Mapping of High Seas Bottom Fishing Effort Data: Purposes, Problems and Proposals

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Introduction

The South Pacific regional Fisheries Management Organisation (SPRFMO) Interim Measures for Bottom Fisheries (SPRFMO 2007a) require participants to:

> *"2. Not expand bottom fishing activities into new regions of the Area where such fishing is not currently occurring." (SPRFMO 2007a)*

The SPRFMO Interim Measures require the Scientific Working Group (SWG) to provide a standard for reviewing assessments for bottom fishing activities in the SPRFMO Area:

> *"12. Apply the following procedures regarding the assessment described in paragraph 11 above:*
>
> *b) The interim Scientific Working Group will review the assessments and proposed management measures and provide comments to the submitting Participant. For the purposes of carrying out such reviews, the interim Scientific Working Group will design a preliminary interim standard for reviewing the assessments and develop a process to ensure comments are provided to the submitting Participant and all other Participants within two months. In the meantime, the submitting Participant may provisionally apply their proposed management measures." (SPRFMO 2007a)*

However, the SPRFMO interim measures provide no guidance on how to define or map areas where fishing is "currently occurring". In developing the required guidelines for conducting impact assessments, one of the first questions that the SWG had to address was how to define areas where fishing was "currently occurring".

This question was raised at the 4th SWG meeting in New Caledonia in September 2007. Penney *et al*. (2007) presented an analysis of New Zealand SPRFMO Area trawl tow data, showing the effect on estimates of "fished area" of mapping fishing effort at resolutions ranging from 50m-buffered trawl tracks (based on an estimated distance of 100m between trawl doors for orange roughy targeted tows - Ministry of Fisheries 2008, Baird & Wood 2010), up to 1° latitude/longitude squares. Results showed that mapping of the 2002 – 2006 New Zealand trawl fishing footprint in the heavily fished Challenger Plateau area as 10 min squares resulted in a six-fold exaggeration of the fishing footprint compared to using 50m buffered trawl tracks. Use of 1° squares resulted in a 12.6-fold exaggeration for the Challenger Plateau, and exaggeration of fished area estimates was even greater in more lightly fished areas (Penney *et al*. 2007, Table 6).

Recognising the confidentiality concerns related to publishing trawl footprint maps at individual trawl track resolution, Penney *et al*. (2007) argued for mapping of the SPRFMO bottom fishing footprint at a resolution of 10 minute squares. However, other participants at that meeting, citing confidentiality and implementation concerns, argued for mapping of the SPRFMO bottom fishing footprint as 20 minute latitude/longitude squares.

Regarding what might be meant by 'currently' fishing, the 4th SWG meeting noted that the interim catch and effort limitations in the SPRFMO interim measures defined 'existing' levels of catch and effort (in a footnote) to be the average annual levels over the period 1 January 2002 to 31 December 2006. At that time, the SWG recommended using the same reference period to define and map areas being 'currently fished'.

Pending finalisation of the FAO International Guidelines for the Management of Deep Sea Fisheries in the High Seas (FAO 2009), and preparation of an FAO-guideline-compliant SPRFMO Bottom Fishery Impact Assessment Standard, the 4th SWG meeting developed an interim Benthic Assessment Framework (BAF) to guide the preparation of assessments until a more detailed SPRFMO assessment standard is adopted. This interim BAF was adopted by the 4th SPRFMO Negotiations (SPRFMO 2007b). In the BAF the SWG recommended that areas being 'currently fished' should be defined by a joint bottom fishing footprint map:

> *"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)

Since then, the SPRFMO bottom trawl fishing footprint has been mapped as any 20 minute latitude/longitude square in which at least one bottom trawl was conducted over the calendar years 2002 – 2006, based on footprint maps submitted by participants. This mapping resolution was recently criticized in the report of the Lisbon scientific workshop on implementation of UNGA Resolutions 61/105 and 64/72 (Weaver *et al*. 2011), in which participants express concern that "*the current definition of the fishing footprint in some areas was too large*", referring specifically to the SPRFMO 20-minute blocks.

The most appropriate spatial resolution for blocks used to map fishing effort was discussed again during a review of the draft SPRFMO Bottom Fishery Impact Assessment Standard at the 9th SWG meeting in Chile in October 2010 (SPRFMO 2010). The report of that meeting notes that "*It was agreed that there would be no suggested change to the current standard 20 x 20 minutes, at this time*", but also notes that "*alternative approaches are being used in other RFMOs*", such as the polygons around fished areas used by the North East Atlantic Fisheries Commission (NEAFC 2010). The report further notes that the 2002 – 2006 reference period would need to be considered further.

The latest revised draft of the SPRFMO Bottom Fishery Impact Assessment Standard is scheduled to be reviewed at the 10th SWG meeting in Vanuatu in September 2011. In view of the international criticism of the 20-minute blocks, and the substantial exaggeration of fished area that results from mapping effort at that resolution, questions regarding how fishing effort distribution should be mapped remain relevant. The objectives of this paper are to consider why we want to map bottom fishing effort, the purposes for which such effort maps might be used and the problems resulting from attempting to produce and use fishing effort maps at various resolutions. The paper makes a number of proposals regarding mapping of high seas bottom fishing effort for different purposes.

Methods

Effort data for New Zealand high-seas bottom trawling in the SPRFMO Area over the period 1990 to 2006 used in this paper were the same as those used in preparation of the New Zealand SPRFMO Bottom Fishery Impact Assessment (Ministry of Fisheries 2008). Bottom trawl data over this period were retrieved from the High Seas Trawl Catch Effort Return (HS-TCER) forms which provide tow-by-tow information, including start and end date, time and location, fishing method and depth for each tow.

This is primarily an orange-roughy (*Hoplostethus atlanticus*) targeted fishery and data were groomed using standardised data grooming procedures for orange roughy-targeted trawl catch and effort data routinely used in analyses of New Zealand high-seas orange roughy catch and effort (e.g. Clark 2008a, 2008b). Grooming procedures are described in Clark *et al*. (2010). Error checks were performed for fishing position and depth, tow speed, duration, distance and target species. All tows determined as being *Position-Reliable* (passed all the above tests) or *Position-OK* (had one problem related to tow length, tow speed or position, but tow length was still acceptable) were initially retained for analyses in this paper. Tows considered to be *Position-Unreliable* (primarily as a result of excessive tow length) were excluded from analyses. Further geospatial grooming conducted is described in the **Effort Mapping - Problems** section below.

These effort data include foreign-flagged vessels operating under charter to New Zealand companies. Whereas foreign-flag data were excluded from the New Zealand SPRFMO impact assessment (Ministry of Fisheries 2008), data for all vessels were used for analyses in this paper to provide best estimates of seabed swept area over the period 1990 to 2006. Also, whereas the New Zealand impact assessment only mapped fishing effort distribution over the 2002 – 2006 reference period, effort mapping for this paper included all reliable data for the entire period 1990 – 2006.

Geospatial analyses were conducted using MapInfo® v10.5 and ESRI ArcGIS® v9.3, using an Albers equal area conic projection centred on 175°E, with standard parallels at 30°S and 50°S. This projection minimizes the distortion of linear scale between the chosen standard parallels in the New Zealand region and provides proportionally correct comparative area estimates. Further details of the geo-spatial analyses conducted are described in the sections below.

