints that have been impacted, with inclusion of substantial unfished areas within these ‘fished footprint’ maps. The actual swept areas are small compared to the footprint maps, with 86% to 91% of a footprint mapped using 6-minute blocks being unfished, and 95% to 96% of a footprint mapped using 20-minute blocks being unfished.

Global predictive habitat modelling studies predict that there would be a high probability of occurrence of vulnerable scleractinian corals and octocorals in unfished areas contained within ‘fished footprint’ areas mapped at coarse resolutions. There are expectations under UNGA 61/105 and 64/72 that vulnerable marine ecosystems (VMEs) occurring within ‘previously fished’ areas will be protected from significant adverse impacts. Approaches are therefore required to protect these VMEs, irrespective of whether they occur within or outside ‘previously fished areas’. The SWG has previously noted that effective protection of benthic VMEs in the Pacific Ocean high seas will probably require the establishment of spatial closures designed to protect adequate and representative areas of vulnerable habitats and ecosystems.

2 Introduction

The original motivation for mapping historical bottom fishing effort by participants in bottom fisheries in the Convention Area of the South Pacific Regional Fisheries Management Organisation (SPRFMO) was to provide some way of defining 'currently fished areas', so that fishing could be limited to within such areas under the SPRFMO interim measures. At the time of adoption of those interim measures (SPRFMO 2007a), the preceding five-year period of 2002-2006 was chosen as the reference period for the purposes of limiting fishing effort or catch to 'existing levels' (Bottom fishing interim measure 1). No guidance was provided at that time on how to define 'areas where such fishing is not currently occurring' (Bottom fishing interim measure 2). The interim scientific working group was therefore asked by participants to recommend a definition of recently fished areas and did so in terms of a mapped 'fishing footprint':

"This joint footprint map is to be expressed as grid blocks of 20 minute resolution, with a 'fished' block being defined as any grid block partially crossed by at least one trawl track. The period 2002 to 2006 is to be used as the reference period for developing this joint trawl footprint map." (SPRFMO 2007b)

Penney (2011) noted that different spatial resolutions are appropriate for different purposes, recommending that individual tow-by-tow data should be used for quantitative, scientific bottom fishing effort analyses, particularly for the purpose of quantitative risk assessments. For general scientific and/or management-related purposes, bottom fishing effort maps should be published using latitude / longitude blocks at 0.1 degree (6-minute) spatial resolution. The mapping resolution of 20-minute blocks has been criticised in an international scientific review of implementation of UNGA Resolution 61/105 as including substantial unfished areas within maps of supposedly fished areas (Weaver et al. 2011). The question of resolution of fishing effort maps was therefore further addressed by the scientific working group during development of the *SPRFMO Bottom Fishing Impact Assessment Standard*, which was adopted at the 3rd session of the Preparatory Conference (SPRFMO 2012) and requires that:

- *"Participants are to provide bottom fishing effort distribution maps of areas that will be fished and areas that have been fished throughout the history of the fishery.*
- *These maps will be prepared at 0.1 degree (6 minute) grid resolution, noting SPRFMO confidentiality provisions.*
- *Areas below fishable depth (currently about 1500m depth for bottom trawl fishing in the SPRFMO Area) should be excluded in maps of fishing effort distribution.*
- *Bottom fishing effort distribution maps should be prepared separately for each of the main bottom fishing methods: trawling, dredging, lining, stationery netting, potting and trap fishing.*
- *Maps of the fishing effort distribution should also be prepared for different periods of years, so that the SWG can evaluate the cumulative duration of fishing impacts in various areas, and also the recovery time for areas fished in the past."* (SPRFMO 2012)

The choice of reference period of 2002–2006 has also been questioned by fishing industry representatives, as not representing the full history of the fishery. Clark et al. (2010) showed that high seas bottom trawl fishing effort has shifted continually to new areas throughout the history of the fishery, with few 0.1° blocks being actively fished for more than 2–3 consecutive years before effort

shifts to another area. Any change or expansion of the period of years over which fishing effort is mapped will therefore result in different area estimates and maps of historically 'fished' areas.

During preparatory bilateral discussions between Australia and New Zealand relating to the development of draft conservation and management measures for bottom fisheries in the SPRFMO Area, these two issues of reference period and resolution for mapping of fishing effort were identified as potentially benefiting from further scientific exploration. The purpose of this paper is to conduct initial analyses of combined Australian–New Zealand bottom trawl effort data for the SPRFMO Convention Area over the period 1990–2006, to investigate the effect of alternative mapping resolutions and of alternative historical time periods on fished area estimates. The results of these analyses may be useful in further informing management discussions relating to development of conservation and management measures for bottom fishing in the SPRFMO Convention Area.

3 Methods

Data filtering and correction

New Zealand high seas tow-by-tow bottom trawl data for the period 1990 – 2006 were obtained previously from the New Zealand Ministry for Primary Industries (MPI, then known as the Ministry of Fisheries) high seas commercial catch-effort landing return (CELR) logbook. These data were used in the New Zealand SPRFMO Bottom Fishery Impact Assessment (Ministry of Fisheries 2008), a paper to SPRFMO on mapping of high seas effort data (Penney 2011) and an evaluation of New Zealand high seas spatial closures (Penney & Guinotte, under review). Australian high seas tow-by-tow bottom trawl data for the period 1990 – 2006 data were obtained from the copy of the Australian Fisheries Management Authority (AFMA) commercial logbook database held by the Australian Bureau for Agricultural and Resource Economics and Sciences (ABARES).

These data were filtered and geo-spatially error corrected using the effort mapping procedures described in Penney (2011) and used for mapping New Zealand within-EEZ trawl effort data by Black et al (2013):

- Tows with no start position were deleted. All tows with no end position, or with an end position equal to the start position, were allocated an end position by adding 0.001 degrees (~111m) to the start latitude and longitude (providing an endpoint northeast of the start point), to ensure that all records could be analysed as trawl lines.
- All start and end positions were then jittered by adding a random offset up to 0.5 minutes (0.00833 degrees) either side of the start and end latitudes and longitudes, to compensate for rounding of tow positions to the nearest 1 minute in logbook reports. This is necessary to more realistically map tows reported as directly overlapping, when this is highly unlikely in reality (Penney 2011, Black et al. 2013)
- Resulting tows were imported into ArcGIS (©ESRI, version 10) as straight lines between the start and end positions, retaining information on the year in which each tow was conducted. The length of each tow (km) was calculated using an Albers equal area conical projection centred on 175°E with standard parallels at 20°S and 50°S. This projection provides proportionally correct error estimates and minimises distortion between the standard parallels.

- Following an analysis of tow length frequency distributions, all tows longer than 40km were deleted. This cut-off length retained over 98% of the tows while filtering out clearly erroneous tows that extended for well over 100km, including into EEZs and across land.
- For the purpose of these analyses, the fishable depth area was considered to be <1600m depth. Previous authors have used 1500m as the cut-off for maximum fishable depth for the New Zealand deepwater trawl fishery (Clark et al 2008a,b, Ministry of Fisheries 2008, Penney et al. 2009). However, Penney & Guinotte (under review) extended this to 1600m to provide for increased fishable area in the Louisville Ridge region, where clusters of valid tows sometimes extend beyond the 1500m depth contour, probably due to deficiencies in the GEBCO bathymetric data for this area (Penney 2011). This extension makes little difference to the estimates of fishable depth area on the larger plateau and ridge systems west of New Zealand.
- All tows in the Louisville Ridge area that were entirely in water deeper than 1600m were transposed to west of 180°E to investigate for possible east-west coding errors (where positions are entered as east of 180°E, but should be west of 180°E). All tows east of 180°E then lying entirely in water deeper than 1600m or within EEZs were deleted. This process resulted in the transposition of a number of tows in unfishable depths around the central Louisville Ridge to valid tow positions on the Challenger Plateau area (Penney 2011).
- Remaining tows lying partially within fishable depth, but extending into water deeper than 1600m, were truncated to the 1600m depth contour, or to the average extent of groups of tows that all extended slightly beyond the 1600m depth contour, but otherwise appeared to be entirely valid. Very few tows extended into unfishable depths on the larger plateau areas (South Tasman Rise, Lord Howe Rise Challenger Plateau, West Norfolk Ridge). This truncation process primarily affected tows on some seamounts along the Louisville Ridge, where some tows extended well into unfishable depths, while others only extended slightly beyond the 1600m depth contour. Groups of apparently valid tows extending into water >1600m depth on some Louisville Ridge seamounts probably indicate that the GEBCO bathymetric data are deficient for these features.
- This process provided a final data set of 44,670 'valid' tows conducted over the period 1990–2006, of which 6,064 (13.6%) were conducted by Australia and 38,606 (86.4%) by New Zealand. After the deletion of tows longer than 40km and truncation of tows to the 1600m depth contour, 90% of tows were shorter than 20 km and 95% of tows shorter than 28km, with a strong mode from 2km to 3km and an average tow length of 5.93km.

Generation of bottom trawl effort maps

Grids of 6-minute and 20-minute blocks (chart datum WGS84) were created entirely covering all trawls in each of the fished areas (ArcGIS Fishnet). These were then intersected with the combined, filtered, error-corrected Australia-New Zealand bottom trawl tow data set for the period 1990-2006 (ArcGIS Select by location—all blocks that intersect with the trawl tow data set) and blocks with no intersecting tows deleted to generate two overall fished footprint maps for the entire period 1990-2006, at 6-minute and 20-minute blocks resolutions. The fishing area name and planar surface area (km², Albers equal area conic projection centred on 175°E with standard parallels at 30°S and 50°S) were calculated for each block.

