A RISK-MANAGEMENT FRAMEWORK FOR AVOIDING SIGNIFICANT ADVERSE IMPACTS OF BOTTOM FISHING GEAR ON VULNERABLE MARINE ECOSYSTEMS

K. Martin-Smith
Australian Antarctic Division
Department of the Environment, Water, Heritage and the Arts
203 Channel Highway, Kingston 7050
Tasmania, Australia
Email – keith.martin-smith@aad.gov.au

Abstract

CCAMLR adopted a new conservation measure in 2007 to ensure that significant adverse impacts of bottom fishing gear on Vulnerable Marine Ecosystems (VMEs) are avoided. Due to the high levels of uncertainty surrounding both the evidence of VME presence and the consequences of interaction with different types of gear, a risk-management framework is proposed, similar to that which has been used successfully to minimise the effects of longline fishing mortality on seabirds. Risk is broadly defined as the conditional probability of adverse impacts given particular bottom fishing activities multiplied by the consequences of those impacts. The aim of the risk-management framework is to avoid significant adverse impacts on VMEs from bottom fishing activities. The framework consists of four steps: (i) Risk analysis of current and proposed fishing activities; evidence of potential VMEs; scale of interactions between fishing activities and VMEs; impact of interactions on VMEs; and recovery potential of VMEs. (ii) Risk evaluation. Information on likelihood and consequences of interactions of bottom fishing gear with VMEs and associated uncertainties from risk analysis is combined to produce risk metrics. (iii) Risk elimination or mitigation. The spatial scale at which this framework operates should be related to the scale of VMEs, presently unknown. However, management at the level of fine-scale rectangles (0.5° latitude by 1.0° longitude) or smaller can be used in the first instance. Temporal scales must be matched to the recovery scale of VMEs, which are probably in the order of many decades or even centuries. Unacceptable levels of risk from bottom fishing activities to VMEs must be eliminated or reduced to acceptable levels through the use of management measures including, *inter alia*, closed areas around identified VMEs, open and closed management areas, by-catch limits for VME-forming organisms, gear modification or spatial distribution of fishing effort. (iv) Review. All of the above steps should be reviewed annually to ensure that all relevant or new information has been included, appropriate scientific research and data collection plans are in place and that risk mitigation measures are successful in their implementation.

Résumé

La CCAMLR a adopté une nouvelle mesure de conservation en 2007 pour veiller à éviter les impacts négatifs significatifs des engins de pêche de fond sur les écosystèmes marins vulnérables (VME). Compte tenu des niveaux élevés d'incertitude entourant tant les preuves de la présence d'un VME que les conséquences de l'interaction avec différent types d'engins, un cadre de gestion du risque est proposé, similaire à celui qui est utilisé pour réduire les effets de la mortalité liée à la pêche à la palangre sur les oiseaux de mer. Le risque est généralement défini comme la probabilité conditionnelle d'impacts négatifs, compte tenu de certaines activités de pêche de fond, multipliée par les conséquences de ces impacts. L'objectif du cadre de gestion du risque est d'éviter les impacts négatifs significatifs des activités de pêche de fond sur les VME. Le cadre de gestion comporte quatre étapes : i) Analyse du risque des activités de pêche actuelles et proposées ; preuves de VME potentiels ; ampleur des interactions entre les activités de pêche et les VME ; impact des interactions sur les VME ; et potentiel de récupération des VME. ii) Évaluation du risque. Les informations sur la probabilité et les conséquences d'interactions d'engins de pêche de fond avec des VME et les incertitudes associées issues de l'analyse du risque sont combinées pour produire des métriques. iii) Élimination ou atténuation du risque. L'échelle spatiale de ce cadre de gestion devrait être en relation avec l'échelle des VME, qui est actuellement inconnue. On peut toutefois procéder en premier lieu à une gestion au niveau des rectangles à échelle précise (0,5° de latitude sur 1,0° de longitude) ou inférieur. Les échelles temporelles doivent correspondre à l'échelle de récupération des VME, qui est probablement de l'ordre de plusieurs décennies, voire même de plusieurs siècles. Les niveaux inacceptables de risque présentés par les activités de pêche de fond pour les

VME doivent être éliminés ou réduits à des niveaux acceptables au moyen de mesures de gestion, entre autres, la fermeture des secteurs entourant les VME identifiés, l'ouverture et la fermeture d'aires de gestion, la limitation de la capture accessoire d'organismes constituant les VME, la modification des engins ou la répartition spatiale de l'effort de pêche. iv) Évaluation. Les étapes ci-dessus devraient être évaluées annuellement pour s'assurer que toutes les informations pertinentes ou nouvelles ont été prises en compte, que des plans appropriés de recherche scientifique et de collecte des données sont en place et que les mesures d'atténuation du risque ont été mises en œuvre avec succès.

Резюме

В 2007 г. АНТКОМ принял новую меру по сохранению в целях обеспечения избежания существенного негативного воздействия на уязвимые морские системы (УМЭ) со стороны донных промысловых снастей. В связи с высоким уровнем неопределенности в отношении как свидетельств наличия УМЭ, так и последствий взаимодействия с различными типами снастей, предлагается система управления рисками, подобная той, которая успешно используется в целях минимизации последствий промысловой смертности при ярусном промысле для морских птиц. Риск в целом определяется как условная вероятность негативных воздействий при наличии конкретной деятельности по донному промыслу, умноженная на последствия этих воздействий. Цель этой системы управления рисками – избежать существенного негативного воздействия на УМЭ со стороны донного промысла. Эта система включает четыре шага: (i) Анализ риска со стороны существующей и предлагаемой промысловой деятельности; свидетельства возможных УМЭ; масштаб взаимодействий между промысловой деятельностью и УМЭ; влияние взаимодействий на УМЭ; и возможность восстановления УМЭ. (ii) Оценка риска. Информация о вероятности и последствиях взаимодействия донных промысловых снастей с УМЭ и соответствующих неопределенностях по результатам анализа риска объединяется для получения показателей риска. (iii) Устранение или смягчение риска. Пространственный масштаб, в котором эта система действует, должен быть связан с масштабами УМЭ, неизвестными в настоящее время. Однако сначала может применяться управление на уровне мелкомасштабных клеток (0.5° широты на 1.0° долготы) или меньше. Масштабы во времени должны соответствовать масштабам восстановления УМЭ, которые, вероятно, составляют порядка многих десятилетий или даже столетий. Недопустимые уровни риска для УМЭ со стороны донного промысла должны быть устранены или сокращены до приемлемого уровня путем использования мер по управлению, включая, среди прочего, закрытие районов вокруг выявленных УМЭ, открытые и закрытые районы управления, ограничения на прилов образующих УМЭ организмов, модификацию снастей или пространственное распределение промыслового усилия. (iv) Пересмотр. Все вышеперечисленные шаги должны ежегодно пересматриваться, с тем чтобы обеспечить включение всей уместной или новой информации, наличие надлежащих планов проведения научных исследований и сбора данных и успешное выполнение мер по снижению риска.

