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NOTIFICATIONS OF NEW ZEALAND'S INTENTION TO CONDUCT EXPLORATORY LONGLINE FISHERIES FOR *DISSOSTICHUS* SPP. IN THE 2008/09 SEASON

Delegation of New Zealand

NOTIFICATION DE L'INTENTION DE LA NOUVELLE-ZÉLANDE DE METTRE EN PLACE DES PÊCHERIES EXPLORATOIRES À LA PALANGRE DE *DISSOSTICHUS* SPP. PENDANT LA SAISON 2008/09

Délégation néo-zélandaise

УВЕДОМЛЕНИЯ О НАМЕРЕНИИ НОВОЙ ЗЕЛАНДИИ ВЕСТИ ПОИСКОВЫЙ ЯРУСНЫЙ ПРОМЫСЕЛ ВИДОВ *DISSOSTICHUS* В СЕЗОНЕ 2008/09 г.

Делегация Новой Зеландии

NOTIFICACIONES DE LA INTENCIÓN DE NUEVA ZELANDIA DE REALIZAR PESQUERÍAS DE PALANGRE EXPLORATORIAS DE *DISSOSTICHUS* SPP. EN LA TEMPORADA 2008/09

Delegación de Nueva Zelandia

ANNEX I – ECOLOGICAL RISK ASSESSMENT

ECOLOGICAL RISK ASSESSMENT OF AUTOLINE LONGLINE FISHING

1. INTRODUCTION

This ecological risk assessment is presented in support of the preliminary assessment of bottom fishing activities in 2008-2009 for New Zealand: implementing Conservation Measure 22-06 (Bottom Fishing in the Convention Area).

Ecological risk assessment (Standards New Zealand and Standards Australia 2006) is evolving in international fisheries fora as a preferred approach to examine fisheries impacts where information is incomplete or uncertain (e.g. Waugh et. al. 2008). This approach allows effective targeting of more detailed monitoring, clarification of research requirements, and a robust approach to precautionary management of the effects of fishing where information is incomplete or uncertain (Waugh et. al. 2008).

The ecological risk assessment reported herein is a Level 1 approach designed to identify hazards to species and systems using qualitative data and expert opinion.

The ecological risk assessment involved three key steps: the compilation of relevant information (e.g. SC-CIRC-08/30); an expert workshop to review the information and agree key analytical frameworks; and, post workshop analysis to deliver the required output.

The expert workshop was held over two days. The workshop reviewed the fishing method in detail, determined a preliminary list of potentially vulnerable taxa including additional indicator species and reviewed the fishery effort to date. That information was used to undertake an assessment of the likely impact of the gear, calculate a footprint and thus estimate the likely impact of the method at the scale of the fishery on potential VMEs. The workshop also discussed fishery independent information and potential responses to the identified impacts

2. HYPOTHESIS

The workshop agreed to define its purpose with reference to a null hypothesis, as follows:

> We are attempting to test the null hypothesis that the risk of significant adverse effect of bottom longline fishing on VMEs is so negligible as to be ignored. If the null hypothesis is rejected, a best estimate of the nature and potential extent of significant adverse effects should be developed.

3. WORKING DEFINITION OF VMEs

The first task of the workshop was to agree upon a practical working definition of Vulnerable Marine Ecosystem (VME). Workshop attendees were aware of the definitions contained in the draft FAO deepsea guidelines (UNFAO 2008) and the

CCAMLR definition and previous discussions on VMEs. These were used those as a basis from which to develop a working definition of a VME.

The VME definition described in the draft FAO deepsea guidelines[1] describes ecosystems, rather than smaller-scale features such as habitats or communities. In the CCAMLR context, the 'ecosystem' in question would perhaps be comparable in scale to the entire Ross Sea region (CCAMLR Subareas 88.1 and 88.2). We understand that CM 22-06 (2007) and the preliminary assessments are attempting to assess the potential adverse effects of fishing at the scale of communities *within* that ecosystem. The notion of 'vulnerable' when applied to ecosystems can imply a whole range of threats including as the vulnerability of target or bycatch species to over-harvest, whereas the CCAMLR definition of VME seems to refer in particular to the physical vulnerability of benthic habitats to disturbance. The workshop therefore proposed that within CCAMLR, VME could perhaps be productively re-defined as 'Vulnerable Biogenic Habitat' (VBH) at the scale of communities within the ecosystem.

For the purposes of the preliminary assessment the workshop adopted the following pragmatic working definition of VBH: as those areas within the Ross Sea region ecosystem which:

(i) Contain intrinsically rare species or communities; or

(ii) Contain endemic species or communities which are constrained in their distribution by available habitat; or

(iii) Supports the presence of depleted, threatened, or endangered species, populations or communities for all or part of their life histories; or

(iv) Are important habitats for species, communities or populations, for which alternative habitats are not known to exist or are uncommon, whether or not the actual functional relationships with habitats are known; or

(v) Contains species, populations or communities that are easily damaged by anthropogenic activities, including fishing, particularly if the species, populations or communities that are damaged have long recovery times or may not recover; or

(vi) Support ecological processes that are highly dependent upon complex physical structures created by biotic features (e.g. corals, sponges, bryozoans).

Within this definition, some seamounts, hydrothermal vents, cold water corals and sponge fields will clearly be classified as VBH.

[1] Paragraph 37 of the FAO' s draft deep sea guidelines has changed over the past few months and its current form is different to that considered in the workshop.

4. METHODOLOGICAL APPROACH

The workshop agreed to the following sequential approach to derive a preliminary assessment of the New Zealand fishery's potential impact on VBH in the Ross Sea region.

1. Introduction
2. Hypothesis
3. Working definition of VMEs
4. Methodological approach
5. Selection of vulnerable taxa
6. Description of fishing activity and estimated spatial footprint
    - 6.1 Gear description.
    - 6.2 Method description, and calculation of spatial footprint for standard set
    - 6.3 Description and spatial footprint of non-standard gear deployment scenarios
7. Vulnerability assessment for selected vulnerable taxa
8. Description of historical fishing effort
9. Impact assessment
    - 9.1 Standardised impact assessment method
    - 9.2 Impact assessment at the scale of the fishery
    - 9.3 Impact assessment in the most heavily fished area
    - 9.4 Spatio-temporal considerations
    - 9.5 Implications for impact mitigation
10. References
11. Figures

5. SELECTION OF VULNERABLE TAXA

Benthic ecologists and other experts at the workshop proceeded to determine what species or taxonomic groups would be considered to be indicative of a VME in the Ross Sea region fisheries, on the basis of the following considerations.

New Zealand's definition of VBH closely follows the characterisation by the FAO in its draft deep sea guidelines (FAO 2008). Both provide several criteria to consider at the species level when selecting taxonomic groups to monitor. The criteria are related to four more general biological characteristics. Vulnerable species are those that create complex benthic biogenic habitat[2], are endemic to a restricted area or are rare, are fragile relative to the impact of longline fishing gear, or that provide ecological functions that are important to community integrity.

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[2] It is a matter of current debate as to whether the term structure is more relevant than habitat. Habitat implies a known association with some inhabiting organism, whereas most of what we know is association at best, e.g. fish may live around corals because both like to live around rocks. For simplicity we continue with habitat in this paper but note that this link with structure will need resolution in future.

Some discussion was directed to question of at what scale should the 'endemism' criterion be applied. It was generally recognised that the criterion itself was scale-dependent, and that in practice some sort of intermediate scale was useful, i.e. an organism endemic to the Ross Sea region only may qualify as a VME indicator, but not so an organism endemic to the whole Southern Ocean. In the workshop the endemism criterion was not applied further in the selection of VME indicator taxa, probably in large part due to the coarse taxonomic aggregations used.

Functionally, these taxonomic groups must be broad enough to include all the species that fit the criteria in a minimal number of groups, but be narrow enough to ensure clear identification criteria and exclude taxa that do not fit the criteria. They must also be taxa that occur in the fishable area of the Ross Sea region and that are vulnerable to impacts by the fishing gear in time, space, and at the scale of the organism.

Data on the distribution of these taxa come from a number of sources, including scientific survey and observational data, fishery observations, and ecological models incorporating biological and environmental data. However, survey information is very limited in scope and often does not overlap the area where fishing takes place. Most of the information on the distribution of species interacting with fishing gear comes from the fishery itself. Therefore, another criterion useful in choosing species to monitor is that they should have some real probability of being captured by the fishing gear. Much of the fishery-dependent data is at a fairly coarse taxonomic resolution, limiting our ability to define VME indicator taxa more specifically.

Using these criteria, 14 groups of organisms were identified that are either vulnerable to fishing impacts or are indicators of vulnerable communities (Table 1). Most were included because they create fragile biogenic structure that may serve as habitat for other organisms, making their role in the community fundamental (sponges, all Anthozoa orders listed, and hydrocorals). Hydroids, Bryozoans and sea squirts were included because of their biogenic structure and exceptionally dense communities that create unique habitats for other organisms, and appear to be prevalent in Antarctic waters based on video survey data. Stalked crinoids and basket stars are included as indicators of areas containing vulnerable communities. Chemosynthetic taxa are included because of their rarity, and likely high degree of endemism. Although not typically observed in fishery data, any observation by either scientific survey or fishing vessels would indicate a vulnerable community.