The numbers of tows intersecting with each block in each year were determined by sub-dividing the joint New Zealand – Australia bottom trawl data layer into 17 separate layers, one for each year from 1990 to 2006, and using a series of spatial joins to add the number of tows intersecting with each block in each year to the attribute tables for the 6-minute and 20-minute footprint layers. The resulting counts of tows per block per year were then be used to generate counts of tows per block over

progressively longer historical time periods extending back by one year each time from 2002–2006 to 1990–2006, to generate 13 sets of tow counts per block, one for each of these historical periods.

In terms of generating maps of overall “area fished”, there was little merit in going forward in time from the SPRFMO reference period of 2002–2006, as both Australian and New Zealand have restricted their vessels to fishing within the 2002–2006 footprint from 2007 onwards. It should be noted, however, that the 2002–2006 SPRFMO footprints were expressed in 20-minute blocks, and there may be relevance in determining whether any new 6-minute blocks within these 20-minute blocks have been fished since 2007, but this was not done for this study. These tow counts could then be used to classify the 1990–2006 6-minute and 20-minute footprint maps by any year, group of years or historical time period by using symbology to hide, show and colour blocks by chosen time periods, making it possible to generate footprint maps at 6-minute and 20-minute resolutions over any time period from 1990–2006.

To generate estimates of actual seabed swept area from the tow-by-tow data, all tows were buffered assuming a 100m swept width (between trawl doors (ArcGIS spatial buffer 50m either side of each tow), this being the typical door spread reported by the New Zealand fishery and used by Baird & Wood (2010). This assumed door spread may over-estimate the actual area swept, particularly on hill tows, and so probably provides a maximum estimate of swept width. The resulting 100m wide polygon trawl tracks were dissolved (ArcGIS / Dissolve) by fishing area for chosen time periods to produce complex merged polygons of swept area.

The areas of these merged swept area polygons were calculated and summed for each fishing area and used to compare the areas of the 6-minute and 20-minute footprints with the estimated swept area, to determine what proportion of unfished seabed is estimated to lie within the 6-minute and 20-minute footprints. Due to intense computational requirements (it can take several days to dissolve the buffered trawl tracks for a chosen time period), swept area estimates were only generated for the SPRFMO reference period (2002–2006) and the full data set from 1990–2006. However, swept area estimates can be generated from the buffered trawl tracks for any chosen time period.

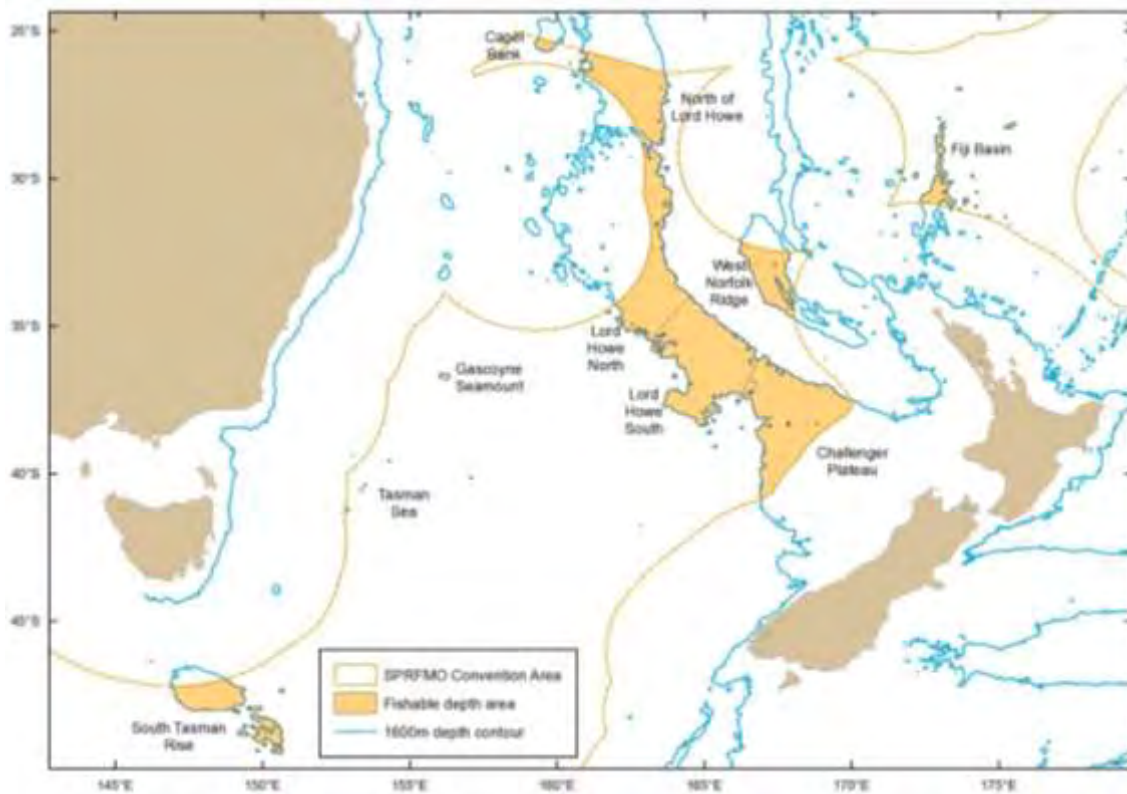
Estimating area of available fishable depth

The GEBCO 30 arc-second bathymetric data set (GEBCO 2011) was used to generate a 1600m depth contour for the western SPRFMO region and this was then used to generate polygons of <1600m fishable depth area in the SPRFMO Convention Area. These were divided into approximate fishing areas after inspection of the overlying trawl tow data.

4 Results

Figures 1 and 2 show maps of the fishable depth areas in the Tasman Sea and Louisville Ridge regions respectively, delineated using the 1600m depth contour derived from GEBCO 30 arc-second bathymetric data. The planar fishable depth area was calculated for each fishing area (Albers equal area projection) and the resulting fishable depth areas by fishing area are summarised in Figure 3.

Figure 1. Map showing fishing area names used in the text, the 1600m depth contour and the area defined using this contour as being of fishable depth in the Tasman Sea region of the SPRFMO Convention Area.



Note: Black lines show the divisions chosen to separate the Challenger Plateau, southern Lord Howe Rise and Northern Lord Howe Rise fishing areas after inspection of the overlying trawl tow data.

Figure 2. Map showing fishing area names used in the text, the 1600m depth contour and the area defined using this contour as being of fishable depth in the Louisville Ridge region of the SPRFMO Convention Area.

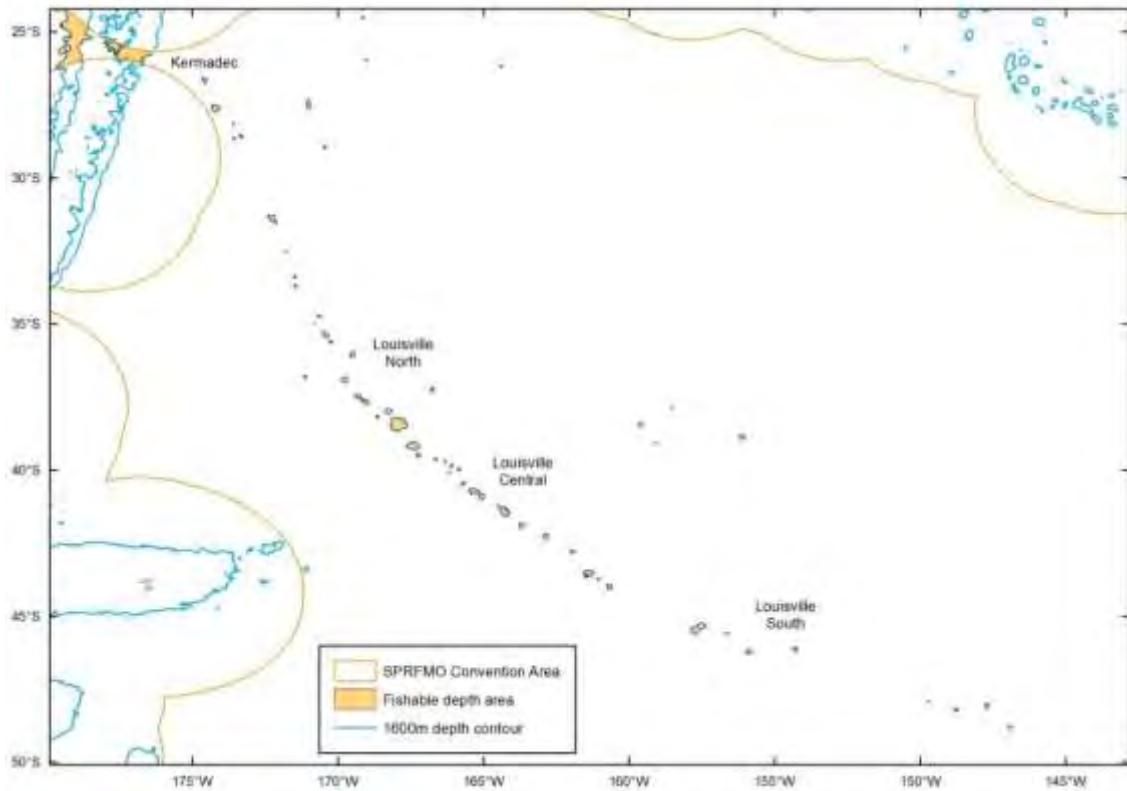
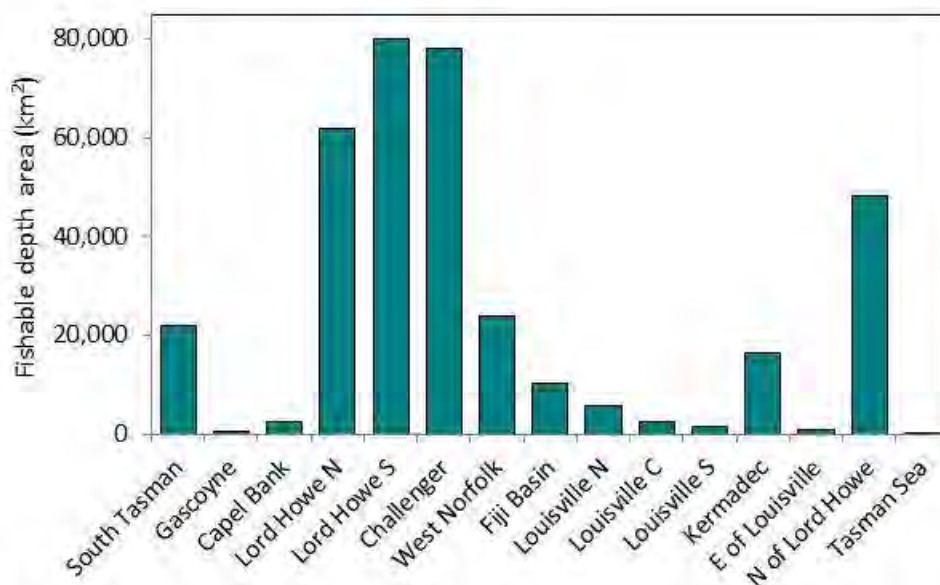