Resumen

La CCRVMA adoptó una nueva medida de conservación en 2007 para evitar que los artes de pesca de fondo causen graves daños en los ecosistemas marinos vulnerables (EMV). Dada la gran incertidumbre en lo que respecta a los indicios de la presencia de un EMV y a las consecuencias de la interacción con distintos tipos de artes de pesca, se ha propuesto un marco para la gestión del riesgo, similar al que se ha utilizado con éxito para minimizar los efectos de la pesca de palangre en la mortalidad incidental de aves marinas. En términos generales, el riesgo se define como la probabilidad condicionada de que se produzca un impacto desfavorable dadas ciertas actividades de pesca de fondo, multiplicada por las consecuencias de ese impacto. El objetivo del marco de gestión del riesgo es evitar que las actividades de pesca de fondo causen graves daños en los EMV. El marco consiste de cuatro etapas: (i) Análisis del riesgo de las actividades de pesca en curso y propuestas; indicios de la presencia de un ecosistema marino potencialmente vulnerable; grado de interacción entre las actividades de pesca y los EMV; impacto de las interacciones en los EMV; y capacidad de recuperación de los EMV. (ii) Evaluación del riesgo. La información sobre la probabilidad y las consecuencias de las interacciones entre el arte de pesca de fondo con los EMV se combina con la incertidumbre asociada al análisis de riesgo para producir índices de riesgo. (iii) Eliminación o mitigación del riesgo. La escala espacial en la que opera este marco debiera relacionarse con la escala de los EMV, que actualmente se desconoce. No obstante, la gestión a nivel de rectángulo a escala fina (0.5° latitud por 1.0° longitud) o menor, puede utilizarse en primera instancia. Las escalas temporales deben coincidir con la escala de recuperación de los EMV, que probablemente son del orden de muchas décadas o hasta siglos. Se debe eliminar cualquier nivel inaceptable de riesgo de las actividades de pesca de fondo para los EMV, o bien reducir el riesgo a un nivel aceptable mediante el uso de medidas de gestión que incluyen, *inter alia*, áreas cerradas alrededor de los EMV identificados, áreas de gestión abiertas y cerradas, límites de captura secundaria para los organismos formadores de EMV, modificación de artes de pesca o distribución espacial del esfuerzo de pesca. (iv) Revisión. Todas las etapas mencionadas deben ser revisadas anualmente para asegurar que toda la información pertinente, o nueva, haya sido incluida, que la investigación científica pertinente y los planes de recopilación de datos hayan sido especificados y que las medidas de mitigación del riesgo hayan sido implementadas con éxito.

Keywords: bottom fishing gear, mitigation, risk assessment, risk management, vulnerable marine ecosystems, CCAMLR

Introduction

Concern over the impacts of anthropogenic activities in marine areas beyond national jurisdiction has grown considerably over the course of the 21st Century. International bodies, including the United Nations General Assembly (UNGA) and the Convention on Biological Diversity (CBD), have identified fishing as a major potential threat to the structure and function of marine ecosystems (e.g. UNGA, 2006; CBD, 2008).

Protection of Vulnerable Marine Ecosystems (VMEs) was identified as a key issue by the United Nations in 2003 (UNGA, 2003). No standard definition of VMEs has been agreed and they are usually defined by example only. The vulnerability of any particular ecosystem is the degree of change sustained on exposure to a particular disturbance regime. Thus, the concept of a VME is therefore only valid when the disturbance regime is specified. This can be most easily understood by considering the example of slow-growing, long-lived deep-sea corals which are damaged or destroyed by bottom trawling (Roberts and Hirshfield, 2004). Common strategies to mitigate this damage include protecting areas of densest concentrations of these organisms from fishing. Such concentrations have come to be known as VMEs as convenient shorthand. However, depending on gear type and frequency of disturbance, other benthic ecosystems (e.g. soft-sediment communities) can show loss of biodiversity and ecosystem function (Cryer et al., 2002). These ecosystems would thus be viewed as VMEs in the context of their particular disturbance regimes.

In 2005, UNGA called upon States and Regional Fisheries Management Organisations and Arrangements (RFMO/As), such as CCAMLR, to consider interim prohibition of bottom fishing on VMEs; to address impacts and ensure compliance; to report on the actions of RFMO/As to deal with adverse impacts on VMEs; and to review progress with a view to further recommendations (UNGA, 2005). In response, a report on the impacts of fishing on VMEs was presented to the 61st session of UNGA (UNGA, 2006) leading to UNGA Resolution 61/105 calling for RFMO/As to ensure that significant adverse impacts on VMEs are avoided (UNGA, 2007).

CCAMLR, as a conservation organisation with the attributes of an RFMO, has implemented measures to deal with the potential impacts of bottom fishing on VMEs. In 2006, the Commission agreed that it would need to be satisfied that bottom trawling would not have a significant adverse impact on VMEs to approve such activities and requested the Scientific Committee to review the use of bottom trawling gear in high-seas areas (CCAMLR, 2006, paragraphs 11.36 and 11.37). As an interim measure, bottom trawling gear was restricted to areas where conservation measures governing bottom trawling activities were in force at that time (CCAMLR, 2006, paragraph 11.38).

In 2007, noting the requirements of UNGA Resolution 61/105, the Scientific Committee of CCAMLR endorsed practical definitions for destructive fishing practices, vulnerability of an ecosystem to fishing and what constitutes significant adverse impacts (Constable and Holt, 2007; SC-CAMLR, 2007a, paragraph 4.163; SC-CAMLR, 2007b, paragraph 14.4). The Scientific Committee agreed that a framework, based on existing practices and procedures, could be used to indicate the research and data activities needed to manage bottom fishing and thus avoid significant adverse impacts on VMEs (SC-CAMLR, 2007a, paragraph 4.164) (Figure 1).

