IDENTIFYING TAXONOMIC GROUPS VULNERABLE TO BOTTOM LONGLINE FISHING GEAR IN THE ROSS SEA REGION

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Abstract

Implementing measures to avoid significant adverse impacts to vulnerable marine ecosystems (VMEs) requires a specific list of the taxa that are considered vulnerable in the fishery being assessed. New Zealand identified an interim list of taxa to monitor in fishery by-catch in the Ross Sea as part of its benthic fisheries impact assessment. The rationale for including or excluding each taxonomic group is described relative to the group's fragility, longevity, organism size and spatial distribution. Additional considerations such as organism mobility, community diversity, endemism, taxonomic resolution and presence in fishery by-catch are also important. Thirteen coarse-resolution taxonomic groups are identified as vulnerable to bottom longline fishing activities in the Ross Sea region, including two indicator-only taxa.

Résumé

Pour mettre en œuvre des mesures visant à éviter des impacts négatifs significatifs sur les écosystèmes marins vulnérables (VME), il est nécessaire de disposer d'une liste spécifique des taxons considérés comme vulnérables dans la pêcherie faisant l'objet de l'évaluation. La Nouvelle-Zélande, dans le cadre de son évaluation de l'impact des pêcheries benthiques, a établi une liste provisoire des taxons à surveiller dans les captures accessoires de la pêcherie de la mer de Ross. Les critères d'inclusion ou d'exclusion de chaque groupe taxonomique sont décrits en fonction de sa fragilité, de sa longévité, de la taille de ses organismes et de sa répartition spatiale. D'autres considérations telles que la mobilité des organismes, la diversité des communautés, l'endémisme, la résolution taxonomique et la présence des organismes dans les captures accessoires de la pêcherie sont également importantes. Treize groupes taxonomiques à résolution grossière sont identifiés comme étant vulnérables à la pêche à la palangre de fond dans la région de la mer de Ross, y compris deux qui servent uniquement d'indicateur.

Резюме

Для выполнения мер по избежанию существенного негативного воздействия на уязвимые морские экосистемы (УМЭ) требуется особый список таксонов, которые считаются уязвимыми в ходе оцениваемого промысла. Новая Зеландия определила предварительный список таксонов, подлежащих мониторингу в промысловом прилове в море Росса в рамках проводимой ею оценки промыслового воздействия на бентос. Обоснование включения или исключения каждой таксономической группы описывается исходя из хрупкости, продолжительности жизни, размера организмов и пространственного распространения этой группы. Также важны такие дополнительные факторы, как подвижность организмов, разнообразие сообществ, эндемизм, таксономическое разрешение и наличие в промысловом прилове. Было идентифицировано 13 таксономических групп с низким разрешением, которые, уязвимы к донному ярусному промыслу в районе моря Росса, включая два только индикаторных таксона.

Resumen

La implementación de medidas para prevenir efectos adversos considerables en los ecosistemas marinos vulnerables (EMV) requiere de una lista específica de los grupos

taxonómicos considerados vulnerables en la pesquería evaluada. Nueva Zelandia elaboró una lista preliminar de taxones para el seguimiento de la captura secundaria de la pesquería en el Mar de Ross, como parte de su evaluación del impacto de las pesquerías de fondo en el bentos. Las razones para la inclusión o exclusión de un grupo taxonómico se describen en relación con su fragilidad, longevidad, tamaño de los organismos y distribución espacial. Otras consideraciones tales como la movilidad de los organismos, la diversidad de la comunidad, el endemismo, la resolución taxonómica y la presencia en la captura secundaria también fueron consideradas importantes. Trece grupos de baja resolución taxonómica han sido identificados como vulnerables a las actividades de pesca con palangres de fondo en la región del Mar de Ross, incluidos dos taxones indicadores solamente.

Introduction

The United Nations General Assembly (UNGA) Resolution 61/105:80 'Calls upon States to take action immediately, individually and through regional fisheries management organizations and arrangements, and consistent with the precautionary approach and ecosystem approaches, to sustainably manage fish stocks and protect vulnerable marine ecosystems (VMEs), including seamounts, hydrothermal vents and cold water corals, from destructive fishing practices, recognizing the immense importance and value of deep-sea ecosystems and the biodiversity they contain' (UNGA, 2007).

Although guidance in developing a generic definition of a VME has been provided by the Fisheries and Agriculture Organisation (FAO, 2009), a practical working definition of a VME for the CAMLR Convention Area is still under discussion by managers and scientists. There is general agreement that areas with certain characteristics would qualify as VMEs (e.g. areas containing high abundances of species that are locally endemic, habitat-forming, vulnerable to fishing gears, or requiring decades for recovery from fishing impacts). Yet, as an area decreases in size, diversity and fragile three-dimensional structural complexity, consensus becomes more difficult to achieve. Identifying and protecting truly vulnerable areas in a structured way will require clear definitions and objectives (Rogers et al., 2008). Each regional fisheries management organisation or agreement (RFMO/A) needs to tailor its definition to be applicable to the particular habitats, benthic assemblages and fisheries it manages.

Vulnerable marine ecosystems are conceptually described in UNGA Resolution 61/105 as '…including seamounts, hydrothermal vents and cold water corals'. CCAMLR has adopted this same language with the addition of sponge fields in Conservation Measure (CM) 22-06 (CCAMLR, 2009). Further, FAO has proposed several specific categories and listed examples of organisms and areas (mega-habitats) considered to be vulnerable (Annex 1 in FAO, 2009). However, by using examples instead of a definition, the guidelines avoid discussion of issues of taxonomic level, organism abundance, or local biodiversity as potential criteria for triggering a management action. The key concepts underpinning VME ecological value and conservation were described by Rogers et al. (2008), but they necessarily still leave many implementation issues to RFMOs, Regional Conservation Organisations (RCOs) (e.g. CCAMLR) and States to develop. These include specifying which taxa to consider vulnerable, how to develop and review impact assessments, how to determine impact thresholds for triggering CMs, and specifying actual criteria for designating an area as a VME.

As part of CCAMLR's consideration of UNGA Resolution 61/105, and in response to Article II of the CAMLR Convention, CM 22-06 (CCAMLR, 2009) requires specific actions to be taken when evidence of a VME is encountered in the course of fishing operations. CM 22-07 (CCAMLR, 2009) builds on this by requiring vessels to monitor by-catch in real time for evidence of an encounter with VME taxa, and to notify CCAMLR when evidence in excess of a predetermined trigger level is observed. CCAMLR then designates a 1 n mile-radius risk area around the location of the longline segment midpoint. Monitoring fishing operations for encounters with evidence of a VME entails identification of specific taxonomic groups of invertebrates, such as sponges or hydrocorals. This is important as there should be no ambiguity regarding what triggers a management action. However, in much of the CCAMLR region in question, neither the distributions of benthic invertebrates, their life histories, nor their various vulnerabilities to different types of fishing gears are known, leaving the details of what to monitor difficult to specify.

In preparing a benthic impact assessment for the New Zealand component of the Ross Sea

bottom longline fishery, New Zealand developed a working definition of what constitutes a potential VME in the CAMLR Convention Area, and identified provisional taxonomic groups to be monitored (New Zealand, 2008). To aid in identification of this subset of benthic invertebrates by observers, a classification guide was also developed (Parker et al., 2008) and was adopted by CCAMLR as an interim list of taxa to be monitored through CM 22-07 (CCAMLR, 2009). The objective of this paper is to provide a rationale for the inclusion or exclusion of particular taxonomic groups in that interim list of monitored taxa. Obviously, this requires interpreting CCAMLR's intent from CM 22-07, and integrating where useful, the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO, 2009). The FAO guidelines list five characteristics of species (ecosystems) in paragraph 42 useful in determining vulnerability.

i.   *Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include:*

  • *habitats that contain endemic species;*

  • *habitats of rare, threatened or endangered species that occur only in discrete areas; or*

  • *nurseries or discrete feeding, breeding, or spawning areas.*

ii. *Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, function, spawning/reproduction or recovery of fish stocks, particular life-history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.*

iii. *Fragility – an ecosystem that is highly susceptible to degradation by anthropogenic activities.*

iv. *Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics: slow growth rates; late age of maturity; low or unpredictable recruitment; or long-lived.*

v.   *Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features. In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.*

To provide a scientific basis for developing an approach to manage impacts to VMEs within the CAMLR Convention Area, CCAMLR sponsored an expert workshop in 2009 to provide advice on the ecology of vulnerable organisms and how they might interact with fishing gears (SC-CAMLR, 2009). An earlier version of this manuscript was a discussion paper for that workshop and the vulnerability table developed at the workshop was based on the vulnerability table developed here. The workshop developed a list of vulnerable taxa which included additional taxa considered by the participating scientists to be vulnerable to bottom longline gear, using a slightly different set of criteria to those discussed here. The intent of this paper is to provide the rationale for selecting a group of taxa to monitor the fishery rather than identifying taxa that may be considered vulnerable based on ecology alone. Consequently, the criteria of presence in fishery by-catch, and difficulty of taxonomic identification by observers are included, and excluded are two criteria considered by the VME Workshop, larval dispersal potential and the presence of rare or unique populations.