Figure 3. Calculated planar area (km²) of the total fishable depth area (0m–1600m depth) in each of the fishing areas used in this paper.



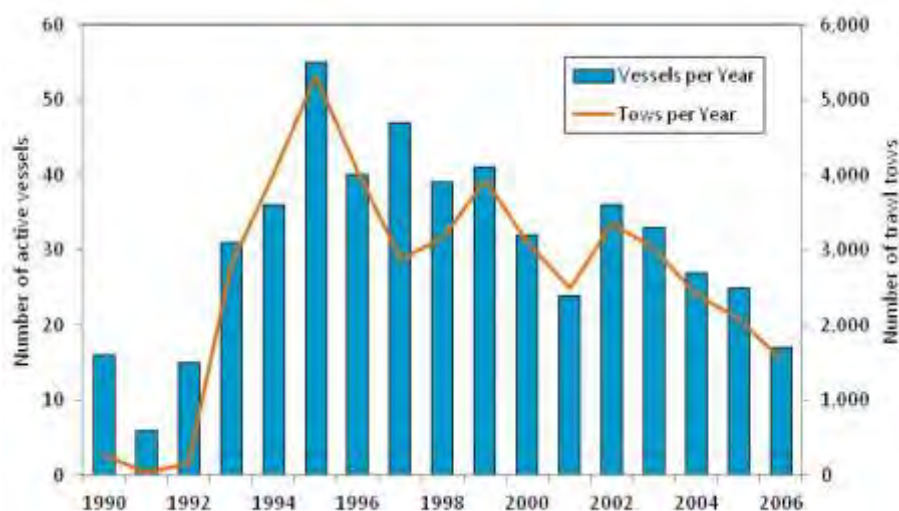
Note: The areas designated ‘E of Louisville’ and ‘N of Lord Howe’ were unfished over 1990–2006 and were not included in further effort mapping. The areas designated as ‘Capel Bank’ and ‘Kermadec’ had only one tow each, but were included in analyses. (Table A10)

Penney et al. (2009) have previously noted that there are substantial differences in the available extent of fishable depth area east and west of New Zealand. The large plateau and ridge areas west of New Zealand provide large areas of fishable depth, ranging from 61,909 km² to 80,064 km² each for the northern Lord Howe Rise, southern Lord Howe Rise and Challenger Plateau areas. In marked contrast, the seamounts along the Louisville Ridge provide very limited fishable depth area, ranging from 5,578 km² for the northern Louisville Ridge to only 1,407 km² for the southern Louisville Ridge (Table A8). This has consequences when mapping fished areas using coarse resolution blocks, the area of which can exceed the actual fishable depth area on seamounts.

Trends in active vessels and fishing effort

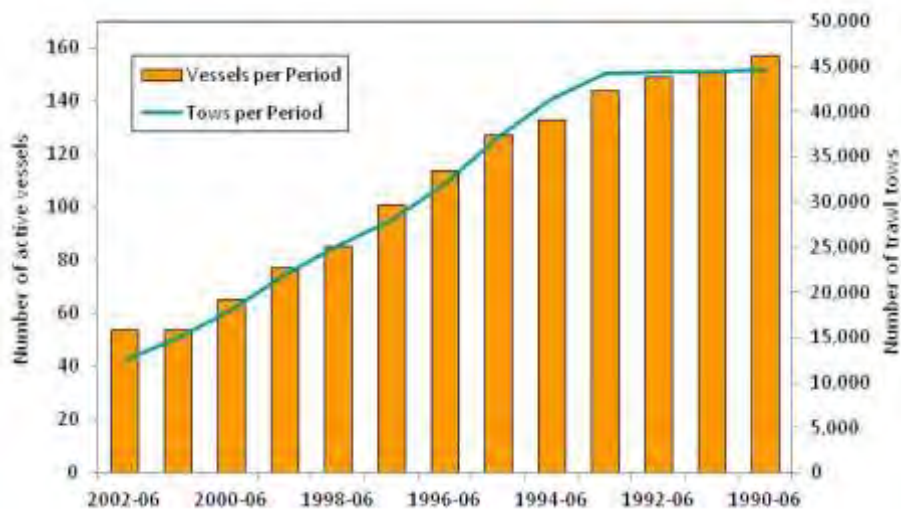
Historical trends in the total number of active bottom trawl vessels and the number of trawl tows conducted (all areas, Australian and New Zealand fleets combined) are shown in Figure 4 (Table A1) by year and cumulatively in Figure 5 (Table A2) by progressively longer historical time period from 2002–2006 to 1990–2006.

Figure 4. Total number of active trawl vessels (all areas, Australia and New Zealand fleets combined) and number of trawl tows conducted per year from 1990–2006 (Table A1).



The total number of active vessels per year (Figure 4) increased rapidly from 6 vessels in 1991 to a peak of 55 vessels in 1995, decreasing steadily thereafter to 17 vessels in 2006. The number of trawl tows conducted per year tracks the number of vessels fairly closely, reaching a peak of 5,325 tows in 1995 and decreasing to 1,558 tows in 2006.

Figure 5. Cumulative total number of active trawl vessels (all areas, Australia and New Zealand fleets combined) and number of trawl tows conducted over progressively longer historical time periods from 2002–2006 to 1990–2006 (Table A2).



The cumulative number of active vessels over progressively longer historical time periods (Figure 5) increased steadily from 54 vessels in 2002–2006 to 127 vessels in 1995–2006, increasing slowly thereafter to a maximum of 157 active vessels over 1990–2006. The cumulative number of tows conducted closely tracks the cumulative number of vessels, but reaching a plateau back from 1995–06 to 1990–06 due to low effort from 1990 to 1995.

Estimates of actual swept area by fishing area

Table 1 shows the estimates of actual planar seabed area swept for the time periods 2002–2006 and 1990–2006. Estimated swept area by all trawl operations totalled 8,142 km² over 2002–2006, increasing to 12,132 km² over the period 1990–2006. Extending the mapping period back to 1990 therefore increases the estimated swept area by about 49% over the current SPRFMO reference period of 2002–2006.

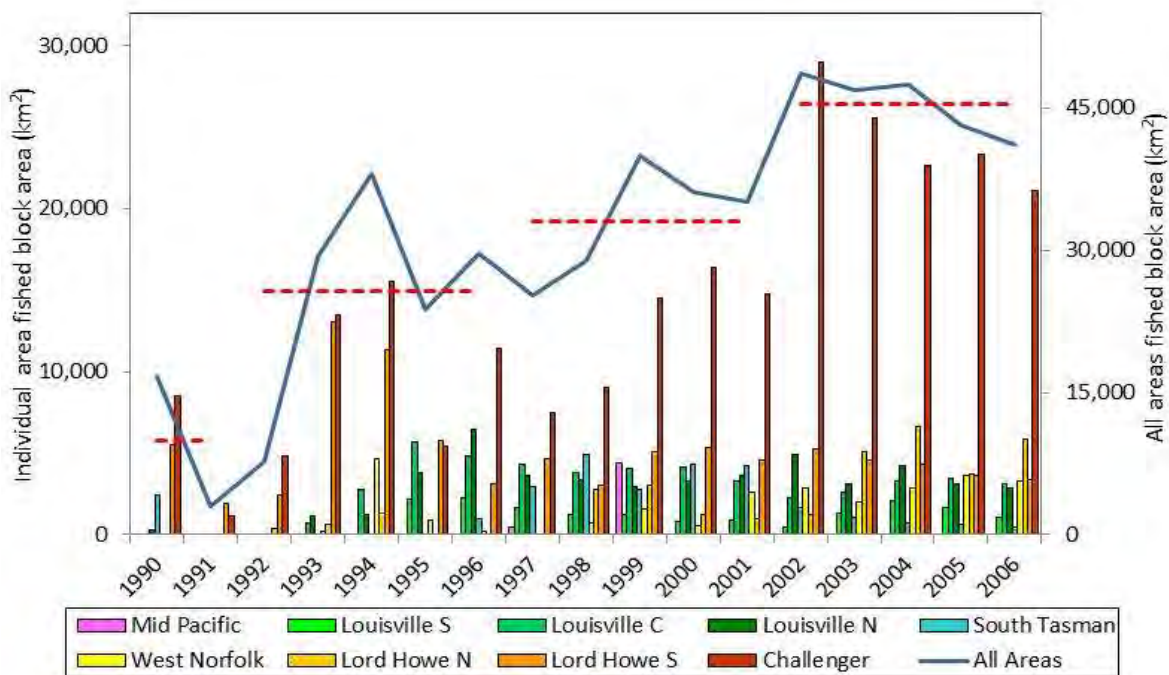
Table 1. Estimated planar swept areas (km², assuming 100m swept width between trawl doors) by fishing area over the periods 2002 – 2006 and 1990 – 2006.