Effort Mapping - Purposes

Before discussing the problems and merits of mapping high seas bottom fishing effort in different ways, we should consider why we want to map fishing effort, and how such effort maps will be used. The original motivation for mapping bottom fishing effort was to provide some way of objectively defining areas being 'currently fished', so as to enable the SWG to determine whether future fishing activities described in impact assessments would be outside of these 'currently fished' areas, and therefore potentially in contravention of SPRFMO bottom fishing interim measure 2.

However, SPRFMO bottom fishery interim measure 3 provides for fishing in new areas, or expanding fishing effort or catch beyond existing levels, from 2010 onwards, provided an assessment has been undertaken and conservation and management measures have been implemented "*to prevent significant adverse impacts on vulnerable marine ecosystems and the long-term sustainability of deep sea fish stocks*" (SPRFMO 2007a). In terms of requirements to conduct assessments and to implement conservation and management measures to prevent significant adverse impacts on VMEs, there is therefore now no distinction between historically fished and new fishing areas.

More importantly, the emphasis in the SPRFMO interim measures on limiting fishing to areas being 'currently fished' has led to the incorrect assumption that mapping of these previously fished areas somehow implies a specific management status of these areas. This has led some to conclude, incorrectly, that mapping of these fished areas somehow equates to declaration of these areas as being open to fishing, with other areas, by implication, being closed to fishing. This has been referred to internationally as the so-called 'freeze the footprint' approach.

This should not be the intention of such mapping, and is not compliant with the requirements of UNGA Resolutions 61/105 and 64/72, or the FAO deepwater guidelines (FAO 2009). These resolutions require participants in high seas bottom fisheries to assess the risk of significant adverse impacts to VMEs in any and all high seas fishing areas, and to implement adequate conservation measures in any area assessed as having a risk of significant adverse impacts on VMEs. The fact that an area has been previously fished does not, in any way, imply that such areas either do or do not contain VMEs, and does not, of itself, imply that an area should remain open, or be closed, to fishing.

The likelihood of occurrence of, and risk of significant adverse impact on, VMEs needs to be determined in a proper, quantitative risk and impact assessment. The spatial distribution and intensity of fishing effort in an area will certainly be an important component of such risk assessments. Catch, by-catch and VME evidence information collected during fishing operations or research surveys will also be important components of risk assessments. The extent to which seabed biodiversity may have been reduced in a fished area may then be a relevant factor to consider when evaluating the risk and cost-benefit of alternative management approaches.

However, the resulting conservation and management measures need to be designed to respond directly to the results of the risk assessments, and to address the risk of significant adverse impacts on VMEs in those areas where such risks exist. Where such management measures include spatial closures, these need to be objectively designed, for example by using spatial planning software such Marxan (Ball *et al*. 2009), and not just based on fishing effort distribution. If management measures primarily rely on the implementation of a move-on rule (SPRFMO 2007a, bottom fishing interim measure 7), then the distribution of previous fishing effort is largely irrelevant.

So, when considering what the purposes of effort mapping might be, we should start by recognising what is not the purpose of effort mapping. The mapping of bottom fishing effort, no matter at what resolution this is done, should not, of itself, constitute or imply an effective management measure.

We can then recognise three common, frequently applied, purposes for the mapping of bottom fishing effort data:

- ⇨ **For use in quantitative risk and impact assessments;**
- ⇨ **For scientific mapping of historical fishing effort;**
- ⇨ **To broadly designate fished areas.**

The above three effort mapping purposes are arranged in descending order of mapping approach and spatial resolution requirements, with the finest possible resolution being required for use in risk assessments, intermediate resolution being adequate for mapping the geographical distribution of fishing effort intensity, and lower resolution perhaps being acceptable for general designation of fished areas. The last purpose above is the one most analogous to the current SPRFMO bottom fishing footprint mapping definition.

Appropriate methods and spatial resolutions for these three approaches are explored in the **Effort Mapping - Proposals** section of this paper.

Effort Mapping - Problems

Many of the problems related to mapping of bottom fishing effort result from errors in the reported or captured effort data. Before using bottom fishing effort data in risk assessments, mapping of effort distribution or designation of fished areas, it is necessary that erroneous data be detected and either deleted or corrected. Sources of data error, and some ways of detecting and correcting data errors, are discussed in this section.

• *Unreliable Tow Positions*

Figure 1 shows a map of New Zealand 1990 – 2006 'high seas' bottom trawl positions considered to be unreliable, as detected by automated data grooming procedures described in Clark *et al*. (2010). This map clearly shows why we need to groom bottom trawl effort data. These tows were identified as being unreliable primarily as a result of excessive tow length and have clearly resulted from very substantial errors, either during data reporting or data capture, in either start or end positions, or both. There are many potential sources of such errors, including:

- GPS error or malfunction, or incorrect recording of positions read off the GPS unit.
- Transposition of numbers, either during position recording or data entry.
- East/West errors across the 180° line of longitude, perhaps resulting from failure to record or capture the minus or E/W sign for positions east of 180°E.
- Illegible positions on hand-written catch and effort returns, with resulting data capture errors.
- Incorrect combination of start and end positions from different tows as a result of partially reading the incorrect line on data forms during data capture.

Without inspection of original data forms, or recourse to an independent data source such as Vessel Monitoring System (VMS) or observer position data, it is difficult to correct these records. For many such records, it is not even possible to determine whether the tows actually occurred on the high seas, or were conducted within the EEZ. It is clear from Figure 1 that mapping of these trawl tow data would be meaningless at any resolution, particularly as 20-minute blocks, which would cover about half of the SPRFMO Area, as well as virtually the entire New Zealand EEZ.

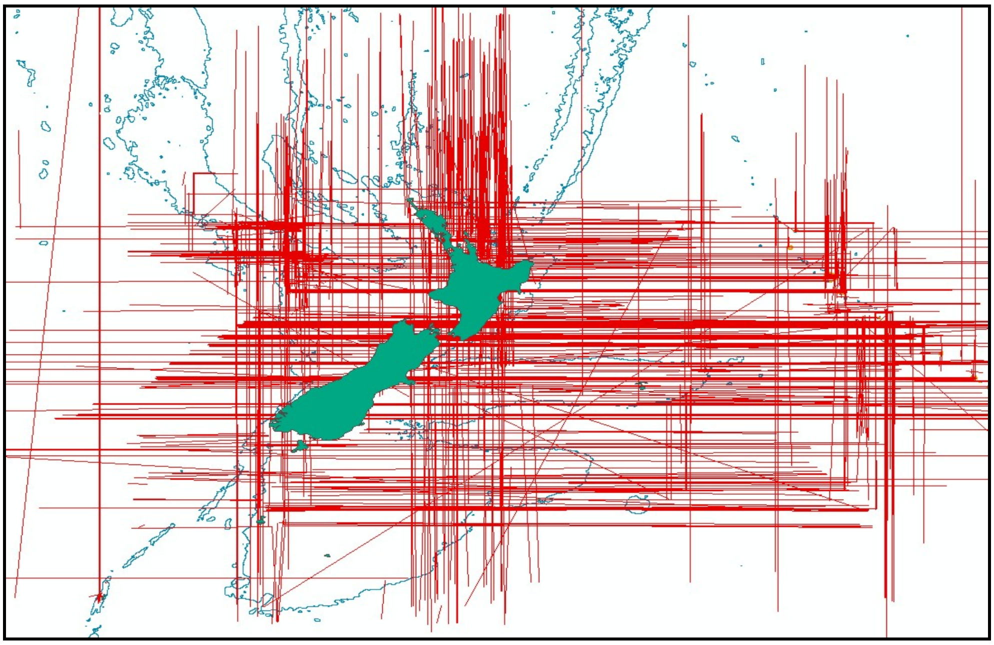

Figure 1. Map of unreliable 'high-seas' bottom trawl tow positions for the New Zealand seas bottom trawl fishery over the period 1990 – 2006, detected by automated grooming procedures, primarily as a result of excessive tow length. The 1600m depth contour is shown to provide an indication of areas of fishable depth.

