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AN IMPACT ASSESSMENT FRAMEWORK FOR BOTTOM FISHING METHODS IN THE CAMLR CONVENTION AREA

B.R. Sharp✉
New Zealand Ministry of Fisheries
101–103 The Terrace
Wellington, New Zealand
E-mail – ben.sharp@vanuatu.com.vu / ben.sharp@fish.govt.nz

S.J. Parker
National Institute of Water and Atmospheric Research Ltd
PO Box 893, Nelson
New Zealand 7040

N. Smith
New Zealand Ministry of Fisheries
101–103 The Terrace
Wellington, New Zealand

Abstract

This paper presents a methodological framework to estimate the likely cumulative impact on fragile benthic organisms from bottom fishing activity. The approach has been designed to facilitate standardised application among various gear types and areas to allow comparisons between fisheries employing different bottom fishing methods. New Zealand implemented this approach in its preliminary assessment of bottom fishing impacts for the 2008/09 toothfish longline fishery. This paper illustrates the utility of the standardised approach and provides a methodological template for systematic impact assessment in fisheries using bottom impacting methods, to inform mitigation efforts and as a necessary component of a full ecological risk assessment.

Résumé

Ce document présente un cadre méthodologique pour estimer l'impact cumulatif probable des activités de pêche de fond sur les organismes benthiques fragiles. Cette méthode a été conçue pour faciliter la normalisation de son application entre les divers types d'engins et secteurs, pour permettre une comparaison entre des pêcheries employant des méthodes de pêche de fond différentes. La Nouvelle-Zélande a appliqué cette méthode dans son évaluation préliminaire de l'impact de la pêche de fond concernant la pêcherie palangrière de légine de 2008/09. Ce document illustre l'utilité de la méthode normalisée et propose la marche à suivre méthodologique pour l'évaluation systématique de l'impact dans les pêcheries utilisant les méthodes ayant un impact sur le fond, pour guider les efforts d'atténuation et en tant qu'élément nécessaire d'une évaluation exhaustive des risques écologiques.

Резюме

В этом документе представлена методологическая система оценки вероятного кумулятивного воздействия донного промысла на уязвимые бентические организмы. Был разработан подход с целью содействия стандартизованному применению для разного типа снастей и районов с тем, чтобы можно было проводить сравнение промыслов, использующих разные методы донного промысла. Новая Зеландия применила этот подход в своей предварительной оценке воздействия донного промысла при ярусном промысле клыкача в 2008/09 г. В данном документе с целью предоставления информации для работы по смягчению воздействия и в качестве необходимого компонента подробной оценки экологического риска иллюстрируется полезность стандартизованного подхода и приводится методологический шаблон для систематической оценки воздействия на промыслах, которые используют воздействующие на дно методы.

Resumen

Se presenta un marco metodológico para estimar el posible impacto acumulativo de las actividades de pesca de fondo en los frágiles organismos del bentos. Este enfoque ha sido diseñado para facilitar la estandarización de la utilización de distintos tipos de artes de pesca en diversas áreas con el fin de permitir la comparación entre pesquerías que emplean distintos métodos para la pesca de fondo. Nueva Zelandia implementó este enfoque en su evaluación preliminar del impacto de la pesca de palangre dirigida a la austromerluza en el lecho marino durante la temporada 2008/09. Este trabajo ilustra la utilidad de la estandarización y proporciona un marco metodológico para la evaluación sistemática del impacto de las pesquerías que utilizan artes de pesca que interaccionan con el lecho marino, con el fin de implementar medidas de mitigación apropiadas y como un componente necesario de una evaluación detallada del riesgo ecológico.