Fishing Area	2002-06	1990-06
South Tasman	36.9	384.2
Gascoyne		1.8
Capel Bank	0.5	0.5
Lord Howe N	236.1	315.2
Lord Howe S	245.0	1,183.3
Challenger	6,812.1	8,234.7
West Norfolk	173.1	237.2
Fiji Basin	50.0	57.3
Kermadec		1.3
Louisville N	294.9	629.6
Louisville C	203.9	854.6
Louisville S	89.9	209.8
E of Louisville		0.2
Mid Pacific		22.9
All Areas	8,142	12,132
% Increase		+49%

Area of 6-minute blocks fished by year

It is informative to consider how area fished in this high seas trawl fishery has varied annually by fishing area. Figure 6 shows the individual areas of fished 6-minute blocks (any fished 6-minute block with >0 tows) by fishing area and year from 1990–2006 (bars). Also shown is the trend in annual total area of fished blocks (solid line) and the average area of fished blocks per year over various 5-year periods back from the SPRFMO reference period of 2002–2006 (dashed lines) (Table A4).

Figure 6. Planar area of fished 6-minute blocks (any block with > 0 tows) by year and fishing area (columns, left hand axis) and total planar area of all fished 6-minute blocks in all areas (line, right-hand axis).



Note: Dashed lines show the average annual planar area of fished 6-minute blocks over various 5-year historical time periods (Table A4).

Over the period 1990–1991, an average 9,900 km² was fished per year, using 6-minute blocks, mainly on the Challenger Plateau and southern Lord Howe Rise. The area of fished 6-minute blocks then increased rapidly to an early peak of 38,050 km² in 1994, with an average area of 25,725 km² being fished per year over 1992–1996, driven by expanding fishing on the Challenger Plateau and southern Lord Howe Rise, followed by a slow expansion onto other areas. From 1995 to 2002 there was a steady expansion in area fished, reaching a historical peak of 48,596 km² in 2002, with an average of 33,084 km² being fished per year over 1997–2001, and 45,448 km² being fished per year over the SPRFMO reference period of 2002–2006. The area of fished 6-minute blocks slowly declined after 2002 to 41,124 km² in 2006.

The amount of area fished has always been strongly dominated by the Challenger Plateau, which is to be expected given the large fishable depth area that this plateau provides, followed by the Lord Howe Rise. Some areas, such as the South Tasman Rise and mid-Pacific Foundation Seamounts, were only really fished for a few years in the late 1990s. Fishing on the Louisville Ridge peaked in the mid-1990s, but with substantial areas fished (given the small amount of available fishable depth) through to 2006,

mainly on the northern and central Louisville Ridge. The West Norfolk Ridge was fished in 1994 and then not again until 1998, with fished area steadily increasing in this area since then.

Effect of mapping resolution on estimates of fished area

The SPRFMO interim measures for bottom fisheries adopted in 2007 did not specify what was meant by “areas previously fished”. As one of the first tasks addressed by the interim science working group towards developing the SPRFMO *Bottom Fishing Impact Assessment Standard*, the science working group recommended the initial adoption of a mapping resolution of 20-minute blocks. This was a compromise at the time between mapping resolution proposals ranging from 10-minutes to 1-degree tabled by various scientific participants. The use of 20-minute blocks by SPRFMO has been internationally criticised (Weaver et al. 2011) as being too large, resulting in the inclusion of large areas of unfished seabed in maps of “previously fished areas”.

The spatial resolution at which effort maps are prepared makes a substantial difference to estimates of ‘previously fished area’. Penney (2011) has shown that, for the New Zealand high-seas trawl data, use of 20-minute blocks results in an average exaggeration in estimates of fished area of about 21-times when compared to swept area of actual trawl tracks (buffered by 100m swept width between trawl doors), ranging from about 8-times for the heavily fished Challenger Plateau to over 1300-times for the very lightly fished mid-Pacific Foundation Seamounts. Use of 6-minute blocks reduces the average exaggeration to about 10-times (range 5-times to 213-times) compared to estimated swept area (Penney 2011).

There is a further aspect that could be considered when determining whether a block has been fished, and that is the number of tows that have actually intersected that block. Despite the data filtering and correction processes used, it is likely that unusually longer tows in the vicinity of numerous shorter tows on the same feature are not correct. Figure 7 shows how these longer tows, which may have incorrect end positions, can result in the inclusion in footprint maps of a large number of additional blocks intersected by only one tow. Penney (2011) recommends that, given the possibility that these may be erroneously long tows and that the actual fished area in a block with a single tow is negligible, consideration should be given to excluding blocks with only one tow from maps of previously fished areas. This recommendation follows the approach developed by the U.S.A. National Marine Fisheries Service for benthic habitat mapping in the Aleutian Islands / Bering Sea groundfish trawl fishery (NMFS 2007), for which NMFS proposed that any area with < 3 tows per 100km^2 (approximately the area of a 6-minute block) would be closed to further fishing.

Figure 7. Illustration of the effect of a few (possibly erroneous) long tows, with starting positions on fishing features, on maps of fished area.



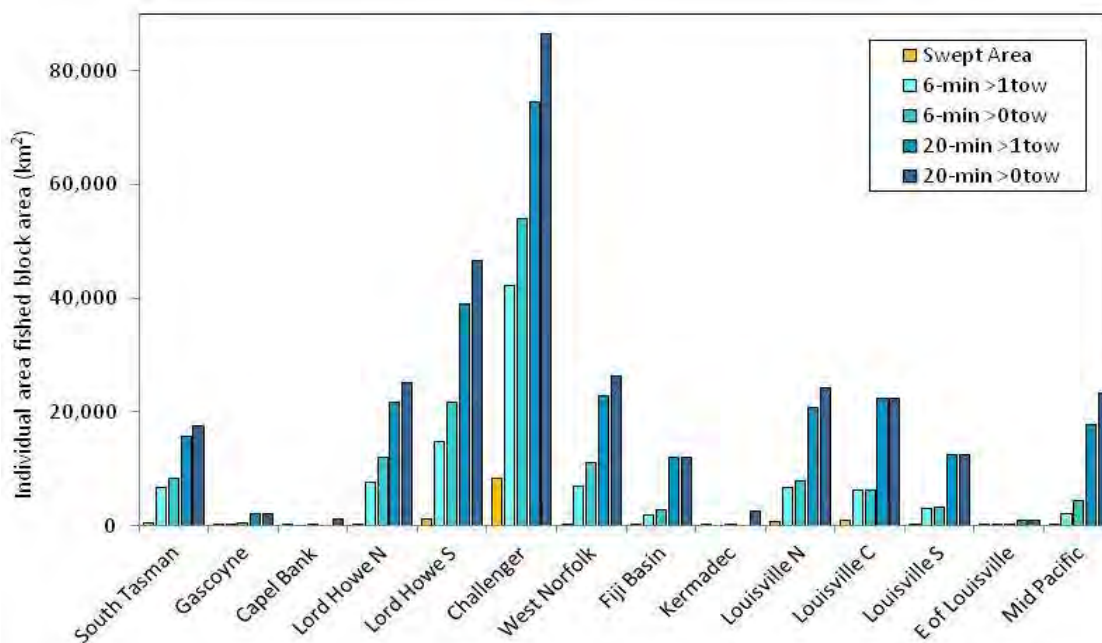
Note: longer tows in this example appear to be inconsistent with the length of other tows on the features concerned, and may indicate incorrect end positions. These result in the inclusion of a large number of additional 6-minute blocks in the 'fished footprint' map intersected by only one tow.

The primary purpose of the NMFS (2007) mapping approach was to ensure that fishing effort remains focused on seabed areas already impacted by past fishing, and to prevent effort from expanding onto adjacent unfished or lightly fished areas. This was one of the first applications of what has become known as the 'freeze the footprint' approach. The exclusion of blocks with only one tow (or some other minimum threshold) reduces the amount of unfished area included in maps of 'previously fished areas'. In addition to generating footprint maps and fished area estimates at 6-minute and 20-minute resolutions using all tows, comparative fished area estimates were therefore also generated for 6-minute blocks and 20-minute blocks excluding those blocks with only one tow, to illustrate the effect of adopting such an approach.

Figure 8 compares the estimated total fished area over the period 1990–2006 using various mapping resolutions: estimated swept areas (Table A10); 6-minute blocks with >1 tow (Table A5); 6-minute blocks with >0 tows (Table A6); 20-minute blocks with >1 tow (Table A7); and 20-minute blocks with >0 tows (Table A8). Total estimated swept area over the entire period 1990–2006 constitutes only 3.4% of the total estimated fishable depth area of 354,774 km². Total estimated swept areas by fishing area over 1990–2006 range from 1–2 km² for the Gascoyne Seamount, Capel Bank, Kermadec Ridge and east of Louisville; to <1000 km² for the South Tasman Rise, northern Lord Howe Rise and Louisville Ridge Areas; to about 1,200 km² for the southern Lord Howe Rise; to a maximum 8,234 km² for the Challenger Plateau (Table 1).