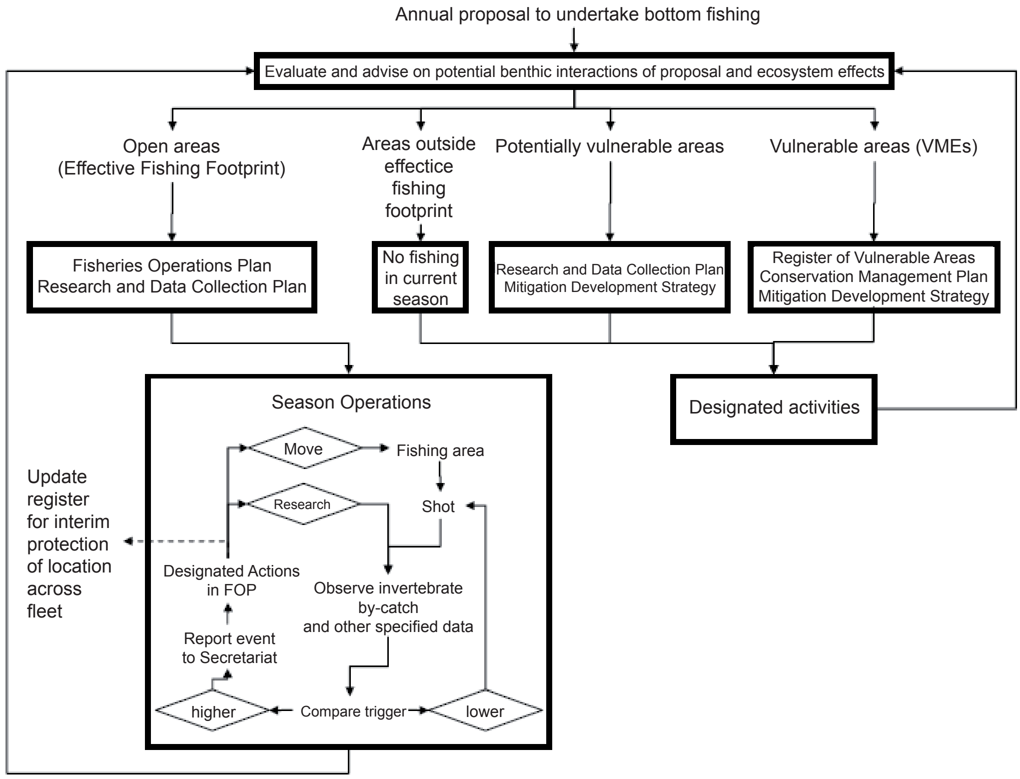

Figure 1: Framework for indicating scientific and data collection activities to manage bottom fishing to avoid significant adverse impacts on VMEs.

This work was endorsed by the Commission, noting that many of the components for managing bottom fishing can draw upon existing practices and procedures (CCAMLR, 2007a, paragraph 5.12). In particular, the endorsed CCAMLR aims for managing interactions with non-target species are, in order of priority (SC-CAMLR, 2003a, paragraphs 4.135 and 4.136; SC-CAMLR, 2003b, paragraph 5.230):

(i) avoidance
(ii) mitigation
(iii) catch limits.

Conservation Measure 22-06 (CCAMLR, 2007b) was adopted to manage bottom fishing in the CAMLR Convention Area. The Commission identified further work that would be necessary to meet the requirements of UNGA Resolution 61/105, including consideration of available management approaches to avoid and mitigate significant adverse impacts on VMEs (CCAMLR, 2007a, paragraph 5.13).

In response to the Commission's requirement for the Scientific Committee to develop scientific advice on managing bottom fishing to avoid significant adverse impacts on VMEs (SC-CAMLR, 2007a, paragraphs 4.164 and 4.165; CCAMLR, 2008a, paragraph 5.12(ii)(a)), this paper outlines a risk-management approach for analysing, evaluating and treating the risks associated with bottom fishing. This approach operationalises Conservation Measure 22-06 using existing practices and is analogous to that used by CCAMLR in successfully minimising the effects of longline fishing mortality on seabirds (Waugh et al., 2008).

What is risk?

In order to properly implement a risk-management framework, the term 'risk' needs to be defined (Kaplan, 1997). Generally, three questions define risk (Kaplan and Garrick, 1981):

(i) What can happen? (Scenario. Denoted by S_i)

(ii) How likely is that to happen? (Likelihood. Denoted by L_i)

(iii) If it does happen, what are the consequences? (Consequences. Denoted by X_i)

Likelihood can be expressed as a frequency (how often does scenario *i* occur?), a probability (for single events) or a probability of frequency (how often might scenario *i* occur given uncertainty over its precise value?) (Kaplan, 1997). Similarly,

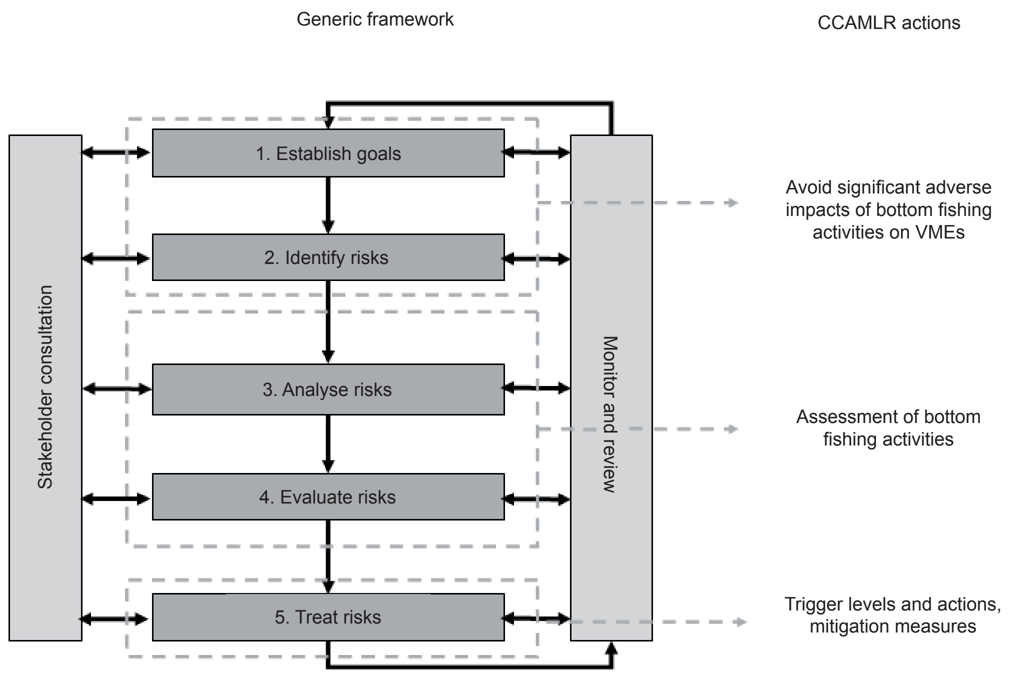

Figure 2: Generic risk-management framework (adapted from Standards Australia, 2004) and relationship with CCAMLR actions with respect to bottom fishing.

the consequences of a scenario can be a vector, a time-dependent response or uncertain, in which latter case it should be expressed as a probability curve (Kaplan, 1997). The general formulation for total risk is therefore the triplet of scenario, likelihood and consequence across the complete set of scenarios c, i.e.

$$R = \{S_i, p_i(\varphi_i), p_i(X_i)\}_c \qquad \text{(1) (Kaplan, 1997)}$$

where $p_i(\varphi_i)$ represents likelihood and $p_i(X_i)$ represents consequences for each scenario S_i.

It should be noted that likelihood is a conditional probability of a particular consequence occurring not the likelihood of the activity occurring (Fletcher et al., 2002).

It has been argued that ‘exposure-effects’ models, also known as ‘dose-response’ models, where the experimenter wishes to quantify the magnitude of adverse consequences given a particular level of exposure, represent a different definition of risk (e.g. Suter, 2006). However, Kaplan (1997) has demonstrated that these types of models can also be accommodated within the general definition provided in equation (1).