Usually, efforts should be made to inspect the data forms for these tows, or to compare them with alternative positional data, to correct as many of them as possible. However, due to time constraints, and for the purposes of analyses presented in this paper, the original data forms for these erroneous records have not been checked and these tows were deleted from the data used for this paper.

• *East / West Errors*

Many of the erroneous east-west orientated trawl tracks shown in Figure 1 appear to result from east / west errors in either the start or end position of the tow. These occur when positions east of 180˚E are incorrectly recorded or captured without the minus sign, i.e. as being E instead of W, or *vice versa*. This is a particular problem for New Zealand bottom trawl operations which occur both east and west of 180°E. Where there are valid fishing areas lying equidistantly east and west of 180°E, this can result in tows being incorrectly allocated to an area to the west of 180°E that should lie to the east, and *vice versa*. For example, tows on the Louisville Ridge might end up being recorded as being on the Challenger Plateau, and *vice versa*.

While it is rather obvious when only the start, or the end, position of a tow have been incorrectly recorded (Figure 1), it is more difficult to detect when both are incorrect. One important check to conduct is to compare tow positions with the availability of fishable depth for the gear type and fishery sector concerned. Tows that occur in areas beyond the fishable depth range for the gear used are also clearly incorrect, and must either be deleted or corrected. This is difficult to do in an automated, mathematical, grooming procedure, and requires geospatial grooming of the data in a GIS system.

Figure 2 shows an example of a number of bottom trawl tows adjacent to a seamount feature on the Louisville Ridge, all of which occur well below fishable depth, in depths > 4000m. These tows were not individually checked against bathymetry during preparation of the 2008 New Zealand SPRFMO bottom fishery Impact Assessment (Ministry of Fisheries 2008), and resulted in the incorrect incorporation of a number of additional 20-minute blocks into the current New Zealand bottom trawl footprint map.

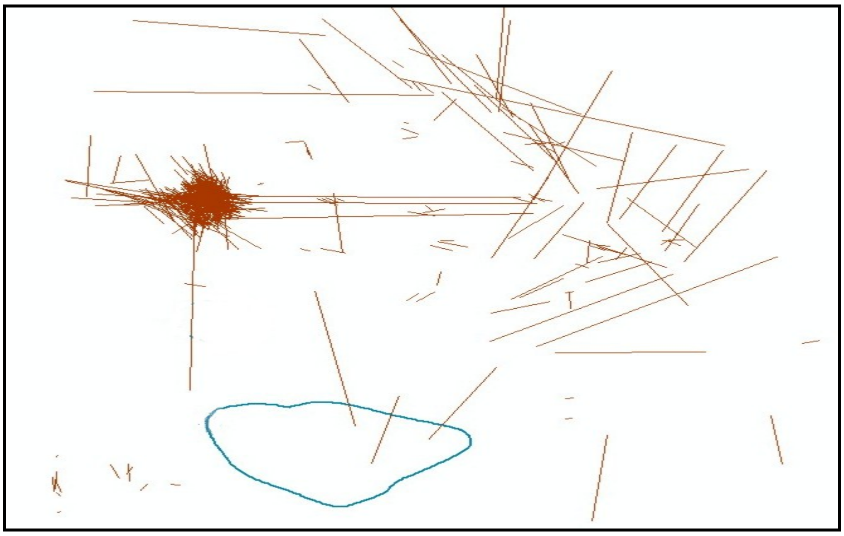

Figure 2. Example of incorrectly reported trawl tows lying outside of fishable depth (the blue line shows the 1600m depth contour) in the vicinity of a seamount feature on the Louisville Ridge. These tows are all at unfishable depths (> 4000m) and are likely to be east-west errors. These tows were probably conducted somewhere on the Challenger Plateau, some possibly within the New Zealand EEZ.

The recent availability of the Global Bathymetric Chart of the Oceans 30-arc-second (~1km^2) bathymetric data (GEBCO 2010) provides improved, high-resolution bathymetric data that can be used to check the depth-validity of reported tow positions. The verified maximum fishing depth recorded in the New Zealand 1990 – 2006 high seas bottom trawl data is about 1600m, and Figure 2 shows the 1600m depth contour derived from the GEBCO 30 arc-second data. The tows shown all lie outside of this fishable depth contour, and appear to have resulted from east/west errors. It is likely that these tows belong somewhere on the Challenger Plateau, some of them possibly within the New Zealand EEZ.

Usually, efforts should be made to inspect the data forms for these tows, or to compare them with alternative positional information, to correct as many of them as possible. However, due to time constraints, and for the purposes of analyses presented in this paper, the original data forms for these erroneous records have not been checked and these tows were deleted from the data used for this paper. This was achieved by using either the 1600m contour from GEBCO 30 arc-second data in ArcView to detect and delete all tows that occurred entirely in areas below 1600m depth, or effort polygons drawn around valid tows that extended slightly beyond the 1600m depth contour (see below).

Table 1 shows a summary of the total number of bottom trawl tows originally retrieved from the database for the period 1990 – 2006, those considered to have reliable positions, those with east/west or other depth errors and those with unreliable positions. After initial grooming and correction, 92% of the total tows were determined to have reliable positions, accounting for 89% of the total reported orange roughy catch and 88% of the all species catch in the original extracted data set. 4% of the tows were considered to be totally unreliable, and 4% were considered to have east/west or other invalid depth position reporting errors.

Table 1. Summary of the total number of New Zealand 'high seas' bottom trawl tows over 1990 – 2006, showing those considered to have reliable positions, east/west or other depth errors or unreliable positions. The total reported orange roughy and all species catches retained and lost after data grooming processes are shown.

Period	Position Status	No. Tows	Orange Roughy Catch (t)	All Species Catch (t)
1990-2006	Pos_Reliable	39,902	54,335	64,189
	E/W/Depth Error	1,627	3,927	4,206
	Pos_Unreliable	1,760	2,622	3,032
Total	All tows	43,289	60,884	75,026

• *Cropping Tows to Fishable Depth*

In addition to tows that lie entirely outside of fishable depth areas (such as those in Figure 2), there are also tows that lie partially within fishable depth, but extend beyond fishable depth into areas that are too deep to be fished using the gear concerned. Figure 3 shows an example of such tows on a seamount feature, extending well beyond a cluster of valid tows. While some trawl tows might start, or might end, in deeper water, these tows cannot have contacted the seabed in areas below fishable depth. It would therefore be incorrect to use portions of tows that occur in areas beyond fishable depth when estimating seabed swept area, or for any other bottom fishing effort mapping purpose. Tows should be cropped to fishable depth before being used to map fishing areas, plotting fishing effort distributions, or determining seabed swept areas for risk assessments.