Keywords: bottom fishing gear, effects of fishing, impact assessment, longline, mitigation, risk assessment, Vulnerable Marine Ecosystem, CCAMLR

Introduction

Background

In 2007 CCAMLR adopted Conservation Measure 22-06 requiring Member countries to assess and manage the risk that bottom fishing methods in the Convention Area may exert significant adverse impacts on certain benthic habitats, termed Vulnerable Marine Ecosystems (VMEs) (CCAMLR, 2007). New Zealand responded with an impact assessment to assess and quantify the likely impact of all New Zealand fishing activities on potential VMEs in the Ross Sea region (Subareas 88.1 and 88.2) in the history of the Ross Sea fishery. The assessment was carried out in two parts: first in a two-day workshop attended by relevant experts (including benthic ecologists, fisheries managers, fisheries observers and vessel captains with extensive experience in the Ross Sea fishery), followed by extensive post-processing of workshop outputs and comparison with relevant literature and records of historical fishing effort. The assessment was submitted to CCAMLR as a part of New Zealand's notification for new and exploratory fisheries in 2008/09 (see New Zealand, 2008).

What follows is an outline of the approach adopted by the New Zealand Antarctic Bottom Fishing Impact Assessment Workshop (hereafter 'NZ Workshop') to assess and quantify the likely cumulative impact on potential VMEs by New Zealand fishing effort in the history of the Ross Sea longline fishery. The process utilises a decision-making analysis termed the analytic hierarchy process, in which complex processes are simplified into component steps, and expert knowledge is incorporated in an objective manner to provide a relative ranking method (Saaty, 1999). The technique has become common in fisheries management specifically because it can easily weight and synthesise both quantitative and more qualitative information (Romero and Rehman, 1987; Mardle and Pascoe, 1999; Mardle et al., 2004; NPFMC, 2006). The impact assessment framework has been distilled and simplified to facilitate standardised application by different fishing nations in different areas, and to allow comparisons among different bottom fishing methods. The purpose of this paper is to illustrate the utility of the standardised approach and provide a methodological template for the risk assessment component of a full ecological risk assessment. Specific examples from the New Zealand assessment are provided for illustrative purposes.

'Risk assessment', 'impact assessment' and the language of risk analysis

The systematic analysis of risk is a field of enquiry fraught with confusion arising from the inconsistent use of language. Numerous authors warn that the term 'risk assessment' is applied to what is in reality a diverse range of analytic approaches, and the words themselves employed in these analyses – i.e. 'risk', 'probability', 'frequency', 'impact', 'event', 'hazard', 'effect', 'consequence', 'uncertainty' – are often imprecisely defined and inconsistently applied (e.g. see Kaplan, 1997; Beer, 2006; Fox, 2006; Kerns and Ager, 2007). It is important then to distinguish between different approaches, to select the most appropriate approach for a particular application, and to be clear about that selection and its implications.

The most common risk assessment approach, dubbed the 'likelihood-consequence' approach, most appropriately addresses the need to manage risks arising from rare and unpredictable events, e.g. earthquakes or storms; total risk is expressed as a product of the expected likelihood and expected consequence of the event, usually combined and assigned a subjective rating or numerical score in a 'likelihood-consequence matrix' (e.g. Australian/New Zealand Standards, 1999; Crawford, 2003; Fletcher, 2005; Martin-Smith, 2008). With its emphasis on discrete low-frequency events, the likelihood-consequence approach is less suited for the assessment of risks arising from activities that are predictable, ongoing and cumulative, such as the environmental effects of fishing.

In particular, both 'likelihood' and 'consequence' are unavoidably scale-dependent. For example, in a typical fishery a fishing 'event' that is 'exceptionally unlikely' (probability <0.01; from Beer, 2006) on a particular day in a particular location will be nonetheless 'virtually certain' (probability >0.99) at the scale of the entire fishery over many seasons. Similarly, the consequence of a fishing event that damages a slow-growing coral may be simultaneously 'catastrophic' (from Fletcher, 2005) at the scale of that particular organism, 'moderate' at the scale of a the local benthic community over years, and 'negligible' at the scale of the entire ecosystem over decades. Any assertions as to the likelihood and the consequence of an 'event' are therefore meaningless without precise definitions of the spatial and temporal scales at which the event and its effects are assessed (Constable and Holt, 2007). For scales at which events are certain and multiple, estimation of actual risk then relies on assessment of how many such events have occurred and of their cumulative impact, i.e. an 'impact assessment', which is the essential first step in an alternative risk assessment approach (see below).