Other potential indicator groups such as asteroidea, and low productivity fishes were considered but not included because they were mobile, widespread and not thought to indicate vulnerable communities reliably. Taxonomic diversity was not included as an indicator because it is difficult to quantify, and not needed for any real time conservation action when bycatch rates are extremely low and very few taxa are normally encountered within the same set. Information about taxonomic diversity will still be available for longer term analysis and development of new conservation measures. Uncertainty in life history traits of the various taxa is included by assessing ecological characteristics in a precautionary manner, and by including all species within a relatively broad group such as Family or Order.

Fishery observer data from the Ross Sea region show that since 1997, observations of vulnerable taxa exist only for sponges, stony corals, sea fans, sea anemones, and sea squirts (SC-CIRC-08/30). However, the two most frequent groups observed were Cnidaria and Invertebrates. Cnidaria likely consists of a variety of Anthozoans, but also is the most precise code available for hydrocorals, which are known to exist in the Ross Sea region from survey information and observer photographs. "Invertebrates" is likely the most common code used because of the historical lack of an invertebrate identification guide, and the current lack of specific invertebrate taxa codes. Recent improvements in invertebrate guide materials, direction to record and retain specimens for identification, and new VME taxa-specific guide for 2008/2009 will improve the specificity and likely the number of observations of vulnerable taxa in the toothfish longline fishery.

Table 1: Vulnerable taxa to be monitored and assessed for fisheries impact. Vulnerable groups are in bold. Non-bold groups refer to a broader taxonomic grouping of the vulnerable taxa. Indent pattern represents nested taxonomic groups (Phylum, Class, Order and Family). Taxa for which no FAO codes currently exist are recorded as '?'.

FAO code	Common name	Taxonomic group
PFR	Sponges	**Phylum Porifera**
CNI		Phylum Cnidaria
AJH		Anthozoa
ATX	Anemones	**Actiniaria**
CSS	Stony corals	**Scleractinia**
AQZ	Black corals	**Antipatharia**
?	Soft corals	**Alcyonacea**
GGW	Sea fans	**Gorgonacea**
?	Sea pens	**Pennatulacea**
?		Hydrozoa
?		Anthoathecate
?	Hydrocorals	**Stylasteridae**
?	Hydroids	**Hydroida**
?	Bryozoans	**Phylum Bryozoa**
ECH		Phylum Echinodermata
CWD		Crinodea
?	Sea lilies	**Non-comatulid**
OWP		Ophiuroidea
?	Basket stars	**Euryalinida**
		Phylum Chordata
SSX	Sea squirts	**Ascidiacea**
?		**Chemosynthetic taxa**

In the use of fishery-dependent data workshop attendees stressed the need to distinguish between passively caught sessile organisms and mobile organisms that may actively seek the baited hooks. Specifically, the latter group includes starfish, which actively target baited longlines and may be caught in large numbers. Proper application of existing fishery dependent data will require that starfish be ignored as indicators of structural habitat. Where bycatch is coded simply 'Invertebrate', as in much of the CCAMLR bycatch data, the inability to distinguish starfish from other passively caught invertebrates will make use of this data difficult. Observer (C2) data is expected to be much better.

CCAMLR and FAO codes are not available for soft corals, sea pens, hydrozoans, hydrocorals or Bryozoans. They are also not available for the indicator taxa of stalked crinoids or basket stars. Finally, no species or group codes exist for chemosynthetic taxa. New Zealand will develop interim codes for observers to use for vulnerable taxa and recommends that CCAMLR work with the FAO to develop universal codes for vulnerable taxonomic groups.

6. DESCRIPTION OF FISHING ACTIVITY AND ESTIMATED SPATIAL FOOTPRINT

The third major task of the workshop was to define as clearly as possible the nature of the fishing activity associated with the New Zealand fleet. Vessels in the Ross Sea region toothfish fishery use one of two kinds of gear: autoline longlines or Spanish longlines. All New Zealand vessels are autoline longline vessels. The following gear description and the subsequent impact analyses apply to autoline longline fishing operations only; Spanish longline operations can be expected to have impacts of a different nature.

6.1 Gear description

Experts with extensive experience in the Ross Sea region fisheries, including fishing boat captains and fisheries observers, produced the following detailed description of the physical gear used by New Zealand vessels in the Ross Sea (refer Figure 1).

At the leading end of the line are large plastic floats, typically with a flag and GPS or radio beacon to aid recovery. These are attached to approximately 500-1000 m of heavy-gauge (16 mm) sinking rope, followed by approximately 1000 m of heavy (16 mm) floating rope. Collectively these are referred to as the ‘downline’. Beneath the downline are attached two short lengths of steel chain attached to the line at one end only, separated from one another by 50 m of floating rope. Each chain is 1.2 m long and weighs approximately 20 kg; these chains act as ‘springs’ to keep tension on the line during descent and to stabilise the end of the line on the ocean floor. An additional 50 m of floating rope separates the second chain from the first of two grapnels. The grapnels weigh 40 kg each; they are 1.2 m long, with three sets of triangular steel prongs (0.4 m wide) designed to grip the ocean floor and prevent movement of the line. The grapnels are separated by 50 m of floating rope. Beyond the second grapnel is the main length of fishing line with the hooks, collectively called the ‘mainline’ or ‘backbone’. The backbone is formed from 11.5 mm integrated-weight (IW) line (i.e. with lead embedded in the core, 50 g/m, to assist sinking). Hooks are spaced every 1.4 m along the backbone, attached by a 40 cm (sinking) snood and a rotor and swivel that are permanently attached to the IW line. Hooks are 14/0 ezi-baiter barbed, with a mild offset and limited recurve (a function of fitting the autoline magazine racks). The typical fishing set uses a backbone approximately 10 km long (i.e. typical set = 7000 hooks). At the other end of the backbone is a symmetrical configuration of grapnels and downline (i.e. 2 grapnels, 2 chains, floating downline, sinking downline, plastic floats) with spacing identical to the leading end.

6.2 Method description, and calculation of spatial footprint for standard set

Experts with extensive experience in various fisheries, both inside and outside the CCAMLR Area, described the use of the gear in a typical fishing gear deployment event, or 'set', as well as for a number of alternate scenarios where unforeseen circumstances or mishaps can be expected to alter the nature and/or extent of the impact. Experts in the fishery including vessel captains and observers explored the consequences of various fishing scenarios and responded to detailed questions from other workshop attendees. The workshop then estimated a 'spatial footprint' to describe the maximum extent of the physical impacts associated with a typical fishing event in each scenario. Note that the spatial footprint describes the typical size of the envelope within impacts will occur; the actual severity of the impacts within that envelope for particular vulnerable taxa are estimated subsequently in Sections 7 and 9.

Scenario 0: typical gear deployment event (normal setting and recovery)

The typical gear deployment (set) proceeds as described below.

- The fishing vessel slows to around 5 knots, and the floats are thrown overboard.
- The vessel maintains this speed in the desired setting direction until the downline is fully deployed. The length of the downline is a function of the depth, weather conditions, and the strength of tidal currents. Because the vessel is moving and the second half of the downline consists of floating rope, the downline remains stretched out on the surface during this stage of deployment.
- The chains and grapnels are thrown overboard. The grapnels and chains sink at a rate of 0.3-0.4 m/s, pulling the downline and the backbone downward with them.
- The backbone is pulled from the storage magazines as the vessel continues at 5-7 knots. Hooks are baited automatically as they feed through the automatic baiting machine and into the water. The backbone sinks at a rate of 0.2-0.25 m/s (i.e. 2 hours to reach the bottom at 1500 m depth).
- At the terminal end of the backbone, another symmetrical configuration of grapnels and chains is thrown overboard.
- The vessel continues to move slowly while the second downline and floats deploy, to avoid entanglements. Downline deployment is aided by the weight of the grapnels and chains.
- The line is left to 'soak' (catch fish) for 12-36 hours, depending on factors such as weather, ice, the number of other lines to be deployed in the same area, and the presence or absence of sea lice.
- The vessel returns to either end of the line, (depending on weather and ice conditions), locates the floats, and begins hauling the downline aboard.
- The vessel follows the course of the line at a speed of 3-5 knots, hauling the line at a rate of approximately 0.5 m/s. The vessel maintains position directly above the line and vessel speed is maintained consistent with hauling speed so that the line is pulled as near as possible directly upward.

- The chains, grapnels, and backbone with fish are hauled aboard, followed by the trailing end grapnels, chains, downline, and floats.

The following aspects of gear deployment were noted to be particularly relevant for informing the assessment of potential benthic impacts.

