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Title

REVISED IMPACT ASSESSMENT FRAMEWORK TO ESTIMATE THE CUMULATIVE FOOTPRINT AND IMPACT ON VME TAXA OF NEW ZEALAND BOTTOM LONGLINE FISHERIES IN THE ROSS SEA REGION

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ABSTRACT

In 2008-2009 New Zealand developed an impact assessment framework to estimate the likely impacts of bottom longline fishing on vulnerable benthic invertebrate taxa, termed Vulnerable Marine Ecosystems (VMEs), consistent with the requirements of Conservation Measure 22-06 (Bottom fishing in the Convention area). The impact assessment framework was subsequently endorsed within CCAMLR for routine application by Members submitting notifications of their intent to participate in new or exploratory fisheries using bottom fishing gear (SC-CAMLR XXVIII, paragraph 4.247 v–vii), and was applied to estimate the cumulative historical bottom fishing footprint of all fisheries in the CCAMLR area. The Scientific Committee called for additional work to address remaining uncertainties about the nature and extent of bottom fishing impacts on potential VMEs (SC-CAMLR-XXVIII paragraph 4.251). The purpose of this paper is: i) to estimate impacts on VMEs per unit effort using a simulation approach with explicit incorporation of uncertainties in the input assumptions; ii) to examine the application of the impact assessment framework at different spatial scales, and implications for the validity of the underlying structural assumptions of the assessment framework; and iii) to express impact estimates in a spatially explicit manner with reference to areas of distinct environmental characteristics arising from a benthic bioregionalisation of the Ross Sea region (Sharp et al. 2010). We conclude that bottom fishing impacts on VME taxa in the Ross Sea are low.

SUMMARY OF FINDINGS AS RELATED TO NOMINATED AGENDA ITEMS

Agenda Item	*Findings*
5, 6	We report on a revised impact assessment to estimate the cumulative footprint and impact of bottom longline fisheries on VME taxa in the New Zealand Ross Sea fishery, in a spatially explicit manner with reference to environmental categories from a bioregionalisation, and with explicit consideration of uncertainty using a simulation approach. We conclude that impacts to date are low.

INTRODUCTION

In 2007 CCAMLR adopted Conservation Measure 22-06 requiring member countries to assess and manage the risk that bottom fishing methods in the Convention Area may exert significant adverse impacts on certain benthic habitats, termed Vulnerable Marine Ecosystems (VMEs). New Zealand responded in 2008 with an impact assessment to assess and quantify the likely cumulative impact of all New Zealand fishing activities on potential VMEs within CCAMLR Subareas 88.1 and 88.2, which was submitted to CCAMLR as a part of New Zealand's notification for new and exploratory fisheries in 2008/09 (New Zealand 2008, Sharp et al. 2008) and updated in 2009 (Sharp 2009). A method description of the impact assessment framework was subsequently published separately (Sharp et al. 2009) for wider consideration within CCAMLR. In 2009 SC-CAMLR adopted aspects of this framework in defining requirements for Bottom Fishing Method Assessments by all nations notifying their intent to participate in new and exploratory fisheries using bottom fishing methods (SC-CAMLR XXVIII, paragraph 4.247v–vii).

In 2009 CCAMLR convened an expert VME workshop (SC-CAMLR-XXVIII/Annex 10) to compile relevant information regarding the vulnerability of benthic taxa and to evaluate and/or recommend potential approaches to manage the risk of significant adverse impacts on VMEs by human activities, in particular bottom fishing, in the CCAMLR area. VME workshop experts reviewed the updated impact assessment approach described in Sharp (2009) and concluded that despite considerable uncertainties the framework was useful for estimating "plausible upper and lower bounds" of impact to date, and "the framework was potentially very useful to compare the relative impacts of fishing operations using different gear or operating in different locations" (SC-CAMLR-XXVIII/Annex 10, paragraphs 4.3-4.5). Consistent with this advice, SC-CAMLR in 2009 utilised the framework to address the need identified in 2008 (CCAMLR-XXVII, paragraph 5.15) to estimate "the magnitude of the existing footprint of bottom fisheries" (SC-CAMLR XXVIII/Annex 5, paragraphs 10.19 and 10.25, and Table 19) and summarized cumulative footprints as a proportion of the total fishable area (SC-CAMLR XXVIII/Annex 5, paragraphs 10.10 to 10.12, Table 18). The VME workshop further recommended (SC-CAMLR XXVIII/Annex 10 paragraphs 4.4) that the framework be applied in combination with a simulation modelling approach, i.e. using actual effort distributions and the impact assessment framework to describe likely impacts, and using a simulation approach to characterise other aspects of the interaction between bottom fishing and VMEs which are unknown, e.g. the spatial distributions of VME taxa. These recommendations of the VME workshop were subsequently reviewed within CCAMLR and have been recommended as the basis for further intersessional work to address outstanding VME issues in 2009-2010 (SC-CAMLR-XXVIII paragraph 4.251 (xii)).

In June 2009 New Zealand hosted a 'Bioregionalisation and Spatial Ecosystem Processes of the Ross Sea Region' expert workshop. The workshop generated spatial classifications of the benthic and pelagic environments of the Ross Sea region and identified functionally important ecosystem processes or areas of importance for conservation, to inform spatial management planning (Sharp et al. 2010). The benthic bioregionalisation classified the benthic environment using a combination of six environmental variables known to influence the distribution and abundance of benthic invertebrate taxa, and defined 17 benthic bioregionalisation (presumed habitat) groups. One application of the benthic and pelagic bioregionalisations is to ensure the representativeness of spatial management (e.g. Marine Protected Area network design) with regards to the classified environment. The establishment of a representative network of MPAs in the CCAMLR area by 2012 has been endorsed by CCAMLR (SC-CAMLR-XXVIII, paragraph 3.25-3.28). With specific reference to VMEs, the consideration of representative spatial closures has been identified as one aspect of developing Conservation Management Plans (CMPs) to avoid or mitigate potential risks to VMEs by bottom fishing (SC-CAMLR XXVIII paragraph 4.250 and Figure 13). A framework for preparing and implementing CMPs for bottom fisheries has not yet been developed within CCAMLR; the development of such a framework has been identified as a priority for further work (SC-CAMLR XXVIII, paragraph 4.251 (xvii). In the absence of such a framework, another application of the benthic bioregionalisation is to provide a basis for the spatially explicit assessment of bottom fishing impacts on benthic habitats, with reference to spatial categories that are biologically meaningful.

The purpose of this paper is as follows:

i) to estimate impacts on VME per unit effort using a simulation approach with explicit incorporation of uncertainties in the input assumptions;
ii) to consider application of the impact assessment framework at different spatial scales, and implications for the validity of the underlying structural assumptions of the assessment framework; and
iii) to express impact estimates in a spatially explicit manner with reference to areas of distinct environmental characteristics arising from a benthic bioregionalisation of the Ross Sea region (Sharp et al. 2010).

1. METHODS

The impact assessment framework is described in Sharp et al. (2009). This paper considers and modifies the assumptions of the original New Zealand assessment (New Zealand 2008, Sharp et al. 2008) and updates (Sharp 2009) with reference to suggestions from CCAMLR working groups regarding the scale at which the impact assessment is applied and the treatment of uncertainty. It also applies the results in a spatially explicit manner at very fine scales and within categories defined by the benthic bioregionalisation described in Sharp et al. (2010).

1.1 VME taxa

The original New Zealand impact assessment (New Zealand 2008) adopted a pragmatic definition of VME as equivalent to ‘Vulnerable Biogenic Habitat’, i.e., benthic organisms that create three-dimensional structure and are likely to be vulnerable to bottom fishing disturbance, as a consequence of their physical structure and life history characteristics. Parker & Bowden (*in press*) operationalized this definition and generated a list of VME taxa aggregated to taxonomic levels that could be readily identified by both CCAMLR observers and vessel-based observers, to report VME taxa bycatch with the aid of a VME Taxa Identification Guide. Parker and Bowden’s (*in press*) criteria and list were expanded at the VME workshop to include 23 taxonomic groups (SC-CAMLR-XXVIII/Annex 10). The updated guide was subsequently endorsed and adopted for general use within CCAMLR (CCAMLR 2009).