Interactions with fishing gear

Benthic invertebrates have been sampled in the Ross Sea for decades, but the spatial distribution, depth range and total numbers of samples are insufficient to describe the full range of species present, their habitats, or their potential distributions. This is especially true in relation to fished areas, as most of the scientific sampling has occurred in shallower waters of the shelf. Extant scientific information should be used to describe the distribution of these species, but it also must be recognised that most of the new information relative to fisheries impacts on VMEs will necessarily come from the fishery itself, especially information concerning the distributions and habitat types of VME taxa. Therefore, in developing a monitoring tool for detecting interactions with potential VMEs, it is important to consider how the fishery will interact with VMEs, what information will be available, and what biases may exist in that information.

CM 22-06 identifies the region to be monitored as including all areas south of 60°S and so includes the entire Ross Sea region (CCAMLR, 2009). The taxa chosen should be considered vulnerable relative to a specific threat (particular fishing methods). The use of commercial trawl gear is prohibited in that region (CM 22-05, CCAMLR, 2009), leaving the impacts to be considered as various types of bottom longline and pot gear. Only bottom longline gear is currently in use and considered here. Within the Convention Area, the Ross Sea region
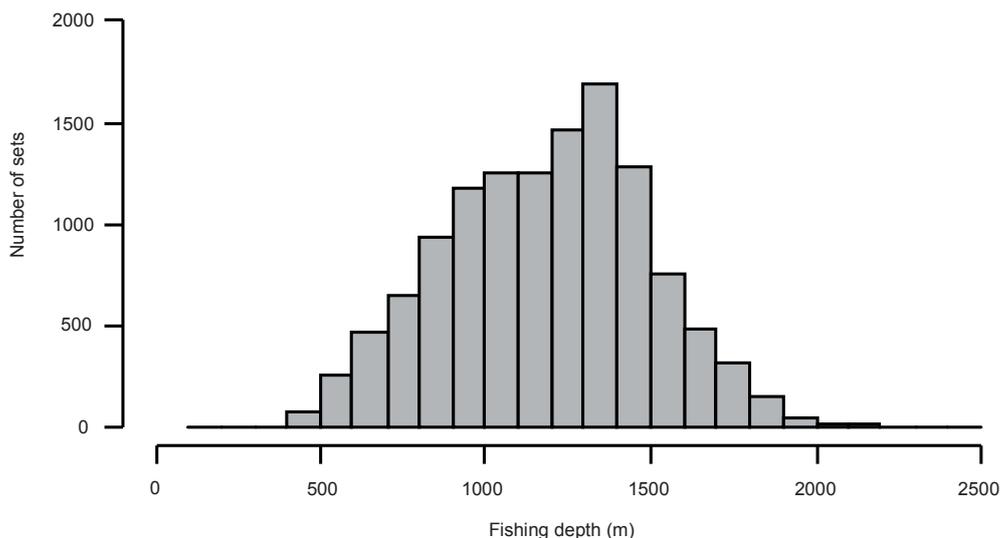
Figure 1: Depth distribution of longline sets for the Ross Sea region fisheries from catch-effort data, 1997–2009.

Table 1: Occurrences (number of times recorded) of selected invertebrate taxa from observer records on New Zealand vessels since invertebrate monitoring began in 2004.

	2004	2005	2006	2007	2008	2009
Anemones	0	43	12	4	23	158
Stony corals	40	24	22	3	45	912
Gorgonians	0	0	1	0	6	118
Sponges	32	9	25	9	28	312
Ascidians	250*	0	14	0	22	77

* Note: it is unclear why the ascidian code was so prevalent in 2004.

toothfish fisheries have typically operated in depths between 500 and 2 200 m (Figure 1). Currently, vessels are restricted to fishing in certain small-scale research units (SSRUs) and depths deeper than 550 m (Stevenson et al., 2008; CMs 41-09 and 41-10 (CCAMLR, 2009)).

The most detailed characterisation of a VME stems from the FAO International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO, 2009). The guidelines defined the term vulnerability as a function of '…the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what timeframe. These are, in turn, related to the characteristics of the ecosystems themselves, especially biological and structural aspects.' The guidelines also noted that vulnerability is a relative term and is particular to the type of threat, as different threats may have different effects (e.g. pollution versus physical disturbance).

Does bottom longline fishing in the Ross Sea encounter fragile, structure-forming organisms? Based on records of invertebrate by-catch solely from New Zealand vessels during the past several fishing seasons, the answer is yes (Table 1). However, impact is expected to vary by taxonomic group, organism size and gear configuration. The objective here is not to define selectivity for a monitoring program, but simply to evaluate whether the frequency of occurrence of each taxon in catch records is high enough to be useful as an indicator. Taxa known only from highly localised populations (e.g. Bowden et al., in press) may be particularly vulnerable to disturbance, and their presence in by-catch may therefore require immediate conservation action. However, because the catchability of some taxa by longline gear is low, rare taxa *per se* are not likely to be effective indicators of potential VMEs. Therefore, a distinction should be made between taxa to consider when designating VMEs and taxa used to monitor fishing activities for evidence of impacts to potential VMEs.

Table 1 illustrates that each year New Zealand vessels have progressively given more attention to invertebrate by-catch, along with improved identification to finer taxonomic levels. By-catch levels vary by nation and likely by fishing gear used (currently, Spanish longline and integrated-weight autoline), but are also simply a function of recording invertebrate by-catch.

Taxonomic identification

An additional constraint on the ability to use fishery by-catch for monitoring impacts to potential VMEs is that VME taxa need to be classifiable in real time by either scientific observers or crew. Although some training and training materials, such as classification guides, are available (Parker et al., 2008), the number of groups must be clearly classifiable using readily apparent characteristics. If taxa within the broad VME categories are to be treated differently in analysis or by management, it will be essential to be able to distinguish individual VME taxa. And importantly, the characteristics used in classification need to reliably distinguish VME taxa from non-VME taxa. A lack of discrimination could result in long-term displacement of fishing effort, impacting fishery performance and potentially spreading impact from an area with little conservation value to an area of higher conservation value. Parker et al. (2009) evaluated the taxonomic identifications of benthic invertebrates retained by New Zealand vessels and found that observers did well in distinguishing between different groups of VME taxa, and were excellent at distinguishing non-VME taxa from VME taxa. The main point of confusion was in classifying pink or white stylasterid hydrocorals (often dead) as Scleractinia (stony corals). This error can likely be resolved through observer training and better classification guides.

Motility

Limiting the list of VME taxa to sessile invertebrates is sensible if the goal is to protect organisms that form biogenic structures which may create or contribute to habitat for other organisms. However, motility is not a binary characteristic, and some motile animals may themselves constitute habitat for others (Tissot et al., 2006). This may be an emergent character of a community. For example, dense populations of anemones may form complex areas where individuals of other taxa find shelter from predation, yet many anemone species may actively move about.

Motile species also afford, at least in theory, the potential to be effective indicators of potential VMEs because some are known to be attracted to fishing baits and thus have a high catchability. For instance, some asteroid species are frequently caught in relatively high numbers consuming bait on longlines. If these species were known to be associated with sessile VME taxa, for instance sponges, they could be indicators of nearby VME taxa that were not sampled directly by the longline gear.