The second, 'exposure-effects' approach to risk assessment is designed to address risks arising from cumulative exposure to influences that are measurable and ongoing (e.g. human deaths due to smoking, or the effects of environmental pollution; see US EPA, 1992, 1998). This approach is arguably more appropriate for ecological risk assessments (ERAs) addressing the effects of ongoing human activities such as fishing (Smith et al., 2007). In this context 'exposure' refers to the total level of impact arising from the activity (e.g. numbers of by-catch species killed, amount of physical habitat impacted). Where impacts are not readily observable this requires a systematic impact assessment to describe and quantify the nature and extent of the impact. The 'effect' refers to the ecological consequences of that impact (e.g. population decline, disruption of ecological processes), the estimation of which requires knowledge of the underlying ecology (Kerns and Ager, 2007). In ERA 'risk' is then the sum of all such effects, or, in a probabilistic sense, the sum of all possible effects multiplied by their probability of occurrence (see Kaplan, 1997), *at a given level of impact*. Impact assessment is a first and essential step in ERA; it is impossible under the exposure-effects approach to define risk to an ecosystem independent of the level of impact.

Note that Kaplan's (1997) definition of risk as 'the summation of the complete set of triplets defining scenario, likelihood and consequence' goes a long way towards unifying the two approaches so long as spatial and temporal scales are defined carefully. However, implicit in Kaplan's definition is the assumption that risks arising from individual events are additive. In ERAs of ongoing activities such as fishing (where 'impact' refers to actual damage and 'risk' refers to ecological consequence) this is unlikely to be the case; the relationship between cumulative impact and total risk will generally be non-linear, subject to negative feedbacks (resilience) or positive feedbacks (disturbance thresholds) at different levels of impact, arising from the complex nature of the underlying ecology. Where Kaplan's formulation is still useful is in the calculation of total *impact*: so long as impact is defined in terms of a simple additive metric, Kaplan's sum-of-triplets (now scenario, *frequency, impact*) approach provides a systematic means of estimating total impact arising from all possible scenarios. This was the approach adopted by the New Zealand Workshop. The estimation of risk associated with that impact will occur subsequently, subject to the limits of existing ecological knowledge.

Risk assessment in the CCAMLR context

The limits of acceptable environmental risk in the CCAMLR context are defined in Article II, as the risk that human activities will: (i) cause harvested populations to decrease to levels threatening stable recruitment; (ii) disrupt the ecological relationships between harvested, dependent and related populations; or (iii) induce changes in the marine ecosystem that are not reversible over the course of two or three decades (CCAMLR, 2008). These guidelines are wholly consistent with the ERA concept of risk expressed in terms of the ecological consequences of human activities; however, the complex and multivariate nature of the ecological relationships to which they refer poses a considerable challenge to ecologists and managers charged with assessing the likely consequences of ongoing activities in the CAMLR Convention Area. Much of the underlying ecology defining the relationship between impact and risk remains unknown, and ecosystem responses are affected simultaneously by other environmental and biological influences interacting at a range of spatial and temporal scales. In situations where available data and ecological knowledge are sufficient, impact assessment can be followed by ERA. However, in data-poor situations, and for poorly understood ecosystem processes, a pragmatic approach is to acknowledge that the ecological consequences of human impacts are likely to remain unknown, and to focus instead on managing the impacts themselves on the assumption that impact reduction is desirable no matter what the actual shape of the relationship between impact and risk. This was the approach adopted by CCAMLR and the Working Group on Incidental

Mortality Associated with Fishing (WG-IMAF) to address seabird mortality from fishing, citing inadequate seabird population data and irresolvable uncertainty about ecological processes governing population responses to seabird mortality (Waugh et al., 2008). This pragmatic decision provides precedent for a formal framework within which Member countries can manage their activities to reduce risk even in the face of considerable uncertainty.