- The portion of the downline connected to the floats is composed of sinking rope, minimising exposure to surface conditions such as moving ice or wind that could otherwise cause the line to move.
- The portion of the downline connected to the chains and grapnels is floating line, to minimise contact with the bottom except in the immediate vicinity of the chains and grapnels themselves.
- The rate at which the backbone sinks (0.2 m/s) is sufficiently slow that the impact of the weight of the line settling onto benthic features or taxa is likely to be negligible or low except for very fragile taxa.
- Because the grapnels sink faster than the backbone, the leading end of the backbone tends to have some initial slack, and may settle onto itself and subsequently tangle. The slack in the line is minimised by feeding out the downline in the water prior to dropping the grapnels; this creates drag as the grapnel drops and ensures that the grapnel does not fall straight down.
- If there is any deep current then remaining slack can be expected to be pulled taut as the line is pulled wide of the straight-line distance between the grapnels. However if there is no current the line can be expected to tangle for the first 100-150 m of backbone. Front-end tangles of this kind are considered a normal aspect of the standard set. Where front-end tangles occur their main effect is to reduce the length of the backbone in contact with the seabed, i.e. reducing the size of the spatial footprint. By ignoring this effect this assessment can be expected to over-estimate the actual size of the impact footprint by 1-2%.
- Because the line is effectively pulled off of the rear of the vessel as the vessel proceeds, the majority of the backbone is deployed under moderate tension. This tension serves to prevent subsequent tangles (except within the first 100-150 m of backbone, above) and also serves to limit the scope for line movement once the line is settled on the bottom.

There was extensive discussion as to whether or not the line moves once it has settled on the bottom. *The workshop judged on the basis of the following considerations that under normal circumstances the line does NOT move once it has settled:*

- Because the IW line settles uniformly on the bottom and is held under moderate tension between heavy grapnels, there is little scope for movement of the backbone due to ‘natural’ forces such as tidal currents
- Due to friction and the weight and tension of the backbone along most of its length, there is little scope for hooked fish to move the backbone laterally beyond the immediate vicinity of the snood and swivel attachment.
- Because the deployed lines are deep (1000-1500 m), heavy, and in uniform contact with the bottom, creating friction, there is little scope for the floats (constrained to a near vertical angle) to exert sufficient lateral force to move the line once it has settled. Even if the floats become entrapped by moving

ice, the most likely scenario is that the line will break near the grapnel (see below).
- The weakest point of the line is the backbone itself; forces great enough to produce significant line movement when in contact with the bottom can be expected to result in a broken line (see below).

There is likely to be a greater potential for line movement not for the backbone but for that section of line between the chains and the grapnels (50-100 m), as a result of forces acting on the floats (i.e. ice or wind) sufficiently strong to move the chains but not the grapnels. Movement here is likely to be greater because the intervening line is floating rather than in contact with the bottom, the chains are lighter than the grapnels, and unlike the grapnels the chains lack prongs to firmly grip the ocean bottom. Vessel captains at the workshop acknowledged that the weight of the chain had to be properly adjusted to ensure no movement. For purposes of calculating the spatial footprint of a standard set, the workshop assumed no movement of this section of line.

The workshop agreed after much discussion that the greatest potential for line movement occurred when hauling the line back to the surface. *The workshop judged on the basis of the following considerations that normal line recovery does NOT result in significant lateral line movement in contact with the ocean floor*.

- Because of the great depths involved (1000-1500 m) even hauling from a position that is not strictly vertical will not result in lateral line movement along the bottom, since at those depths the actual angle of hauling will vary only slightly.
- Hauling from a position substantially different than directly vertical generally results in a broken line. Captains and observers confirmed that it proper hauling requires a lot of 'finesse and patience' to avoid breaking the lines.

On the basis of these assumptions, *the workshop defined a maximum spatial footprint for a typical gear deployment event with the following characteristics* (Table 2).

- The footprint of the grapnels and chains will be confined to the locations where they fall when initially deployed
- The footprint of the floating line will be negligible.
- The footprint of the backbone will extend 0.5 m on either side of the IW line (i.e. 1 m width) along its full length

6.3 Description and spatial footprint of non-standard gear deployment scenarios

The following alternate/ non-standard gear deployment scenarios were considered.

Scenario 1: Broken-off downline and partial line dragged by ice

The workshop considered a scenario in which floats at one end of the line are overtaken by moving ice.

- The best case (minimum impact) scenario is that the line does not move, either because the ice movement is not sufficiently powerful to disengage the grapnel from the sea bed or because the floats are able to pass under the ice floe without becoming entangled. If the line does not move then the impact of this event is no different from that of a standard set.

Table 2: Estimated spatial footprints for various gear components in a standard set (scenario 0).

Gear deployment event	Spatial footprint of impact by gear component				
	Backbone*	Grapnel (x 4)	Chain (x4)	Floating line	Sinking line
Scenario 0: Standard set	1000 m* x 1 m	1.2 m x 0.5 m	1.2 m x 0.5 m	negligible	none
Total footprint per km of line	**1000 m^2**	**-**	**-**	**-**	**-**
Total footprint per set	**-**	**4.8 m^2**		**0**	**0**

*Note: The typical backbone length is 10 km. Note however that because effort is reported in terms of total length of line as well as of numbers of sets, it is possible to use actual length rather than estimated length when scaling up to assess impacts at the geographic scale of the fishery (section 6, below). Footprint for the backbone is therefore expressed per 1 km of line, whereas footprints for the other gear components and non-standard deployment scenarios are calculated per set.

- Assuming that the floats do become entangled, the most likely scenario is that the line breaks somewhere on the backbone. The IW line of the backbone is the weakest part of the set. Where broken lines have been subsequently recovered, *the majority have broken within the first 100-200 m of backbone.*
- The remainder of the backbone will be hauled normally from the other end.
- Vessel captains and observers attending the workshop agreed that it is unlikely that the line can withstand significant lateral sweeping movement before breaking. This assertion is consistent with the experience of hauling lines, in which it is important to avoid any lateral tension on the line in order to avoid breakage.
- A typical Scenario 1 event will thus involve the dragging of two chains, two grapnels, and 200 m of (potentially tangled) backbone (with hooks) in a straight line until such time as it is dragged into water deeper than the length of the downline (i.e. typically 1500 m depth).
- In the Ross Sea region prevailing surface currents move down-slope (i.e. offshore) over the continental shelf break. Because the majority of fishing in the Ross Sea region occurs on the shelf slope or on isolated undersea features such as seamounts, *it can be assumed that the typical Scenario 1 event carries the gear into deeper water within 3 km or less* (i.e. the typical maximum distance over which the slope drops beyond fishable depths).

On the basis of these assumptions, the workshop estimated the spatial footprint for a Scenario 1 event to be confined to a 1 m x 3000 m swath. Actual impact within that footprint is assumed to arise from the sequential passage of both chains, both grapnels, and 200 m of line (with hooks) along the seabed (see Table 3).

Scenario 2: (Alternate gear configuration): the use of 'JB' lines with submerged endpoints

In order to minimise exposure of the line to the movements of surface ice, some New Zealand vessels have pioneered the use of a novel gear configuration ('JB lines') in which a downline extending from the grapnels to the surface is instead replaced by a partial downline with floats suspended in midwater, to be re-located by radio transmitter and snagged by the fishing vessel using some sort of retrieval grapnel. Typically this configuration is used in the middle of two otherwise normal full-size lines.

Because normal retrieval of JB lines involves dragging a recovery grapnel in mid-water to snag the suspended portion of the line, *the estimated benthic impact of the use of these lines is identical to that for the typical set, Scenario 0.* The primary effect of using JB lines is to reduce the risk of Scenario 1 events.

Scenario 3: Attempted recovery of lost gear

The workshop discussed situations in which downlines at both ends of the line become broken or lost, either due to entrapment by moving ice (Scenario 1) or due to breakage during hauling, e.g. caused by failure to maintain vessel position directly above the line. This results in a backbone lying directly on the seabed unconnected to any means of retrieval. The workshop determined the following:

- Because the gear is valuable and vessel captains have a good idea as to the location of the line on the seabed, vessels will typically make multiple attempts at gear recovery, even over the course of days or weeks. Generally the only reason to abandon lost gear is if a subsequent Subarea closure forces the vessel to move on.
- Recovery is attempted by dragging a 'recovery grapnel' along the seabed at right angles to the direction of line deployment.
- The recovery grapnel is 2 m long, with four sets of 40 cm diameter hooks or tines designed to snag the backbone without re-breaking it. The recovery grapnel is significantly lighter than the main grapnels at either end of the backbone. The width of the impact footprint is assumed to be 0.5 m, i.e. only slightly wider than the 40 cm diameter recovery grapnel.
- There was considerable discussion as to whether or not in a successful snagging attempt the backbone moves laterally before coming off the seabed. The consensus was that there was very little lateral movement on consideration of the extreme vertical orientation of the recovery line during snagging attempts and the high longitudinal tension/ lateral friction of the backbone resisting lateral movement on the seabed. Vessel captains and observers note that skill is required to keep the recovery grapnel in contact with the seabed even before it successfully snags the backbone of the lost line; once the backbone is snagged its tendency is to rise immediately.
- 100 m2 was added to the total spatial footprint to account for the possible impact of lateral movement of the successfully snagged backbone. The

workshop agreed that this is conservative (i.e. is likely to overestimate impact).