The rationale for excluding motile species can also be questioned based on life-history characteristics relating to vulnerability. If mobile species are long-lived, with low productivity, and fragile relative to the disturbance in question, then they meet the FAO characterisation of vulnerable. Vulnerability is a continuum among species, with clear examples at either extreme, but in the middle, categorising some species as vulnerable or not will ultimately be subjective.

The VME Workshop included mobile invertebrates but not fishes in its list of VME taxa, as impacts on fishes are managed through other CMs (SC-CAMLR, 2009). While motile invertebrates were included by the workshop, vulnerability was nonetheless considered to be ameliorated by motility as nearby adults could move to inhabit and recolonise impacted areas.

Presence in by-catch

The relative frequency observed in the by-catch and likelihood that various taxa could be reliably identified by observers in the Ross Sea was assessed by Parker et al. (2009). Presence in the by-catch is important to consider in designing a monitoring program, but is not required to assess vulnerability of a particular taxonomic group to fishing impacts.

Life-history characteristics

The main rationale for classifying an organism as vulnerable to particular types of fishing gear is that certain life-history characteristics make recovery from disturbance extremely slow. These characteristics are typically inter-related. Slow growth is an important limiting factor with regard to creating complex three-dimensional biogenic structure. Related to slow growth is longevity and late age-at-maturity. These three characteristics, when combined with environmental constraints on recruitment (such as limited larval dispersal, limited appropriate settlement habitat, or restrictive environmental conditions for survival), lead

to low and variable rates of colonisation and consequently slow recovery following disturbance. Given the ages estimated for many benthic taxa in the Antarctic (decades, if not centuries, see below), recovery times are likely to be extremely long relative to the likelihood of repetitive fishery impacts in a given area.

Because vulnerable taxa to be monitored via fishery data are necessarily defined at higher-level groupings such as families or orders (species-level identification is typically restricted to experts), summarising life-history characteristics of species-level attributes is problematic, especially when the full range of species in question is not known and the life histories for the known species in the deep sea are mostly unknown. Taxonomic relationships, even for higher-level taxa of several invertebrate phyla, are still uncertain, making it difficult to characterise features of selected groups. For the corals, this paper follows the high-level taxonomic classification described in Hourigan et al. (2007). For non-coral species, the classification follows the World Registry of Marine Species (www.marinespecies.org). At these higher taxonomic levels (Phylum, Class, Order), phylogenetic uncertainty is less of an issue, although the classification of basket stars and snake stars remains uncertain in this application.

Scoring process

Vulnerability is a function of the intrinsic physical (e.g. fragility) and ecological (e.g. growth rate, longevity) characteristics of the organism or taxa, and the nature of the threat, without reference to the scale or intensity of the threat. Scalar aspects of gear interactions, such as the frequency or intensity of fishing effort, are multiplied by fragility to generate an estimate of total impact (Sharp et al., 2009). Each of the characteristics contributing to vulnerability was classified as low, medium or high with reference to its contribution to the potential impact of the fishery on subsequent recovery (i.e. taxa rated 'high' could be considered at a higher risk than organisms rated 'low' for that characteristic) (Table 2).

Studies on the life-history characteristics of deep-sea invertebrates in the Ross Sea are rare, especially at the depths of the fishery. Therefore, it is necessary to extrapolate life-history characteristics derived for members of each taxon from deep-sea environments in other parts of the world. And even then, essential characteristics are not known for many groups. Where possible, characteristics relating to vulnerability such as size, growth rate, longevity, fragility, distribution, fishery observations and species associations are summarised here for

the relevant taxonomic groups. If existing literature was inadequate for some groups, the characteristic was not scored. The VME Workshop (SC-CAMLR, 2009) consisted of a number of Antarctic benthic ecology experts and additional expert knowledge was available to score some taxa. Where the scores were different, the scores of the workshop participants have been adopted.

Size

Size is an important component of structural habitat and is a useful first criterion for classifying structure-forming organisms. Lissner and Benech (1993) noted changes in community structure when substrate relief exceeded 1 m in height. Tissot et al. (2006) considered invertebrates as structure-forming if they were large (>50 cm in height), exhibited complex morphology (a strong three-dimensional aspect), or if they were >5 cm in height and occurred in high densities that changed the character of the habitat (e.g. aggregations of urchins). Organisms that typically exceed 5 cm in height above the substrate, especially if they are found in dense aggregations (e.g. encrusting ascidians) are included here for discussion. The taxa considered here have been selected primarily on the criteria of size, sessile or restricted motility epifaunal habit, three-dimensional structure and association with such habitat-forming taxa. The phyla included are Porifera, Cnidaria, Bryozoa, Brachiopoda, Chordata (sessile ascidians only) and Echinodermata (Crinoidea, Ophiuroidea and Echinoidea) (Table 2).

Growth

To scale recovery potential in relation to the frequency of impacts, a benchmark of recovery time must be proposed. Organisms that grow for decades prior to maturation may be considered as being at risk because their recovery rates could be much less than a hypothesised rate of disturbance. The potential rate of repeated disturbance in the Ross Sea fisheries is unknown as it depends on a number of factors (e.g. lateral line movement, targeting ability, total effort level and ice constraints on fishing locations). A conservative assumption is made here that organisms that require more than 10 years to mature should be considered potentially vulnerable to disturbance. Therefore, growth rates that would not allow recovery to reproductive potential within 10 years are classified as 'High' (high vulnerability). Similarly, organisms that typically live less than 10 years are assigned a longevity class of Low, 10–30 years as Medium, and more than 30 years as High.

Table 2: Summary of criteria used in assessing the potential vulnerability of selected invertebrate taxonomic groups relative to bottom longline fishing in the Ross Sea. Values are scaled to Low, Medium or High and based on the likely maximum for known species*.

Phylum	Lower taxonomic group	Size >50 cm	Longevity	Growth rate	Fragility	By-catch	Distribution	Identification
Porifera	Hexactinellida	H	H	H	H	H	H	H
Porifera	Demospongiae	H	H	H	H	H	H	M
Porifera	Calcarea							
Cnidaria	Actiniaria	L	H	L	L	H	H	H
Cnidaria	Scleractinia	H	H	H	H	L	M	L
Cnidaria	Antipatharia	M	H	H	H	L	L	H
Cnidaria	Alcyonacea	M	M	L	M	L	L	M
Cnidaria	Gorgonacea	M	H	H	H	H	H	H
Cnidaria	Pennatulacea	L	H	M	H	L	M	H
Cnidaria	Hydrozoa, Anthoathecata, Stylasteridae	H	H	M	H	H	H	L
Cnidaria	Hydroida	L			L	L		L
Bryozoa		H	H	M	H	L	H	L
Echinodermata	Crinoidea: Non-comatulid	L	H		H	L		M
Echinodermata	Ophiuroidea: Euryalida	L			H	L		H
Echinodermata	Echinoidea	L	L	L	M	L		H
Chordata:	Ascidiacea	M		L	L	M	H	M
Brachiopoda		L	H	L	M	L		M

* Size: (L = few observations exceed 50 cm in height; M = individuals may exceed 50 cm; H = many observations exceed 50 cm)

Longevity: (L = <10 years; M = 10–30 years; H = >30 years)

Growth rate: (L = mature <10 years; M = mature 10–20 years; H = mature >30 years or evidence for sporadic recruitment events)

Fragility: (L = Flexible, strong; M = somewhat flexible or tough integument; H = complex 3-d structure of brittle material)

By-catch: (L = <5% frequency of occurrence in the 2009 by-catch samples retained by New Zealand scientific observers; M = 5–10%; H = >10% (see Parker et al., 2009))

Distribution: (L = little overlap of the group within the fishery footprint based on fishery and scientific collections; M = some overlap; H = high amount overlap)

Identification: (L = significant errors distinguishing the group from other similar groups in the field (from Parker et al., 2009); M = some errors; H = very few errors). Note this score indicates the suitability for use as a monitored taxonomic group, not vulnerability.