Trawl tows could potentially be automatically cropped to any selected fishable depth contour using GIS software. However, caution needs to be exercised before simply using contour lines based on GEBCO bathymetric data to automatically crop trawl tow lines to a selected depth contour. In some areas, bathymetric data are sparse and, as a result, the GEBCO bathymetric data can under-represent fishable depth in some areas.

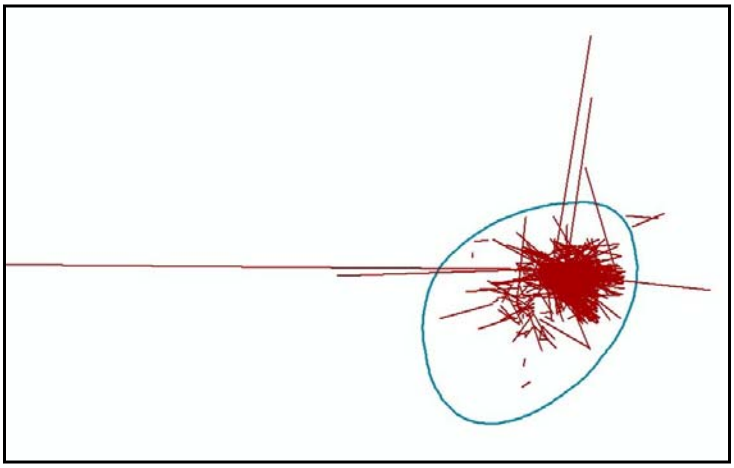

Figure 3. Example of tow lines on a seamount feature, some of which extend well beyond the 1600m maximum fishable depth contour (blue line). These extended tows are probably incorrect, and should be cropped to the fishable depth area.

Figure 4 shows an example of a group of trawl tows on a seamount feature, where a substantial number of tows extend slightly beyond the 1600m maximum fishable depth contour. These tows otherwise appear to be entirely valid. Either there was some consistent offset between the vessel position and the actual trawl net position, or the GEBCO bathymetric data are inadequate in this area. Either way, these tows should not be automatically cropped to the 1600m depth contour in the area of substantial overlap.

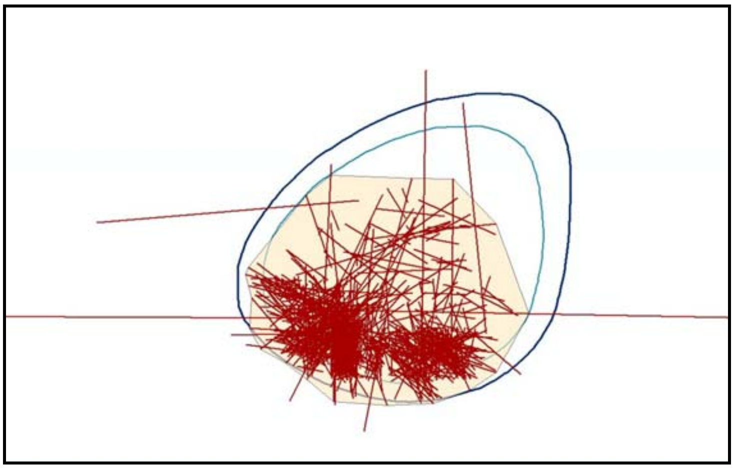

Figure 4. Example of tow lines on a seamount feature, many of which extend beyond the 1600m depth contour (thin blue line). These tows otherwise appear to be valid tows, suggesting that the GEBCO data are inadequate in this area, or that there is some consistent offset between the vessel and net positions. The shaded polygon shows an alternative 'fished area' depth polygon drawn to encompass the valid trawl tow lines, and allowed to extend beyond the 1600m depth contour where this appears to be appropriate, guided by the 2000m contour (thick blue line).

A better alternative is to draw a 'fished area' polygon that encompasses all the apparently valid tows, cropped to the 1600m maximum fishable depth contour where this appears to be appropriate, but allowed to extend beyond the 1600m contour when the distribution of trawl tows indicates that the depth contour may be incorrect. Tows can then be cropped to this polygon. Figure 4 shows an example of a fished area polygon that has been allowed to extend beyond the 1600m depth contour, guided instead by the 2000m depth contour.

The position offset of the net behind the reported vessel position could also theoretically be corrected using water depth and warp length, but this was not done for this paper.

For the purposes of this paper, fished area polygons were drawn around identifiable aggregations of trawl tows in all of the fishing areas, constrained by the 1600m depth contour in most cases. However, where aggregations of tow lines consistently extended beyond the 1600mm depth contour, suggesting that the bathymetric data might be inadequate in those areas, the polygons were allowed to extend beyond the 1600m depth contour, guided instead by the 2000m depth contour. This did not occur on any of the larger Challenger Plateau, Lord Howe Rise, West Norfolk Ridge and Three Kings Ridge fishing areas, and only occurred on a few seamount features on the Louisville Ridge. Tows were then automatically cropped to these fished area polygons.

• *Reducing the Effect of Overly Influential Tows*

The current SPRFMO bottom trawl footprint is defined as including any 20-minute latitude/longitude block touched by at least one tow over the period 2002 – 2006 (SPRFMO 2007b). In some areas, this definition results in the addition of a large, unfished areas to the fishing footprint map. This occurs particularly in lightly fished areas where small numbers of tows are widely scattered across a large area. The resulting exaggeration of the fished area is further increased if tows are incorrectly reported as being longer than they actually were, such as the erroneous long tows illustrated in Figures 3 and 4.

Depth-related grooming can be used to crop erroneously long tows where they extend into unfishable depths. However, where such long tows occur entirely within fishable depths, or are contained entirely within effort polygons drawn around valid tows, they will not be deleted or cropped by the depth-validity grooming procedures described above. It may also not be possible to distinguish between genuine long tows, and those that result from errors in start or end positions.

Consideration should therefore be given to an alternative method for reducing the fished-area exaggeration caused by these overly influential tows. Figure 5 shows an example of an area where three moderately long trawl tows result in the addition of two 20-minute blocks, and a substantial amount of seabed area, to the New Zealand bottom trawl footprint. Alternatively, expressing the footprint map in terms of 0.1 degree (6-minute) blocks, these tows result in the addition of nine 6-minute blocks to the footprint map, although still with a substantial exaggeration of fished area.