- It is sometimes the case that portions of the backbone remain stuck fast to benthic features even after a section of it has been successfully brought to the surface. In these instances the recovered section of line is affixed with new floats, and further recovery attempted as normal with repeat snagging attempts further along its length.
- It was assumed that the typical recovery attempt involves an average of 5 drags before recovery is successful.
- Vessel captains estimated that the typical New Zealand vessel will perform 50-100 gear recovery drags per season.

On the basis of these assumptions, the workshop calculated the spatial footprint of attempted line recovery operations to be (5 x 400 m x 0.5 m) + 100 m^2 = 1100 m^2 per lost and recovered line (see Table 3).

<u>Scenario 4: Abandoned gear</u>

Where recovery attempts are unsuccessful or where a Subarea closure subsequent to gear loss prevents recovery, lines may be 'abandoned'. Lines are classed 'abandoned' if they remain on the seabed at the end of the fishing season in which they were deployed. Because there is little to no opportunity for further line movement once a line has been abandoned (i.e. lines will not be abandoned with floats still attached), *the spatial footprint of abandoned gear is assumed to be identical to that for the standard set.* The spatial footprint of (here unsuccessful) recovery attempts is already captured in effort reporting for scenario 3.

Note that the scope of the workshop was explicitly limited to considering the impact of fishing on physical / biogenic benthic habitats. It is likely that lost fishing gear has other impacts, e.g. 'ghost fishing' that are outside the scope of this workshop but worthy of investigation in their own right.

Vessel captains and observers with experience in the fishery estimated the frequency of occurrence of the various non-standard gear deployment scenarios, above (see Table 3). Note that for the purposes of impact estimation all gear deployments are assumed to have an initial footprint associated with the standard set; the spatial footprints defined for non-standard scenarios in Table 3 are *in addition to* the footprint associated with every standard set calculated in Table 2. Note also that the frequency of occurrence for non-standard scenarios are independent of one another (i.e. do not necessarily sum to 1), because it is possible to experience multiple complications with the same set. Thus, for the purposes of assessing impact at the scale of the whole fishery, or in particular areas (Section 9, below), the cumulative impact of each gear deployment scenario can be calculated from these data independently.

Table 3: Estimated frequency of occurrence and spatial footprints for non-standard gear deployment events (scenarios).

Non-standard scenario	**Description**	**Freq. of occurrence** (per set)	**Spatial footprint of additional impact** (per occurrence)		**Description of additional impact**
Scenario 1	Downline on one end dragged by ice	0.15	3000 m x 1 m	3000 m^2	(2 chains + 2 grapnels + 200m backbone with hooks) dragged until water becomes deeper than downline
Scenario 2	'JB' lines	n/a	none	0	No additional impact relative to standard set.
Scenario 3	Attempted recovery of lost gear	.02	5(400 m x 0.5 m) + 100 m^2	1100 m^2	Lightweight recovery grapnel dragged approx 5 times until backbone caught
Scenario 4	Abandoned gear	n/a	none	0	Impact of (unsuccessful) recovery attempts already quantified under scenario 3; no additional impact greater than scenario 0

7. VULNERABILITY ASSESSMENT FOR SELECTED VULNERABLE TAXA

The workshop systematically considered the likely impact of different gear components for the standard set (Table 2) and for non-standard gear deployment scenarios (Table 3) on every category of vulnerable taxa. The results are shown in Table 4.

Table 4 also includes the estimated recovery time for each vulnerable taxa, as follows: 'short' = 1-5 y; 'medium' = 5-20 y; 'long' = 20-100 y; 'very long' (Xt) = 100+ y. These estimates are not used in subsequent estimates of cumulative impact scaled up to the scale of the Ross Sea region fisheries because the fishery itself is young (< 10 y) relative to recovery times and the density of fishing effort is sufficiently dispersed relative to the impact footprints (see below) that repeat impacts on the same location can be assumed to be negligible. For fisheries where impact footprints can be expected to overlap on a single location within the recovery period of the impacted organisms, estimating impact in a temporally explicit way becomes much more critical.

Impacts were estimated at three levels of severity: 0 = no impact; 1 = sub-lethal impact; 2 = lethal impact. Note that for colonial organisms such as corals, definitions of 'lethal' vs. 'sub-lethal' are not always straightforward. Because our definition of VBH emphasizes biogenic structure, the workshop characterised as 'sub-lethal' any level of impact that resulted in damage to the physical structure of the colonial organism that could re-grow from the remaining structure without the need for re-colonisation or re-growth from substrate level (e.g. breaking an arm off of a branching coral); we characterised as 'lethal' any impact that destroyed the physical structure of the organism sufficient to require re-colonisation of the substrate at that location, or

Table 4: Estimated impacts on vulnerable taxa of different gear components and non-standard gear deployment scenarios within the spatial footprints defined in Tables 2-3.

Vulnerable taxa			**Impact of gear component or non-standard scenario** (0 = no impact; 1 = non-lethal impact; 2 = lethal impact)			
		Recovery time*	**Scenario 0:** Backbone	**Scenario 0:** Grapnels+Chains	**Scenario 1** (Broken end dragged by ice)	**Scenario 3** (Attempted gear recovery)
•Phylum Porifera	**•Phylum Porifera** (sponges)	Med	0(95) 1(0) 2(5)	0(50) 1(25) 2(25)	0(0) 1(5) 2(95)	0(20) 1(30) 2(50)
•Phylum Cnidaria	**–Actiniaria** (anemones)	Med	0(95) 1(0) 2(5)	0(70) 1(15) 2(15)	0(0) 1(25) 2(75)	0(30) 1(40) 2(30)
Anthozoa	**–Scleractinia** (stony corals)	Xt	0(90) 1(5) 2(5)	0(0) 1(50) 2(50)	0(0) 1(20) 2(80)	0(10) 1(30) 2(60)
	–Antipatharia (black corals)	Long	0(90) 1(5) 2(5)	0(0) 1(60) 2(40)	0(0) 1(20) 2(80)	0(10) 1(30) 2(60)
	–Alcyonacea (soft corals)	Med	0(95) 1(0) 2(5)	0(50) 1(25) 2(25)	0(0) 1(5) 2(95)	0(20) 1(30) 2(50)
	–Gorgonacea (gorgonians)	Xt	0(90) 1(5) 2(5)	0(0) 1(50) 2(50)	0(0) 1(20) 2(80)	0(10) 1(30) 2(60)
	–Pennatulacea (sea pens)	Med-Long	0(95) 1(0) 2(5)	0(65) 1(25) 2(10)	0(0) 1(5) 2(95)	0(20) 1(30) 2(50)
Hydrozoa	**•Anthoathecate: Stylasteridae** (hydro corals)	Long	0(90) 1(5) 2(5)	0(0) 1(50) 2(50)	0(0) 1(20) 2(80)	0(10) 1(30) 2(60)
	•Hydroida (hydroids)	Med	0(95) 1(0) 2(5)	0(50) 1(25) 2(25)	0(0) 1(5) 2(95)	0(20) 1(30) 2(50)
•Phylum Bryozoa	**•Phylum Bryozoa** (bryozoans)	Short-Med	0(95) 1(0) 2(5)	0(50) 1(25) 2(25)	0(0) 1(20) 2(80)	0(10) 1(30) 2(60)
•Phylum Echinodermata	**Crinodea – stalked** (sea lilies)	Short-Med	0(90) 1(5) 2(5)	0(65) 1(10) 2(25)	0(0) 1(5) 2(95)	0(20) 1(30) 2(50)

re-growth from the substrate level (i.e. the same coral re-growing from its basal attachment to the underlying rock).

The impact estimates in Table 4 represents the *probability of a particular organism within the spatial area of the footprint (from Table 2-3) experiencing the given severity of impact.* Estimates for the three severity levels by definition sum to one. These tables cannot be interpreted independently; the estimated impact proportions in Table 4 are only valid in explicit reference to a particular spatial footprint assumption (e.g. doubling the size of the assumed footprint in Tables 2-3 would imply halving estimates for sub-lethal and lethal impacts in Table 4).

Critically, the application of these impact estimates *is not density dependent* with respect to the organisms themselves, i.e. a particular organism is assumed to suffer the same risk of impact regardless of whether or not there are other organisms of the same kind present. This allows us to scale up the estimated impacts to the scale of the fishery without making any assumptions about the actual composition of biological communities in particular areas. This capability is critical in the Ross Sea region where our ability to map benthic community patterns in space is severely limited.

The following considerations influenced the workshop's assessment of probable impacts for particular gear components/ non-standard scenarios.

<u>Standard set: backbone</u>

Impacts may arise from the initial settling of the line onto the organisms, the subsequent retrieval of the line during hauling, and the actions of hooked fish during the intervening period.