Fragility

Rating an organism's fragility relative to damage or dislodgement by the various components of bottom longline gear is necessary to assess vulnerability, and was evaluated through an expert assessment process (Sharp et al., 2009). Through this process, organisms that are flexible or with tough integuments were scored lower than organisms that are brittle, delicate, or have a morphology very susceptible to entanglement in longline gear.

Distribution

To describe the distribution of potentially vulnerable taxa in the Ross Sea region, data for each taxon were extracted from three sources: NIWA's Invertebrate Collection (NIC) (http://obis.niwa.co.nz/index.do), the Scientific Committee on Antarctic Research's portal for the Marine Biodiversity Information Network (SCAR-MarBIN, www.scarmarbin.be), and samples retained by New Zealand scientific observers during the 2009 Ross Sea toothfish bottom longline fishery (NZ Ministry of Fisheries). Data collected on specimens of selected taxa catalogued in each of these databases were groomed and combined to provide an indicator of the occurrence, distribution, depth and diversity of those taxa within the Ross Sea region (60–80°S 150°E–150°W). The resulting dataset includes 7 084 observations of relevant taxa in the Ross Sea region. These distributions were used to assess potential overlap with fishing effort (Table 2). The VME Workshop recommended

that distribution should be assessed relative to the distribution of fishing effort but not as an intrinsic component of vulnerability (SC-CAMLR, 2009).

Indicators of vulnerable taxa

One important but difficult to assess aspect of VME characterisation is the degree of association between various invertebrate groups. Associations are typically found between certain species, not broad taxonomic groups. The actual mechanism of linkage is not important for VME characterisation. Simple spatial co-occurrence is all that is required for use as an indicator. Because so few direct observations have been made, it is not known if any observed associations are obligatory or facultative (Auster, 2005). If associations are known (either through similar habitat preferences or linked ecologies), that information should be incorporated into the evaluation and designation of VMEs. Long-term associations of basket stars and snake stars on gorgonians and antipatharians are well known (Grange, 1991; Metaxas and Davis, 2005), and several fish species are known to live among corals and sponges (Brodeur, 2001; Heifetz, 2002; Husebø et al., 2002; Krieger and Wing, 2002; Buhl-Mortensen and Mortensen, 2005; Etnoyer and Warrenchuck, 2007). If these associations could be used in a predictive sense, they would be useful taxa to include in habitat suitability (such as maximum entropy) models for predicting potential locations of VMEs (Elith et al., 2006; Tittensor et al., 2009).

Phylum Porifera

Sponges are abundant throughout the Ross Sea region and after asteroids they are the most frequently recorded invertebrate taxon (Parker et al., 2009). The depth range over which they are encountered in the fishery is 1 000–1 300 m (Figure 2), but scientific collections show sponges are common on the Ross Sea shelf and extend from the littoral to more than 4 000 m depth (Janussen et al., 2004). Many sponges are small, but several species can attain large size (>1 m) and may be locally very abundant. All three classes of Porifera exist in Antarctic waters, and although Demospongiae is the most speciose class (McClintock et al., 2005), hexactinellid sponges are highly abundant and can occur in extremely dense patches, creating spicule mats up to 2 m thick. These mats can be extensive and form a habitat for many other species (Barthel, 1992; Gutt, 2007). Although patchiness in distribution is mainly driven by ice-scouring patterns on the shelf, the presence of spicule mats is considered to be one of the major community structuring factors in the Antarctic benthos (Barthel and Gutt, 1992; Gutt and Koltun, 1995).

Leys and Lauzon (1998) reported growth rates of 1.98 cm year^{-1} of the hexactinellid sponge *Rhabdocalyptus dawsoni* in a British Columbia fjord, extrapolated to 220 years of age for large specimens. Recent dating work indicates that Antarctic sponges of the common genus *Rossella* can be more than 400 years old (Fallon et al., 2010). For sponges such as *Rossella* which exhibit indeterminate growth, individual colony size can indicate relative age. However, growth rates for some sponge species in McMurdo Sound have been reported to be irregular, some showing no growth for over a decade, and others showing relatively large interannual changes in size (Dayton, 1979). Although the marine invertebrate growth rates in the Antarctic are slow compared with similar organisms elsewhere, growth rates among Antarctic marine invertebrates are variable and will influence the recovery of these organisms from anthropogenic disturbance.

Resistance of sponges to damage or mortality from longline gears has not been quantified but would obviously vary with organism size, shape and attachment method, and therefore taxonomic species. Sponges are often retained and brought to the surface by longline hooks (Parker et al., 2009). Changes in orientation due to dislodgement would influence a sponge's ability to filter water. Sponges monitored for recovery after damage have shown variable responses, some repairing the damage quickly, while others cease growth or subsequently die (Dayton, 1979; Kaiser et al., 2006). Sponges are also known to serve as habitat for a myriad of species, making them important factors in structuring community composition (Klitgaard, 1995; Beaulieu, 2001).

Phylum Cnidaria

The life histories of Cnidarians vary significantly among the various classes and orders. Class Cubozoa and Scyphozoa are not benthic and are not considered here. Within the Anthozoa, the hexacoral orders Scleractinia, Antipatharia, Actiniaria, Zoanthidea, and the octocoral orders Alcyonacea, Gorgonacea and Pennatulacea are sessile and many species contribute to biogenic structural habitat. Subclass Ceriantipatharia was not considered structure-forming by Hourigan et al. (2007), but NAFO's rationale for VME taxa does include tube-dwelling anemones as vulnerable (and also includes black corals in the subclass Ceriantipatharia instead of Hexacorallia,
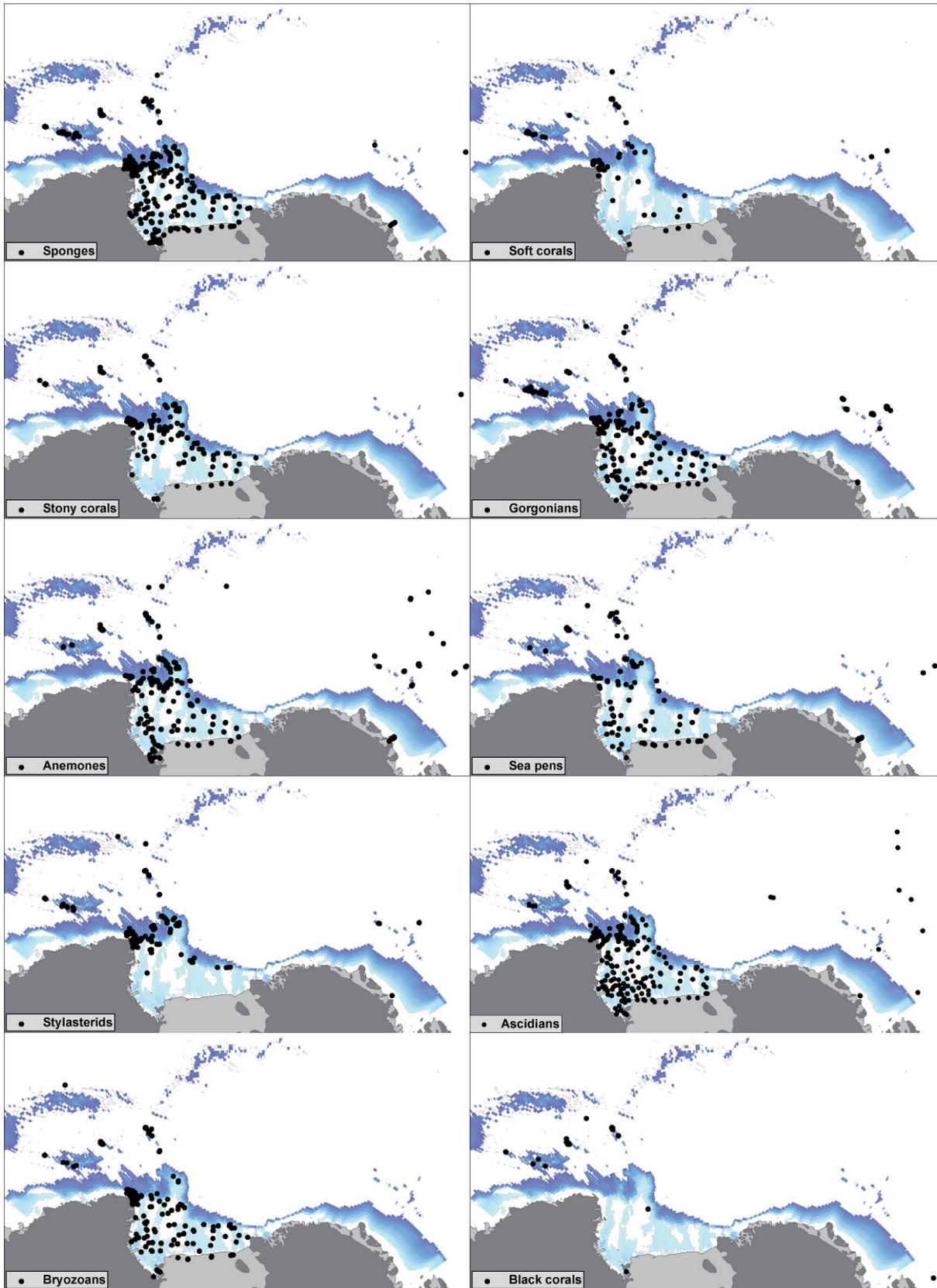
Figure 2: Distribution of selected taxonomic groups in the Ross Sea region based on samples from New Zealand's NIWA Invertebrate Collection, SCAR MarBIN and CCAMLR-2009 retained samples from New Zealand scientific observers. Bathymetry from 500–2 500 m is shaded light to dark.
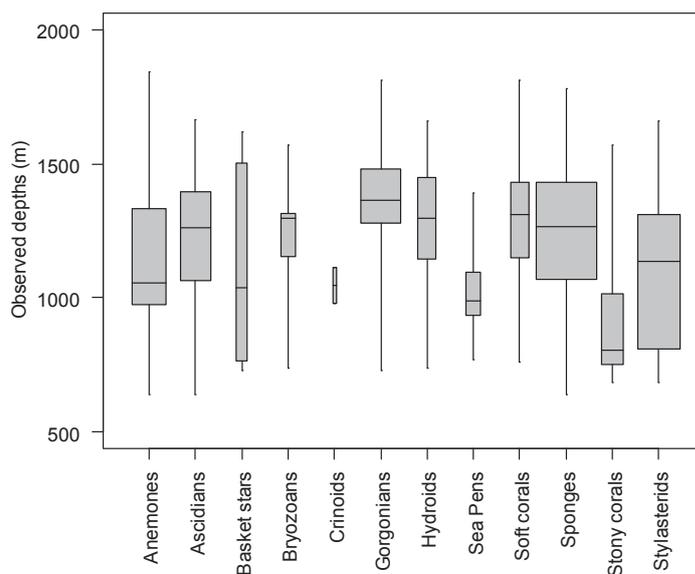
Figure 3:   Scaled depth distribution of potentially vulnerable taxonomic groups from the 2009 Ross Sea longline fishery. Boxes show inter-quartile range, horizontal line indicates median and vertical lines indicate range. Box width is proportional to number of observations. Note, fishing is not allowed in waters shallower than 550 m (Conservation Measures 41-09 and 41-10 (CCAMLR, 2009)).