Generic risk-management framework

The approach proposed in this paper is based on a generic risk-management process for fisheries as described in Fletcher (2005). This approach has also been used in CCAMLR for assessing the impacts of longline fishing on seabird mortality as described in Waugh et al. (2008) and implemented each year since 1997 by the ad hoc Working Group on Incidental Mortality Associated with Fishing (WG-IMAF). In the WG-IMAF assessments, however, likelihood and consequence are not explicitly enumerated, rather a single risk score is produced. Similar risk-management frameworks are used by Antarctic Treaty Parties and the Committee for Environmental Protection when dealing with protected areas, environmental monitoring or designations of Antarctic Specially Protected Species. It is also used extensively in fisheries management (e.g. Campbell and Gallagher, 2007; Smith et al., 2007). The risk-management framework is shown in Figure 2.

Specific risk-management framework

The goal and specific risk in dealing with interactions of fishing gear with VMEs within CCAMLR have been identified in Conservation Measure 22-06, paragraph 7, i.e. ‘to ensure that all bottom fishing activities are assessed and managed to prevent significant adverse impacts on VMEs or are not authorised to proceed’. The remaining four steps in the process can be summarised as follows:

(i) Risk analysis of:

   (a) current and proposed fishing activities in specified area including method and footprint (spatial and temporal extent, frequency);

   (b) evidence of potential VMEs in an area of fishing activity with associated uncertainty;

   (c) magnitude of interactions between fishing activities and VMEs with associated uncertainty;

   (d) impact of interactions on VMEs with associated uncertainty;

   (e) recovery potential of VMEs.

(ii) Risk evaluation – Combine information on likelihood and consequences of interactions of bottom fishing gear with VMEs and associated uncertainties from risk analysis to produce risk metrics.

(iii) Risk elimination or mitigation – Unacceptable levels of risk from bottom fishing activities to VMEs must be eliminated or reduced to acceptable levels through the use of management measures including, *inter alia*, closed areas around identified VMEs, open and closed management areas, by-catch limits for VME-forming organisms, gear modification or spatial distribution of fishing effort.

(iv) Review – All of the above steps should be reviewed regularly to ensure that all relevant or new information has been included, appropriate scientific research and data collection plans are in place and that risk mitigation measures are successful in their implementation. Annual review of the risk-management approach is appropriate in the first instance, in line with many other CCAMLR processes.

As mentioned above, both likelihood and consequence will each have associated levels of uncertainty (Beer, 2006). Such uncertainty can be associated with natural randomness in system processes or imperfect information. In situations where uncertainty is largely due to imperfect information, qualitative categories of likelihood and consequence must be used based on expert opinion (Fletcher et al., 2002; Fletcher, 2005; Waugh et al., 2008). WG-IMAF uses this method when assessing the risk of interactions between seabirds and fisheries in the CCAMLR area (WG-IMAF, 2007). A standard scale for likelihood is given in Table 1.

Similarly, qualitative and quantitative consequence levels have been developed for the impacts of activities, including fisheries (e.g. Fletcher et al., 2002). Table 2 provides both qualitative and semi-quantitative criteria for a six-level scale of the impacts of bottom fishing on VMEs. The combination of likelihood and consequence provides a semi-quantitative estimate of risk (Table 3) that can be used to initiate different classes of management action, reporting etc. (Fletcher et al., 2002). WG-IMAF provides advice to the Scientific Committee by statistical area with different provisions, e.g. length of fishing season based on its assessment of risk (WG-IMAF, 2007).

Consideration of scale

Temporal and spatial scales are extremely important when considering the ecological impacts of bottom fishing on VMEs (see White and Pickett, 1985; Wiens, 1989 for consideration of ecological effects of scale). In order to operationalise the risk-management framework, appropriate scales will need to be chosen that reflect the process of interaction of VMEs with bottom fishing activities. For temporal scale, the reciprocal of the average frequency of interactions with bottom fishing activities needs to be smaller than the recovery time of the VME in order to ensure that cumulative impacts are avoided. Although the recovery time of VMEs in the Southern Ocean is not known precisely, available evidence would suggest that communities may take many decades or even centuries to recover from disturbance effects (Teixidó et al., 2007; Barnes and Conlan, 2007). The appropriate spatial scale for consideration should be related to the size distribution of the VMEs (CCAMLR, 2008a, paragraphs 5.12 and 5.13). However, if this information is not known, as is the case for VMEs in the Southern Ocean, an appropriate spatial scale for management activities can be derived from the bottom fishing gear used. An area of 0.5° latitude by 1.0° longitude has been endorsed by the Scientific Committee as appropriate for risk characterisation (SC-CAMLR, 2008) although smaller spatial scales may be needed.

Evidence of VMEs

In assessing the likelihood of interactions of bottom fishing gear with VMEs in the Southern Ocean, the greatest uncertainties are associated with the location and extent of these ecosystems, as

Table 1: Qualitative likelihood of significant adverse impacts on VMEs conditional on bottom fishing activities (adapted from Standards Australia, 2004).

Level	Verbal expression	Description
1	*Remote*	Theoretically possible but never observed
2	*Rare*	May occur in exceptional circumstances
3	*Unlikely*	Could occur at some time
4	*Possible*	Might occur at some time
5	*Likely*	Will probably occur in most circumstances
6	*Almost certain*	Is expected to occur in most circumstances

Table 2: Qualitative and semi-quantitative consequence scale for impacts of bottom fishing on VMEs, adapted from Fletcher et al. (2002).

Level	Descriptor	Description	Spatial extent (% of VME affected)	Time scale for recovery
0	*Negligible*	Effects are undetectable relative to natural variability of ecosystem.	<1	
1	*Minor*	No effect on overall ecosystem structure or function. Small changes in abundance of some species.	1–5	Weeks–months
2	*Moderate*	Small effect on ecosystem structure or function. Small changes in abundance of many species or large changes in some species.	5–25	Months–one year
3	*Major*	Measurable effects on ecosystem structure or function. Large changes in abundance of many species and/or some extirpations.	25–50	One–few years
4	*Severe*	Substantial loss to structure or function of ecosystem. Many species extirpated.	50–90	Years–decades
5	*Catastrophic*	Complete loss of ecosystem. All species extirpated.	>90	Centuries–never

Table 3: Risk analysis matrix based on likelihood and consequence scales presented above. Different shading refers to different subjective levels of risk (modified from Fletcher et al., 2002). Scores in table are multiplicative, i.e. consequence x likelihood. Correspondence with WG-IMAF risk categories: 0 = low, 1–6 = average-to-low, 8–12 = average, 15–18 = average-to-high, >18 = high.