1.2 VME glossary

Consistent with the advice of SC-CAMLR XXVIII (paragraph 4.251 (iii) and Annex 5, paragraph 10.40), to facilitate clarity in subsequent discussions pertaining to VMEs, New Zealand has produced a glossary of relevant definitions consistent with previous CCAMLR text and the outputs of the VME workshop. See Sharp & Parker (2010). This glossary is proposed for discussion and wider adoption within CCAMLR. In particular note that *fragility* has replaced New Zealand’s prior use of *vulnerability* to describe the physical susceptibility of a VME organism to damage at the moment of contact with the fishing gear. Hereafter *vulnerability* includes *fragility* but also incorporates other spatio-temporal and ecological factors affecting the nature and extent of impact and/or recovery from impact over time — e.g., growth rate, dispersal and colonisation, habitat patch size and configuration, and possible spatial associations between the habitat and the *threat* (i.e., fishing effort). Hence fragility is conceptually and mathematically straightforward (ranging 0 to 1 to represent proportional mortality within the footprint), whereas vulnerability requires the use of modelling approaches (as in Dunn et al. 2010) or simplifying assumptions (see below).

1.3 Benthic bioregionalisation

The initial New Zealand assessment summarized effort patterns at the extremes of large and small spatial scales but without reference to any environmentally meaningful spatial categories at intermediate scales. The benthic bioregionalisation described in Sharp et al. (2010) addresses this gap with 17 benthic environment classification groups defined with reference to environmental variables known to reflect or influence the spatial distribution of benthic invertebrate communities. These groups were defined by cluster analysis of spatially continuous environmental data layers with a spatial resolution of 4 km pixels; resulting polygons range in size from 25 km^2 to 3.97 million km^2 (Figure 1). These polygons are expected to reflect likely contrasts in benthic invertebrate communities, including VME taxa, such that communities occurring in a particular bioregionalisation group are likely to be similar to communities in the same group in other locations, and different from communities in different groups. The association of particular benthic communities with particular bioregions awaits further data collection and analysis. The polygons in Figure 1 are generally thought to be too large-scale to predict the distributions of particular VME habitats (i.e. habitats with high abundance or diversity of VME taxa). New evidence emerging from fishery bycatch and fishery-independent research suggest that actual VME habitats are in reality very difficult to define due to the fractal-like nature of their distribution, but that where spatial habitat affinities are evident they are at scales considerably smaller than the bioregions, on the order of kilometres to tens of kilometres (Parker et al. 2010a).

1.4 Impact assessment framework input assumptions

The actual behaviour of demersal longline fishing gear in contact with the sea floor — and thus the nature and spatial extent of associated impacts on benthic organisms including VME taxa — is subject to great uncertainty, in large part due to the inherent difficulty of observing longline deployments in deep water without potentially influencing the behaviour of the gear. Previous iterations of the impact assessment framework expressed this uncertainty by estimating impacts associated with different sets of input assumptions representing the high and low-impact extremes of plausible gear behaviour (SC CAMLR XXVIII/10, paragraph 4.3).

One strength of the assessment framework is that all operative assumptions are transparent, testable, and easily updated, and the consequences of altered assumptions for total impact arise logically from the framework. Consequently the impact estimates in the New Zealand assessment have changed with each iteration as new data become available. Scenario testing of plausible impact scenarios reveals that the most important input assumptions are those regarding the frequency and spatial extent of lateral longline movement in contact with the sea floor (i.e. affecting the size of the impact footprint). Assumptions about the fragility of VME taxa (i.e. % mortality within the footprint) are of secondary importance.

The consequences arising from each set of input assumptions are expressed by two numbers, the '*footprint index*' and the *'impact index'*, calculated as follows:

$$\textit{Footprint index} = A_o + f_1A_1 + f_2A_2,+ \ldots$$
$$\textit{Impact index} = A_oF_o + f_1 A_1F_1 + f_2 A_2F_2 + \ldots$$

where: A_o = area of the standard footprint (km^2 per km of line);

F_o = fragility (proportion of VME taxa lethally impacted) within the standard impact footprint (range 0-1);

f_1 = frequency (0-1) of non-standard scenario 1;

A_1 = area of the footprint associated with scenario 1;

F_1 = fragility (0-1) of VME taxa within the scenario 1 footprint;

... etc,.

Units are in km^2 per km of line. The *footprint index* and *impact index* are then multiplied by an effort density (km of line per km^2) for any area over which effort has been summarized to estimate the proportion of the area covered by a fishing footprint, and the proportion of the relevant VME taxa in the area lethally impacted by fishing gear, respectively. Note that setting fragility = 1 for all scenario footprints (i.e., 100% mortality within all footprints) implies an *impact index* identical to the *footprint index*. Note also that actual fragility ratings, and hence impact indices, are different for different VME taxa, but in practice the *impact index* is only shown for the most vulnerable taxa (e.g., gorgonians in Sharp et al. 2009).

Note that the original New Zealand assessment (New Zealand 2008) examined impacts separately for different portions of the longline gear (anchors and chains vs. main line) and also for nonstandard gear deployment scenarios (e.g. downline snagged and anchors dragged by moving ice, line breakage and loss), and expressed associated impacts as scenarios 1–4. However the influence of scenarios 1–4 on assessment outputs is inconsequential (<0.001%) relative to scenario 5 (lateral line movement during line retrieval) for all plausible non-zero values of f_5. For clarity and to streamline simulations (below) input assumptions associated with scenarios 1–4 are not shown here or retained in subsequent calculations for which $f_5 > 0$.

Values reflecting input assumptions for the standard set and for scenario 5 (lateral line movement) utilized in previous iterations of the assessment are shown in Table 1. Evidence supporting the values utilized in each of these assumption sets is reviewed below.

1.4.1 Assumption set A (New Zealand 2008)

The original New Zealand assessment (New Zealand 2008) held that impacts from bottom longlines on potential VMEs were contained within a spatial footprint 1 m wide, and that bottom longlines did not move laterally in contact with the sea floor. The footprint width was defined as the maximum spatial envelope within which hooks on 0.4 m snoods could extend away from the main line when resting on the sea floor. The assumption of no lateral line movement was made on the basis of:

i) Trigonometric considerations, i.e. even a major lateral hauling offset by the retrieving vessel results in only a minor deviation from vertical in the force felt by the line at the bottom, due to the extreme depths of a typical fishing set (offset angle = [90 - arctangent(offset/depth)])

ii) observations from fishers and fishery observers that lines are frequently broken or lost if hauled from a position other than directly vertical, or if they are hauled under extreme tension. Fishers maintain that it is generally not possible to drag an entire longline (~ 7 km) along the seabed without breaking it.

Note that footprint and impact metrics under Assumption set A in Table 1 also incorporate non-standard scenarios 1-4 (not shown). See New Zealand (2008).

1.4.2 Assumption set B (Welsford & Kirkpatrick 2008)

In 2008 Welsford & Kirkpatrick (2008) summarized new information using tethered cameras attached to bottom longlines, in which 1 of 5 successful camera deployments revealed lateral line movement during hauling. During the observed lateral movement the line was not constantly in contact with the sea floor but was low enough to contact benthic organisms over a spatial footprint approximately 24 m wide. The Welsford & Kirkpatrick (2008) analysis was not explicit with regards to various line deployment variables likely to influence the frequency and width of lateral movement (e.g. depth) and did not explicitly address the likely mechanisms by which lateral movement occurred (i.e. interacting forces including tension, drag, friction in contact with the sea floor, lateral currents acting on the camera and the line during deployment, lateral currents acting on the suspended portion of the line during hauling). The video analysis also revealed intermittent parallel line movement as the line came under tension prior to lifting off from the sea floor, with slight sideways creep, sufficient to leave a visible track or groove in the soft sediment. Hereafter the ‘standard footprint width’ refers to the width of this track within which the line is dragged in a parallel direction in constant contact with the sea floor as it comes under tension; the ‘lateral movement width’ refers to the width over which the line sweeps sideways immediately prior to lift-off, not necessarily in contact with the sediment but sufficiently low to contact upright benthic taxa.