Use of 6-minute blocks increases these estimates of fished area by about 10-times (over estimated swept area) to between 5,000–8,000 km² for most areas; over 20,000 km² for the southern Lord Howe Rise; and over 50,000 km² for the Challenger Plateau. Use of 6-minute blocks with >0 tows provides an area estimate some 35% higher than restricting this to 6-minute blocks with >1 tow.

Figure 8. Total estimated planar areas fished (km²) by fishing area over the period 1990 – 2006 at different spatial mapping resolutions.

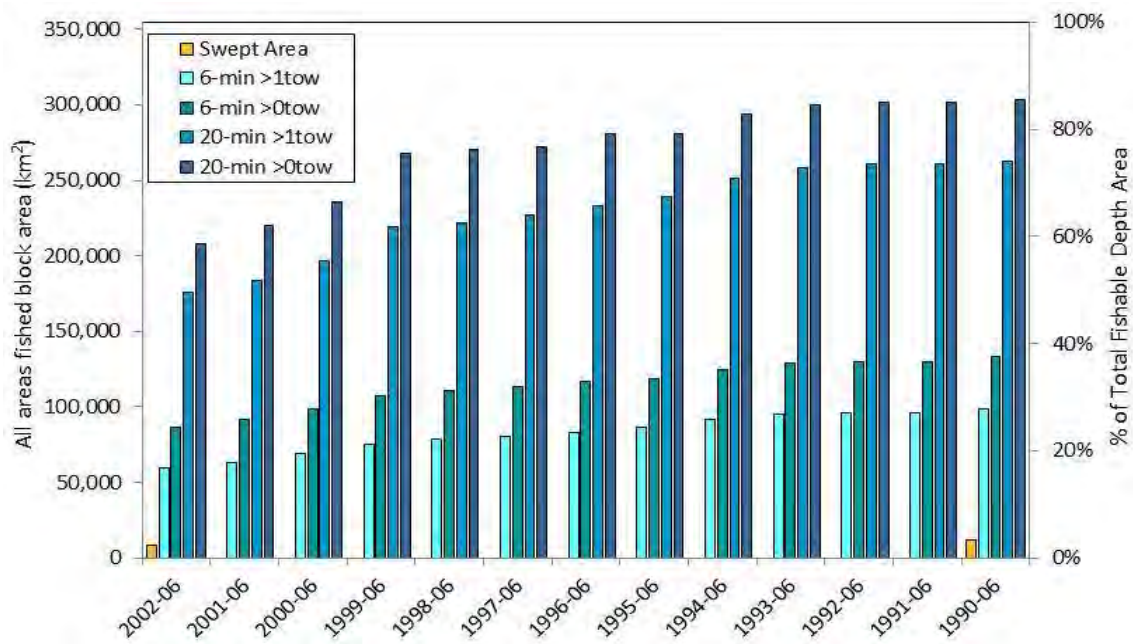


Note: Mapping resolutions shown are estimated swept area, 6-minute blocks with either more than one or more than zero tows and 20-minute blocks with either more than one or more than zero tows (Tables A5, A6, A7 and A8).

Use of 20 minute blocks further increases estimates of fished area by about 2.3-times over the 6-minute blocks (or 25-times the estimated swept area), increasing estimates of fished area to around 20,000 km² for most areas; 46,671 km² for the southern Lord Howe Rise; and 86,445 km² for the Challenger Plateau. Use of 20-minute blocks with >0 tows provides an area estimate some 16% higher than restricting this to 20-minute blocks with >1 tow. Using 20-minute blocks with >0 tows, the estimate of fished area on the Challenger Plateau, West Norfolk Ridge and Fiji Basin actually exceeds the available fishable depth, reaching levels of 400%–800% of the fishable depth area on the Louisville Ridge (Table A8).

Figure 9 shows how the total estimated fished area (all fishing areas combined) increases, using the various alternative mapping resolutions shown in Figure 8, as one extends the mapping period back in time from the current SPRFMO reference period of 2002–2006, one year at a time, back to 1990–2006. There is a fairly steady increase in estimated ‘fished area’ at all mapping resolutions, somewhat more rapid over 2002–2006 to 1990–2006, but increasing back at least to 1993–2006 (there was comparatively little fishing over the period 1990–1992) (Tables A5, A6, A7 and A8). The percentage increase in fished area from 2002–06 to 1990–2006 differs depending on the mapping resolution used: 65% for 6-minute blocks with <1 tow; 54% for 6-minute blocks with >0 tows; 49% for 20-minute blocks with <1 tow; and 46% for 20-minute blocks with >0 tows. There is less change when using 20-minute blocks as use of such coarse mapping resolution results in those blocks rapidly covering large areas of the fishery.

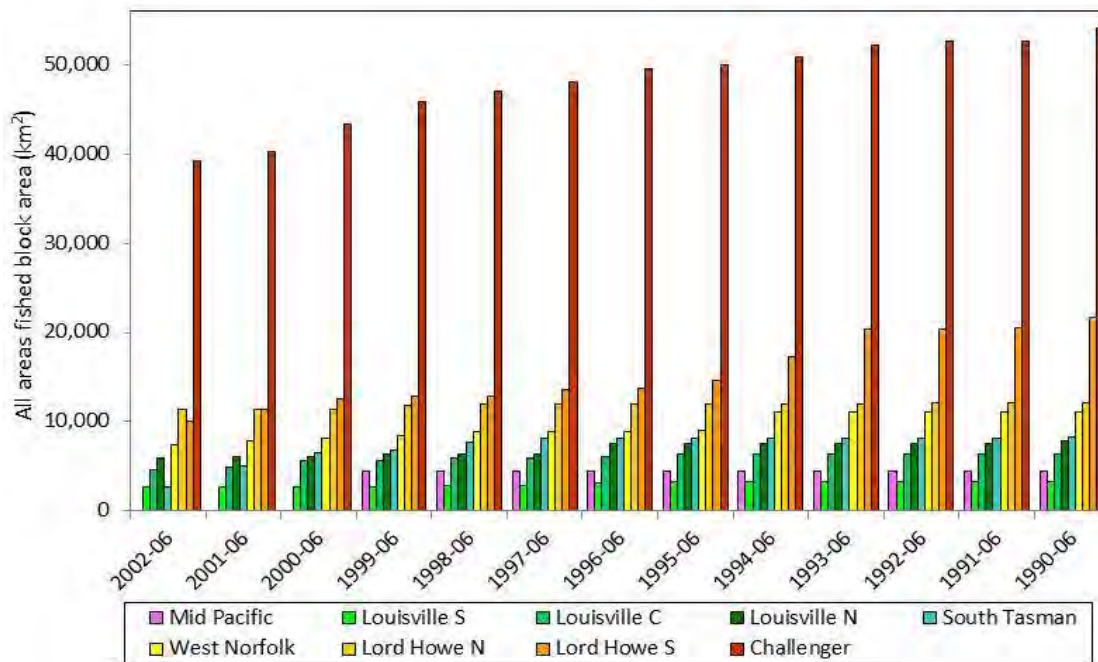
Figure 9. Change in total planar fished area (km²) in the western SPRFMO Area calculated using various spatial mapping resolutions.



Note: Mapping resolutions shown range from estimated swept area to 20-minute blocks with >0 tows over progressively longer historical time periods from 2002 – 2006 to 1990 – 2006. Swept area was only calculated for 2002–2006 and 1990–2006 due to computational time. (Tables A5, A6, A7 and A8)

The different fishing areas have experienced different fishing histories, with some (such as the Challenger Plateau and Lord Howe Rise) being fished throughout the period, some (such as the South Tasman Rise and the mid-Pacific Foundation Seamounts) only being fished over a few years, and some either being fished more in the past and less now (the Louisville Ridge), or less in the past but currently experiencing increasing fishing effort (the West Norfolk Ridge). Fished area estimates have therefore changed differently over time in these different areas. The change in estimates of area of fished 6-minute blocks in each individual fishing area over progressively longer historical time periods from 2002–2006 to 1990–2006 is shown in Figure 10.

Figure 10. Change in planar fished area (km²) of fished 6-minute blocks >0 tows on the different fishing areas in the western SPRFMO Area.