		Consequence					
		Negligible (0)	*Minor* (1)	*Moderate* (2)	*Major* (3)	*Severe* (4)	*Catastrophic* (5)
Likelihood	*Remote* (1)	0	1	2	3	4	5
	Rare (2)	0	2	4	6	8	10
	Unlikely (3)	0	3	6	9	12	15
	Possible (4)	0	4	8	12	16	20
	Likely (5)	0	5	10	15	20	25
	Almost certain (6)	0	6	12	18	24	30

opposed to the fishing footprint which is well quantified. In the absence of other information, the precautionary approach of CCAMLR (see Constable et al., 2000 for review) will result in the likelihood of significant adverse encounters with VMEs being considered as *Likely*. Taxa that may indicate VMEs have been caught in all bottom fishing activities (CCAMLR, 2008b). However, as further information is collected, it is possible to revise these likelihoods in an adaptive manner (Moyle, 2005), as is currently done for toothfish stock assessments in new and exploratory fisheries through data collection and research plans (CCAMLR, 2007a).

Evidence of VMEs can be obtained from a number of different types of information, which have different levels of uncertainty associated with each:

(i) directly measured
(ii) inferred from indirect measurements, or
(iii) predicted from various models.

A summary of these types of information and examples from the Antarctic and Southern Ocean, where possible, are given in Table 4.

Direct evidence of VMEs from publicly accessible databases (such as SCAR-MarBIN www.scarmarbin.be or Seamounts Online http://seamounts.sdsc.edu) are concentrated in areas that have been the subject of greater research effort, in particular the continental shelf near national research stations, the Ross Sea and around the Antarctic Peninsula. Syntheses of other data are publicly available, e.g. distribution of hexactinellid sponges in the Weddell Sea (Barthel and Gutt, 2002; Janussen and Tendal, 2007). Further data are available in national research programs or from fisheries observer records of by-catch collected by CCAMLR.

Similarly, indirect evidence of VMEs is available through public databases, primary literature or national research programs, as are modelling studies (e.g. Clark et al., 2006).

At present in longline fisheries, the major bottom fishing method in use in the Convention Area, feasible methods of gathering evidence of potential VMEs are through observation of by-catch or acoustic signatures of habitat features. Longline-mounted cameras have been developed and deployed to a limited extent on commercial vessels providing for direct visual observation of a small section of line (Constable et al., 2007). Evidence that can be gathered through these methods can be used as indicators of different types of VME (Table 5).

Effects of bottom fishing gear on VMEs

The consequences of the interactions of bottom fishing gear with VMEs in the Southern Ocean are also associated with a high degree of uncertainty. However, there is information on the interactions of bottom fishing gear on VMEs formed by similar organisms elsewhere in the world which can be used to predict the impacts in the Southern Ocean. In the absence of other information, a default consequence of major disturbance is consistent with the precautionary approach used by CCAMLR in new and exploratory fisheries. Again, as new data are collected, e.g. by using video cameras deployed on trawls and longlines (Constable et al., 2007), the consequences of interactions of gear with VMEs can be revised.

Bottom fishing gear that has been used historically within the CCAMLR area includes benthic or demersal trawls, pots/traps and bottom-set longlines (CCAMLR, 2008b). Currently bottom trawling is restricted to a small-volume fishery in CCAMLR Division 58.5.2 while bottom-set longlines are used throughout the CCAMLR area, although they are not permitted in depths shallower than 550 m (CCAMLR, 2008c). Of these gear types, considerably more research has been undertaken on the effects of towed fishing gear, trawls and dredges, than on either pots or longlines, for which very little information exists (Eno et al., 2001; Johnson, 2002; Troffe et al., 2005) (Table 6). Furthermore, much of the information which exists can only be used in a qualitative manner, as the frequency and spatial extent of fishing disturbance was not quantified in many studies. For example, damage to *Lophelia pertusa* reefs off Norway was estimated to be 30–50%, but the fishing effort that had caused this impact could not be quantified (Fosså et al., 2002).

A recent meta-analysis of experimental studies has demonstrated that the direct effects of towed fishing gear were strongly habitat-specific with the most severe impacts occurring in biogenic habitats, i.e. habitats formed by biota (Kaiser et al., 2006). Decreases in abundance of benthic organisms of 64–96% were observed following trawling in biogenic habitats and significant decreases in abundance were also found with other combinations of gear and habitat, e.g. beam trawling on sand. Sponges and soft corals were identified as taking the longest time to recover from disturbance (Kaiser et al., 2006). However, none of the experimental studies used in the analysis were undertaken in the deep ocean nor in the Southern Ocean. Many of the life-history characteristics of Southern Ocean organisms, including slow growth rates, high longevity, dispersal and reproductive modes, would

Table 4: Types of information that can be used to infer presence of VMEs.

Class	Category	Observation	Methods	Level of certainty	Notes	Examples (* where not from Antarctic)
Empirical	Direct	Visual presence of VME	Diver observation or underwater photographic/video equipment	Certain		Sponges in McMurdo Sound (Dayton et al., 1974), hydrocorals off Terre Adélie (Australia, 2008)
	Direct	Acoustic presence of VME	Multi-beam or side-scan sonar	Very high	Requires validation of acoustic signatures	* Coral reefs in Gulf of Carpentaria (Harris et al., 2004)
	Direct	Presence of VME-forming organisms	Benthic sampling gear including trawl, dredge, grab or longline	High	Does not provide information on density of VME-forming organisms nor spatial extent of VME	Hexactinellid sponges in the Weddell Sea (Janussen and Tendal, 2007)
	Indirect	Presence of surrogate, e.g. VME-associated organisms	Benthic sampling gear	Moderate	Requires knowledge of degree of association	* Species associations with cold-water corals in Alaska (Heifetz, 2002)
	Indirect	Presence of habitat feature	Single, multi-beam or side-scan sonar, satellite sea surface height anomalies	Moderate	Requires knowledge of degree of association between habitat feature and VME	Seamount distribution (Kitchingman and Lai, 2004)
Derived	Predicted	Predicted occurrence of VME	Models based on measurable physical or biological variables	Low–moderate	Assumes measured variables determine distribution of VMEs	Predicted coral habitat on seamounts (Clark et al., 2006)
	Predicted	Extent of suitable depth range	Extrapolation from known occurrences	Low	Provides general locations only	

Table 5: Potential by-catch and acoustic observations from longline fisheries and corresponding potential VMEs.

By-catch observation	Acoustic observation	Potential VME-forming species indicated
Coral or hydrocoral colonies/fragments	Submerged edges and slopes Summits and flanks of seamounts, guyots, banks, knolls and hills Canyons and trenches	Certain cold-water corals and hydroids, e.g. reef builders including: • Stony corals (Scleractinia) • Alcyonaceans and gorgonians (Octocorallia) • Black corals (Antipatharia) • Hydrocorals (Stylasteridae)
Sponge colonies/fragments	Submerged edges and slopes Summits and flanks of seamounts, guyots, banks, knolls and hills	Some types of sponge dominated communities
Hydroid or erect bryozoan colonies/fragments	Summits and flanks of seamounts, guyots, banks, knolls and hills	Communities composed of dense emergent fauna where large sessile protozoans (xenophyophores) and invertebrates (e.g. hydroids and bryozoans) form an important structural component of habitat
Vestimentiferan worm tubes/fragments	Hydrothermal vents Cold seeps	Seep and vent communities comprised of endemic invertebrate and microbial species
No organisms present	All of above	Range spanning from none to all of above and other potential VMEs, depending on sampling characteristics of gear

Table 6: Indicative effects of fishing on different types of VME.