The 2009 updated assessment (Sharp 2009) included assumptions consistent with the Welsford & Kirkpatrick (2008) observation, but noted the many remaining uncertainties and urged systematic investigation of the various factors potentially affecting line movement. These assumptions are retained here as Assumption set B in Table 1, including lateral line movement frequency = 0.2 (1 of 5 camera deployments) and fragility = 0.5 for VME taxa within the lateral movement footprint.

1.4.3 Assumption set C: CCAMLR 2009 upper bound footprint

In 2008 the single observation of lateral line movement in Welsford & Kirkpatrick (2008) was used by CCAMLR as a basis for the plausible upper bound of total footprint area associated with bottom longlines as a proportion of the fishable area. The New Zealand assessment was adopted as a plausible lower bound; hence in that report and subsequently within CCAMLR the cumulative spatial footprint of bottom longlines has been reported assuming footprint width of 1–25 m (SC-CAMLR XXVIII/Annex 5, paragraphs 10.10 to 10.12, Table 18). The reality is almost certainly somewhere in between; note for example that 24 m lateral movement with a frequency of 0.2 (i.e. 1 of 5 deployments) implies an average footprint width of approximately 6 m (i.e., *footprint index* = 0.0058 in Table 1). Furthermore assigning any fragility value less than 1 implies that impact will be lower than the cumulative footprint. Although unlikely to be realistic, Assumption set C is reproduced here to illustrate the consequences of adopting these upper-bound assumptions.

1.5 Fishing effort summary and spatial scale of impact estimation

Sharp et al (2009) summarized cumulative fishing effort (1997–2008) and corresponding impact estimates at the scale of the entire Ross Sea (all fishable depths in Subareas 88.1 and 88.2) and also within the most heavily fished 1^o x 1^o pixel. Subsequent response within CCAMLR (WG-SAM-09 paragraph 4.9) interpreted these choices as an indication that the assessment assumed that VMEs are evenly or randomly distributed over the entire area. In reality the assessment makes no assertion as to the distribution (or even presence) of VME taxa within the smallest assessed area (pixel) and can be applied at any spatial scale for which spatially resolved fishing effort data are available.

In this iteration of the New Zealand impact assessment we summarize effort distributions within pixels measuring 0.05^o latitude by 0.177^o longitude, i.e. 5.6 km in the N-S dimension and approximately 4.4-9.2 km in the E-W dimension depending on latitude. Because the lines themselves average 7.17 km in length, this pixel size summarizes effort distributions at a scale comparable to or finer than the length of impact in a typical effort deployment. The width of the impact itself is of course significantly narrower (on the scale of metres to tens of metres) and skilled fishers can presumably target their line deployments with a degree of accuracy on the scale of 100s of metres, but the much greater length of the lines implies that fishers cannot exclusively target features at scales of 1–3 kilometres without also impacting adjacent habitats up to 3 km distant. For this reason effort distributions within pixels of the chosen size are not expected to reveal significant finer-scale structure. The VME workshop (SC-CAMLR XXVIII/Annex 10 paragraph 4.3) recognized that at spatial scales where effort distributions are not clustered in space, there can be no systematic spatial association between effort patterns and VME taxa distributions; there is then no practical need to summarize effort distributions at smaller scales to make valid the structural assumptions of the impact assessment.

To test the assumption that effort distributions within the summarized pixels are not clustered, we examined the actual distribution of all historical longline deployments in the most heavily fished area, at a range of spatial scales, with pixel sizes from 100 kilometres down to 100 metres (Figure 2). There is considerable spatial structure apparent at the 100 kilometres scale (a), indicating that summarizing effort at this scale potentially invalidates the primary structural assumption of the impact assessment framework. At scales less than 10 km (b) but greater than 1 kilometre (c) the effort distribution rapidly becomes sufficiently disordered that we can reasonably assume no systematic association between VME taxa and effort distributions at that scale, regardless of the actual distribution of VMEs. We conclude that the use of pixels measuring 0.05^o latitude by 0.177^o longitude to summarize effort distributions is conservative and appropriate.

2. RESULTS

2.1 Effort distributions

Cumulative New Zealand fishing effort (1997–2009) within the 17 benthic bioregionalisation groups is shown in Table 2. To facilitate standardized treatment within the impact assessment framework, all effort is expressed as an effort density, in kilometres of line per km^2, with the area in the denominator referring to the total area of the benthic bioregionalisation group in Figure 1.

Examination of Table 2 reveals patterns of effort concentration relative to presumed benthic habitat groups. Group 1, which includes deeper portions of the continental shelf and shallower portions of the Ross Sea slope, has the highest amount of absolute effort (7 937 km) but a moderate effort density (0.027 km line / km^2) due to its relatively large area. Fishing effort is more concentrated on the deeper portions of the slope, i.e. bioregionalisation groups 4 and 6, with average effort densities of 0.0689 and 0.0694 km line / km^2 in these two groups, respectively. Effort densities in bioregionalisation groups off the shelf to the north are relatively low. Note however that localized areas of higher effort concentration do occur on bathymetric features in the northern area, and that more than 3300 km of historical longline effort appears in Group 9 (the deepest habitat group), including effort apparently at depths greater than the known maximum depth at which fishing is possible. This suggests that the poor resolution of the underlying GEBCO2004 bathymetric data layer utilised by the bioregionalisation workshop may limit the accuracy of the benthic classification on small topographic features in the northern area. The extent to which local conditions on these features influence VME distributions is unknown. Use of improved bathymetric data at higher spatial resolution (as in Parker et al. 2010b) is likely to improve the utility of bioregionalisation outputs in these areas.

To examine the plausible upper bound of potential impacts at a highly localised scale irrespective of bioregions, effort densities are also reported for the two most heavily fished pixels (in the Ross Sea region. Pixel A is located on the Ross Sea slope; pixel B is located in the northern area. These two pixels contained 336.7 km and 334.5 km of cumulative New Zealand longline effort, respectively, or 9.8 and 7.1 km of line per km^2. Pixel A is depicted relative to actual line positions Figure 2b. Subsequent impact estimates for these two pixels represent the plausible upper bound of potential impacts on VME taxa at a highly localized scale.

2.2 Impact index simulations incorporating uncertainty

In response to SC-CAMLR-XXVIII/5, paragraphs 4.9 and 4.16, and to more realistically express the consequences of combining multiple input assumptions each subject to uncertainty, this iteration of the impact assessment framework abandons the use of distinct assumption sets as in Table 1, and instead expresses each input assumption as a prior distribution and uses a simulation approach to generate corresponding posterior distributions of impact estimates. The shapes of the prior distributions for each input were selected to be consistent with all available data as summarized in the assumption sets A-B, above. Two simulations were performed, one utilising normal distributions (Figure 3a) and one utilising a combination of uniform distributions for those inputs bounded 0-1, and lognormal distributions for previously unbounded inputs (Figure 3b).

Posterior distributions for both model outputs, i.e. the *footprint index* and the *impact index*, are shown in Figure 4 and described in Table 3. The mean simulated values are of comparable magnitude to the indices derived from the most plausible assumption sets described in Table 1.