indicating the uncertainty in taxonomic position) (Fuller et al., 2008; NAFO, 2008). Within the class Hydrozoa, only the order Hydroida and the family Stylasteridae (Anthoathecata) were included here as structure-forming taxa. Other orders have not been reported in by-catch samples to date from the Ross Sea region.

Scleractinia

Stony corals are found in the Ross Sea but the species present are solitary cup corals, not reef-forming species such as *Solenosmilia variabilis*, which is present elsewhere in the South Pacific. Matrix-forming scleractinians have been observed within the Southern Ocean (A. Rogers, pers. comm.), but not within the Ross Sea region. In the Ross Sea region, scleractinians have mostly been found on the outer shelf near the slope edge and on some seamounts to the north and west of the Ross Sea. Within the depths fished in 2009, they are uncommon in waters deeper than 1 000 m (Figure 3). The species recorded are mostly *Caryophyllia antarctica*, *Gardineria antarctica* and *Flabellum impensum*. These species are relatively small (<10 cm), and often grow attached to other biogenic structure, although *F. impensum* is free-living and may live on soft sediments. Some deep-water cup corals

(e.g. *Desmophyllum* sp.) grow very slowly (0.5–2 mm year⁻¹) and may live for more than 200 years (Risk et al., 2002; Adkins et al., 2004).

Actiniaria

Anemones are found throughout the Ross Sea and in eastern regions of Subarea 88.2. Observations from the fishery show anemones are common in by-catch from 1 000–1 300 m depth, though anemones from scientific collections have been sampled from the littoral to 5 000 m. Specimens from at least 13 families encompassing 19 species have been documented in the region. The most commonly observed species are *Stomphia selaginella*, *Capnea georgiana* and *Hormathia lacunifera*. Lacking permanent structural components, anemones are difficult to age, though monitored specimens from tropical reefs and in aquaria have lived for decades, and temperate anemones have been estimated to reach 50–210 years (Ottaway, 1980). Anemones can provide a structural component of habitat because of their size or creation of surface complexity when in dense patches. Anemones may be less fragile to some types of fishing gears than other taxa with hard skeletons because they can contract, flex and right themselves when impacted by gear as long as they are not hooked.

Zoanthidea

Although zoanthids occur in many forms, the individuals of the genus *Gerardia* may reach 3 m in height are found in deep waters globally (at least to 400–600 m). A *Gerardia* specimen taken from 630 m near the Bahamas was aged using amino acid composition at 250 years, which conflicted with a radiocarbon age estimate of 1 800 years (Goodfriend, 1997). Subsequently, several specimens have been shown to be extremely long lived with estimated trunk radiocarbon ages of more than 2 000 years (Roark et al., 2006). Zoanthids had been observed in the Ross Sea, and accordingly were not included in the proposed list of vulnerable taxa. However, expert opinion at the VME Workshop indicated that they did exist in the Southern Ocean and should be included in a monitoring program.

Antipatharia

Black corals, though present in the Ross Sea, appear to be more common near the Balleny Islands and on seamounts to the north. They are very rare in fishery by-catch, but are observed occasionally. They can be large, reaching over 3 m in height and may exhibit branching (bushy, pinnate or fan shaped) or whip-like growth forms (Lumsden et al., 2007). They have been found from very shallow water on the Ross Sea shelf to almost 5 000 m depth. The most common genus observed is *Bathypathes*, but another nine genera have been documented and a number of specimens in collections have not yet been identified to genus level. Although no data on the longevity of antipatharians in the Southern Ocean exist, antipatharian corals have been observed to grow relatively quickly in waters near Hawaii (>60 mm year^{-1}) (Grigg, 1976) and live about 40 years. A black coral specimen off the California coast was estimated to be more than 140 years old (Love et al., 2007). But species in deeper waters grow much more slowly and have been estimated to live more than 2 300 years (Roark et al., 2006; Roark et al., 2009; Sherwood and Edinger, 2009).

Alcyonacea

Soft corals have been sampled relatively infrequently deep on the Ross Sea shelf, slope, and on some of the northern seamounts and seamounts in Subarea 88.2. However, some species are abundant in shallow water and their ecology has been described in McMurdo Sound (Slattery and McClintock, 1997). Depth distribution in the Ross Sea overlaps fishery depths, but no soft corals have been observed deeper than 2 000 m. Some of the deep-sea species can be large and a few species can form dense aggregations, forming an encrusting layer of polyps. The most commonly observed genus in deeper water is *Anthomastus*, which can be large and exhibit a complex three-dimensional structure. Little is known about the longevity or growth rates of soft corals, especially in deep-ocean environments, but growth models to date suggest deep-ocean species grow slowly and live longer than the 30 years estimated for more shallow species (McFadden, 1991; Cordes et al., 2001). Experiments conducted with shallow-water soft corals in McMurdo Sound indicated fast growth rates relative to other taxonomic groups while they were small (up to 80 mm year^{-1}), but that growth slows dramatically, or even stops, once the mean colony size is attained (Slattery and McClintock, 1997).