Type of VME	Fishing gear	Disturbance regime	Location	Effects	References
Sponge/gorgonian	Trawl	Single tow	NW shelf, Australia	14% removal of sponges, 3% gorgonians. Larger sponges impacted more than smaller sponges	Wassenberg et al., 2002
Sponge/soft coral/ gorgonian	Demersal trawl	Multiple tows	NW shelf, Australia	16% removal of benthos per pass	Moran and Stephenson, 2000
Sea whip	Beam trawl, prawn trap	Single tow or set	British Columbia	Entanglement of sea whips in gear and damage to 50% of these colonies	Troffe et al., 2005
Sponge	Trawl	Single tow	Gulf of Alaska	Significant decrease in density of vase sponges, morel sponges and anthozoans	Freese et al., 1999
Bryozoan reef	Otter trawl	Qualitative only	Tasman Bay, NZ	Reduction in bryozoan mounds	Bradstock and Gordon, 1983
Bryozoan/tubeworms	Otter trawl, scallop dredge	Qualitative only	Georges Bank, Gulf of Maine	Significant reduction in cover of bryozoans, hydroids and tubeworms	Auster et al., 1996 ; Collie et al., 1997, 2000
Bryozoan, sponge, hydroids	Trawl	Qualitative only	Scotian Shelf, Canada	No cumulative effects from three years of pulsed trawling	Henry et al., 2006
Sea pens, sea fans	Crustacean pots	Multiple pot sets	UK	Detachment and damage to ross coral colonies but little effect on sea pens and sea fans	Eno et al., 2001
Sponge/coral	Trawl	Single tow	Georgia, USA	Damage to 32% sponges, 30% stony corals, 4% octocorals. Density of barrel sponges significantly reduced. No significant differences between trawled and control sites after 12 months	Van Dolah et al., 1987
Solenosmilia reef	Trawl	Semi-quantitative	Tasman seamounts	Biomass of benthos 106% greater and species diversity per sample 46% greater for undisturbed seamounts	Koslow et al., 2001

indicate that benthic communities will take much longer to recovery from fishing disturbance – in the order of many decades to centuries – than similar communities elsewhere in the world (Clarke, 1983; Gutt and Starmans, 2001; Barnes and Conlan, 2007; Teixidó et al., 2007).

Risk evaluation

Once the evidence of VMEs has been assessed along with its associated uncertainty, a likelihood score is assigned as per the categories in Table 1 with a default uncertainty (and hence likelihood) of 5 (*Likely*) when no information is available. Similarly, a consequence score for the impacts of bottom fishing on VMEs is assigned from Table 3 with a default uncertainty (consequence) of 3 (*Major*) when no information is available. The overall risk of bottom fishing activities on VMEs is then calculated from the risk-analysis matrix in Table 3, which can be categorised into the five classes used by WG-IMAF, if desired. As with the annual WG-IMAF assessments, advice will be provided to the Scientific Committee on the basis of the assessed overall risk.

Risk mitigation

CCAMLR has used a range of management options to mitigate different forms of risk, in particular spatial management (open and closed areas, depth restrictions), temporal management (closed seasons), gear management and catch controls (by-catch limits, control of IUU fishing) (CCAMLR, 2007a). Some of these approaches can be adapted to lower the risk of significant adverse impacts of bottom fishing gear on VMEs, for example:

(i) Spatial management –

(a) Closures around known VMEs with appropriate buffers – In the absence of information on the impacts of bottom fishing gear, closing areas around known VMEs will reduce the risk to zero from vessels authorised by CCAMLR. Buffer zones should be large enough to account for uncertainty in the extent of the VME or position of fishing gear.

(b) Uncertainty-based special management arrangements – Spatial closures around particular features with which VMEs are normally associated (e.g. canyons, seamounts, plate boundaries or other indicators) with appropriate buffers should be used to appropriately limit operations to avoid significant adverse impacts on VMEs while information is collected to determine how fishing might proceed. For example, areas around such features may be closed while strategic, highly controlled research fishing is undertaken to ascertain risks in one or a few target areas with those features present.

(c) Open and closed areas – Appropriate spatial distribution of open and closed areas would provide a means by which the effects of fishing gear on potentially vulnerable marine ecosystems could be assessed in the long term and, as such, whether the strategy for avoiding significant adverse impacts on VMEs is working.

(d) Spatial distribution of fishing effort within existing fishing footprint – Cumulative adverse impacts of fishing gear can be avoided by distributing fishing effort over a wide area. This measure is implemented by separating shots by a minimum distance for each vessel, limiting effort in particular areas and/or general mechanisms to spread fishing effort across the area. This strategy will only be effective if it reduces the average frequency of interactions below the recovery period of the VME.

(ii) Gear management – Changes to the configuration, materials or deployment of gear can be used to reduce the consequences of interactions with bottom fishing gear. Associated research on effects of bottom fishing gear on VMEs and recovery trajectories of the organisms involved will be needed to demonstrate the effects of gear modification.

(iii) Catch controls –

(a) By-catch limits for VME-indicator organisms with move-on provisions if these limits are exceeded – Appearance of VME-indicator organisms in the catch of bottom fishing gear would be monitored and trigger levels established. If these trigger levels are reached, then a move-on provision would operate, as with current by-catch measures. Note that these will only be applicable when there is a reasonable chance that indicator biota will be caught by the fishing gear.

(b) Reduction of IUU fishing – While the mitigation measures 1 to 6 will be effective in reducing risk from vessels authorised by CCAMLR, there will still be residual risk from IUU fishing which can only be minimised through enforcement and compliance measures.

Conclusions

The protection of VMEs in the Convention Area requires a risk-management approach to encompass the requirements of the Commission, noting both the framework for scientific and data collection activities (CCAMLR, 2007b, paragraph 5.12) and the necessity to develop an approach for identifying VMEs, assessing benthic interactions of bottom fishing, and managing fishing to avoid and mitigate significant adverse impacts on VMEs (CCAMLR, 2007b, paragraph 5.13).

The approach outlined here provides an approach that will help CCAMLR meet its obligations under UNGA Resolution 61/105. Specifically, the steps are: (i) Risk analysis, (ii) Risk evaluation, (iii) Risk mitigation and (iv) Review. There is an imperative to implement precautionary management of interactions of bottom fishing gear with VMEs which cannot wait for complete information. Risk management provides a practical adaptive solution to ensure adequate protection of VMEs.