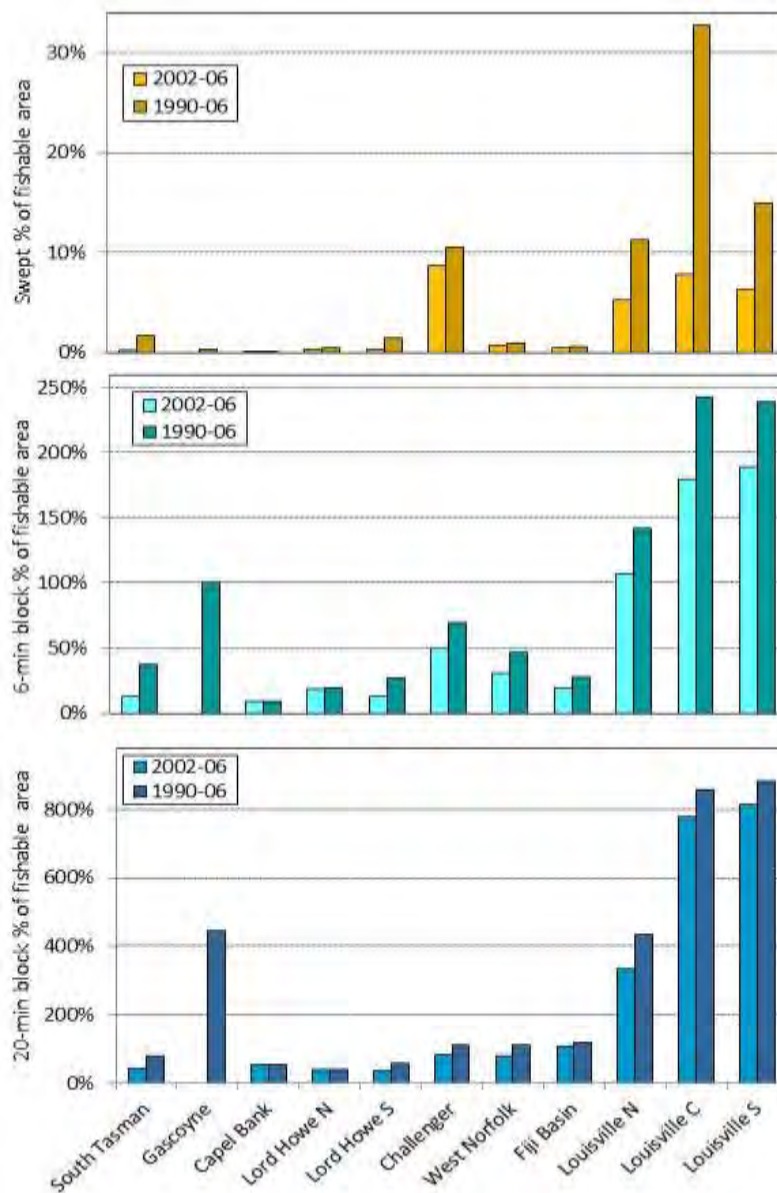
Note: Area of fished 6-minute blocks with >0 tows is shown over progressively longer historical time periods from 2002 – 2006 to 1990 – 2006 (Table A4).

The overall trend in fished area over alternative time periods in Figure 9 is primarily driven by the large area fished on the Challenger Plateau. However, there are other noteworthy trends. For example, a substantially larger area of the southern Lord Howe Rise was fished prior to 1995, with area estimates increasing rapidly as one extends the mapping period back earlier than this. The mid-Pacific Foundation seamounts only appear in the series from 1995–2000. Areas such as the South Tasman Rise and West Norfolk Ridge have primarily been fished over a few years so changes to the mapping period can substantially change the estimate of fished area in those fishing areas. Estimates of fished area on the northern Lord Howe Rise and Louisville Ridge change less, but also increase back in time. Changes in the mapping period therefore have different implications for different fishing areas.

Effect of mapping resolution on ‘fished’ proportion of fishable depth area

Figure 11 compares the estimated total ‘previously fished area’ in each of the fishing areas over the two periods 2002–2006 (the SPRFMO interim reference period) and 1990–2006 (the full data set) using three alternative mapping resolutions: estimated swept area; 6-minute blocks with at least one tow; and 20 minute blocks with at least one tow.

Figure 11. Comparisons between the percentage of fishable depth fishing area covered by maps of ‘previously fished area’ between the 2002–2006 reference period and 1990–2006 using alternative mapping resolutions.



Note: Percentages of fishable depths covered by the effort maps are shown for swept area (top), 6-minute blocks with at least one tow (middle) and 20-minute blocks with at least one tow (bottom) (Tables A9 and A10).

Estimated swept areas are below 10% of fishable depth area for all fishing areas over the period 2002–2006 (Table A9). Swept area estimates increase to above 10% of fishable depth area for the Challenger, Louisville North and Louisville South areas, and to above 30% for the Louisville Central Area, over 1990–2006. Use of 6-minute blocks >0 tows increases the estimates of “fished” area to around 50% of fishable depth area for the Challenger area, 100% on the Gascoyne Seamount and to between 100% and 250% for the Louisville Ridge area (Table A9). Use of 20-minute blocks >0 tows increases the estimates of “fished” area to around 100% of fishable depth area on the Challenger, West Norfolk and

Fiji Basin areas, over 400% of the Gascoyne Seamount and between 400% and 800% on the Louisville Ridge (Table A10).

Use of coarser mapping resolutions results in progressively smaller changes in estimates of 'previously fished area', with larger blocks already covering larger areas outside the swept area, and therefore changing less rapidly as the underlying swept area increases. Between 2002–2006 and 1990–2006, the actual swept area increased substantially for a number of areas, doubling for the northern and southern Louisville Ridge areas and quadrupling for the central Louisville Ridge (Table A9). In contrast, use of 6-minute blocks results in less than a 50% increase in 'fished area' between 2002–2006 and 1990–2006 for most areas (Table A9), while use of 20-minute blocks results in the increase being only about 10% for most areas (Table A10). Perhaps more importantly, use of any mapping resolution other than swept area results in the incorporation of substantial unfished areas within maps of 'previously fished area', increasing as the mapping resolution becomes coarser.

Compared to estimated swept area:

- Use of 6-minute blocks >1 tow results in inclusion of 86%–88% of unfished seabed in the footprint (Table A5).
- Use of 6-minute blocks >0 tows results in inclusion of 91% of unfished seabed in the footprint (Table A6).
- Use of 20-minute blocks >1 tow results in inclusion of 95% of unfished seabed in the footprint (Table A7).
- Use of 20-minute blocks >0 tow results in inclusion of 96% of unfished seabed in the footprint (Table A8).

5 Conclusions

Alternative time periods and mapping resolutions both have a substantial effect on effort maps and fished area estimates for bottom trawl fisheries in the western SPRFMO Convention Area. The likely effect of using different historical time periods was already evident from the analysis of shifts in orange-roughy targeted fishing effort by the New Zealand high seas bottom trawl fleet presented by Clark et al. (2010). Their analysis showed that fishing effort has shifted fairly constantly over the history of the fishery, with few 0.1° blocks being substantially fished for more than 2-3 consecutive years before orange roughy catch rates decline and vessels move to other areas. The fishery showed a period of continual exploration and shift in fishing area over the years 1985 to about 2005, followed by a recent period over which fishing effort has tended to remain on fewer, more recently fished and more productive areas since 2005.

The analyses in this paper confirm that the use of different years for mapping of fishing effort results in inclusion or exclusion of different geographic areas or blocks, as a result of blocks having been fished in some years and not in others. Coupled with the changes in fishing effort that have occurred, use of different historical periods therefore results in different estimates of 'fished area', with larger areas being fished annually at times of higher overall fishing effort and smaller areas being fished at times of lower fishing effort (Figure 6). Use of increasingly longer historical reference periods extending back in time from the current SPRFMO reference period of 2002–2006 results in a fairly steady increase in estimates of 'fished area'. Compared to 2002–2006, using 6-minute blocks, extending the analysis back in time adds about 5% to the estimated 'fished area' with each additional year, with the 1990–2006

estimated fished area being about 60% greater than over 2002–2006. Using 20-minute blocks, extending the analysis back in time adds about 4% to the estimated ‘fished area’ with each additional year, with the 1990–2006 estimated fished area being about 48% greater than over 2002–2006 (Figure 9, Tables A5-A8).

Perhaps the most important observation from these analyses is that estimates of ‘fished area’ generated using any mapping resolution other than actual trawl tracks include substantial unfished areas in the resulting ‘fished footprint’. The resulting estimates of ‘fished area’ are substantial exaggerations of the areas within the footprints that have actually been impacted. The actual impacted areas are small compared to the footprint maps, with 86% to 91% of a footprint mapped using 6-minute blocks being unfished, and 95% to 96% of a footprint mapped using 20-minute blocks being unfished.

Mapping of previously fished areas as actual trawl tracks is likely to be impractical for management purposes and would create substantial confidentiality, implementation and compliance difficulties. Whether 6-minute or 20-minute blocks (or any other coarse resolution) are used for effort mapping, it is inevitable that maps of ‘previously fished areas’, over any time period, will include substantial unfished areas within these footprints. Global predictive habitat modelling studies predict that there would be a high probability of occurrence of vulnerable scleractinian corals (Davies & Guinotte 2011) and octocorals (Yesson et al. 2012) in unfished areas within those ‘fished footprint’ areas.

Penney (2011) has noted that effort mapping should not, of itself, be interpreted as implying a management approach, or conferring any particular management status on the mapped areas. There remain expectations under UN General Assembly Resolutions 61/105 (UNGA 2007) and 64/72 (UNGA 2010) that vulnerable marine ecosystems (VMEs) occurring within coarsely mapped previously fished areas will still be protected from significant adverse impacts. Some other approach is therefore required to protect these VMEs, irrespective of whether they occur within or outside ‘previously fished areas’.

The SPRFMO interim scientific working group has noted that effective protection of benthic VMEs in the Pacific Ocean high seas will probably require the establishment of spatial closures designed to protect adequate and representative areas of vulnerable habitats and ecosystems (SPRFMO 2007c). It therefore seems prudent to move towards the planning of spatial closures, objectively designed to protect areas of particularly vulnerable and biodiverse VMEs. Such closures may not consist of numerous latitude / longitude blocks, but would be better designated using polygonal boundaries resulting from multivariate risk assessment and cost-benefit analysis of a range of alternative closure proposals. Historical fishing effort distribution maps would form only one of the contributory data sets to such a process.