Available data for assessing and monitoring benthic habitats in the Southern Ocean are even sparser than for seabirds, and scientific understanding of ecological processes potentially affected by benthic disturbance is rudimentary at best. For these reasons the NZ Workshop concurred with the approach of the CCAMLR/WG-IMAF seabird mortality assessment and sought to define and quantify as clearly as possible the nature, extent and spatial distribution of likely impacts by the New Zealand longline fishery on fragile benthic fauna in the Ross Sea, without reference to the anticipated ecological consequences to communities or populations. The impact assessment framework described here enables transparent, quantitative and objective comparison of impacts associated with fishing activities in different areas or using different fishing methods. Where ecological knowledge is sufficiently robust to inform meaningful evaluation of the ecological consequences of those impacts, impact assessments of this kind will also provide a sound basis on which to complete an ERA in future.

Definition of 'Vulnerable Marine Ecosystem'

The term 'Vulnerable Marine Ecosystem' is subject to variable interpretation, potentially referring to populations of particular vulnerable taxa, entire benthic assemblages or communities, ecosystems and associated processes, particular species at the scale of the whole Southern Ocean, or physical habitat features (e.g. seamounts) that may support vulnerable taxa (NAFO, 2008; Rogers et al., 2008; Parker et al., in press). Constable and Holt (2007) propose that the definition of VME should incorporate the spatial extent of the disturbance process (e.g. fishing effort) and the expected ability of the ecosystem to recover, implying that the results of a completed impact assessment are a necessary prerequisite for defining a VME. The NZ Workshop adopted a pragmatic definition of a VME as equivalent to 'vulnerable biogenic habitat', i.e. slow-growing sessile benthic organisms that create three-dimensional structures and may provide habitat within a community, and are likely to be vulnerable to disturbance by bottom fishing gear. A more formal process to define the term VME and to produce guidelines for impact or risk assessments relating to bottom fishing methods is currently in progress by several Regional Fishery Management Organisations globally (NAFO, 2008; SEAFO, 2008; CCAMLR, 2007).

Selection of vulnerable taxa

At the NZ Workshop, benthic ecologists and other experts identified 14 groups of VME taxa or 'VME indicator taxa' (i.e. taxa indicative of habitats or communities where VME organisms occur) (Parker et al., 2008). Variable levels of taxonomic aggregation were chosen to reflect functional groupings and the practical limits of taxonomic classification possible by fisheries observers under field conditions. Briefly, these are organisms that create biogenic structures, are fragile relative to the fishing gears in question, are potentially rare or endemic, and have life-history traits that imply slow recovery from disturbance (Rogers et al., 2008; FAO, 2008). The chosen groups are sufficiently broad (generally family or order level) as to be applicable throughout the CAMLR Convention Area and were implemented as a putative list for monitoring in Conservation Measure 22-07 (CCAMLR, 2007). Different groups have been identified by other RFMOs to date (NAFO, 2008; SEAFO, 2008; Parker et al., in press).

Benthic impacts of bottom longline gear

Consideration of the effects of bottom longline fishing gear on benthic organisms is a relatively new development, arising primarily in response to recent United Nations resolutions on sustainable fisheries (UNGA, 2005, 2006). To date there have been no peer-reviewed studies based on actual observations of the effects of bottom longline gear on benthic organisms, in contrast to a multitude of comparable studies of the effects of trawl gear (e.g. see Thrush and Dayton, 2002). This is due in large part to the inherent difficulty of achieving independent observation of a bottom longline set. Tethered cameras (e.g. Constable et al., 2007) show some promise but there is considerable uncertainty as to the extent to which the cameras themselves, which are considerably more bulky than the fishing gear to which they are attached, will influence the movement of the line during setting and subsequent retrieval. Truly independent observation will likely require the use of towed cameras (i.e. on a line other than the longline itself) or Remotely-Operated Vehicles (ROVs), but because longline impacts occur primarily during gear retrieval or from unforeseen events (see below) directly observing impacts as they occur will remain a challenge. Unlike heavy trawl gears that may leave a visible track (Hall-Spencer et al., 2002), the impact footprint of a bottom longline set is likely to be difficult to discern after the fact.