Acknowledgements

Many thanks are due to Andrew Constable, Gill Slocum and Dirk Welsford for their discussions and input into the ideas behind this manuscript. I would also like to thank Neville Smith and Chris Jones for their help in revising the document and the valuable discussions provided by the members of WG-EMM and WG-FSA. The manuscript was strengthened by the comments provided by two anonymous reviewers.

References

Auster, P.J., R.J. Malatesta, R.W. Langton, L. Watling, P.C. Valentine, C.L.S. Donaldson, E.W. Langton, A.N. Shepard and I.G. Babb. 1996. The impact of mobile fishing gear on seafloor habitats in the Gulf of Maine (northwest Atlantic): implications for the conservation of fish populations. *Rev. Fish. Sci.*, 4 (2): 185–202.

Australia, Delegation of. 2008. Notification of vulnerable marine ecosystems in Statistical Division 58.4.1. Document *SC-CAMLR-XXVII/13*. CCAMLR, Hobart, Australia: 13 pp.

Barnes, D.K.A. and K.E. Conlan. 2007. Disturbance, colonization and development of Antarctic benthic communities. *Phil. Trans. Roy. Soc. B*, 362: 11–38.

Barthel, D. and J. Gutt. 1992. Sponge associations in the eastern Weddell Sea. *Ant. Sci.*, 4 (2): 137–150.

Beer, T. 2006. Ecological risk assessment and quantitative consequence analysis. *Human Ecol. Risk Assess.*, 12 (1): 51–65.

Beer, T. and F. Ziolkowski. 1995. Environmental risk assessment: an Australian perspective. *Supervising Scientist Report*, 102, Canberra, Australia: 125 pp.

Bradstock, M. and D.P. Gordon. 1983. Coral-like bryozoan growths in Tasman Bay, and their protection to conserve commercial fish stocks. *NZ J. Mar. Freshwat. Res.*, 17: 159–163.

Campbell, M.L. and C. Gallagher. 2007. Assessing the relative effects of fishing on the New Zealand marine environment through risk analysis. *ICES J. Mar. Sci.*, 64 (2): 256–270.

CCAMLR. 2006. *Report of the Twenty-fifth Meeting of the Commission (CCAMLR-XXV)*. CCAMLR, Hobart, Australia: 242 pp.

CCAMLR. 2007a. *Report of the Twenty-sixth Meeting of the Commission (CCAMLR-XXVI)*. CCAMLR, Hobart, Australia: 219 pp.

CCAMLR. 2007b. *Schedule of Conservation Measures in Force, 2007/08*. CCAMLR, Hobart, Australia: 192 pp.

CCAMLR, 2008a. *Report of the Twenty-seventh Meeting of the Commission (CCAMLR-XXVII)*. CCAMLR, Hobart, Australia. 201 pp.

CCAMLR. 2008b. *CCAMLR Statistical Bulletin*, Vol. 20 (1997–2007). CCAMLR, Hobart, Australia: 265 pp.

CCAMLR. 2008c. *Schedule of Conservation Measures in Force, 2008/09*. CCAMLR, Hobart, Australia: 226 pp.

CBD. 2008. Report of the Subsidiary Body on Scientific, Technical and Technological Advice on the Work of its Thirteenth Meeting. Document *UNEP/CBD/COP/9/3*: 61 pp.

Clark, M.R., D. Tittensor, A.D. Rogers, P. Brewin, T. Schlacher, A.A. Rowden, K. Stocks and M. Consalvey. 2006. *Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction*. UNEP-WCMC, Cambridge, UK: 81 pp.

Clarke, A. 1983. Life in cold water: the physiological ecology of polar marine ectotherms. *Oceanogr. Mar. Biol. Ann. Rev.*, 21: 341–453.

Collie, J.S., G.A. Escanero and P.C. Valentine. 1997. Effects of bottom fishing on the benthic megafauna of Georges Bank. *Mar. Ecol. Prog. Ser.*, 155: 159–172.

Collie, J.S., S.J. Hall, M.J. Kaiser and I.R. Poiner. 2000. A quantitative analysis of fishing impacts on shelf-sea benthos. *J. Anim. Ecol.*, 69 (5): 785–798.

Constable, A. and R. Holt. 2007. Bottom fishing in high-seas areas of CCAMLR. Document *SC-CAMLR-XXVI/10*. CCAMLR, Hobart, Australia: 18 pp.

Constable A.J., W.K. de la Mare, D.J. Agnew, I. Everson and D. Miller. 2000. Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). *ICES J. Mar. Sci.*, 57 (3): 778–791.

Constable, A., D. Welsford, S. Doust and R. Kilpatrick. 2007. Demersal fishing interactions with marine benthos in the Southern Ocean: an assessment of the vulnerability of benthic habitats to impact by demersal gears. Document *SC-CAMLR-XXVI/BG/30*. CCAMLR, Hobart, Australia: 13 pp.

Cryer, M., B. Hartill and S. O'Shea. 2002. Modification of marine benthos by trawling: toward a generalization for the deep ocean? *Ecol. App.*, 12 (6): 1824–1839.

Dayton, P.K., G.A. Robilliard, R.T. Paine and L.B. Dayton. 1974. Biological accommodation in benthic community at McMurdo Sound, Antarctica. *Ecol. Monogr.*, 44 (1): 105–128.

Eno, N.C., D.S. MacDonald, J.A.M. Kinnear, S.C. Amos, C.J. Chapman, R.A. Clark, F.St.P.D. Bunker and C. Munro. 2001. Effects of crustacean traps on benthic fauna. *ICES J. Mar. Sci.*, 58 (1): 11–20.

Fletcher, W.J. 2005. The application of qualitative risk assessment methodology to prioritize issues for fisheries management. *ICES J. Mar. Sci.*, 62 (8): 1576–1587.

Fletcher, W.J., J. Chesson, M. Fisher, K.J. Sainsbury, T. Hundloe, A.D.M. Smith and B. Whitworth. 2002. *National ESD Reporting Framework for Australian Fisheries: The 'How To' Guide for Wild Capture Fisheries*. FRDC Project 2000/145, Canberra, Australia: 120 pp.

Fosså, J.H., P.B. Mortensen and D.M. Furevik. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fisheries impacts. *Hydrobiologia*, 471: 1–12.

Freese, L., P.J. Auster, J. Heifetz and B.L. Wing. 1999. Effects of trawling on seafloor habitat and associated invertebrate taxa in the Gulf of Alaska. *Mar. Ecol. Prog. Ser.*, 182: 119–126.

Gutt, J. and A. Starmans. 2001. Quantification of iceberg impact and benthic recolonisation patterns in the Weddell Sea (Antarctica). *Polar Biol.*, 24 (8): 615–619.

Harris, P.T., A.D. Heap, T. Wassenberg and V. Passlow. 2004. Submerged coral reefs in the Gulf of Carpentaria. *Mar. Geol.*, 207: 185–191.