2.3 Footprint and impact estimates

Actual footprint and impact estimates in particular locations are obtained by multiplying fishing effort densities for any area over which effort has been summarized by the *footprint index* and *impact index* values in Table 3 (* 100%). The answers represent the % of VME taxa within that area either contained within the total fishing footprint, or lethally impacted by bottom fishing gear, respectively. Footprint and impact calculations were performed for the 17 benthic bioregionalistion groups and for the two most heavily impacted pixels described in Table 2. The resulting footprint and impact estimates are shown in Table 4.

Simulations using normally and lognormally distributed input variables yielded similar outputs; subsequent discussions refer to outputs from the lognormal-input simulations. Under these assumptions the most heavily impacted bioregionalisation groups (Groups 4 and 6) have experienced approximately 0.013% lethal impact of the most vulnerable VME taxa, with an upper bound (95th quantile) estimate of 0.03% lethal impact. Within the most heavily impacted pixel the lognormal input model yields lethal impact estimates of 1.8% (mean) or 4.2% (95th quantile).

2.4 Spatially explicit impact estimates

To examine impacts in a spatially explicit and biologically meaningful way at a finer scale than whole bioregion groups, impact densities were assigned to every polygon of the benthic bioregionalisation (see Figure 5). These effort densities can then be translated directly into footprint and impact estimates within each polygon by multiplying the effort density depicted in Figure 5 by the appropriate index in Table 3.

Because the impact assessment framework can be applied at any spatial scale, it is possible to translate any available map of fishing effort distributions into a corresponding impact estimate map at the same scale. The 0.05^{o} latitude by 0.177^{o} longitude pixels utilised in the impact analysis are not reproduced here in spatially explicit format, to protect commercially sensitive information. Of 117 083 pixels in the Ross Sea region, 1737 included non-zero values for New Zealand fishing effort, and 115 296 (98.4%) were unfished. The mean New Zealand effort density in these fished pixels was 0.53 km line / km^2. Applying the lognormal-input *impact index* estimates in Table 3 implies a mean impact within New Zealand fished pixels of 0.099% (mean estimate) or 0.23%, (95^{th} quantile upper bound estimate).

A summary histogram of effort densities associated with the New Zealand fished pixels is shown in Figure 6. Even within fished areas it is clear that fishing effort is highly concentrated in preferred locations; i.e. 94% of the fished pixels had effort densities less than 1.5 km of line / km^2, and only 13 individual pixels (0.7%) had effort densities in excess of 4 km of line per km^2. Applying the mean lognormal-input *impact index* estimate (1.84×10^{-3}) to the effort density distribution in Figure 6 implies that VME taxa in 94% of historically fished locations have experienced lethal impacts less than 0.28%, and in only 0.7% of fished locations have VME taxa experienced impacts of greater than 0.74%, to a maximum lethal impact of 1.8%. Applying the 95^{th} quantile upper bound *impact index* estimate of 4.31×10^{-3} increases the corresponding lethal impact estimates by a factor of 2.3.

3. DISCUSSION

Total cumulative impacts by New Zealand bottom fishing vessels in the Ross Sea fishery on benthic organisms are low, subject to the assumptions of the impact assessment. Distributions of input assumptions as represented in Figure 3 are consistent with the available evidence but remain subject to uncertainty. Further investigation of the behaviour of bottom longline fishing gear in contact with the sea floor, including systematic analysis of other variables likely to affect line movement (e.g. depth, current speed, benthic substrate) remains a high priority. Other simplifying assumptions of the original assessment were chosen to be conservative (impact-maximising); i.e. the assessment framework assumes that all impacts are permanent (no recovery of VME taxa) and that multiple impacts in the same pixel are non-overlapping (i.e. to maximise the size of the footprint).

3.1 Spatial associations between fishing effort and VME taxa

There is one remaining structural assumption of the impact assessment framework that requires discussion. The assessment methodology assumes no systematic relationship between the spatial distributions of fishing effort and of VME taxa within spatial scales at which effort and corresponding impacts are summarized (i.e. ‘within the pixel’). At large spatial scales (i.e. 100s of kilometres to 1000s of kilometres) this assumption is almost certainly false; spatial distributions of fish, of fishing, and of benthic invertebrate abundance may be influenced by a similar suite of environmental variables (e.g., depth, benthic topography, water temperature) and are thus potentially correlated (positively or negatively). Where the relationship is positive the assessment framework will underestimate impacts; where the relationship is negative it will overestimate impacts. However at the smallest scales (10s of ms to 100s of ms) the assumption of no correlation is inescapably true. This is because even if targeted fish and VME taxa were perfectly correlated, the ability of fishers to exclusively target fine-scale features (without also impacting adjacent features), in depths of 800–2000 m, using lines averaging 7 km in length, is limited. In 2009 the VME workshop recognized that if impacts are estimated at a sufficiently fine scale that effort distributions appear random or uniform within the smallest summarized area (i.e., pixel size) then the assumption of no correlation between VMEs and fishing effort is valid at that scale regardless of actual VME distributions (SC-CAMLR XXVIII/10 paragraph 4.3).

Examination of actual effort distributions within the most targeted areas (Figure 2, above) strongly supports the assumption of no systematic relationship at the scale of 0.05^{o} latitude by 0.177^{o} longitude pixels. To further search for evidence of a spatial relationship between VME taxa and fishing effort at intermediate scales, Parker and Mormede (2009) compared toothfish catch rates with VME taxa bycatch rates on New Zealand longlines in the Ross Sea, and reported no apparent correlation at the scale of an individual longline (i.e., approximately 7 km). In 2009 CCAMLR WG-FSA recommended that the same analysis be repeated at a finer scale by examining catch patterns at the scale of longline segments (approx 1.2 km) rather than entire sets, and to search for taxon-specific specific relationships. The results of that updated analysis reinforce our conclusion that there is no meaningful correlation between fishing effort and VME taxa occurrence at the scale of 1 kms to 10s of kms (Parker and Smith 2010). It appears then that the structural assumptions of the impact assessment framework are valid, and that the plausible ranges of footprint and impact estimates reported in Table 4 are likely to be reasonable. We conclude that that the total cumulative impact on VMEs of New Zealand effort in the Ross Sea fishery is very low.

We also note also that the impact assessment framework can be re-run with alternate input assumptions and alternate prior distributions to generate revised mean and upper bound footprint and impact indices as required, and with the aid of GIS software, these can be applied at any spatial scale and in any location within the Ross Sea region to generate spatially explicit footprint and impact estimates for any set of impact assumptions. New Zealand encourages further research to investigate the nature and extent of impacts on VME taxa by bottom fishing methods, to inform modifications of the impact assessment assumptions supported by evidence.

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Table 1: Input assumptions consistent with previous and newly available information indicative of the nature and extent of impacts by bottom longlines on VME taxa, and associated *footprint index* and *impact index* values. Index units are in km^2 per km of line.

Assumption set	standard footprint width (m*)	F_o: standard footprint fragility	f_5: lateral movement frequency	lateral movement width (m*)	F_5: lateral movement fragility	footprint index	impact index
A: New Zealand 2008	1	0.2	0	N/A	N/A	1.1×10^{-3}	0.25×10^{-3}
B: Welsford and Kirkpatrick 2008	1	0.2	0.2	24	0.5	5.8×10^{-3}	2.6×10^{-3}
C: CCAMLR 2009 upper bound footprint	1	1	1	24	1*	25.1×10^{-3}	N/A

* footprint widths are expressed here in m for ease of interpretation; multiply by 10^{-3} km/m to calculate footprint area in km^2

Table 2. Total cumulative (1997 – 2009) New Zealand fishing effort within 17 benthic bioregions, as described in Sharp et al. (2010), and in the two most heavily fished pixels (0.05^{o} lat x 0.177^{o} long) in the Ross Sea region.