The need to make decisions in such a data-poor setting favours the use of impact assessment approaches to address bottom longline impacts. However, carefully designed research to test the most sensitive assumptions of the assessment process remains a high priority.

Materials and methods

The impact assessment framework

The NZ Workshop developed the following process to estimate the cumulative impact of New Zealand fishing activity on individual vulnerable taxa (Parker et al., 2008) in the Ross Sea region. Results at each step are displayed in tabular form (Table 1) and combined to derive an estimate of total cumulative impact in Step 6.

Step 1: Description of fishing gear

New Zealand vessels in the Ross Sea fishery employ a single consistent gear type, i.e. 'autolongline' sets. A detailed description of the physical fishing gear and its deployment process was presented (Fenaughty and Bennett, 2005; Fenaughty, 2008) that included a detailed breakdown of the different functional components of the gear, including weight, size, material properties, sink rates in water etc., so that impact estimates could be derived separately for each gear component.

Step 2: Description of fishing activity, and definition of spatial footprint for a typical fishing gear deployment event

The behaviour of the fishing gear in a typical gear deployment event (i.e. the 'standard set') was detailed using expert knowledge. The aim was to define as precisely as possible the 'spatial footprint' of a standard set. The spatial footprint is defined as the maximum spatial envelope within which impacts on VME taxa will be confined (i.e. expressed in m^2 per unit effort). Note that there is no assumption at this stage as to the extent or severity of the actual impact within the footprint. For example, the footprint of a benthic longline was assumed to be 1 m wide (absent line movement, see below), because the hooks can extend a maximum of 0.5 m on either side of the line; however, only a fraction of the VME organisms within that footprint will actually be contacted by a hook (since adjacent hooks are more widely spaced). Estimation of actual impact occurs later in Step 4, and takes into account different levels of vulnerability among VME taxa.

Spatial footprints are assigned separately to different components of the gear identified in Step 1. For example, in the New Zealand case, the impact of an anchor falling on the sea floor was assumed to be different from the impact of the backbone (main line) with attached hooks. Similarly, an assessment of the impacts of bottom trawling would be expected to define separate footprints for the passage of different portions of a trawl net over the ocean floor (e.g. trawl doors, sweeps, ground gear only, net only etc.).

It is important when defining footprint 'per unit effort' that the effort units are chosen to be commensurate with historical and ongoing records of total fishing effort, so that footprints per unit effort can be scaled up in the calculation of total cumulative impact (Step 6). For example, effort reporting in the Ross Sea longline fishery includes both numbers of sets and line length per set, enabling calculation of the anchor footprint on a per-set basis (i.e. two anchors on either end of the line) and calculation of the backbone footprint based on actual length.

Considerations of compatibility between impact estimation and effort reporting will also be important in the development of future CCAMLR data collection and reporting protocols, so that appropriate data can be made available for subsequent impact assessments.

Step 3: Description of non-standard gear deployment scenarios, and associated footprints

Various non-standard gear deployment scenarios that can be expected to cause the impact of the fishing activity to be different than that described in the standard set were identified. For example, vessel captains occasionally employ alternate gear configurations with slightly different impacts, and accidents or mishaps can result in unexpected gear movement on the ocean floor or gear loss requiring improvised recovery attempts. Impact footprints were then defined for each of these non-standard deployment events to capture impacts additional to the impact of the standard set. Expressing non-standard impacts relative to the standard set is necessary to avoid double-counting of impacts when the cumulative impacts of all scenarios are summed in Step 6.

Table 1: Example of Impact Assessment Framework Step 6: Calculation of cumulative historical impact of bottom fishing on sample VME taxon (stony coral) for all New Zealand auto-longline vessels in the history of the Ross Sea fishery (Subareas 88.1 and 88.2, 1997–2008). A full impact assessment table would include separate impact vulnerability and total impact columns (i.e. columns H–I) for each vulnerable taxon.