Many taxonomists consider Alcyonacea to include gorgonians, however, they are separated here because of the contrast in structure-forming characteristics.

Gorgonacea

Gorgonians are the typical example used when describing the characteristics of VME taxa (Figure 4) and are a major structure-forming coral group with diverse morphologies in the deep ocean (Hourigan et al., 2007). Some species can be more than 3 m tall, consisting of complex branching structures with brittle skeletons that can be easily dislodged, broken, or entangled in fishing gear. A specimen of the genus *Primnoa* was documented at more than 7 m in width in Alaska (Krieger and Wing, 2002) and specimens of *Paragorgia arborea* of similar size have been recorded in by-catch from deep-water fisheries in New Zealand waters. Age and growth estimates exist from several families of deep-sea gorgonians because many species have hard, calcified or proteinacious skeletons. Growth rates are very slow (linear growth estimates of 1.5–40 mm year^{-1}; and radial growth of 0.05–1.3 mm year^{-1} (Grigg, 1976; Risk et al., 2002; Andrews et al., 2002; Andrews et al., 2005; Mortensen and Buhl-Mortensen, 2005; Tracey et al., 2007; Sherwood et al., 2006; Sherwood and Edinger, 2009)). Corresponding age estimates of these samples range up to 700 years. Gorgonians include the Isididae (bamboo corals), Coralliidae (red and pink corals), Paragorgiidae (bubble gum corals) and Primnoidae. These families are commonly observed and mostly distinguishable by gross morphometric characters, making field identification possible by fishery observers. In the Ross Sea, specimens are dominated by the primnoids (especially *Thourella* spp.) and bamboo corals. Gorgonian depth distributions in the Ross Sea ranges from very shallow to more than
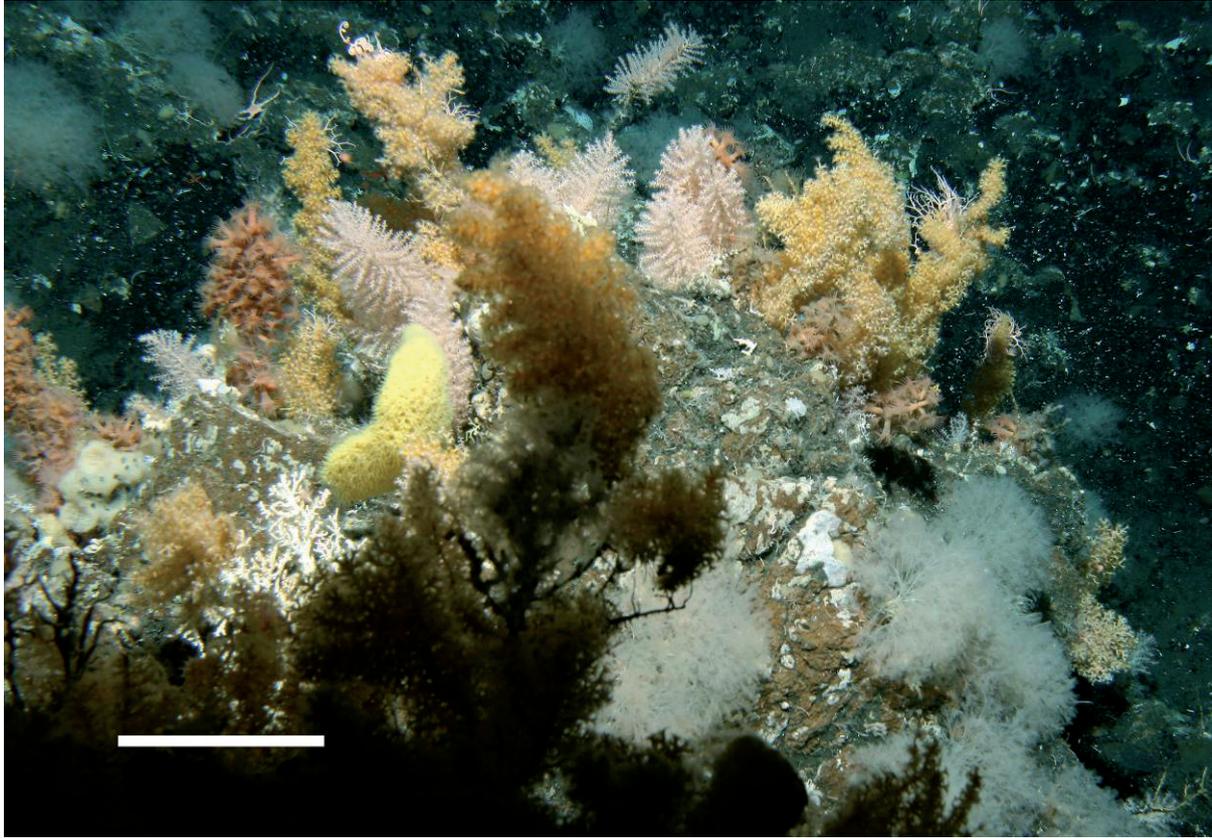
Figure 4: Assemblage dominated by gorgonian sea fan corals (*Thourella* spp.), soft corals (Alcyonacea), bryozoans and sponges at 550 m depth. Scale bar shows 20 cm. Photo by NIWA.

Figure 5: Bryozoan assemblage at 450 m depth on the Ross Sea shelf. Scale bar shows 20 cm. Photo by NIWA.

3 000 m, but they are most common in the fishery at 1 300–1 500 m. Worldwide, they have been found at more than 3 500 m depth (Etnoyer and Morgan, 2005). Interestingly, fishery samples have included a number of Coralliidae specimens (Parker et al., 2009), which have not been noted to date in scientific collections from the region. However, this may be a sampling artefact because fishery depths are not well represented in the scientific collections.

Pennatulacea

Sea pens are adapted to live in softer sediments, and may therefore have a different exposure to fishing gear depending on the habitat targeted by the fishery. Sea pens are found from littoral to abyssal depths (Williams, 1995), but in the Ross Sea longline fishery by-catch they are most common near 1 000 m depths. Scientific and fishery samples in the Ross Sea have been dominated by the genus *Umbellula*, which can be well over 1 m in height with a head of large polyps on a flexible thin stalk. The axial rods of sea pens are easily damaged by trawl gears as shown in the Bering Sea (NPFMC, 2009). Longevity of *Halipteris willemoesi*, found in dense aggregations in the Bering Sea, was estimated at approximately 50 years (Wilson et al., 2002). Dense aggregations of sea pens have also been noted to harbour exploited fish species, such as *Sebastes alutus* (Brodeur, 2001).

Hydrozoa: Hydroida and Stylasteridae

Within the class Hydrozoa, two groups could be considered to be structure forming: the hydroids and stylasterid hydrocorals. Hydroids are relatively common on the Ross Sea shelf and shelf break in scientific observations, but are not often observed in fishery by-catch (<2% of VME taxa observations in 2009). The most common genus observed is *Staurotheca*. It is not known if hydroids are simply not common at fishery depths, are not retained by fishing gear, or if their relatively small size limits catchability. Hydroids are also often found attached to other structure-forming species, making their use as indicators of vulnerable taxa less informative.

The major structure-forming hydrozoans in the deep ocean are stylasterid hydrocorals (order Anthoathecata). Other families within Anthoathecata occur in shallow water and are not present in Antarctic waters. Although stylasterids can be found in shallow water, they are common throughout the depth range of the Ross Sea longline toothfish fishery, particularly in areas of high current flow along the continental shelf break and upper slope. They are rarely observed deeper than 1 500 m and their relative absence on the Ross Sea shelf is conspicuous (Figure 2). However, stylasterids were the most common VME indicator organism by-catch observed in the 2009 New Zealand Ross Sea longline fishery, at 31% of the specimens collected (Parker et al., 2009). Little information on growth rate or longevity is available, but some estimates of individual colony ages in New Zealand fjords approached 30 years of age (Miller et al., 2004). Stylasterids can be large, up to 1 m in height in Alaska (Stone, 2006), and having a coarse texture and brittle skeleton makes them very susceptible to fishing gear impacts, which may be the reason behind the high number of observations in the fishery relative to scientific observations.