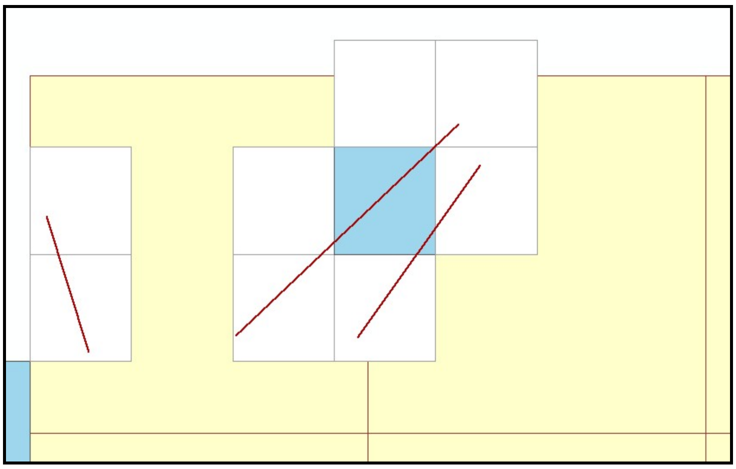

Figure 5. Example of scattered, highly influential tows, where three trawl tows result in the addition of two 20-minute blocks (yellow), or nine 0.1 degree (6-minute) blocks (blue and white) to a trawl footprint map. Only one of the 6-minute blocks (blue) includes more than one tow.

The exaggeration that results from generating fishing footprint maps as aggregations of blocks can be reduced both by reducing the size of the blocks, and by setting some minimum threshold for the number of tows for the inclusion of a block in the footprint. Essentially, such an approach argues that an area with fewer tows than the threshold number has actually not been fished, at least not for the purpose of effort mapping. Figure 5 shows an example based on 6-minute blocks where all but one of the 6-minute blocks (shaded blue) would be excluded from the footprint by requiring a block to have more than one tow to be included in the effort map.

- *Addition of Trawl Position Offsets*

The New Zealand trawl fishery is required to report trawl start and end positions rounded to the nearest 1 minute (0.01667 degrees). From discussions with industry representatives, observers and fisheries researchers, it is understood that they do, in fact, report positions rounded to the nearest 1 minute, i.e. not to the nearest minute below. The real trawl start and end positions will therefore be distributed up to 0.5 minutes (0.00833 degrees) latitude and longitude either side of the reported positions.

In areas with established trawling lanes, fishermen often report the same start and/or end positions for numerous repeated tows. This results in an artificial exact overlaying of start positions or entire trawl tracks. As a result of the rounding of reported positions to the nearest minute, GPS error, wind and current drift, variable offset between the vessel and net positions and the fact that trawl tows are not likely to be perfectly straight lines, it is almost certain that these start positions and tow lines do not exactly overlay one another. Rounding of start and end positions can therefore result in an under-estimate of seabed swept area calculated from overlaying trawl track positions.

One method for adjusting for the rounding of start and end positions is to re-introduce a random offset, or jitter, to the reported start and end positions. This was done for all tows used in these analyses by adding a random offset 0.5 minutes either side of the reported latitude and longitude (MS Excel®: (RAND()-0.5)*0.01667 deg). The effect of adding these offsets is shown in Figure 6, showing the separation of start positions and overlying trawl tows that were originally reported as overlaying one another (Figure 6b).

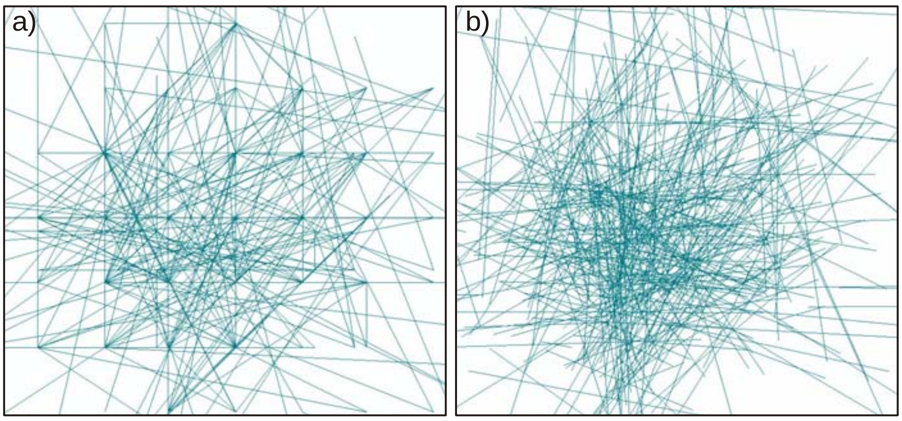

Figure 6. The effect of adding a random offset (+-0.5 minutes) to the start and end positions of bottom trawls on an underwater topographic feature showing: a) the original reported trawl start and end positions aligned with rounded 1 minute positions; and b) tow positions after the addition of random offsets, showing the resulting separation of start positions and overlying tow lines that originally resulted from reporting positions to the nearest 1 minute.

All bottom trawl effort maps and GIS buffered seabed swept area calculations in this paper were generated using jittered trawl tow positions calculated as described above.

• *Exaggeration of Different Mapping Resolutions*

A key component of discussions at the 4th SWG meeting in 2007 relating to development of the interim Benthic Assessment Framework (SPRFMO 2007b) revolved around concerns at the exaggeration of fishing footprints that result from mapping fishing effort at low resolution, such as the 20-minute blocks currently used by SPRFMO. These concerns have been re-iterated at the Lisbon scientific workshop on implementation of UNGA Resolutions 61/105 and 64/72 (Weaver *et al*. 2011).

After all of the filtering and error-corrections described above were implemented, the resulting groomed trawl tow data set was used to explore five alternative approaches to mapping the New Zealand 1990 – 2006 high seas bottom trawl fishing effort:

- Actual trawl tracks buffered with a geospatial buffer 50m both sides of each track and then merged to produce an estimate of actual swept area.
- Effort polygons drawn around (depth constrained) groups of tows in fished areas.
- Effort mapped as 0.1 degree (6 minute) blocks touched by at least one (depth cropped) tow.
- Effort mapped as 0.1 degree (6 minute) blocks touched by more than one (depth cropped) tow.
- Effort mapped using the current SPRFMO footprint definition, using 20 minute blocks touched by at least one (depth cropped) tow.

Table 2 provides a summary of the resulting estimates of actual GIS-buffered seabed swept area, compared with the estimates of footprint area obtained using the other four approaches. Figure 7 shows a plot of the resulting exaggeration factors by fishing area.

The inclusion of data back to 1990 adds a large number of tows to all of the fishing areas compared with the 2002 – 2006 data used in mapping the New Zealand SPRFMO bottom trawl footprint (Ministry of Fisheries 2008). These data also add two additional fishing areas: the South Tasman Rise and the Mid-Pacific (Foundation Seamounts) areas that have not been fished by New Zealand since 2001. The overall exaggeration factors by fishing area are inversely related to the level of historical fishing effort (number of tows or cumulative tow length) by area. Using the current SPRFMO footprint definition of 20 minute blocks, the exaggeration of 'fished' area over actual swept area ranges from 7.8-times for the most heavily fished Challenger Plateau (14,541 tows), to 1,315-times for the lightly explored Mid-Pacific area (96 tows).

All of the alternative mapping approaches result in lower exaggeration factors than using 20-minute blocks. Using effort polygons around depth-constrained tows results in a similar overall exaggeration factor (9.5-times) to using 0.1 degree blocks containing at least one tow (9.6-times), depending on the clustering of tows and how much un-trawled area is contained within an effort polygon. In areas where tows are highly clustered, effort polygons provide the most accurate, and least exaggerated, depictions of fished area. In areas where tows are scattered across an area, 0.1 degree squares provide a more accurate, but graphically more complex, depiction of fished area.