Source of impact (standard gear component or non-standard scenario)	A	B	C	D	E	F	G	H	I
	(Step 5)	(Step 3)	= (A x B)	(Steps 2–3)	= (C x D)/ 1 000 000	(from Step 5)	= (E/F) * 100%	(Step 4)	= (G x H)
	Cumulative effort (km of line or # of sets)	Frequency of scenario (per set)	Cumulative impact events	Footprint size per event (m^2)	Cumulative footprint (km^2)	Total area (km^2)	Percent of total area within footprint	Lethal impact (stony coral)	Percent of taxa lethally impacted (stony coral)
Impact assessment at scale of entire fishery (Statistical Subareas 88.1 and 88.2, 600–2 000 m depth, excludes areas under permanent ice)									
Standard set: Backbone	32 667	1	32 667	1 000	32.7	435 826	0.0075	0.05	0.00037
Standard set: Anchors+chains	4 657	1	4 657	4.8	0.022	435 826	0.000005	0.4	0.000002
Scenario 1: Dragged downline	4 657	0.15	699	3 000	2.1	435 826	0.00048	0.8	0.00038
Scenario 3: Lost gear recovery	4 657	0.02	93.1	1 100	0.10	435 826	0.000023	0.6	0.000014
Totals (not including Scenario 5)					**34.9**		**0.0080**		**0.00080**
Scenario 5: Lateral movement	32 667	0.2	6 533	24 000	157	435 826	0.036	0.2	0.0072
Totals (including Scenario 5)					**191.9**		**0.044**		**0.0080**
Impact assessment within most heavily fished 1° x 1° pixel (176–177°E, 71–72°S)									
Standard set: Backbone	3 615.2	1	3 615.2	1 000	3.62	4 351	0.083	0.05	0.0041
Standard set: Anchors+chains	474	1	474	4.8	0.0022	4 351	0.00005	0.4	0.000021
Scenario 1: Dragged downline	474	0.15	71.1	3 000	0.21	4 351	0.0049	0.8	0.0039
Scenario 3: Lost gear recovery	474	0.02	9.48	1 100	0.010	4 351	0.00024	0.6	0.00014
Totals (not including Scenario 5)					**3.8**		**0.088**		**0.0082**
Scenario 5: Lateral movement	3 615.2	0.2	723.0	24 000	17.4	4 351	0.40	0.2	0.080
Totals (including Scenario 5)					**21.2**		**0.49**		**0.088**

The following non-standard scenarios were identified for the New Zealand fishery in the Ross Sea:

- Scenario 1: Longline floats entrapped and dragged by moving ice (additional impact footprint arises from anchors and broken backbone being dragged along the seafloor prior to breaking off or moving into deep water).

- Scenario 2: Alternate gear configuration with submerged floats connecting two separate lines (no impact additional to that of the standard set).

- Scenario 3: Floats on both ends lost; attempted recovery of lost gear (additional impact arises from dragging a recovery grapnel to snag and recover the lost backbone).

- Scenario 4: Gear recovery failed; gear abandoned (no additional impact relative to Scenario 3).

Because Scenarios 2 and 4 were judged to have no additional impact on VMEs relative to that already calculated, they were ignored in subsequent impact calculations.

The frequency of occurrence of non-standard deployment scenarios was derived from available data or estimated by workshop attendees and expressed in units commensurate with total effort reporting. For example, the workshop estimated that 15% of all sets also involve a Scenario-1 event, and 2% of all sets involve a Scenario-3 event.

Step 4: Vulnerability assessment of VME taxa

The workshop systematically considered the likely impact of different gear components for the standard set (Step 2) and for non-standard gear deployment scenarios (Step 3) on each of the 14 VME taxonomic groups. Care was taken to consider impacts arising from every stage of the fishing process described in Steps 2 and 3, i.e. (for auto longlines) gear deployment, gear 'soaking' (i.e. time spent fishing) and gear recovery. Care was also taken to consider the impacts of localised conditions (i.e. occurring over just a portion of the line) that can be expected to produce local impacts in excess of the average impact, and to adjust the overall impact calculations accordingly based on their estimated frequency of occurrence. For example, the destructive impact on VME taxa of hooked fish struggling to escape was estimated with reference to fishery data indicative of average catch rates per deployed hook.