Phylum Bryozoa

In the Antarctic, bryozoans are a diverse group (Barnes and Griffiths, 2008), with a large proportion of erect and foliose growth forms, and they form an important structural component of the benthic assemblages (Figure 5). Colonies can exceed 30 cm in height, and on the Ross Sea shelf often exist in high densities that create a complex substrate. Bryozoa are distributed across the entire Ross Sea shelf, and are also present around the Balleny Islands and northern area seamounts. No samples have been collected from the eastern Ross Sea region, but they are found along the Antarctic Peninsula, sub-Antarctic islands and southern Chile, and they have been collected throughout the depth range of the fishery. Erect growth forms are brittle and easily damaged by fishing gear impacts, and in all forms growth is slow (~2–8 mm year^{-1}) (Barnes, 1995; Barnes et al., 2006; Bowden et al., 2006; Barnes and Conlan, 2007; Smith, 2007).

Phylum Chordata, class Ascidiacea

Ascidians are sessile tunicates that can form dense populations in the Antarctic, particularly in shallower shelf waters (Primo and Vázquez, 2007). The larger solitary and stalked species, such as *Cnemidocarpa verrucosa*, can grow to 30 cm or more and can dominate benthic assemblages. From existing scientific collections, ascidians appear to be ubiquitous in the Ross Sea, with observations throughout the shelf, slope, northern seamounts, and on seamounts to the east in Subarea 88.2 (Figure 2). Indeed, SCAR-MarBIN's database includes over 2 300 samples from the Antarctic region, with most of those samples from the Antarctic Peninsula. Little information exists on longevity, but growth rates of ascidians generally are fast, and experiments have indicated genetic control of lifespan in some colonial species which
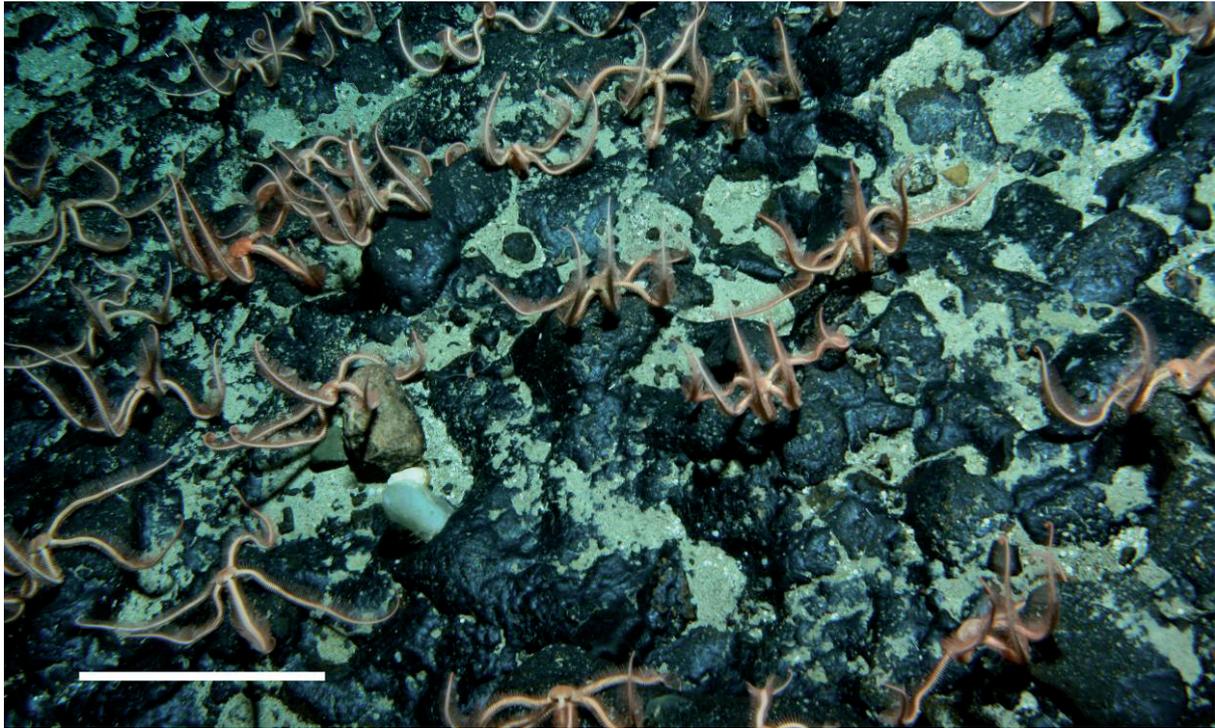
Figure 6:   Aggregation of suspension-feeding ophiuroids (*Ophiocamax* sp.) at 790 m depth. Scale bar shows 20 cm. Photo by NIWA.
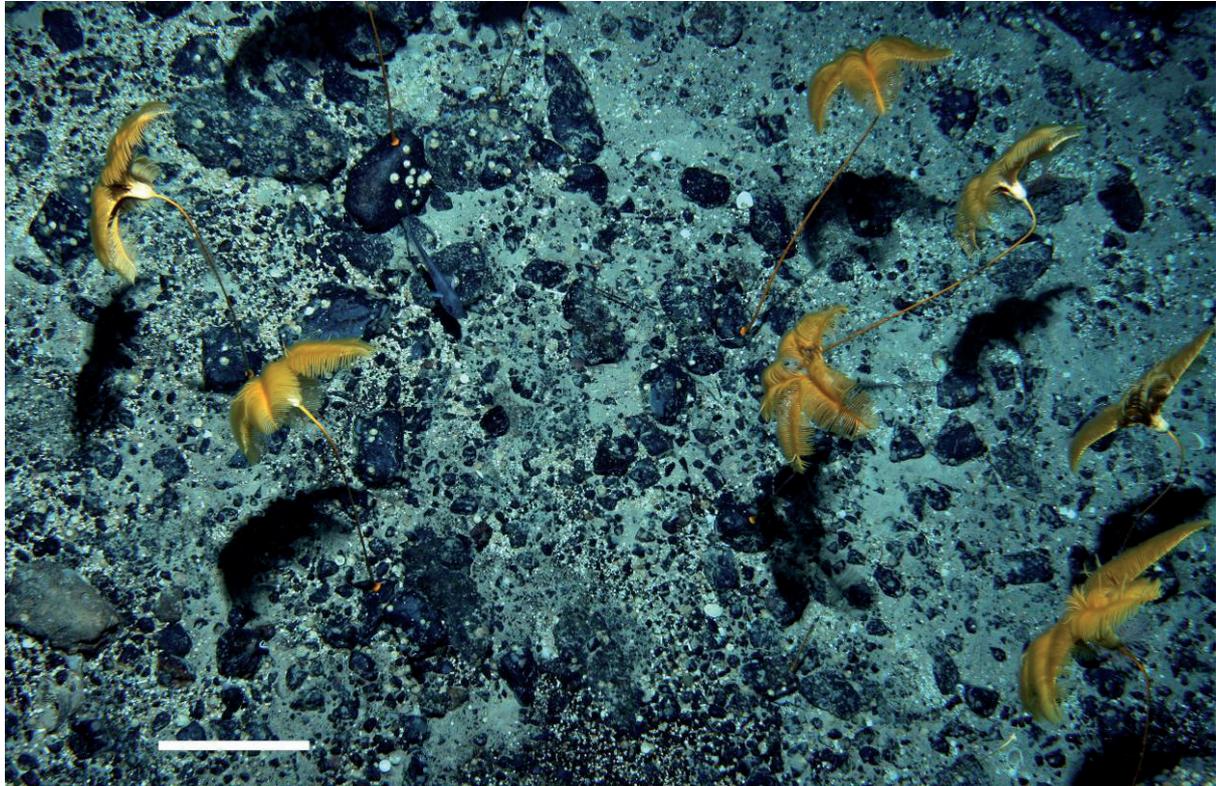

Figure 7:   Stalked crinoids (Hyocrinidae, genus and species undescribed) on Admiralty seamount. Scale bar shows 20 cm. Photo by NIWA.

could limit maximum age (Chadwick-Furman and Weissman, 1995; Rinkevich et al., 1992). Data available for Antarctic species are mostly limited to distribution and population density, but recruitment studies indicate more rapid growth than for other common Antarctic sessile taxa such as bryozoans and sponges, with some solitary species growing to 25 cm in three years (Rauschert, 1991). It is likely that solitary and stalked ascidians will be susceptible to longline hooks, but fragility will be dependent primarily on size and potentially tunic structure, as solitary species have tough leathery walls, while colonial species are structurally less robust.