Benthic Bioregionalisation Group	Area (km^2)	Cumulative NZ fishing effort (km of line)	Effort density (km of line per km^2)
1	293567	7937	0.0270
2	187589	3726	0.0199
3	129379	628	0.0049
4	97677	6734	**0.0689**
5	91982	132	0.0014
6	82396	5724	**0.0694**
7	51732	17	0.0003
8	14023	0	0
9	3971285	3372	0.0008
10	209034	1744	0.0083
11	51777	1358	0.0262
12	1803	0	0
13	990	20	0.0198
14	1402	10	0.0068
15	100	0	0
16	58833	433	0.0073
17	38193	57	0.0015
highest-impact pixel A	34.2	337	**9.836**
highest-impact pixel B	47	334	7.114

Table 3. Summary statistics for posterior distributions in Figure 4 predicting *footprint index* and *impact index* values.

	footprint index			*impact index*		
	mean	median	95% quantile	mean	median	95% quantile
Normal input distributions (Figure 3a)	3.58×10^{-3}	3.36×10^{-3}	6.47×10^{-3}	2.31×10^{-3}	2.13×10^{-3}	4.43×10^{-3}
Lognormal and uniform input distributions (Figure 3b)	2.92×10^{-3}	2.55×10^{-3}	6.15×10^{-3}	1.84×10^{-3}	1.53×10^{-3}	4.31×10^{-3}

Table 4. Estimated cumulative footprints and impacts associated with all New Zealand effort in the history of the Ross Sea fishery (Areas 88.1 and 88.2, 1997-2009), within 17 benthic bioregionalisation groups (from Sharp et al. 2010) and at the scale of the two most heavily impacted pixels (0.05° lat x 0.177° long). Mean and upper bound confidence interval (95th quantile) values are shown. Estimates are obtained by multiplying fishing effort from Table 2 by the *footprint index* and *impact index* posterior distribution statistics in Table 3 (* 100%). Numbers referred directly in the text are bolded.

		SIMULATION 1: NORMAL INPUT DISTRIBUTIONS				SIMULATION 2: LOGNORMAL INPUT DISTRIBUTIONS			
		% area in footprint		% lethal impact		% area in footprint		% lethal impact	
Bioregion Group	effort density (km of line /km2)	mean	95th quantile	mean	95th quantile	mean	95th quantile	mean	95th quantile
1	0.0270	0.0097	0.0175	0.0058	0.0120	0.0079	0.0166	0.0050	0.0117
2	0.0199	0.0071	0.0129	0.0042	0.0088	0.0058	0.0122	0.0037	0.0086
3	0.0049	0.0017	0.0031	0.0010	0.0021	0.0014	0.0030	0.0009	0.0021
4	**0.0689**	0.0247	0.0446	0.0147	0.0305	**0.0201**	**0.0424**	**0.0127**	**0.0297**
5	0.0014	0.0005	0.0009	0.0003	0.0006	0.0004	0.0009	0.0003	0.0006
6	**0.06947**	0.0249	0.0449	0.0148	0.0308	**0.0203**	**0.0427**	**0.0128**	**0.0299**
7	0.0003	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001
8	0	0	0	0	0	0	0	0	0
9	0.0008	0.0003	0.0005	0.0002	0.0004	0.0002	0.0005	0.0002	0.0004
10	0.0083	0.0030	0.0054	0.0018	0.0037	0.0024	0.0051	0.0015	0.0036
11	0.0262	0.0094	0.0170	0.0056	0.0116	0.0077	0.0161	0.0048	0.0113
12	0	0	0	0	0	0	0	0	0
13	0.0198	0.0071	0.0128	0.0042	0.0088	0.0058	0.0122	0.0037	0.0086
14	0.0068	0.0024	0.0044	0.0015	0.0030	0.0020	0.0042	0.0013	0.0029
15	0	0	0	0	0	0	0	0	0
16	0.0073	0.0026	0.0048	0.0016	0.0033	0.0022	0.0045	0.0014	0.0032
17	0.0015	0.0005	0.0010	0.0003	0.0007	0.0004	0.0009	0.0003	0.0006
highest Pixel A	**9.836_**	3.5213	6.3639	2.0951	4.3574	**2.8721**	**6.0492**	**1.8098**	**4.2393**
highest Pixel B	7.114_	2.5471	4.6032	1.5154	3.1518	2.0775	4.3756	1.3091	3.0665
Mean fished effort	**0.5363**	0.192	0.347	0.1142	0.2376	**0.1566**	**0.3298**	**0.0987**	**0.2311**

Figure 1. The benthic bioregionalisation of the Ross Sea region, from Sharp et al. (2010).