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7 Annex A: High seas trawl effort and fished area summary tables

Table A1. Estimated number of active bottom trawl fishing vessels (Australian and New Zealand fleets combined) per year on the various fishing grounds. Most vessels fished a number of fishing areas so the number fishing per area does not sum to the total number of active vessels per year.

Fishing Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
South Tasman	2						3	20	16	17	15	5	6	6	5	1	1
Gascoyne				1	1					1		1					
Lord Howe N			3	5	7				7	8	3	4	4	9	5	8	4
Lord Howe S	4	3	7	21	26	9	5	10	8	19	9	11	12	13	10	13	9
Challenger	6	2	5	22	26	14	13	14	15	27	17	15	27	23	18	19	10
West Norfolk				2	8	3	1	2	2	3	2	4	5	9	2	7	8
Louisville N	8	2	2	11	15	27	24	16	16	15	12	11	14	7	10	6	5
Louisville C	4	1	5	5	10	41	26	21	15	21	13	10	10	8	9	7	6
Louisville S						10	12	8	5	9	5	5	3	8	7	8	5
Mid-Pacific						1	9	5	2	2	1						
All Areas	16	6	15	31	36	55	40	47	39	41	32	24	36	33	27	25	17

Table A2. Cumulative number of active trawl fishing vessels (Australian and New Zealand fleets combined) on the various fishing grounds over progressively longer historical time periods from 2002–2006 to 1990–2006. Most vessels fished a number of fishing areas so the number fishing per area does not sum to the total number of active vessels per time period.

Fishing Area	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	9	9	16	22	26	32	33	33	33	33	33	33	34
Gascoyne		1	1	2	2	2	2	2	3	4	4	4	4
Lord Howe N	19	21	23	25	29	29	29	29	34	38	39	39	39
Lord Howe S	25	28	31	38	40	43	43	49	62	73	75	76	77
Challenger	39	40	47	57	59	64	68	74	82	93	93	93	94
West Norfolk	20	21	22	23	25	25	25	26	32	34	34	34	34
Louisville N	22	22	28	33	35	39	46	54	55	60	60	61	63
Louisville C	21	21	27	35	39	48	55	70	73	75	80	81	85
Louisville S	18	18	19	24	27	31	35	38	38	38	38	38	38
Mid-Pacific			1	3	5	10	16	17	17	17	17	17	17
All Areas	54	54	65	77	85	101	114	127	133	144	149	151	157

Table A3. Total number of valid bottom trawl tows conducted by New Zealand and Australia by fishing area and year in the SPRFMO Convention Area from 1990 – 2006.

Fishing Area	Number of Tows per Year																Total Tows	
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005		2006
South Tasman	30						26	596	1,298	1,110	1,081	172	137	49	40	36	7	4,582
Gascoyne				4	1					1		1						7
Capel Bank													1					1
Lord Howe N			3	11	7				499	124	21	18	12	175	312	79	398	1,659
Lord Howe S	55	14	82	992	1,396	148	142	230	124	294	204	224	149	251	125	140	85	4,655
Challenger	184	20	72	1,752	2,192	707	451	519	494	1,220	960	1,251	2,046	1,850	836	974	397	15,925
West Norfolk				1	42	12	1		7	12	9	71	279	102	105	254	196	1,091
Fiji Basin					7	1	2				1		5	79	10			105
Kermadec										1								1
Louisville N	2			8	12	221	1,286	501	201	107	309	358	558	278	541	119	131	4,632
Louisville C				30	346	3,855	1,582	812	451	855	479	290	135	211	285	261	233	9,825
Louisville S						381	555	210	98	123	35	106	29	38	165	225	111	2,076
E of Louisville							2											2
Mid Pacific								8		101								109
Total Tows	271	34	157	2,798	4,003	5,325	4,047	2,876	3,172	3,948	3,099	2,491	3,351	3,033	2,419	2,088	1,558	44,670

Table A4. Planar area (km²) of fished 6-minute fished blocks (any block with > 0 tows) by year from 1990 – 2006.

Fishing Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
South Tasman	2,438	0	0	0	0	0	1,007	2,939	4,953	2,773	4,358	4,200	1,679	1,094	756	671	504
Gascoyne	0	0	0	198	99	0	0	0	0	99	0	99	0	0	0	0	0
Capel Bank	0	0	0	0	0	0	0	0	0	0	0	0	223	0	0	0	0
Lord Howe N	0	0	409	614	1,332	0	0	0	2,774	3,081	1,230	1,027	1,230	5,123	6,673	3,695	5,846
Lord Howe S	5,498	1,898	2,404	13,039	11,317	5,816	3,108	4,705	3,009	5,109	5,313	4,602	5,307	4,613	4,318	3,612	3,412
Challenger	8,519	1,169	4,881	13,460	15,551	5,447	11,397	7,507	9,052	14,528	16,400	14,806	29,030	25,564	22,703	23,385	21,083
West Norfolk	0	0	0	205	4,655	927	205	0	727	1,547	515	2,573	2,877	2,054	2,887	3,602	3,291
Fiji Basin	0	0	0	0	1,066	0	213	0	0	0	107	0	639	1,407	543	0	0
Kermadec	0	0	0	0	0	0	0	0	0	224	0	0	0	0	0	0	0
Louisville N	287	0	0	1,155	1,255	3,789	6,457	3,612	3,406	2,926	3,318	3,599	4,883	3,124	4,205	3,128	2,828
Louisville C	0	0	0	750	2,776	5,700	4,877	4,315	3,854	4,049	4,129	3,314	2,298	2,575	3,303	3,490	3,124
Louisville S	0	0	0	0	0	2,163	2,254	1,649	1,216	1,214	774	867	431	1,298	2,057	1,640	1,035
E of Louisville	0	0	0	0	0	0	96	0	0	0	0	0	0	0	0	0	0
Mid Pacific	0	0	0	0	0	0	0	503	0	4,416	0	0	0	0	0	0	0
All Areas	16,742	3,067	7,694	29,422	38,050	23,842	29,616	25,229	28,992	39,965	36,143	35,088	48,596	46,853	47,445	43,223	41,124

Table A5. Planar area (km²) of fished 6-minute blocks (any block with > 1 tow) by fishing area and progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	1,428	3,027	4,447	4,951	5,871	5,955	5,955	5,955	5,955	5,955	5,955	5,955	6,628
Gascoyne	0	0	0	0	0	0	0	0	0	198	198	198	198
Capel Bank	0	0	0	0	0	0	0	0	0	0	0	0	0
Lord Howe N	6,667	6,667	6,872	7,078	7,386	7,386	7,386	7,386	7,489	7,489	7,591	7,591	7,591
Lord Howe S	5,416	6,016	7,119	7,819	8,120	8,120	8,320	9,721	12,322	14,333	14,333	14,531	14,830
Challenger	29,628	30,111	32,429	33,975	35,526	35,819	36,984	37,659	38,635	40,184	40,576	40,673	42,195
West Norfolk	4,220	4,735	4,839	5,355	5,460	5,460	5,562	5,872	7,009	7,009	7,009	7,009	7,009
Fiji Basin	1,402	1,402	1,402	1,402	1,402	1,402	1,616	1,616	1,935	1,935	1,935	1,935	1,935
Kermadec	0	0	0	0	0	0	0	0	0	0	0	0	0
Louisville N	4,789	5,176	5,176	5,369	5,562	5,854	6,436	6,533	6,533	6,533	6,533	6,533	6,629
Louisville C	4,043	4,135	4,778	4,963	5,238	5,332	5,426	6,155	6,155	6,155	6,155	6,155	6,155
Louisville S	2,235	2,235	2,322	2,322	2,322	2,584	2,932	3,097	3,097	3,097	3,097	3,097	3,097
E of Louisville	0	0	0	0	0	0	96	96	96	96	96	96	96
Mid Pacific	0	0	0	2,006	2,006	2,208	2,208	2,208	2,208	2,208	2,208	2,208	2,208
All Areas	59,827	63,505	69,385	75,240	78,893	80,119	82,921	86,299	91,435	95,193	95,688	95,984	98,573
% Increase over 2002-06		+6%	+16%	+26%	+32%	+34%	+39%	+44%	+53%	+59%	+60%	+60%	+65%
% Unfished	86%												88%

Table A6. Planar area (km²) of fished 6-minute blocks (any block with > 0 tows) by fishing area and progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	2,774	5,124	6,540	6,875	7,713	8,133	8,133	8,133	8,133	8,133	8,133	8,133	8,301
Gascoyne	0	99	99	198	198	198	198	198	297	496	496	496	496
Capel Bank	223	223	223	223	223	223	223	223	223	223	223	223	223
Lord Howe N	11,394	11,394	11,394	11,807	11,910	11,910	11,910	11,910	11,910	11,910	12,115	12,115	12,115
Lord Howe S	10,128	11,423	12,626	12,925	12,925	13,622	13,821	14,627	17,223	20,441	20,441	20,540	21,639
Challenger	39,144	40,208	43,271	45,869	46,936	48,083	49,537	49,924	50,797	52,158	52,647	52,647	54,074
West Norfolk	7,420	7,934	8,141	8,451	8,868	8,868	8,868	8,971	11,149	11,149	11,149	11,149	11,149
Fiji Basin	1,940	1,940	2,046	2,046	2,046	2,046	2,153	2,153	2,792	2,792	2,792	2,792	2,792
Kermadec	0	0	0	224	224	224	224	224	224	224	224	224	224
Louisville N	5,953	6,050	6,147	6,342	6,438	6,438	7,533	7,631	7,631	7,631	7,631	7,631	7,917
Louisville C	4,685	4,961	5,602	5,696	5,878	5,972	6,065	6,339	6,339	6,339	6,339	6,339	6,339
Louisville S	2,661	2,661	2,661	2,661	2,836	2,923	3,184	3,358	3,358	3,358	3,358	3,358	3,358
E of Louisville	0	0	0	0	0	0	96	96	96	96	96	96	96
Mid Pacific	0	0	0	4,416	4,416	4,518	4,518	4,518	4,518	4,518	4,518	4,518	4,518
All Areas	86,321	92,017	98,750	107,734	110,613	113,159	116,466	118,306	124,691	129,468	130,162	130,261	133,241
% Increase over 2002-06		+7%	+14%	+25%	+28%	+31%	+35%	+37%	+44%	+50%	+51%	+51%	+54%
% Unfished	91%												91%