The lowest overall exaggeration factor of the alternative approaches used (7.2 times) is obtained using 0.1 degree blocks touched by more than one tow. The effort polygon and 0.1deg>1tow approaches each provide the lowest exaggeration for five of the fishing areas, depending on the degree of clustering of tows, with effort polygons being more accurate in densely fished areas and 0.1 degree blocks being more accurate in areas with scattered fishing effort. The degree of exaggeration will be further reduced by setting a higher number of tows threshold for 0.1 degree blocks to be included.

Table 2. Summary of the number of *position_reliable* tows, total (cropped) tow length (km) and estimated actual (GIS buffered trawl track) swept area (km^2) in each of the ten high-seas fishing areas fished by New Zealand bottom trawl vessels over the period 1990 – 2006. Fishing areas are ranked in descending order of the cumulative total tow length (km) over the period. Estimated actual swept areas are compared with the total 'fished' footprint area that results from four alternative approaches to mapping the 'fished' area in these ten fishing areas: i) Effort polygons drawn around reliable, cropped tows; ii) 0.1 degree blocks touched by more than 1 tow; iii) 0.1 degree blocks touched by at least 1 tow; and iv) 20 minute blocks touched by at least 1 tow. The each case, the resulting exaggeration of 'fished' area over the actual swept area is shown. Exaggeration factors (see also Figure 7) range from 3-times to 1,315-times, depending on the mapping approach and the intensity of fishing in the area.

Fishing Area	No. Reliable Tows	Tow Length (km)	Actual Swept Area (km^2)	Effort Polygons		0.1deg - >1Tow		0.1deg - All Tows		20min Blocks	
				Area (km^2)	Exag	Area (km^2)	Exag	Area (km^2)	Exag	Area (km^2)	Exag
Challenger Plateau	14,541	178,425	8,579	48,996	5.7	38,504	4.5	45,585	5.3	67,197	7.8
Louisville Central	10,167	28,975	882	2,531	2.9	6,154	7.0	6,608	7.5	23,445	26.6
Lord Howe South	4,135	23,726	1,188	27,849	23.4	14,933	12.6	20,344	17.1	37,818	31.8
Louisville North	5,000	14,929	642	3,442	5.4	6,635	10.3	7,833	12.2	21,929	34.1
Louisville South	2,463	5,571	214	1,044	4.9	2,927	13.7	3,188	14.9	12,427	58.2
Lord Howe North	1,284	4,290	272	15,658	57.6	6,358	23.4	12,009	44.2	25,075	92.3
West Norfolk Ridge	1,187	3,594	226	10,539	46.6	6,386	28.2	11,038	48.8	27,566	121.9
South Tasman Rise	927	1,692	91	4,251	46.6	2,351	25.8	3,781	41.4	9,331	102.3
Three Kings Ridge	102	706	52	631	12.1	1,511	28.9	2,262	43.3	10,769	206.1
Mid-Pacific Ridge	96	196	17	655	38.6	1,807	106.5	3,614	213.0	22,314	1,315.0
Totals	39,902	262,104	12,162	115,596	9.5	87,568	7.2	116,261	9.6	257,870	21.2

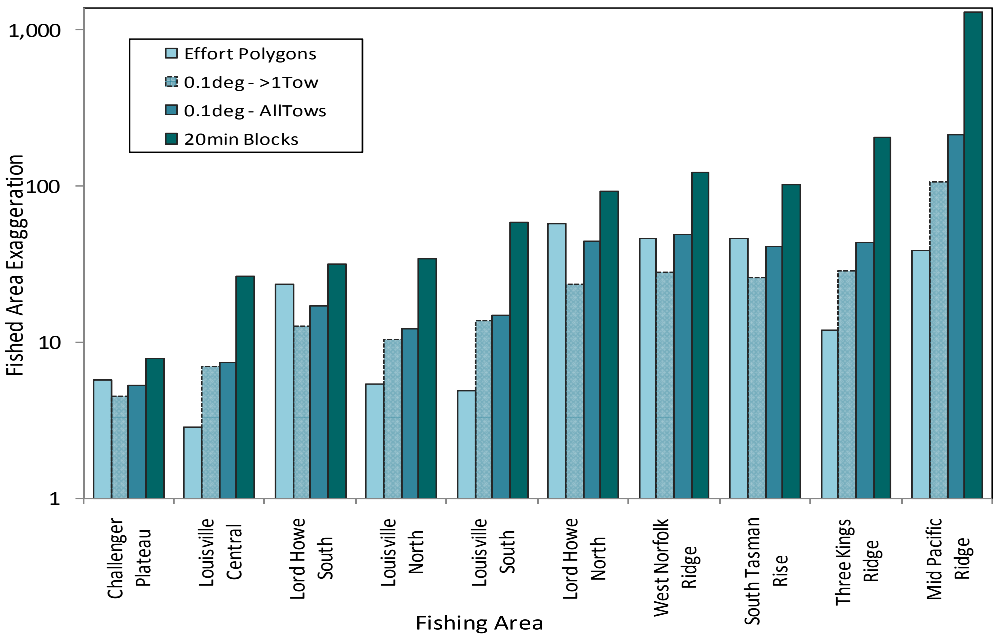

Figure 7. Exaggeration of estimates of 'fished' area resulting from mapping bottom trawl effort as: effort polygons; 0.1 degree blocks with >1 tow; 0.1 degree blocks with at least 1 tow; or 20 minute blocks (data from Table 2). Note the exponential scale on the y-axis.

Examples of the fishing footprint maps that result from the four alternatives to using actual buffered trawl tracks are shown in Figure 8 for the most heavily fished Challenger Plateau, and in Figure 9 for the most lightly fished Mid-Pacific area. The differences between these two extremes illustrate the effect of fishing intensity and scattering of tows on effort maps, as well as the fished area exaggeration resulting from using the alternative approaches. The 0.1-degree (6-minute) blocks in these figures have been shaded by fishing effort (number of tows) to illustrate how mapping at this resolution can be used to display effort distribution, and to illustrate the effect of excluding blocks with only one tow (shaded white in the Figures 8b and 9b) from effort maps at this resolution.