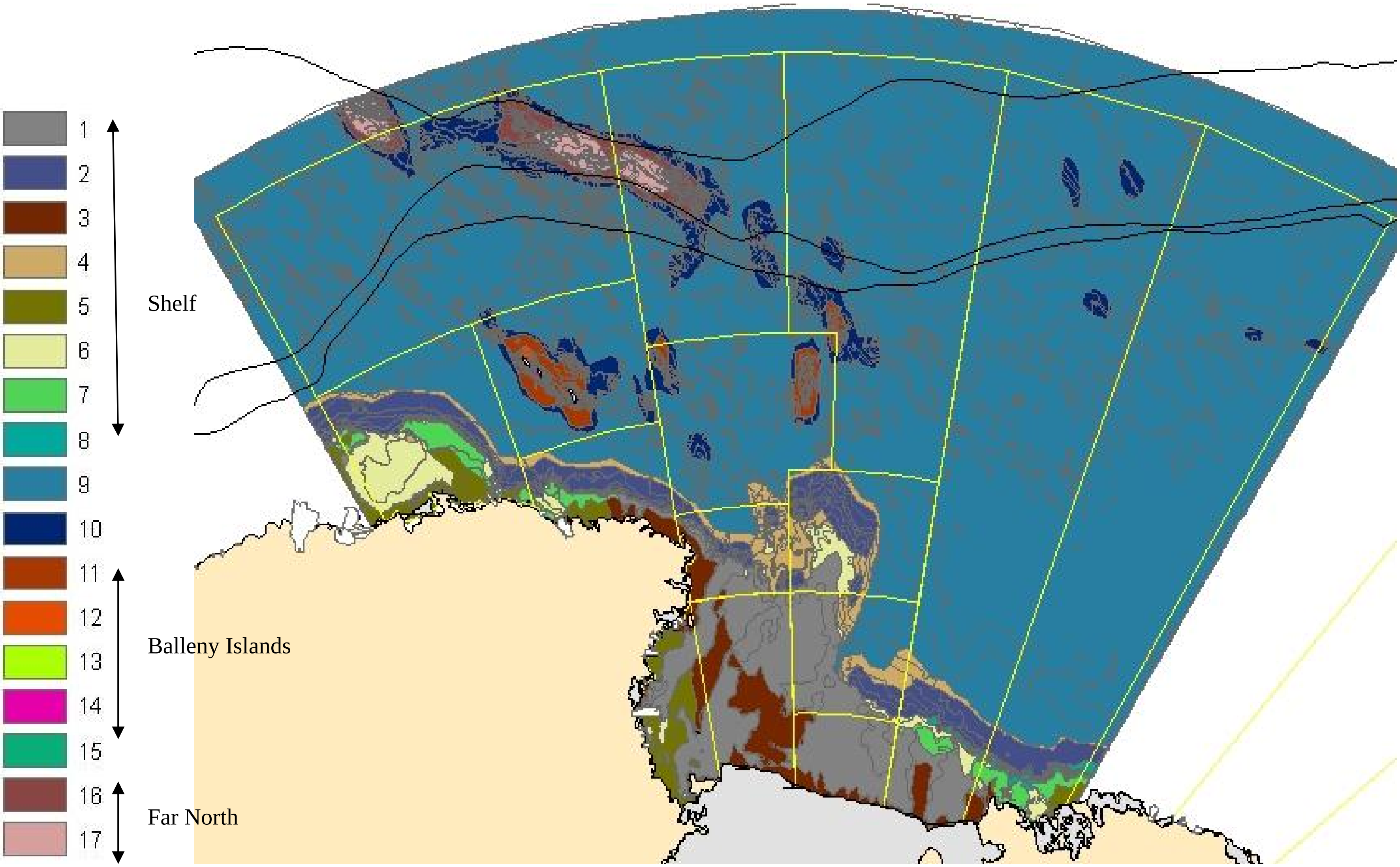
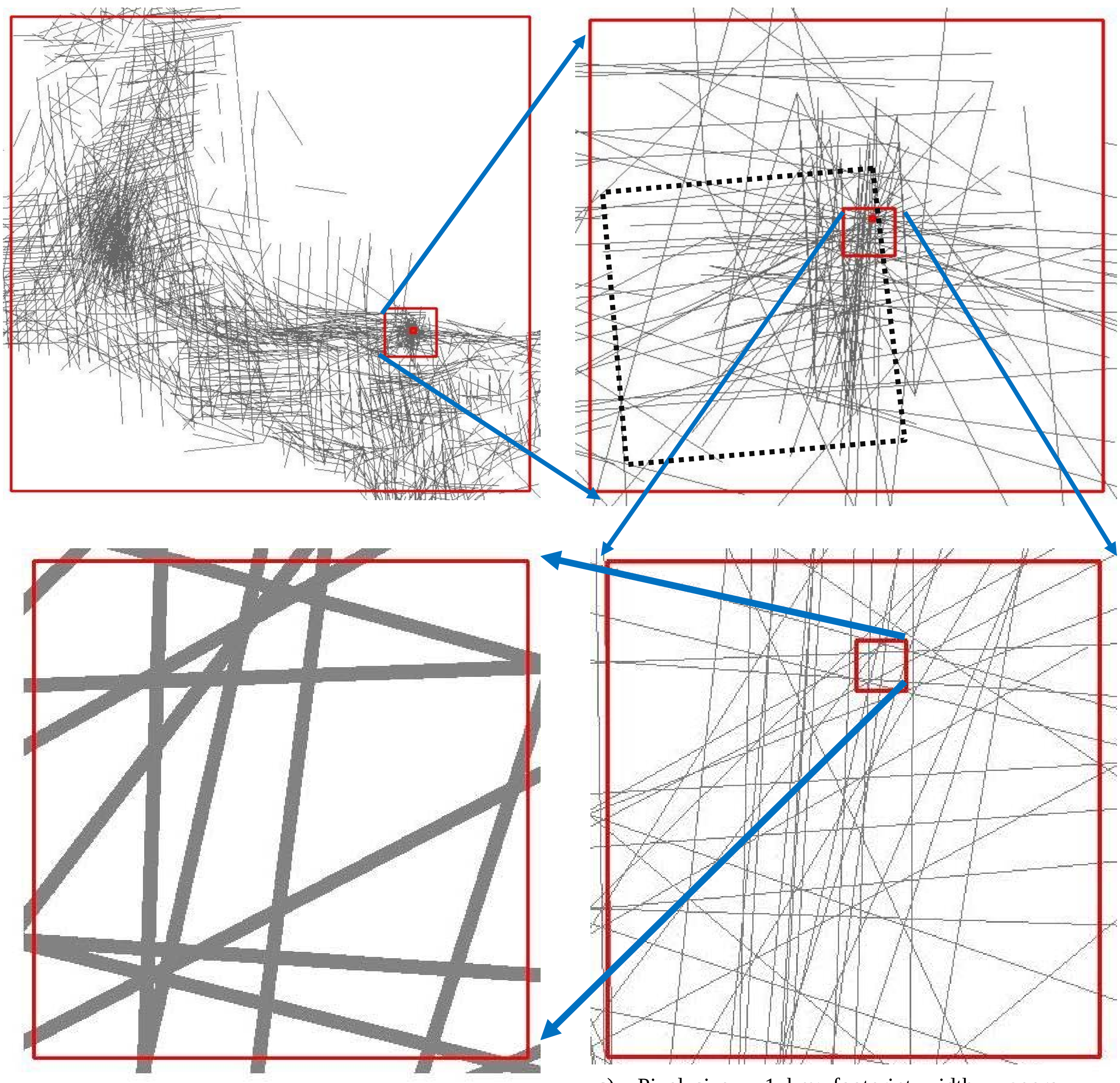


Figure 2. Cumulative historical spatial footprints of all longline deployments (all countries, 1997-2009) in the most heavily fished pixel of the Ross Sea fishery, at a range of spatial scales, with pixel sizes from 100 km down to 100 m. Note that considerable internal spatial structure is evident at the scale of the 100 km pixel, whereas effort distributions begin to appear random at scales smaller than 10 km pixels. The width of the spatial footprints in a) and b) are not drawn to scale because plausible footprint widths would be invisible at this scale. Footprints in c) and d) are depicted as approximately 3.5 m wide (i.e. *footprint index* = 0.0035), consistent with mean values in the most plausible assessment outputs (Table 3, below).

a) Pixel size = 100 km; footprints not drawn to scale

b) Pixel size = 10 km; footprints not drawn to scale. The dashed box indicates the extent of the most heavily fished 0.05o latitude by 0.177o longitude pixel at within which effort is summarized (pixel A in Table 2).



d) Pixel size = 100 m; footprint width = approx. 3.5 m

c) Pixel size = 1 km; footprint width = approx. 3.5 m

Figure 3a. Prior distributions for model inputs used in the impact simulation, assuming normal distributions.