Impacts were considered at the scale of individual organisms (or structural forms, for colonial organisms such as corals) and assigned to one of three categories, i.e. no impact/non-lethal impact/lethal impact. Lethal impact for a colonial organism was any impact that necessitates re-growth from the substrate level, but not necessarily a new colonisation event.

Note that impact estimates are only meaningful with explicit reference to the size of the footprints defined in Steps 2 and 3. For example, assigning 50% lethal impact within a 1 m wide footprint would be mathematically identical to assigning 25% lethal impact within a 2 m wide footprint. The impact estimation process essentially asserts that X% of all individuals of particular VME taxon Y occurring *within the spatial extent of the footprint* will be lethally/non-lethally affected by a particular gear component or deployment scenario. The agreed impact table was the outcome of considerable discussion by the assembled experts, with reference to the expected behaviour of the fishing gear and the biology and physical structure of the organisms in question. The final numbers were an attempt to be as conservative as possible, i.e. to represent the *maximum* likely impact while recognising the large degree of uncertainty.

It is crucial to note that because the impact estimates are completely independent of the abundance (or even presence) of VME taxa within the footprint (i.e. expressed as a *proportion* rather than absolute numbers) the application of this approach does not rely on accurate knowledge of the occurrence, abundance or distribution of benthic organisms. However, these factors will likely become important in the consideration of spatial management responses to mitigate risk identified by a formal risk assessment process.

Step 5: Description of total historical fishing effort

During and subsequent to the NZ Workshop, attendees examined the distribution and intensity of historical fishing effort in the Ross Sea, both for the New Zealand fishery in isolation and for all nations collectively. Effort was converted to units commensurate with the definition of impact footprints in Steps 2 and 3 (i.e. km of longline for backbone impacts, and number of longline sets for anchor and non-standard scenario impacts), to facilitate the calculation of total impacts in Step 6.

Effort maps were then examined to reveal spatial and temporal patterns. These plots revealed that New Zealand fishing effort in the Ross Sea