The impact of the initial settling of the line was assumed to be minimal, due to the slow sink rate (0.2 m/s) and low weight of the line. A greater proportion of the impact is assumed to occur during line retrieval, when the line may snag on and break rigid or branched organisms such as corals. The greatest portion of the impact is assumed to arise from the action of the hooks. For soft-textured and discrete organisms (e.g. anemones, sea pens) the estimated lethal impacts represent whole organisms hooked and brought to the surface; for rigid colonial organisms (e.g. black corals, gorgonians) the mixture of sub-lethal and lethal impacts represents portions of the organisms hooked and broken off, or organisms dislodged from the substrate after being hooked near their base. The high proportion of 'no impact' estimated for all taxa reflects the spacing of the hooks (1 hook/ 1.4 m on a 40 cm snood) and the fact that particular hooks can only affect a small portion of the 1 m wide footprint theoretically within their reach.

Considerable discussion was devoted to estimating the effect of hooked fish on vulnerable taxa. It is thought that toothfish do not struggle as vigorously as do comparably sized fish in warmer waters, due to their slower metabolism and as evidenced by the fact that recovered fish are rarely exhausted or dead. Nonetheless they are large powerful fish, and even moderate fish movement on the hook could be expected to break or dislodge benthic organisms. The workshop agreed to assume a maximum possible impact, i.e. 100% lethal impact within 1 m radius of every hooked fish. Using the historical average catch rate of approximately 1 fish per 100 m of backbone, this implies a 2% lethal impact on all vulnerable taxa attributable to the effect of hooked fish.

The workshop recognised that all impact estimates are subject to considerable uncertainty. The agreed numbers are the outcome of considerable discussion by the assembled experts, with reference to the known behaviour of the fishing gear and the biology of the organisms in question, and with considerable application of common sense. The final numbers represent an attempt to be as conservative as possible, i.e. to represent the *maximum* likely impact within the range of estimated uncertainty.

The following assumptions and/or observations were recorded with respect to particular vulnerable taxa:

- *sponges:* lethal impact will be via being hooked and brought to the surface; non-lethal impacts should be negligible. Observers report retrieving approximately 2 sponges per week per vessel
- *anemones:* vulnerability similar to sponges
- *stony corals*: likely susceptible to breakage by empty hooks, with mostly sub-lethal effects; there is little evidence of large stony corals being dislodged from the substrate – the 5% lethal impact estimate (i.e. 2% fish effect and 3% additional) is thought to be conservative (high)
- *black corals:* susceptible to hooking due to branching structure, but flexibility should limit impact; the estimates are thought to be conservative
- *soft corals*: vulnerability similar to sponges
- *gorgonians:* brittle and can be large; vulnerability similar to stony corals
- sea pens: vulnerability similar to sponges
- *hydrocorals*: tall and brittle: vulnerability similar to stony corals
- *hydroids:* small and brittle; vulnerability similar to sponges
- *bryozoans:* small and brittle; vulnerability similar to sponges
- *sea lilies*: vulnerability similar to sponges
- *sea squirts*: flexible/ soft structure: vulnerability similar to sponges
- *chemosynthetic taxa:* includes a diverse range of taxa; tube worms are likely to be most susceptible to damage; other taxa may be relatively impervious.

Standard set: grapnels and chains

The grapnels and chains are heavy and have a more rapid sink rate than the backbone (0.3 m/s). Effects on vulnerable taxa will arise from direct impact as the gear initially settles on the sea floor, and to a much lesser extent from very minimal lateral movement as the gear is lifted during hauling. The grapnels are larger and heavier than the chains but on hard substrates will have less contact with the bottom due to the length of the prongs (40 cm diameter); the chain is lighter but will have greater contact with the bottom. These considerations are assumed to roughly cancel each other, such that the impact of each is assumed to be comparable. The spatial footprint of the grapnels and chains is small (Table 2). Within that footprint large and brittle organisms will be most vulnerable; small and flexible organisms are more likely to escape damage.

Scenario 1: Broken-off downline and partial line dragged by sea ice

Impacts from Scenario 1 events are assumed to arise from the passage of two chains, two grapnels, and 200 m of backbone (with hooks) along the seabed. The backbone itself may or may not be tangled, but this can be expected to have negligible effect on the magnitude of the impact.

Note that the impact estimates are based upon conservative assumptions, since some scenario 1 lines can be expected to break at an earlier location (e.g. between the chains and grapnels, if the grapnels become firmly stuck on the seabed) such that less gear is being dragged. The prospect of a later break (i.e. with more backbone being dragged) is less likely due to the uniform strength of the backbone and the rapidly increasing friction associated with dragging additional hooks. In any event it is assumed that the greatest impact arises from the dragging of the grapnels and chains. Within the footprint of the dragged gear, impacts are estimated to be fairly high for all vulnerable taxa. Impacts will be highest for taxa that are easily dislodged from the substrate without the ability to re-attach (e.g. sponges), and less high for taxa that may be capable of ‘righting’ themselves (i.e. anemones and sea squirts). See Table 4.

Scenario 3: Attempted recovery of lost gear

Impacts from Scenario 3 events arise from the passage of the recovery grapnel over the sea bed. The recovery grapnel is considerably smaller and lighter than the anchor grapnels at either end of the main line. On hard substrates the recovery grapnel will have reduced contact with the seabed due to the length of its tines and the likelihood that it will bounce over some of the organisms in its path. Erect and brittle taxa are likely to be most susceptible to damage (see Table 4).

Scenario 4: Abandoned gear

Because there is little scope for fishing lines to move once they have been abandoned, there is assumed to be no additional benthic impact from abandoned gear relative to the impact of a standard (recovered) set. For some abandoned lines, unsuccessful attempts will have been made to attempt recovery before the decision is made to abandon the line; however these gear recovery attempts are reported and their impacts estimated separately (Scenario 3) regardless of whether or not the line is actually recovered. Therefore no additional impact is calculated for abandoned gear relative to the standard set.

This is most likely a conservative assumption (i.e. one that will tend to *overstate* the level of impact) because in a standard set most of the impact of the backbone will occur during recovery and hauling. However along some sections of the line this impact will have still accrued during attempted recovery if the recovery grapnel hooked and raised a line that subsequently broke off and was re-lost. Furthermore if an abandoned line continues to catch fish then the effect of hooked fish may exceed the 2% lethal impact ‘fish effect’ that was assumed for successfully recovered gear in Scenario 0. For these reasons the impact estimates were not revised downward for Scenario 4 relative to Scenario 0.

8. DESCRIPTION OF HISTORICAL FISHING EFFORT

The workshop examined the distribution and intensity of historical fishing effort in the Ross Sea, both for the New Zealand fishery in isolation and for all nations collectively. Total New Zealand fishing effort is shown in Figure 2. Total effort for all nations is shown in Figure 3. These figures reveal that fishing effort is highly concentrated in preferred areas of the continental slope in depths of 800-1500 m, and to a lesser extent on features or seamounts further north at similar depths. Fishing effort outside of these preferred areas represents exploratory fishing, either early in the development of the fishery or to meet CCAMLR research requirements (e.g. the historic fine scale rectangle approach). When patterns are examined on a year-by-year basis it is apparent that fishing in particular non-preferred areas has generally occurred in a single year after which the area was not revisited. In contrast, core areas are repeatedly targeted (see impact assessment for the most heavily fished 1^{o} x 1^{o} area, in Section 9, below). This tendency to re-visit preferred areas is graphically evident in Figure 4, which suggests that the total number of pixels fished is approaching an asymptotic limit, and illustrated in Figure 5.

In Table 5 historical effort is summarised by year and in total for New Zealand vessels, and in total for non-NZ autoline longline vessels and for Spanish longline vessels. New Zealand effort comprises slightly more than half of all cumulative autoline longline effort, and approximately one quarter of all cumulative effort to date (although the proportion of the total effort has decreased on an annual basis in recent years). Note however that the impact assessment completed here cannot be applied to the Spanish longline method, so comparisons of total effort for the different methods do not imply conclusions about the relative proportions of their respective impacts.

Table 5: Historical fishing effort by year for all New Zealand autoline longline vessels in the Ross Sea region fishery. Cumulative totals for non-NZ autoline and for Spanish longliners are provided for comparison only.

	Fishing year	No. sets	Total length of sets (km)	Average length of sets (m)
NZ autoline longliners only				
	1997	2	4.1	2064
	1998	82	337.0	4110
	1999	252	1727.7	6856
	2000	489	2816.6	5760
	2001	555	3729.6	6720
	2002	434	3449.9	7949
	2003	547	3675.8	6720
	2004	624	4402.9	7056
	2005	539	3244.8	6020
	2006	371	2986.6	8050
	2007	420	2940.0	7000
	2008	342	3351.6	9800
NZ autoline longliner total:		**4657**	**32666.7**	**7015**
Non-NZ autoline longline total:		**3824**	**25102.8**	**6565**
Spanish longliner total:		**2400**	**32333.8**	**13472**

9. IMPACT ASSESSMENT

9.1 Standardised impact assessment method

The process of estimating cumulative impact of the New Zealand fishery on potential Vulnerable Marine Ecosystems (vulnerable benthic habitats) is as follows:

1. Multiply the size of the 'standard set' gear deployment footprints per unit effort (Table 2) by total historical effort (Table 5) to yield total historical footprint per gear component for standard sets.