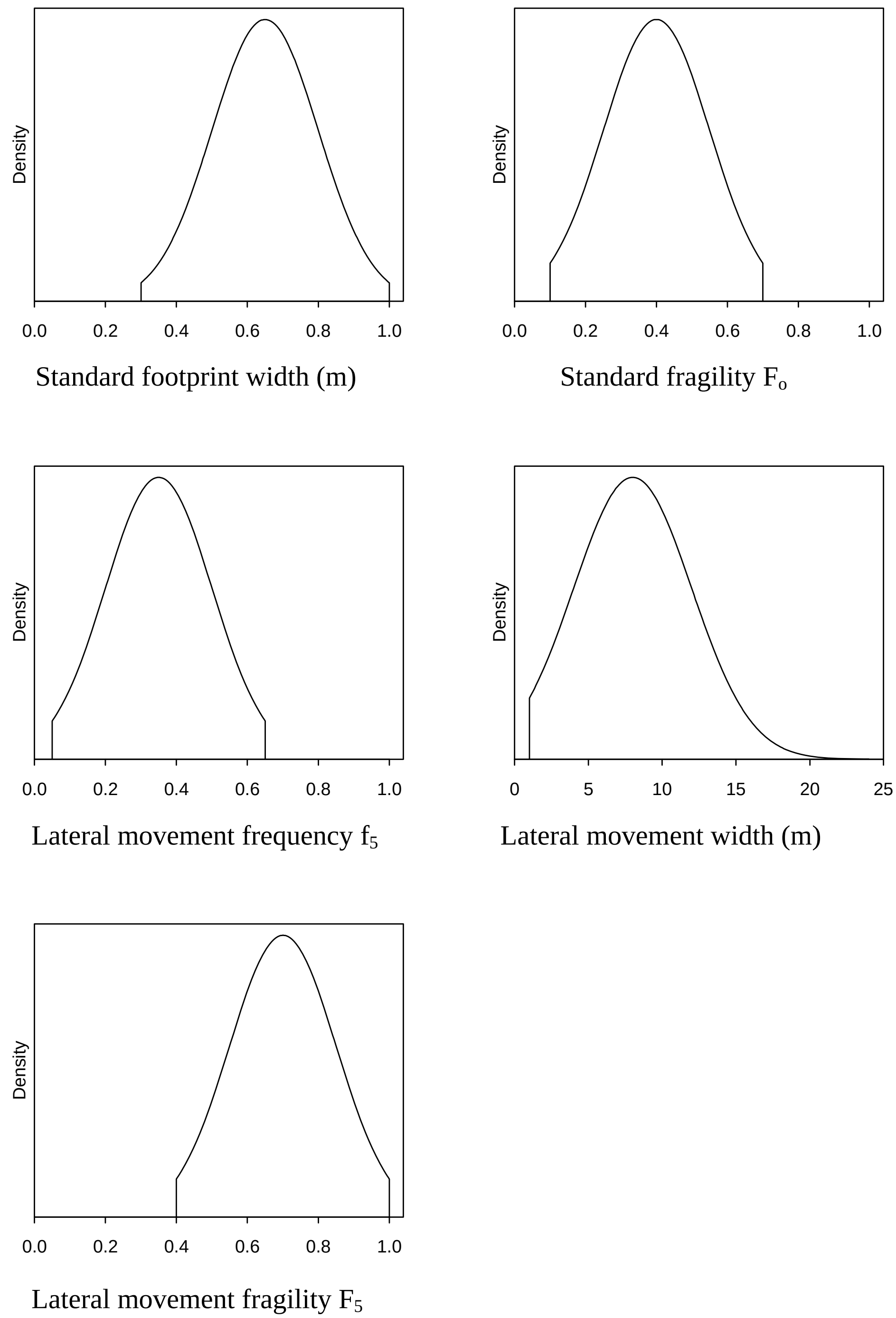


Figure 3b. Prior distributions for model inputs used in the impact simulation, assuming uniform distributions (where bounded 0-1) or lognormal distributions (where previously unbounded).

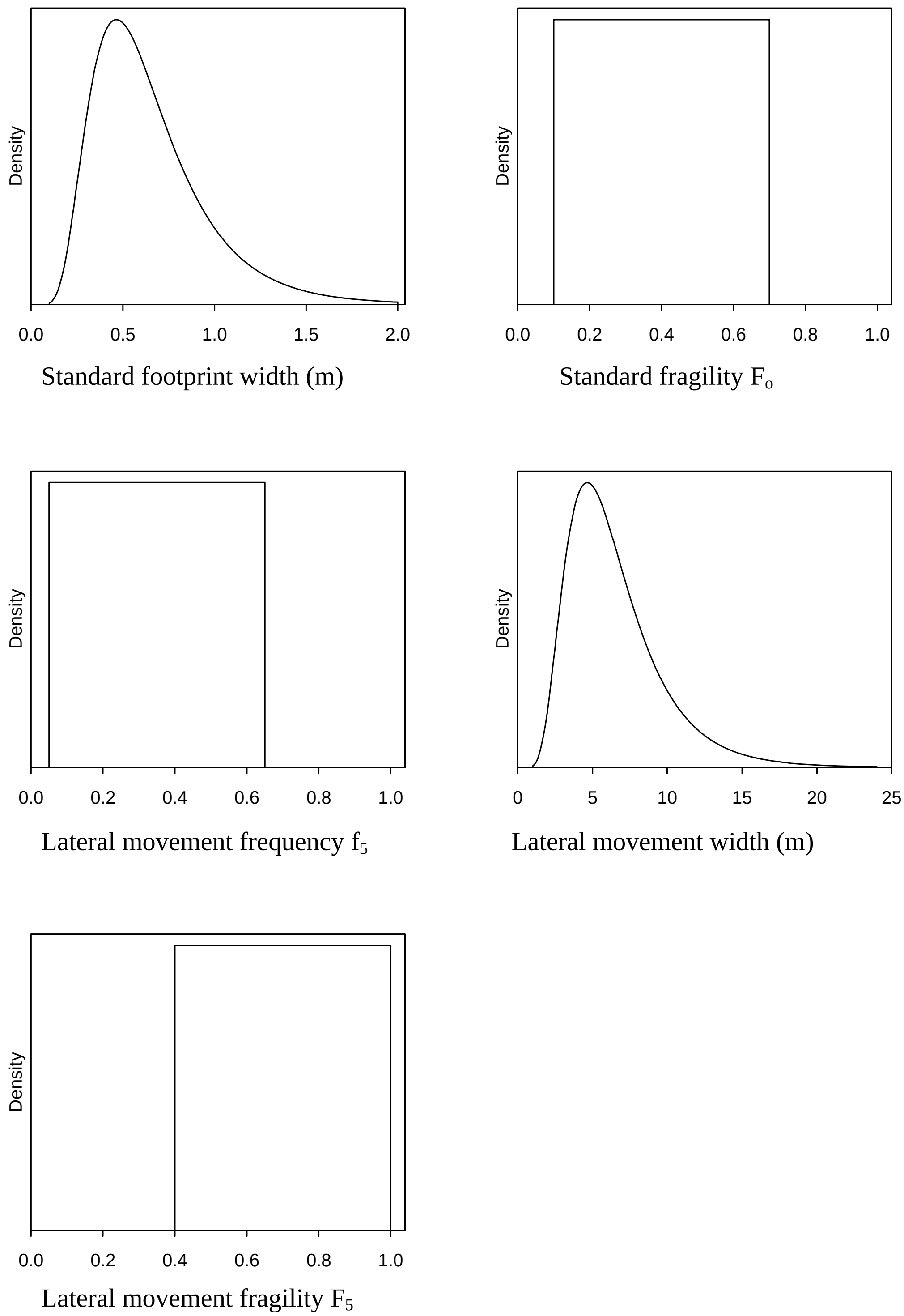
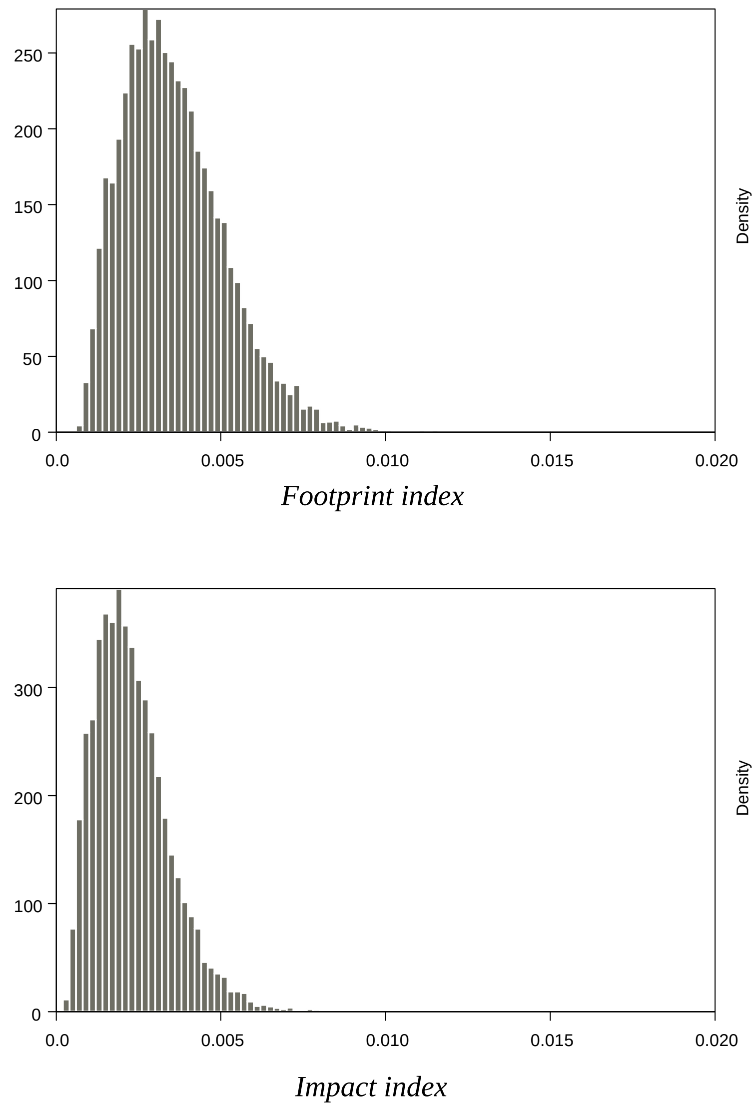


Figure 4. Posterior distributions of the *footprint index* and *impact index* predicted from the impact simulation.

a) Posterior distributions assuming normally distributed inputs as in Figure 3a.



b) Posterior distributions assuming uniform and lognormally distributed inputs as in Figure 3b.