Heifetz, J. 2002. Coral in Alaska: distribution, abundance, and species associations. *Hydrobiologia*, 471: 19–28.

Henry, L.A., E.L.R. Kenchington, T.J. Kenchington, K.G. MacIsaac, C. Bourbonnais-Boyce and D.C. Gordon Jr. 2006. Impacts of otter trawling on colonial epifaunal assemblages on a cobble bottom ecosystem on Western Bank (northwest Atlantic). *Mar. Ecol. Prog. Ser.*, 306: 63–78.

Janussen, D. and O.S. Tendal. 2007. Diversity and distribution of Porifera in the bathyal and abyssal Weddell Sea and adjacent areas. *Deep-Sea Res. II*, 54 (16–17): 1864–1875.

Johnson, K. 2002. A review of national and international literature of the effects of fishing on benthic habitats. NOAA National Marine Fisheries Service Technical Memorandum NMFS-F/SPO-57.

Kaiser, M.J., K.R. Clarke, H. Hinz, M.C.V. Austen, P.J. Somerfield and I. Karakassis. 2006. Global analysis of response and recovery of benthic biota to fishing. *Mar. Ecol. Prog. Ser.*, 311: 1–14.

Kaplan, S. 1997. The words of risk analysis. *Risk Anal.*, 17 (4): 407–417.

Kaplan, S. and B.J. Garrick. 1981. On the quantitative definition of risk. *Risk Anal.*, 1 (1): 11–27.

Kitchingman, A. and S. Lai. 2004. Inferences on potential seamount locations from mid-resolution bathymetric data. In: Morato, T. and D. Pauly (Eds.). *Seamounts: Biodiversity and Fisheries*. UBC Fisheries Centre, Vancouver, Canada: 7–12.

Koslow, J.A., K. Gowlett-Holmes, J.K. Lowry, T. O'Hara, G.C.B. Poore and A. Williams. 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Mar. Ecol. Prog. Ser.*, 213: 111–125.

Moran, M.J. and P.C. Stephenson. 2000. Effects of otter trawling on macrobenthos and management of demersal scalefish fisheries on the continental shelf of north-western Australia. *ICES J. Mar. Sci.*, 57 (3): 510–516.

Moyle, B. 2005. Making the precautionary principle work for biodiversity: avoiding perverse outcomes in decision-making under uncertainty. In: Cooney, R. and B. Dickson (Eds). *Biodiversity and the Precautionary Principle*. Earthscan, London: 159–172.

Roberts, S. and M. Hirshfield. 2004. Deep-sea corals: out of sight, but no longer out of mind. *Frontiers Ecol. Environ.*, 2 (3): 123–130.

SC-CAMLR. 2003a. *Report of the Twenty-second Meeting of the Scientific Committee (SC-CAMLR-XXII*). CCAMLR, Hobart, Australia: 563 pp.

SC-CAMLR. 2003b. Report of the Working Group on Fish Stock Assessment. In: *Report of the Twenty-second Meeting of the Scientific Committee (SC-CAMLR-XXII)*, Annex 5. CCAMLR, Hobart, Australia: 297–542.

SC-CAMLR. 2007a. *Report of the Twenty-sixth Meeting of the Scientific Committee (SC-CAMLR-XXVI)*. CCAMLR, Hobart, Australia: 702 pp.

SC-CAMLR. 2007b. Report of the Working Group on Fish Stock Assessment. In: *Report of the Twenty-sixth Meeting of the Scientific Committee (SC-CAMLR-XXVI)*, Annex 5. CCAMLR, Hobart, Australia: 251–406.

SC-CAMLR. 2008. Report of the Working Group on Fish Stock Assessment. In: *Report of the Twenty-seventh Meeting of the Scientific Committee (SC-CAMLR-XXVII)*, Annex 5. CCAMLR, Hobart, Australia: 305–407.

Smith, A.D.M., E.J. Fulton, A.J. Hobday, D.C. Smith and P. Shoulder. 2007. Scientific tools to support the practical implementation of ecosystem-based fisheries management. *ICES J. Mar. Sci.*, 64 (4): 633–639.

Standards Australia. 2004. *Risk Management*. AS/NZS 4360: 2004 3rd Edition. Standards Australia, Canberra: 28 pp.

Suter, G.W. II. 2006. *Ecological Risk Assessment*, 2nd Edition. CRC Press, Boca Raton: 643 pp.

Teixidó, N., J. Garrabou, J. Gutt and W.E. Arntz. 2007. Iceberg disturbance and successional spatial patterns: the case of the shelf Antarctic benthic communities. *Ecosystems*, 10 (1): 143–158.

Troffe, P.M., C.D. Levings, G.E. Piercey and V. Keong. 2005. Fishing gear effects and ecology of the sea whip (*Halipteris willemoesi* (Cnidaria: Octocorallia: Pennatulacea)) in British Columbia, Canada: preliminary observations. *Aquat. Cons. Mar. Freshwat. Ecosys.*, 15 (5): 523–533.

UNGA. 2003. Oceans and the law of the sea. Report of the Secretary-General. Document *UNGA A/58/65*. UNGA, New York: 80 pp.

UNGA. 2005. Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relations to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. Document *UNGA A/RES/59/25*. UNGA, New York: 16 pp.

UNGA. 2006. Impacts of fishing on vulnerable marine ecosystems: actions taken by States and regional fisheries management organizations and arrangements to give effect to paragraphs 66 to 69 of General Assembly Resolution 59/25 on sustainable fisheries, regarding the impacts of fishing on vulnerable marine ecosystems. Document *UNGA A/61/154*. UNGA, New York: 46 pp.

UNGA. 2007. Sustainable fisheries, including through the 1995 Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relations to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and related instruments. Document *UNGA A/RES/61/105*. UNGA, New York: 21 pp.

Van Dolah, R.F., P.H. Wendt and N. Nicholson. 1987. Effects of a research trawl on a hard-bottom assemblage of sponges and corals. *Fisheries Res.*, 5 (1): 39–54.

Wassenberg, T.J., G. Dews and S.D. Cook. 2002. The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. *Fisheries Res.*, 58 (2): 141–151.

Waugh, S.M., G.B. Baker, R. Gales and J.P. Croxall. 2008. CCAMLR process of risk assessment to minimize the effects of longline fishing mortality on seabirds. *Mar. Policy*, 32 (3): 442–454.

WG-IMAF. 2007. IMAF risk assessment of fisheries by statistical area. Document *SC-CAMLR-XXVI/BG/31*. CCAMLR, Hobart, Australia: 28 pp.

White, P.S. and S.T.A. Pickett. 1985. Natural disturbance and patch dynamics: an introduction. In: Pickett, S.T.A and P.S. White (Eds.). *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, New York: 3–13.

Wiens, J.A. 1989. Spatial scaling in ecology. *Func. Ecol.*, 3 (4): 385–397.

Liste des tableaux

Liste des figures

Список таблиц

Список рисунков

Lista de las tablas

Lista de las figuras