2. Multiply the frequency of non-standard gear deployment events (Table 3) by total historical effort (Table 5) to yield a total occurrence estimate for each non-standard event.

3. Multiply the size of the non-standard gear deployment footprints per event (Table 3) by total non-standard event occurrence (step 2) to yield total historical footprint per non-standard gear deployment scenario.

4. Divide the total historical footprint for each gear component and gear deployment scenario (steps 2 and 3) by the size of the fishable area to yield a total historical footprint per gear component/ scenario expressed as a proportion of the total area.

5. Multiply the results of step 4 by the impact matrix (Table 4) to yield the total historical impact of the fishery on each vulnerable taxa, expressed as a percentage (e.g. x% of taxa A has been lethally impacted at the scale of the entire fishery, y% of taxa B has been sub-lethally impacted at the scale of the fishery, etc.).

This same process can be applied to the estimation of impact at the scale of the entire fishery or for particular areas, for example areas of highest cumulative fishing effort or areas of 'typical' effort, by simply replacing the total effort and total fishable area figures with numbers derived from the specific area of interest. In the worked example below (Table 6) we calculate the total historical impact of the NZ longline fishery on vulnerable taxa at the scale of the entire fishery and within the single most heavily fished 1^{o} x 1^{o} area in the fishery.

This same process can be applied to any fishing method for which historical effort data is available, informing an objective means of comparing the impacts of dissimilar methods. A comparative exercise could productively be applied to assess the relative and absolute impacts of autoline longlines, Spanish longlines, and bottom trawls within the CCAMLR Area.

9.2 Impact assessment at the scale of the fishery

Table 6 illustrates two worked examples to calculate the cumulative historical impact of all New Zealand fishing effort at the scale of the entire Ross Sea region fisheries and within the most heavily fished 1^{o} x 1^{o} rectangle. Impacts are calculated for New Zealand effort only.

Table 6: Cumulative historical fishing footprint and impact assessment for sample vulnerable taxon (stony coral) for all New Zealand autoline longline vessels over the life of the Ross Sea region fisheries (Areas 88.1 and 88.2, 1997-2008).

	A	B	C	D	E	F	G	H	I
	(Table 5)	(Table 3)	(A x B)	(Tables 2-3)	(=C x D / 1,000,000	(see below)	(E / F) * 100%	(Table 4)	(G x H)
Source of impact (standard gear component or non-standard scenario)	**Total effort** (km of line OR # of sets)	**Freq of scenario** (per set)	**Total impact events**	**Footprint size per event** (m^2)	**Total footprint** (km^2)	**Total area** (km^2)	**Percent of total area within footprint**	**Lethal impact** (stony coral)	**Percent of taxa lethally impacted** (stony coral)
Impact assessment at scale of entire fishery (Areas 88.1 and 88.2, 600 – 2000 m depth)									
Scenario 0: Backbone	32666.7	1	32666.7	1000	32.6667	435826	0.007495	0.05	0.000374
Scenario 0: Grapnel+chains	4657	1	4657	4.8	0.0223	435826	0.000005	0.4	0.000002
Scenario 1: Dragged downline	4657	0.15	698.55	3000	2.0956	435826	0.000480	0.8	0.000384
Scenario 3: Lost gear recovery	4657	0.02	93.14	1100	0.1024	435826	0.000023	0.6	0.000014
Totals					34.8871		**0.008004**		**0.000775**
Impact assessment within most heavily fished 1° x 1° pixel (176-177° E, 71-72 ° S).									
Scenario 0: Backbone	14726.9	1	14726.9	1000	14.7269	4351	0.338472	0.05	0.016923
Scenario 0: Grapnel+chains	1543	1	1543	4.8	0.0074	4351	0.000170	0.4	0.000068
Scenario 1: Dragged downline	1543	0.15	231.45	3000	0.6943	4351	0.015958	0.8	0.012766
Scenario 3: Lost gear recovery	1543	0.02	30.86	1100	0.0339	4351	0.000780	0.6	0.000468
Totals					15.4626		**0.355381**		**0.030226**

The impacts of non-New Zealand autoline longline effort are expected to be roughly equal to New Zealand effort (Table 5); impacts for the Spanish longline method are not assessed here.

Impact is estimated here for stony corals, the taxonomic group with the highest estimated vulnerability in Table 4. The same process can be applied to any of the identified vulnerable taxa by inserting impact estimates from Table 4 into Column H.

The total fishable area in the Ross Sea region fisheries was calculated as follows: the areal extent of seabed depth in the Subareas of 88.1 and 88.2 was estimated using GIS. Polygons encompassing the defined SSRU areas 88.1A-L and 88.2A-G were overlaid on a blended 1 minute GEBCO bathymetric grid (S2004) containing the average depth and area for each 0.2 degree by 0.2 degree cell. Depth values for each cell were allocated to 100 m bins. All areas shallower than 600 m or deeper than 2000 m were excluded; negligible fishing effort occurs outside of this range. Areas under permanent ice cover were also excluded. *This process yielded an estimate of 435,826 km2 between 600-2000 depth within areas 88.1 and 88.2* (column F).

This exercise yields a number of important conclusions. First, the cumulative spatial footprint of all historical New Zealand fishing effort is vanishingly small when viewed at the scale of the total fishable area of the Ross Sea. Summing across all gear components and all impact scenarios, approximately 0.008% of the ocean floor at fishable depths has come within reach of New Zealand fishing gear (Column G). Because the magnitude of impact for the various scenarios has been estimated separately for different vulnerable taxa (Table 4), it is important that the spatial footprints and impact estimates in columns G-H remain disaggregated until applied to particular taxa of interest. When applied to stony corals, the most vulnerable taxon assessed, we calculate that *approximately 0.0008% of stony corals within fishable depths of the Ross Sea region have been lethally impacted by New Zealand fishing gear within the life of the fishery.*

9.3 Impact assessment in the most heavily fished area

Effort within the area of highest historical fishing activity (see Figure 2) was calculated by extracting from the raw data all historical sets beginning or ending inside of the single busiest 1^o x 1^o rectangle in the fishery (176-177^o E, 71-72 ^{o} S).

Within this area there have been 1543 New Zealand sets, totalling 14,726 km of line (Column A). These numbers illustrate the highly concentrated nature of the effort; fishing activity within this 1^o x 1^o area comprises fully 33.1% of all New Zealand effort in the history of the Ross Sea region fishery.

One degree longitude at 72^o is ~34.46 km; one degree latitude is 111.12 km. However because the effort calculation includes sets that straddle the boundary of this 1^o x 1^o rectangle, the actual area of effort for this calculation was expanded by 3.5 km (i.e. half of a typical set length) in both dimensions. *This yields an area of 37.96 km x 114.62 km = 4351 km^2* (column F).

The results indicate that *even within the most heavily fished area of the Ross Sea region fisheries, only 0.35% of the ocean floor has come within reach of New Zealand* *fishing gear. We estimate that 0.03% of stony corals have been lethally impacted within this 1^o x 1^o area.*

9.4 Spatio-temporal considerations

Figure 5 illustrates the density of effort in the busiest 0.1^o x 0.1^o subset of this busiest 1^o x 1^o rectangle in which the impact has been calculated in Table 6. The tracks in this figure represent the 1 m wide footprints of individual lines. The width of these lines in the figure will overstate the actual footprint width at the display or print resolution achievable at this scale; lines drawn to scale would be too fine to see, with even more white space between them. It is graphically evident then that even in the most heavily fished areas there is negligible spatial overlap of the fishing impact footprints from multiple sets, except perhaps within very heavily targeted corridors that are themselves very narrow.

This observation validates our decision to ignore the temporal nature of the impacts. Because the intersection of overlapping spatial footprints is so vanishingly small, we can effectively assume that every new impact is occurring on a previously un-impacted track of the seabed, eliminating the need to consider temporal dynamics such as recovery time between subsequent impact events. In fisheries where cumulative effort is greater or where impact footprints are wider, it becomes necessary to conduct a more sophisticated temporally explicit impact assessment, in which the average interval between subsequent impacts at particular locations is assessed relative to the presumed recovery rate of the vulnerable taxa. This approach is likely to be necessary for fishing methods with considerably wider spatial footprints, i.e. bottom trawling.