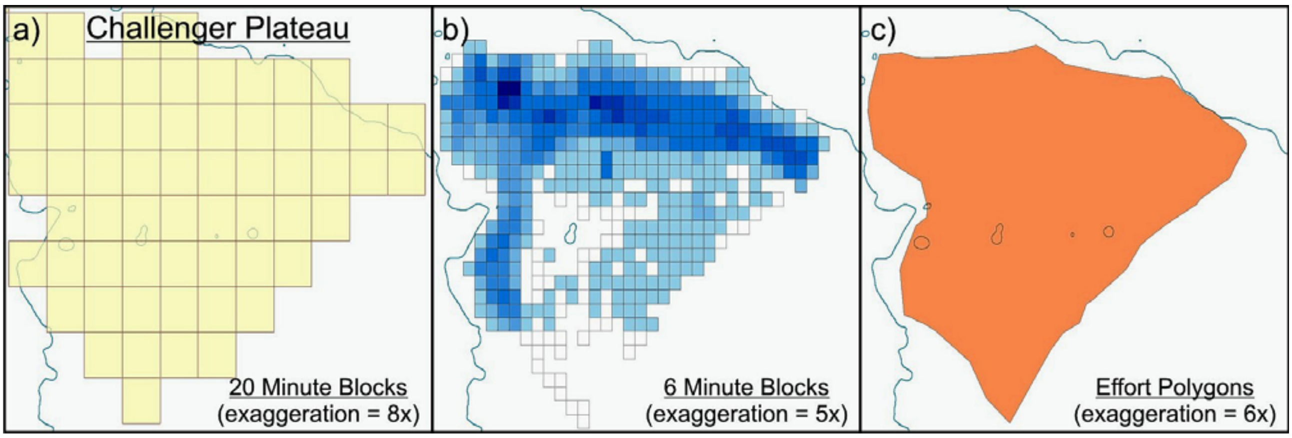

Figure 8. Exaggeration of estimates of 'fished' area on the Challenger Plateau (14,541 tows) resulting from mapping the fishing footprint as: 20 minute blocks (62 blocks); 0.1 degree (6-minute) blocks (467 blocks with at least 1 tow); or an effort polygon. The 6-minute blocks are shaded by fishing effort (number of tows), with blocks with only 1 tow being left white to illustrate the result of excluding these from the map. Blue lines show the 1600m depth contour.

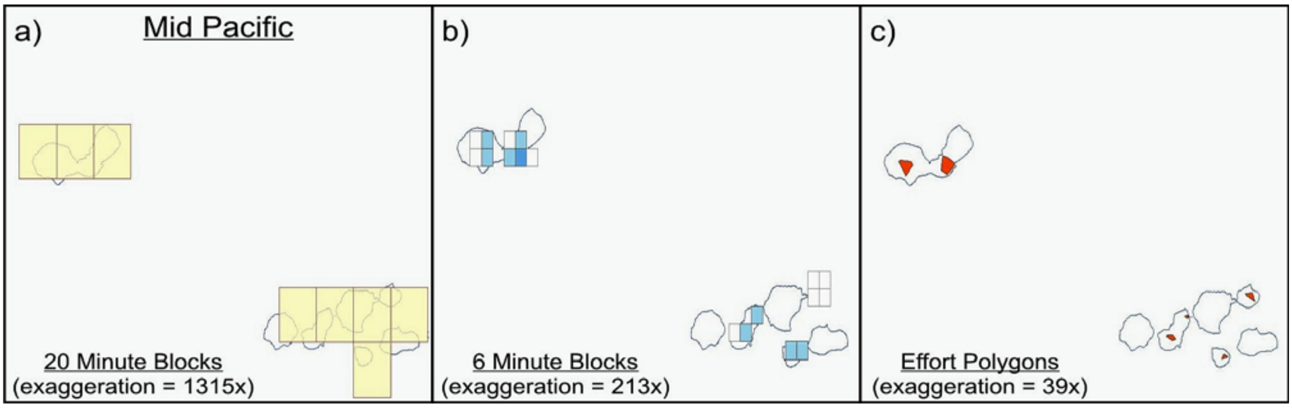

Figure 9. Exaggeration of estimates of 'fished' area in part of the Mid-Pacific area (96 tows in the whole area) resulting from mapping the fishing footprint as: 20 minute blocks (20 blocks); 0.1 degree (6-minute) blocks (36 blocks with at least 1 tow); or as effort polygons. The 6-minute blocks are shaded by fishing effort (number of tows), with blocks with only 1 tow left being white to illustrate the result of excluding these from the map. Blue lines show the 2000m depth contour.

Effort Mapping - Proposals

• *Time Period for Effort Maps*

The reference period of 2002 – 2006 recommended by the SWG in 2007 (SPRFMO 2007b) as the basis for mapping areas 'currently fished' is becoming increasingly inappropriate as a definition of 'current' fishing as the years go by. Other than to assist participants to comply with SPRFMO bottom fishing interim measure 2 prior to 2010, we should reconsider why we want to define and map areas being 'currently fished'. Whether for risk assessment, for other scientific analysis, or simply for publishing maps of fishing effort, what is really required is to produce maps of the distribution of fishing effort over various historical periods of the fishery, as required for particular analyses.

There is accumulating scientific evidence to show that deepwater benthic communities take decades to centuries to recover from loss of biodiversity and bio-structured habitat resulting from bottom fishing impacts. Of direct relevance to the SPRFMO Area, Williams *et al*. (2010) found no evidence of recovery in multivariate assemblage patterns on trawled areas on seamounts off New Zealand and Australia over a 5 – 10 year timeframe. Recent work on age determination of the New Zealand region dominant habitat forming scleractinian coral *Solenosmilia variabilis* by Neil *et al*. (2011) has predicted that re-establishment of small colonies could take hundreds of years, while re-establishment of large colonies (2 – 3 m across) could take thousands of years.

For the purpose of risk assessment, cost-benefit analysis and spatial protection planning, it is therefore required to analyse and map bottom fishing effort distribution patterns over the entire history of the fishery. Even for general purpose mapping of fishing effort, or for designation of 'fished' areas, effort data for the entire period of the fishery should be mapped. Where there are requirements to analyse aspects like recovery potential, changes in fishing areas or changes in effort over time, effort maps may be required for a number of different historical time periods across the history of the fishery.

⇨ **The entire historical period of a fishery should be used when analysing and mapping bottom fishing effort data. This could be divided into different historical periods for the purpose of analysing changes in the fishery over time.**

• *Approach for Risk and Impact Assessments*

Turning now to approaches for the three effort mapping purposes identified in the section of **Effort Mapping – Purposes**: for all analyses related to risk and impact assessments, actual tow-by-tow or set-by-set bottom fishing trawl or set tracks and positions should be used. The highest resolution data are necessary to properly quantify seabed swept area, map the geospatial distribution of fishing effort and analyse fishing intensity by area. Within the context of a quantitative risk assessment, accurate fishing position and seabed swept area data are required for comparison with data on known or predicted distribution of benthic species contributing to VMEs. Objective planning of spatial protection measures and cost-benefit analysis of alternative spatial management approaches also requires use of actual tow-by-tow data.

Figure 10 shows examples of seabed swept area maps that result from the data grooming, correction, geospatial buffering and merging procedures described in this paper. Figure 10a shows the coverage of long trawl tracks in a heavily fished, flat plateau area, using an estimated swept width of 100m. Figure 10b shows a cluster of shorter tows on an underwater topographic feature surrounded by flatter area. Addition of random offsets to the reported start and end positions provides a more realistic distribution of tows. The resulting separation of trawl tracks that originally overlay one another due to reporting start and end positions to the nearest minute is evident in Figure 10b.