Phylum Brachiopoda

Brachiopods are sessile, similar in appearance to bivalve molluscs with very fragile shells, are typically less than 40 mm in diameter and can occur in dense aggregations. They are captured as by-catch in the Ross Sea longline fishery, though often likely misidentified as molluscs. Growth rates for the common species *Liothyrella uva* on the Antarctic Peninsula are in the region of 1–2 mm year^{-1} (Peck et al., 1997). Life spans for Antarctic species are estimated at more than 50 years (Brey et al., 1995b; Peck and Brey, 1996). Based on video observations, brachiopods can occur in dense aggregations, but are caught infrequently by longlines or other gears and thus are poor VME indicators for present purposes.

Phylum Echinodermata

The echinoderms are a diverse group with many species that generally do not fit the criteria for vulnerability to longline gear neatly. Some groups, such as asteroids, are commonly observed in scientific collections and as fishery by-catch, the latter enhanced by an attraction to longline baits. Many other groups have not been observed as by-catch in the fishery, are small, motile and do not form dense aggregations. However, some groups, such as stalked crinoids clearly do match the criteria, and still others, such as some ophiuroid and echinoid species may be considered vulnerable because they form dense aggregations that change the structural character of the substrate (Tissot et al., 2006) (Figure 6).

In defining vulnerable taxa, New Zealand included the concept of indicator taxa. That is, organisms that were marginally vulnerable by the FAO criteria, or organisms that were likely to be associated with vulnerable taxa or their habitats. This was done to utilise as much information as possible from the known distribution of invertebrates in the Ross Sea and from fishery by-catch. Stalked crinoids (non-comatulid) and basket stars (defined as order Euryalida) were considered for these reasons. Although vulnerable to damage and capture by longline fishing gear, their contribution to structural habitat, limited information on longevity and limited potential motility led New Zealand to classify them as indicator taxa that were useful to monitor relative to the distribution of other vulnerable taxa.

Stalked crinoids are likely to be especially vulnerable to longline gear, but are not often observed as by-catch at the surface. Only two specimens have been recorded from almost 500 observed longline sets in the Ross Sea. It is not known if this is because of little overlap with fishery habitat, rareness, or poor catchability. Video recordings from the Admiralty seamount show patchy aggregations of these crinoids on knolls on the north and south flanks of the seamount (Figure 7). Longevity for some stalked crinoid species in the tropics has been predicted from growth experiments to be 10–15 years, with a range of reported growth rates (Duco and Roux, 1981; Messing et al., 2007). However, the hyocrinid species found recently in the Ross Sea, particularly at Admiralty seamount, are apparently highly localised in distribution and are thought to be slow-growing and considerably older than the tropical taxa (C.G. Messing, pers. comm.).

Basket stars were also included as a monitored group because they are filter-feeders, and are often observed on hard-substrate habitats associated with other vulnerable taxa. Because of their relatively large size and complex morphology, it is thought that their catchability by longline gear is higher than for other more fragile taxa. Their response to disturbance is typically to coil their arms, which results in entanglement or arm loss when the disturbance is from fishing gear. Longevity of basket stars is not known but ophiuroids generally, including polar species, are thought to live typically to 10–15 years (Tyler and Gage, 1980; Quiroga and Sellanes, 2009).

Echinoids (sea urchins) are motile, relatively small (~5 cm in height) and in the deep Southern Ocean have not been reported to form dense aggregations. Thus, they do not rank highly as habitat-forming taxa. However, cidaroid urchins ('pencil' urchins) are well represented in the Southern Ocean and are known to host distinctive assemblages of sessile organisms on their spines. The most abundant Antarctic echinoid, *Sterechinus neumayeri*, grows slowly and in the McMurdo Sound region attains maximum size after ~40 years, but longevity beyond this is unknown (Brey et al., 1995a). Although echinoids are found from littoral through

abyssal depths, they are rarely captured in the Ross Sea fishery (and then usually as small individuals living on another taxon). However, deep-sea echinoids are fragile, and the impact of laterally moving bottom longline gear (or heavy components of that gear) may lethally impact individuals.

Chemosynthetic taxa

Chemosynthetic taxa fit the definition of vulnerable mainly due to their dependence on highly localised and relatively rare habitats for an energy source. Many of these fauna also characteristically form dense aggregations and thus create significant three-dimensional structures. There are no published records of chemosynthetic ecosystems in the Antarctic, but recent discoveries of hydrothermal activity in the Scotia Arc make it probable that chemosynthetic fauna will be found (A. Rogers, pers. comm.). Further consideration of these specialised groups, and research concerning their spatial distribution, will be needed.

Other taxa

Several additional taxonomic groups abundant in the Antarctic have been omitted from this characterisation because they do not meet the main vulnerability criteria of having large size, contribute large-scale structural components to habitat, have high longevity and slow growth, and are fragile relative to bottom longline fishing gear. Many groups of infauna (e.g. annelids) could be classified this way, as could some macro invertebrates (e.g. larger crustaceans). The VME Workshop (SC-CAMLR, 2009) methodically evaluated potential additional taxonomic groups and included an additional five groups as vulnerable: Serpulid worms, barnacles of the family Bathylasmatidae, the Antarctic scallop (*Adamussium colbecki*), Phylum Pterobranchia, Phylum Xenophyophora and communities associated with chemosynthetic vents. It noted that the life-history characteristics and physical structure of these groups made them fragile to bottom longline impacts, although the actual risk associated with those impacts would depend on the scale and intensity of the fishing effects.

Diversity and endemism

Both high biodiversity and high levels of endemism have been cited as reasons for the protection of VMEs from human disturbance. The Antarctic benthos in general is characterised by high levels of endemism in many taxonomic groups (Clarke and Johnston, 2003). However, endemism at the scale of community assemblages within the Antarctic is much harder to define because much of the region has not been sampled, and there is increasing evidence that species previously assumed to be circumpolar in occurrence are actually comprised of multiple cryptic species (Rogers, 2007). Incorporating some measure of community biodiversity (especially diversity of vulnerable taxa) into VME designation criteria would be desirable but should not be allowed to obscure the potential for low-diversity or single-species aggregations to constitute potential VMEs. Several measures of diversity might be used, ranging from simple counts of the species or operational taxonomic units recorded, to more sophisticated measures such as indices of taxonomic distinctness (Clarke and Warwick, 1998, 2001). As noted above, however, VME designation cannot be based solely on diversity and some process in which all available information is incorporated with appropriate weightings will be necessary.

Conclusion

Vulnerability is a continuum, not a binary characteristic of a species or assemblage. Therefore, designating a list of coarse taxonomic groups as being vulnerable will inevitably exclude some species that are potentially vulnerable to the effects of bottom fishing gear, and may include some species that are less vulnerable. The list generated here incorporates the FAO criteria for evaluating vulnerability, but also adds criteria specific to monitoring fishery impacts on vulnerable taxa. It also considers constraints on making the list operational, and includes integrative aspects such as utilising indicator taxa, endemism and taxonomic diversity as potential factors to consider in designating an area as a potential VME, or in triggering a move-on rule.

Acknowledgements

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de las muestras recogidas por observadores científicos de Nueva Zelandia y retenidas en 2009 de acuerdo con las disposiciones de la CCRVMA. El intervalo de profundidad de 500–2 500 m ha sido sombreado de claro a oscuro.

Figura 3: Distribución batimétrica proporcional de los grupos taxonómicos potencialmente vulnerables de la pesquería de palangre efectuada en el Mar de Ross en 2009. Las cajas muestran el rango intercuartílico, la línea horizontal representa la mediana y las líneas verticales, el rango. El ancho de la caja es proporcional al número de observaciones. Nótese que la pesca no está permitida en aguas de menos de 550 m de profundidad (Medidas de Conservación 41-09 y 41-10 (CCAMLR, 2009)).

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