9.5 Implications for impact mitigation

A potentially insightful conclusion of the cumulative impact assessments is that the estimated total impact from Scenario 1 events (in which the floats, downline, and grapnels on end of the line are captured and dragged by moving ice) is of comparable magnitude to the total impact of all standard sets (see Table 6, Column I). Despite the much smaller total footprint for all Scenario 1 events (Column E), the actual impact on vulnerable taxa is comparable because this scenario involves significant movement of heavy gear across the sea floor. This result may also reflect the conservative nature of our assumptions: the workshop assumed that all Scenario 1 events involve the movement on the sea floor of both chains and both grapnels over a distance of 3 km; in reality a significant proportion of dragged gear is likely to hang up and/or break within much shorter distances. To the extent that it is valid, this result suggests that perhaps the most effective means of impact mitigation would be to modify fishing practices and/or gear configurations to reduce the frequency of Scenario 1 events. One means of achieving this end has already been described: ‘JB lines’ (Scenario 2) use downlines with submerged floats that are relocated using a radio beacon and retrieved with a mid-water recovery grapnel, reducing the exposure of surface floats to moving ice. Other, less technologically challenging mitigations may include technical modification of surface floats to allow moving ice to pass over them without snagging or to otherwise reduce their chances of being captured.

This result also reinforces one conclusion asserted by vessel captains and observers at the workshop, that among the most important (but intangible) factors influencing the impact of fishing activities will be the specific experience of the vessel captain in Ross Sea region conditions. Workshop attendees emphasized that many of the presumably higher-impact scenario events arise directly from interactions with moving sea ice or from the added difficulties of conducting fishing operations in sea ice conditions, and that the frequency of these events declines significantly as vessel captains gain experience in the Ross Sea region fisheries. Encouraging vessel captain training, information-sharing, and the use of 'best practice' during icy fishing conditions may therefore substantially reduce future impacts. Vessel captains also suggested that regulations constraining fishing effort in space or time may have the effect of forcing vessels to fish in sub-optimal ice conditions, with an associated higher frequency of higher-impact events; conversely, allowing flexibility in fishing effort may serve to reduce associated impacts.

10. REFERENCES

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10. FIGURES

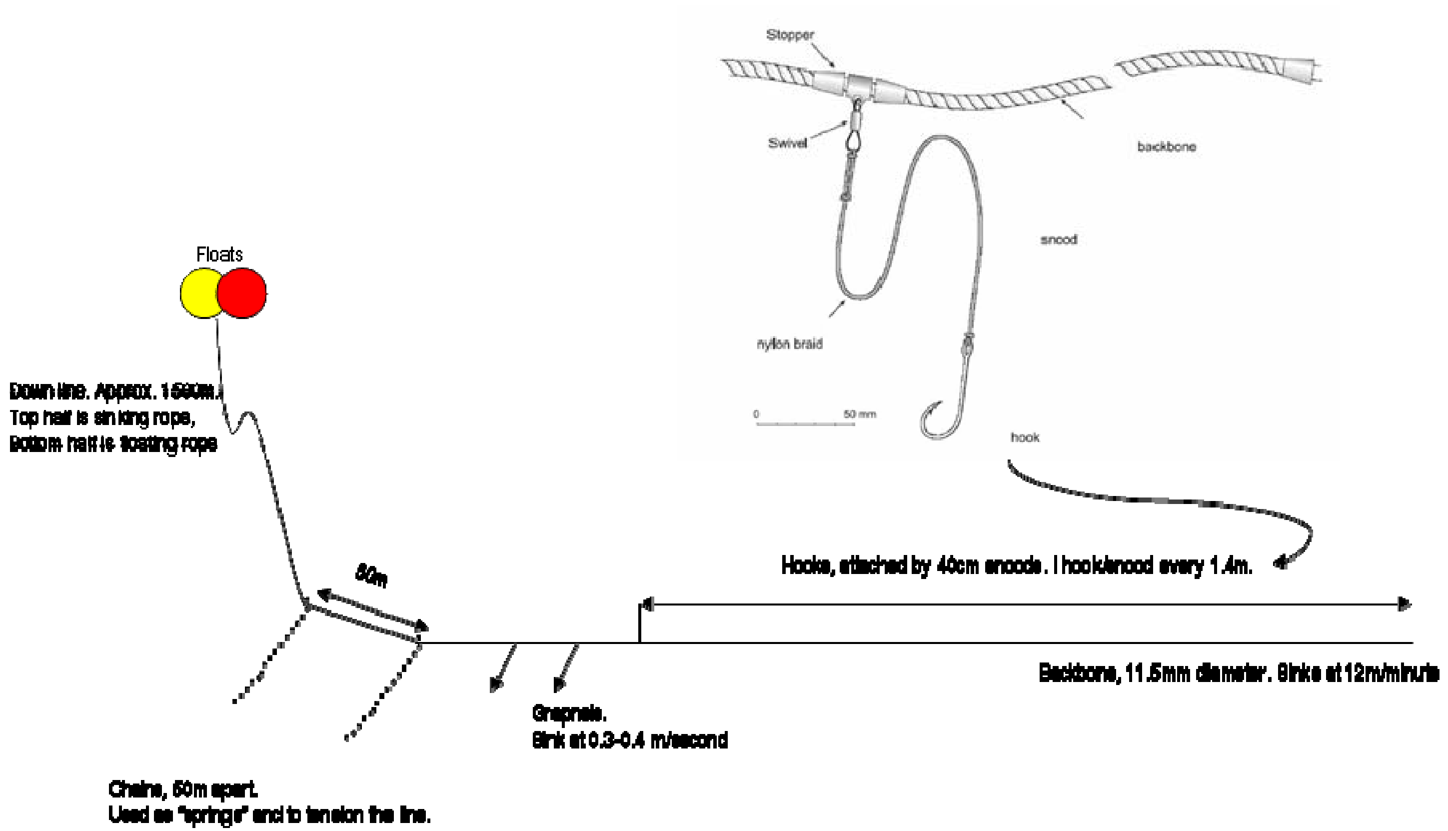

Figure 1: Standard gear deployment configuration for autoline longline vessels utilised by the New Zealand fishery. The typical line is approximately 7000 m long. A symmetrical down-line configuration occurs at each end of the line (only one end shown).

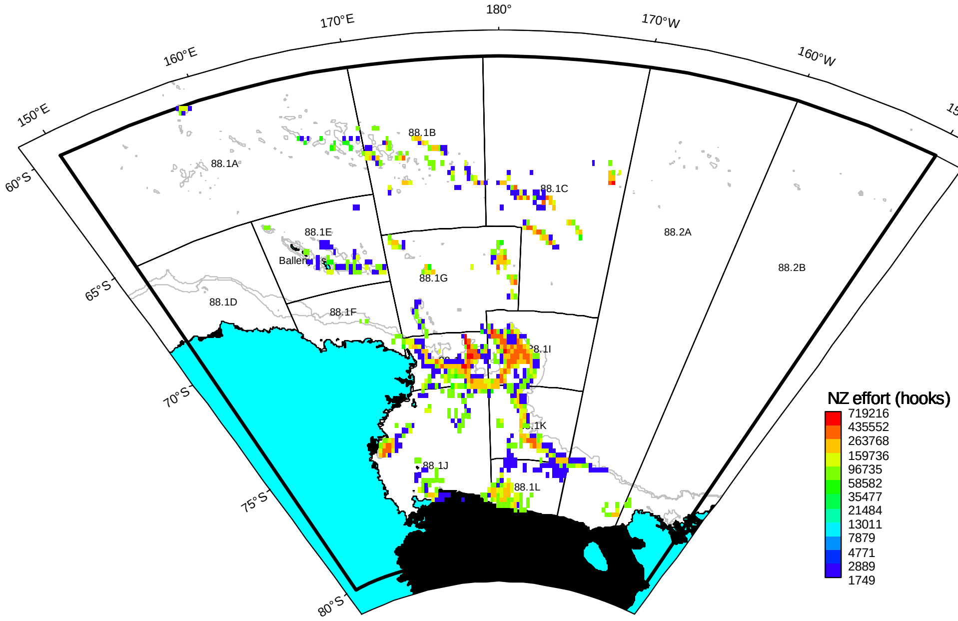

Figure 2: NZ effort in the Ross Sea region in number of hooks, from 1997 to 2008. Each rectangle is approximately 0.4° longitude by 0.2° latitude flattened. The grey lines represent 1000m and 2000m depth contours. Effort can be expressed in length of line by assuming 1 hook per 1.4 m of line.