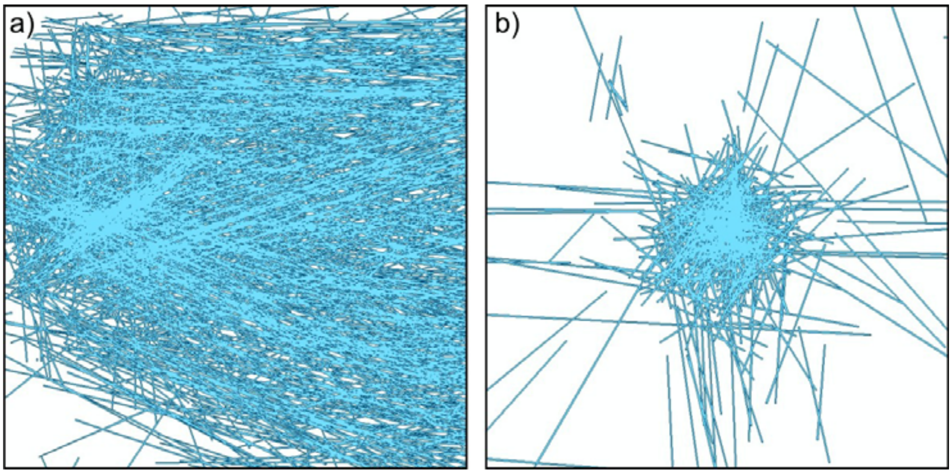

Figure 10. Examples of GIS buffered (100m swept width) and merged bottom trawl tracks showing: a) a flat plateau area; and b) an underwater topographic feature. The separation of start and end points, and of overlaying trawl tracks resulting from addition of offsets to the start and end positions is evident in b).

⇨ **Individual tow-by-tow or set-by-set data should be used for all quantitative, scientific bottom fishing effort analyses, particularly for the purpose of quantitative risk assessments.**

Where analyses related to quantitative risk assessments include the use of raster (gridded point) data sets, these analyses should be conducted at the finest possible resolution. Globally, the finest resolution in general use is ~1km^2 (30 arc-seconds), driven by the availability of the GEBCO 30 arc-second global bathymetric data set (GEBCO 2010). Relevant recent analyses at 1km^2 resolution include the global predictive coral habitat suitability model by Davies & Guinotte (2011). Williams *et al*. (2011) provide an example and recommend the use of gridded data at 1km^2 resolution for fine-scale risk assessment and planning of spatial protection measures.

• *Approach for Scientific Mapping of Effort Distribution*

The fishing industry has confidentiality concerns around publication of maps of actual tow-by-tow bottom fishing data, such as those in Figure 10. While data at this resolution should be used in risk assessments and other quantitative effort analyses, a lower resolution mapping approach may be required for publication of resulting scientific effort analyses and maps. However, for any purpose that requires geospatial mapping of fishing effort at a resolution that is useful for science or management, the existing 20-minute blocks are too large, and provide substantially inaccurate depictions of 'fished area'.

The SPRFMO Data Standards require un-aggregated tow-by-tow data for all fishing methods, including bottom fishing, to be collected to the nearest 0.1 degree (SPRFMO 2011). At the latitudes covered by the SPRFMO Area, 0.1 degree blocks average 10 x 10 km in size, ranging in area from 108 km^2 in the northernmost Mid-Pacific area to 84 km^2 in the southernmost South Tasman area (Albers equal area projection). Within high seas bottom trawl areas fished by New Zealand over 1990 – 2006, the maximum number of (groomed, corrected, cropped) tows ranges between fishing areas from 37 to 2,374 tows per 0.1 degree block, averaging 61 tows per 0.1 degree block across all fished areas.

With reliable tow length in this fishery averaging 6.5 km, and tows on seamounts or hill features being shorter than this, there should be no real confidentiality concerns with effort mapped as 0.1 degree blocks. Actual bottom trawl start positions and catch rates for the New Zealand high seas bottom trawl fishery have already been reported at original resolution in descriptive analyses of this fishery (see Clark 2008a, 2008b). Fishing effort intensity maps for the New Zealand within-zone bottom trawl fishery are being increasingly published by industry consultants at a resolution of 0.1 degree squares (see e.g. Starr & Kendrick 2010, Starr *et al*. 2010a, 2010b). The Australian SPRFMO bottom fishery impact assessment (Williams *et al*. 2011) also recommends the use of 0.1 degree squares for general scientific analysis of bottom fishing effort distribution, and bases the quantitative evaluation of fishing effort overlap with biologically important depth ranges on 0.1 degree squares.

⇨ **For 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. These should be aligned on whole 0.1 degree positions, using the WGS84 chart datum and geographic coordinate system.**

For any effort mapping approach involving blocks, consideration should be given to how to reduce the effect of blocks with only one, or very few, tows. This is most appropriately dealt with by coding and shading blocks by effort. Figures 8b and 9b show examples of 0.1 degree blocks shaded by number of tows, with blocks with only 1 tow being shaded white. Provided blocks are shaded by effort in this way, there is no need to lose data by excluding blocks with, for example, one tow from maps of fished areas. However, where blocks are not being shaded by effort, consideration could be given to implementing a threshold for the minimum number of tows for a block to be considered to have been fished, and included in the effort map.

• *Approach for General Designation of Fished Areas*

Mapping the distribution of fishing effort at any lower resolution than using actual trawl tracks or small (0.1 degree) squares has little scientific purpose. However, the use of low-resolution approaches to effort mapping may be useful for broad designation of fishing areas, such as for the display and publication of simplified effort distribution maps for general descriptive purposes.

Even for general illustrative purposes, effort maps should minimise the exaggeration of fished area, when compared with the actual fishing position data. The use of 20-minute blocks may be acceptable on large, heavily fished plateau areas. For example, the overall exaggeration using 20-minute blocks for the Challenger Plateau of only 7.8 times (Table 1). However, for widely scattered fishing positions across sparsely fished areas, or for small features such as the Louisville Ridge seamounts, the use of 20-minute blocks results in massive exaggeration of fished area: about 40-times for the Louisville Ridge, over 100-times for the South Tasman Rise, West Norfolk Ridge and Three Kings Ridge, and over 1000-times for the Mid-Pacific area. Effort maps using 20-minute blocks are highly misleading for these areas, even for general illustrative purposes (Weaver *et al*. 2011).

Given the substantial differences in seabed morphology (plateau *vs*. seamount) and fishing intensity in the different fishing areas, the most appropriate approach to low-resolution, general purpose effort mapping is probably to use bounding polygons drawn around groomed, error-corrected, valid depth tows, such as the examples shown in Figures 4, 8c and 9c. For example, fished area polygons are used by the North East Atlantic Fisheries Commission for general purpose mapping of fished areas on the Rockall and Hatton Banks (NEAFC 2009).

⇨ **For non-scientific, general illustrative purposes, bottom fishing effort could be mapped as bounding polygons drawn around aggregations of groomed, error-corrected, valid depth fishing position data.**

It should be noted, however, that of all of the effort mapping options described in this paper, the process of drawing effort polygons is the most subjective. There are many choices and arbitrary decisions to be made in deciding how to draw such polygons and the result cannot be considered to be of any real scientific or management value, other than for general purpose illustration of fishing areas.

The subjective nature of effort polygon mapping could be reduced by, for example, basing those polygons on an underlying distribution of 0.1 degree squares, with exaggeration being reduced by excluding 0.1 degree squares with fewer than some threshold number of tows. However, in that case, given that there should be no real confidentiality concerns around effort maps drawn at 0.1 degree block resolution, use of 0.1 degree blocks could be a better alternative for all published effort mapping purposes.

Finally, as pointed out in the **Introduction**, it must again be emphasized that none of the effort mapping approaches described in this paper should be interpreted as implying a particular management approach, or conferring any particular management status on the mapped areas. All management measures, particularly spatial management measures such as closed areas, need to be objectively designed, based on the results of quantitative risk assessments and objective spatial planning approaches.

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