Table A7. Planar area (km²) of fished 20-minute blocks (any block with > 1 tow) by fishing area and progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	6,521	11,204	13,937	13,937	15,787	15,787	15,787	15,787	15,787	15,787	15,787	15,787	15,787
Gascoyne	0	0	0	0	0	0	0	0	1,100	2,205	2,205	2,205	2,205
Capel Bank	0	0	0	0	0	0	0	0	0	0	0	0	0
Lord Howe N	20,533	20,533	20,533	21,679	21,679	21,679	21,679	21,679	21,679	21,679	21,679	21,679	21,679
Lord Howe S	22,296	22,296	25,633	27,833	27,833	28,938	28,938	30,047	34,465	37,825	38,934	38,934	38,934
Challenger	59,585	60,651	63,858	65,970	67,041	68,107	68,107	70,273	70,273	72,482	73,563	73,563	74,624
West Norfolk	13,733	13,733	16,044	17,194	17,194	17,194	17,194	18,352	22,966	22,966	22,966	22,966	22,966
Fiji Basin	8,382	8,382	8,382	8,382	8,382	8,382	9,568	9,568	11,929	11,929	11,929	11,929	11,929
Kermadec	0	0	0	0	0	0	0	0	0	0	0	0	0
Louisville N	16,301	16,301	16,301	16,301	16,301	16,301	19,713	19,713	19,713	19,713	19,713	19,713	20,774
Louisville C	18,320	20,386	21,401	21,401	21,401	21,401	21,401	22,436	22,436	22,436	22,436	22,436	22,436
Louisville S	10,537	10,537	10,537	10,537	10,537	11,507	11,507	12,426	12,426	12,426	12,426	12,426	12,426
E of Louisville	0	0	0	0	0	0	1,071	1,071	1,071	1,071	1,071	1,071	1,071
Mid Pacific	0	0	0	15,597	15,597	17,847	17,847	17,847	17,847	17,847	17,847	17,847	17,847
All Areas	176,208	184,023	196,626	218,829	221,750	227,142	232,811	239,199	251,693	258,367	260,557	260,557	262,679
% Increase over 2002-06		+4%	+12%	+24%	+26%	+29%	+32%	+36%	+43%	+47%	+48%	+48%	+49%
% Unfished	95%												95%

Table A8. Planar area (km²) of fished 20-minute blocks (any block with > 0 tows) by fishing area and progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	9,325	13,059	16,700	16,700	17,625	17,625	17,625	17,625	17,625	17,625	17,625	17,625	17,625
Gascoyne	0	1,100	1,100	2,205	2,205	2,205	2,205	2,205	2,205	2,205	2,205	2,205	2,205
Capel Bank	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238	1,238
Lord Howe N	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075	25,075
Lord Howe S	27,842	32,233	35,569	35,569	35,569	35,569	35,569	35,569	41,083	44,452	45,562	45,562	46,671
Challenger	64,945	67,092	74,552	76,643	77,743	79,871	82,080	82,080	83,184	86,445	86,445	86,445	86,445
West Norfolk	18,317	18,317	19,475	21,783	21,783	21,783	21,783	21,783	26,410	26,410	26,410	26,410	26,410
Fiji Basin	10,751	10,751	10,751	10,751	10,751	10,751	10,751	10,751	11,929	11,929	11,929	11,929	11,929
Kermadec	0	0	0	2,492	2,492	2,492	2,492	2,492	2,492	2,492	2,492	2,492	2,492
Louisville N	18,515	18,515	18,515	18,515	18,515	18,515	23,110	23,110	23,110	23,110	23,110	23,110	24,172
Louisville C	20,386	21,401	21,401	21,401	21,401	21,401	22,436	22,436	22,436	22,436	22,436	22,436	22,436
Louisville S	11,456	11,456	11,456	12,426	12,426	12,426	12,426	12,426	12,426	12,426	12,426	12,426	12,426
E of Louisville	0	0	0	0	0	0	1,071	1,071	1,071	1,071	1,071	1,071	1,071
Mid Pacific	0	0	0	23,379	23,379	23,379	23,379	23,379	23,379	23,379	23,379	23,379	23,379
All_Areas	207,849	220,235	235,830	268,176	270,200	272,328	281,239	281,239	293,663	300,293	301,403	301,403	303,573
% Increase over 2002-06		+6%	+13%	+29%	+30%	+31%	+35%	+35%	+41%	+44%	+45%	+45%	+46%
% Unfished	96%												96%

Table A9. Total planar area (km²) of fishable depths (0m – 1600m) of each fishing area and percentage of each fishing area covered by fished 6-minute blocks (any block with > 0 tows) over various progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	Fishable Area	Swept Area		6-Minute Blocks > 0 tows												
		2002-06	1990-06	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	22,097	0.2%	1.7%	13%	23%	30%	31%	35%	37%	37%	37%	37%	37%	37%	37%	38%
Gascoyne	494.8	0.0%	0.4%	0%	20%	20%	40%	40%	40%	40%	40%	60%	100%	100%	100%	100%
Capel Bank	2,366	0.0%	0.0%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
Lord Howe N	61,909	0.4%	0.5%	18%	18%	18%	19%	19%	19%	19%	19%	19%	19%	20%	20%	20%
Lord Howe S	80,064	0.3%	1.5%	13%	14%	16%	16%	16%	17%	17%	18%	22%	26%	26%	26%	27%
Challenger	78,267	8.7%	10.5%	50%	51%	55%	59%	60%	61%	63%	64%	65%	67%	67%	67%	69%
West Norfolk	23,914	0.7%	1.0%	31%	33%	34%	35%	37%	37%	37%	38%	47%	47%	47%	47%	47%
Fiji Basin	10,133	0.5%	0.6%	19%	19%	20%	20%	20%	20%	21%	21%	28%	28%	28%	28%	28%
Louisville N	5,578	5.3%	11.3%	107%	108%	110%	114%	115%	115%	135%	137%	137%	137%	137%	137%	142%
Louisville C	2,614	7.8%	32.7%	179%	190%	214%	218%	225%	228%	232%	243%	243%	243%	243%	243%	243%
Louisville S	1,407	6.4%	14.9%	189%	189%	189%	189%	202%	208%	226%	239%	239%	239%	239%	239%	239%
Kermadec E of Louisville	16,417	0.0%	0.0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
N of Lord Howe	48,280	0%	0%													
Tasman Sea	318	0%	0%													
All Areas	354,774	2.3%	3.4%	24%	26%	28%	30%	31%	32%	33%	33%	35%	36%	37%	37%	38%

Table A10. Total planar area (km²) of fishable depths (0m – 1600m) of each fishing area and percentage of each fishing area covered by fished 20-minute blocks (any block with > 0 tows) over various progressively longer historical time period from 2002 – 2006 to 1990 – 2006.

Fishing Area	Fishable Area	Swept Area		20-Minute Blocks > 0 tows												
		2002-06	1990-06	2002-06	2001-06	2000-06	1999-06	1998-06	1997-06	1996-06	1995-06	1994-06	1993-06	1992-06	1991-06	1990-06
South Tasman	22,097	0.2%	1.7%	42%	59%	76%	76%	80%	80%	80%	80%	80%	80%	80%	80%	80%
Gascoyne	494.8	0.0%	0.4%	0%	222%	222%	446%	446%	446%	446%	446%	446%	446%	446%	446%	446%
Capel Bank	2,366	0.0%	0.0%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%	52%
Lord Howe N	61,909	0.4%	0.5%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%	41%
Lord Howe S	80,064	0.3%	1.5%	35%	40%	44%	44%	44%	44%	44%	44%	51%	56%	57%	57%	58%
Challenger	78,267	8.7%	10.5%	83%	86%	95%	98%	99%	102%	105%	105%	106%	110%	110%	110%	110%
West Norfolk	23,914	0.7%	1.0%	77%	77%	81%	91%	91%	91%	91%	91%	110%	110%	110%	110%	110%
Fiji Basin	10,133	0.5%	0.6%	106%	106%	106%	106%	106%	106%	106%	106%	118%	118%	118%	118%	118%
Louisville N	5,578	5.3%	11.3%	332%	332%	332%	332%	332%	332%	414%	414%	414%	414%	414%	414%	433%
Louisville C	2,614	7.8%	32.7%	780%	819%	819%	819%	819%	819%	858%	858%	858%	858%	858%	858%	858%
Louisville S	1,407	6.4%	14.9%	814%	814%	814%	883%	883%	883%	883%	883%	883%	883%	883%	883%	883%
Kermadec E of Louisville	16,417	0.0%	0.0%	0%	0%	0%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
N of Lord Howe	48,280	0%	0%													
Tasman Sea	318	0%	0%													
All Areas	354,774	2.3%	3.4%	59%	62%	66%	76%	76%	77%	79%	79%	83%	85%	85%	85%	86%