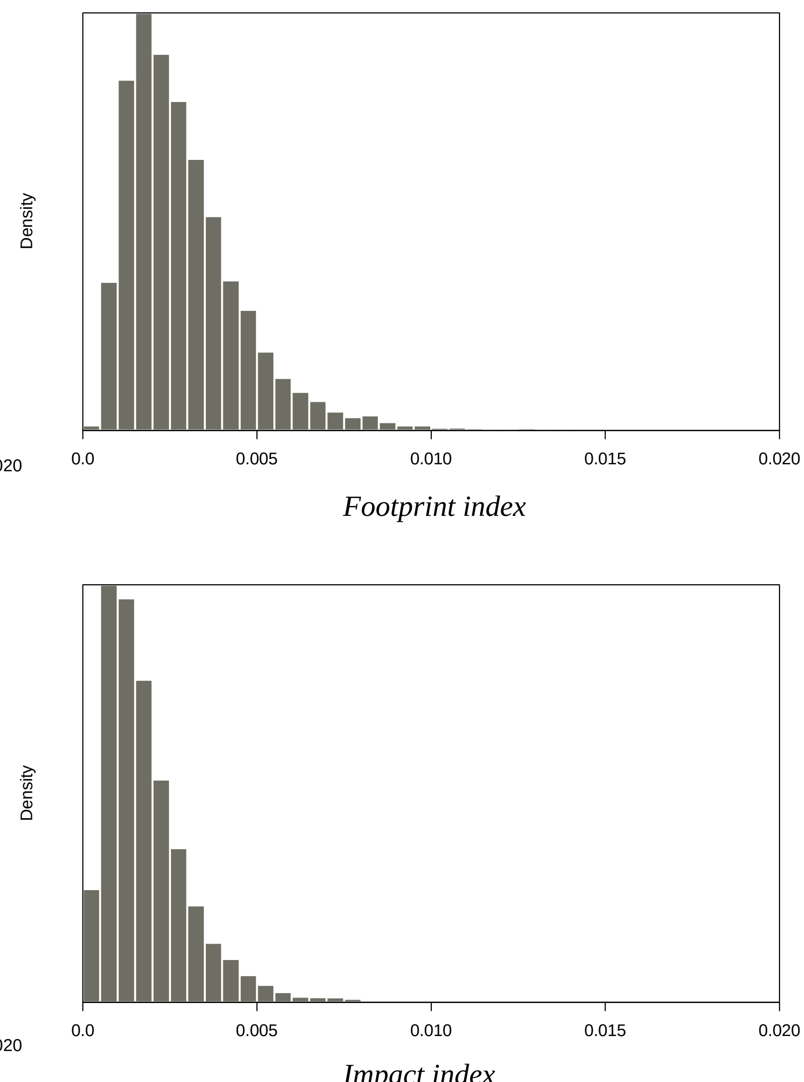


Figure 5. Effort density within bioregion polygons. Highest effort densities (3-5 km of line / km^2) are associated with polygons too small to be seen at this scale. The effort density associated with the polygon on Mawson Bank (indicated by the arrow) is 2.5 km of line / km^2.

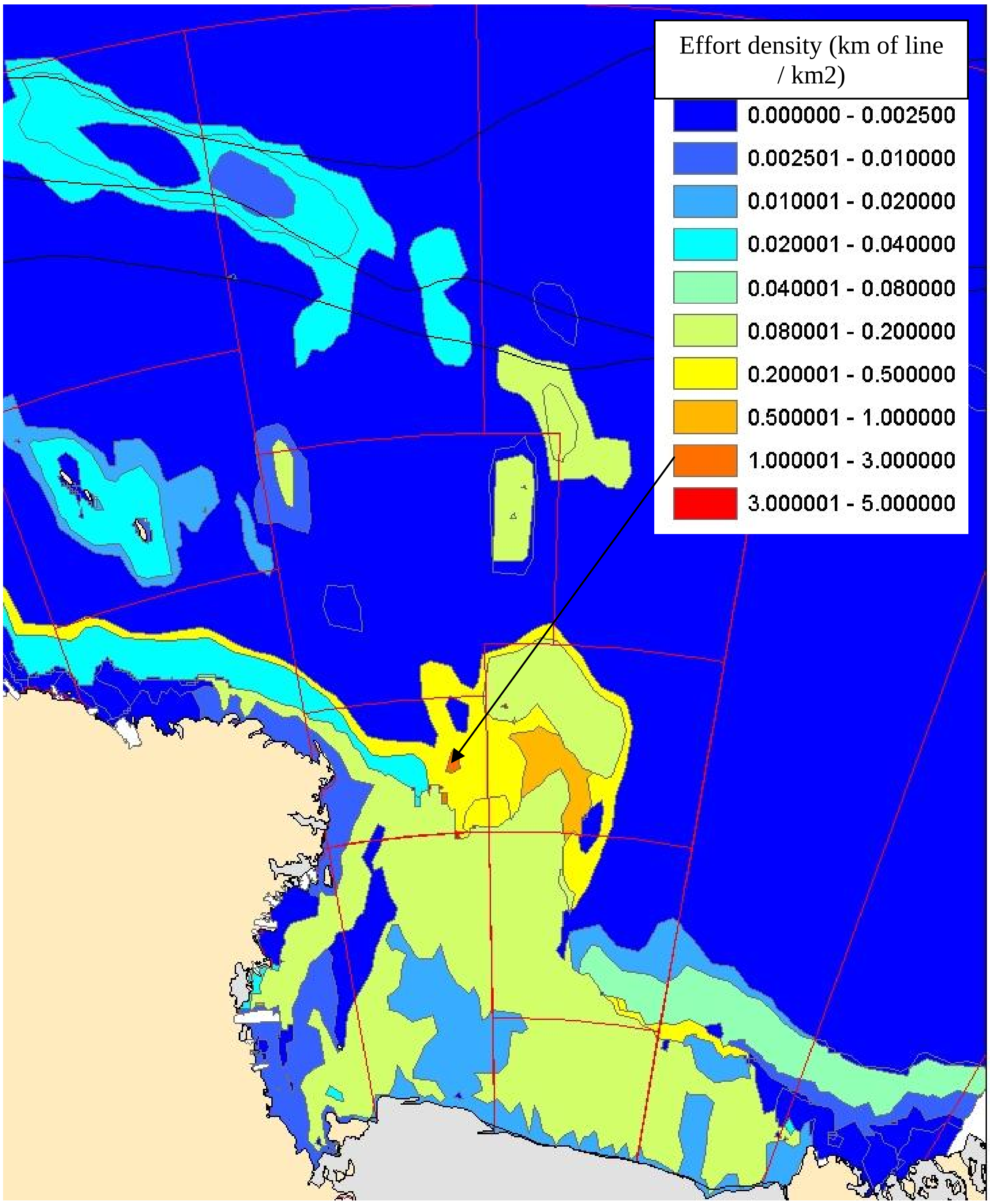


Figure 6. Spatial concentration of all historical New Zealand fishing effort in the Ross Sea fishery. The histogram sorts 1737 non-zero-effort pixels (0.05° latitude x 0.177° longitude) as a function of cumulative effort density (in km of line per km2). Note that the horizontal scale is not linear. Note also that an additional 115,296 pixels in the Ross Sea region with zero New Zealand effort (98.4% of the total) are not shown.