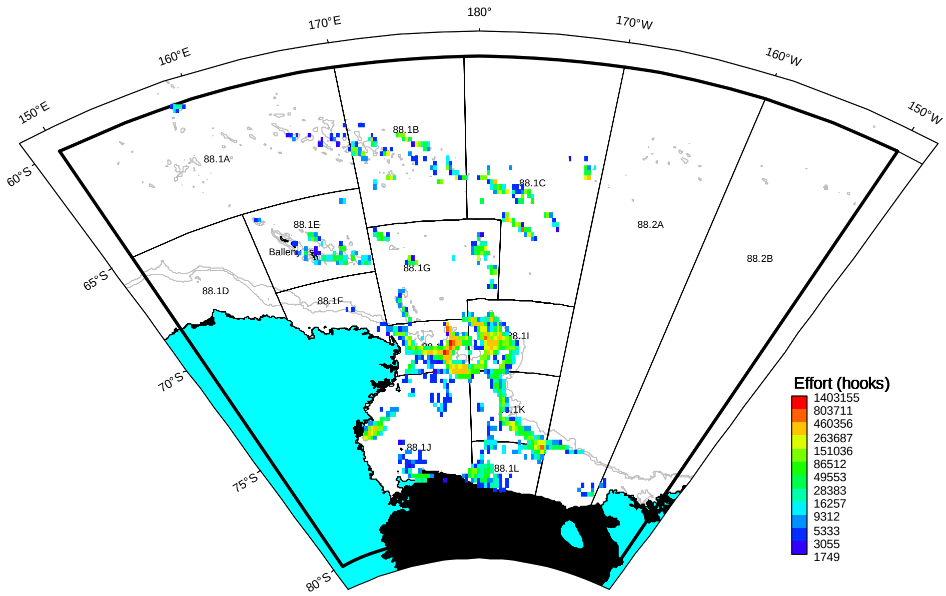

Figure 3: Total historical fishing effort in the Ross Sea region in number of hooks, from 1997 to 2008. Each rectangle is approximately 0.4° longitude by 0.2° latitude flattened. The grey lines represent 1000m and 2000m depth contours.

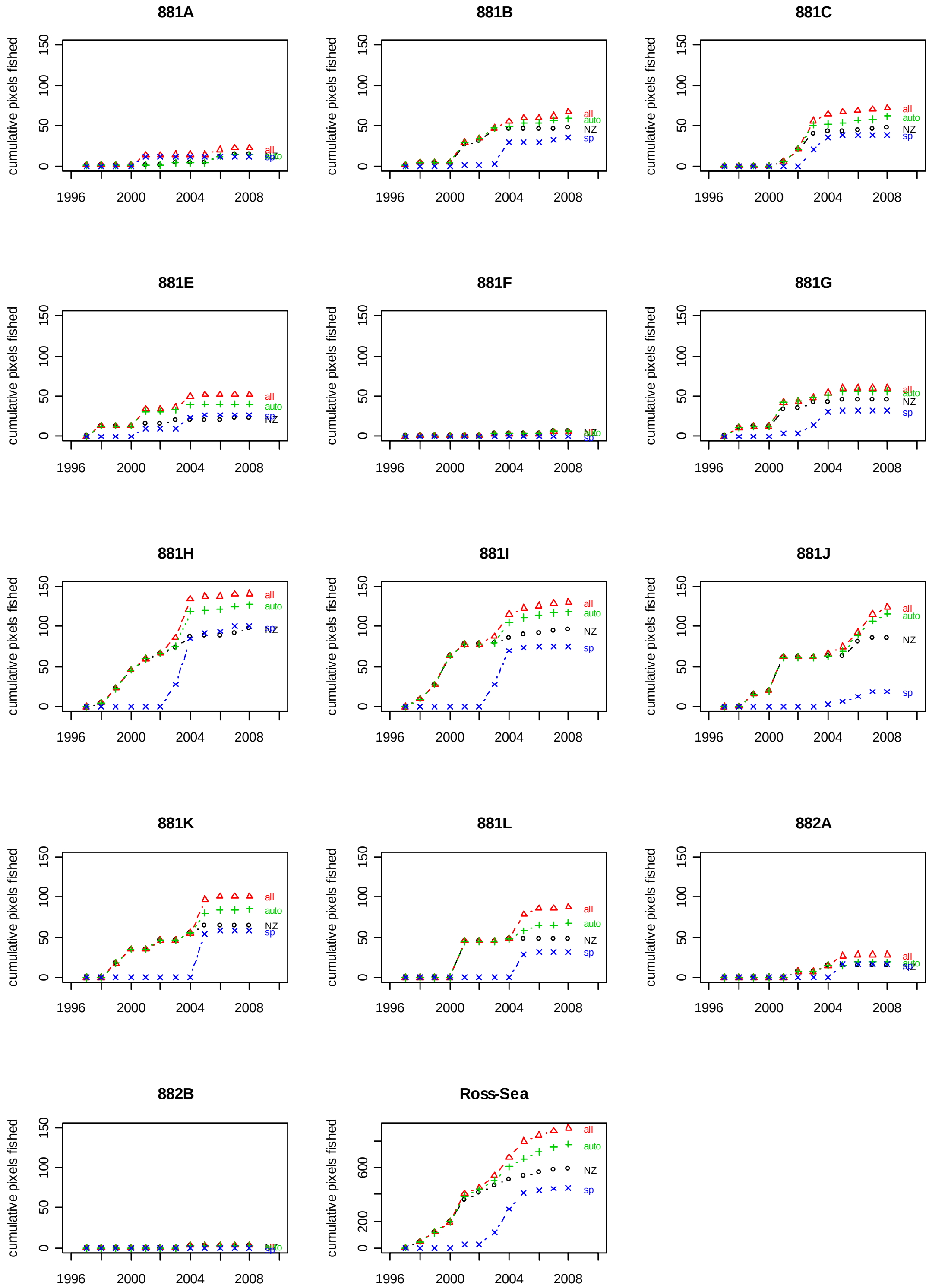

Figure 4: Cumulative number of pixels ever fished each year in each SSRU and in all SSRUs of the Ross Sea region (each pixel is approximately 0.4° longitude by 0.2° latitude flattened) by the NZ fleet, the entire fleet, all autoliners and all Spanish longliners separately.

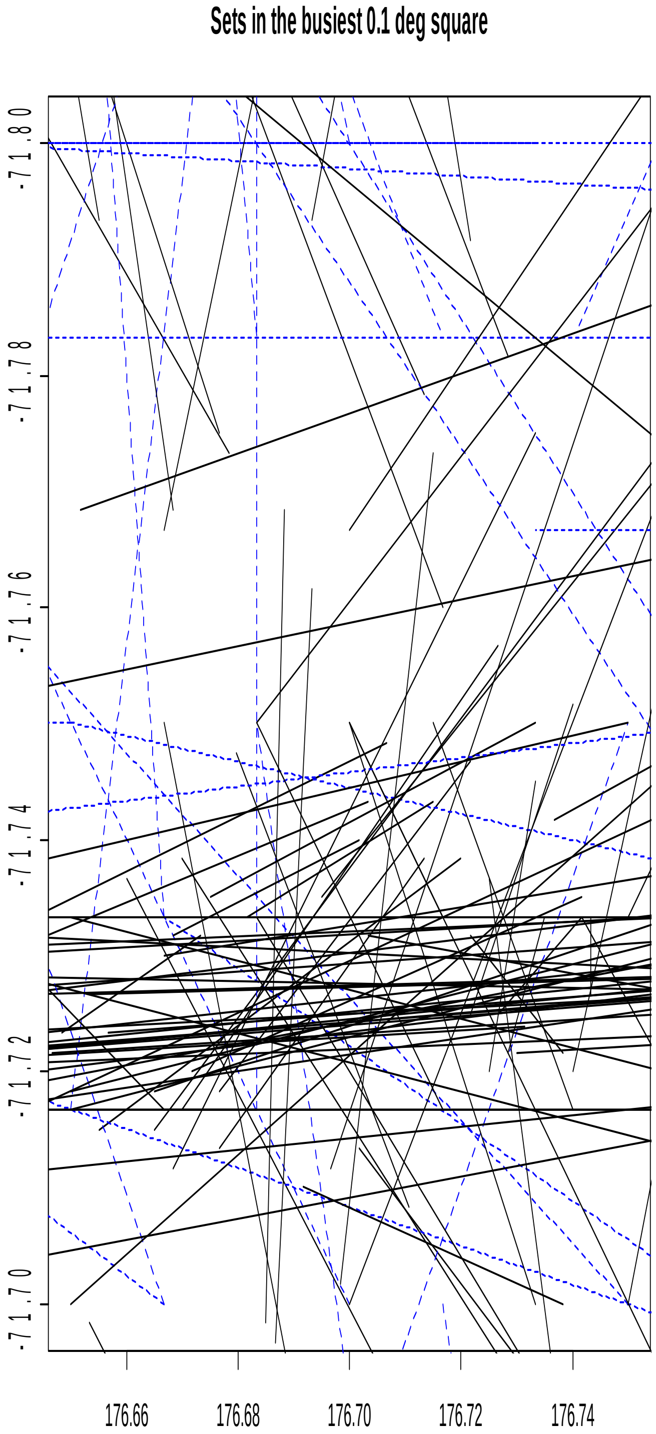

Figure 5: Location of all historical fishing sets in the most heavily fished 0.1° longitude by 0.1° latitude rectangle from 1997 to 2008. Dimensions at this latitude are approximately 3.45 km x 11.1 km. Black continuous lines represent NZ effort; blue dotted lines represent non-NZ effort. Footprints represented by these lines are assumed to be 1 m wide.