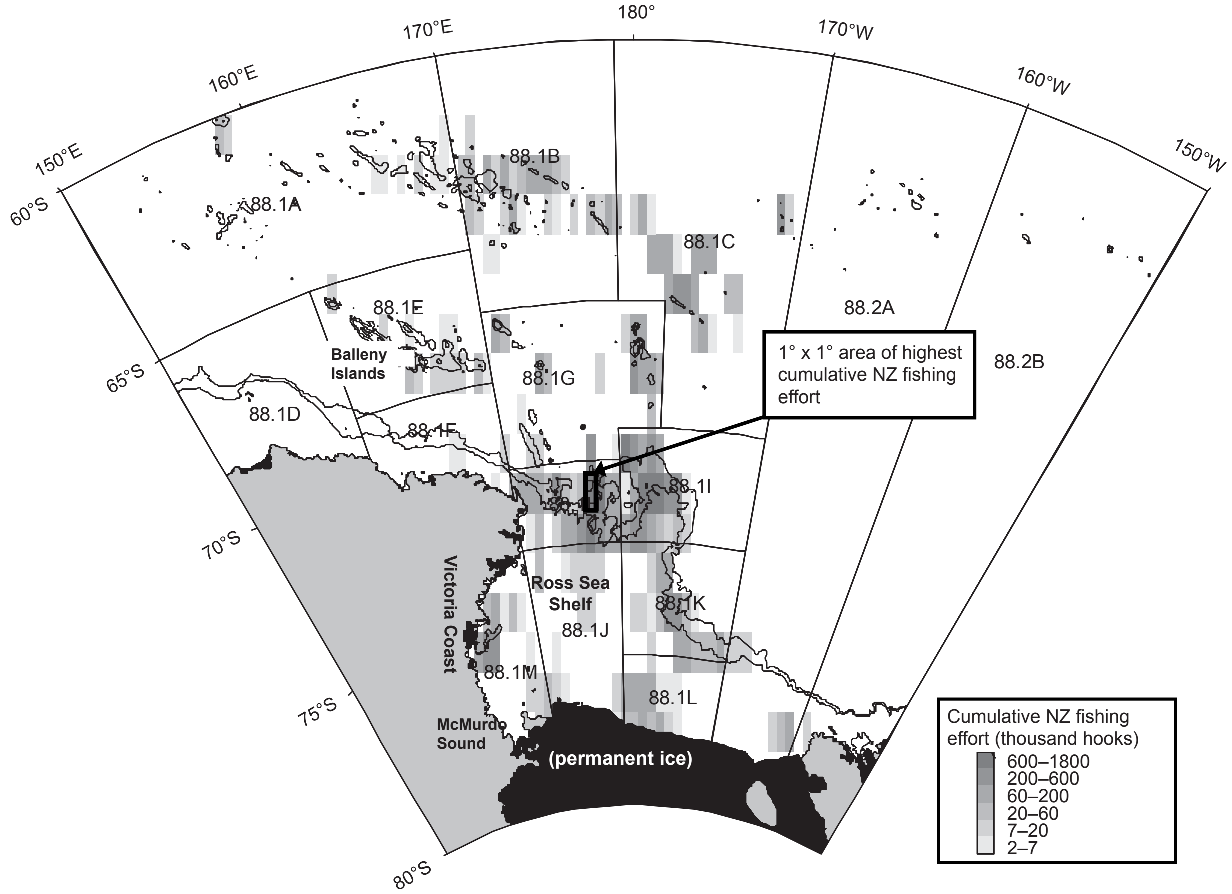

Figure 1: Cumulative New Zealand fishing effort in the Ross Sea fishery (Subareas 88.1 and 88.2, 1997–2008). The 1° x 1° area of highest cumulative effort (176–177°E, 71–72°S) is shown. Contours indicate 1 000 and 2 000 m depth. Note that the spatial resolution of effort data has been blurred to protect proprietary information.

is highly concentrated in preferred areas, e.g. the continental slope in depths of 800–1 500 m, and, to a lesser extent, on features or seamounts further north at similar depths (see Figure 1). When patterns were examined on a year-by-year basis it was apparent that fishing in non-preferred areas has been mainly exploratory, i.e. fishing occurred in a single year after which the area was not revisited. In contrast, core areas are repeatedly targeted. This result illustrates the importance of examining historical impacts in a spatially and temporally explicit way, so that potentially important patterns are not missed.

To examine the consequences of this highly uneven distribution of effort, the cumulative impact calculation in Step 6 was carried out twice, once for the single most heavily fished 1° x 1° pixel (which was 4 351 km^2), and again across all fishable depths in the entire Ross Sea region. For the latter calculation it was necessary to define the 'total fishable area'; this was accomplished by defining fishable depth limits (600–2 000 m) based on visual examination of effort distribution maps and then calculating the total using GIS, excluding areas under permanent ice (total fishable area = 436 000 km^2 within Subareas 88.1 and 88.2; see Figure 1).

Step 6: Calculation of total cumulative impact

Upon completion of Steps 1–5, above, it was possible to calculate the total cumulative impact for each VME taxonomic group, utilising the following formula:

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

6.2 Multiply the frequency of occurrence of non-standard gear deployment events (Step 3) by total historical effort (Step 5) to yield a cumulative numerical occurrence estimate for each non-standard scenario.

6.3 Multiply the size of the non-standard gear deployment footprints per event (Step 3) by total non-standard event occurrence (Step 6.2) to yield total historical footprint per non-standard gear deployment scenario.

6.4 Divide the total historical footprint for each gear component and gear deployment scenario (Steps 6.1 and 6.3) by the size of the fishable area (or specific area of interest; Step 5) to yield a cumulative total historical footprint per gear component/scenario expressed as a proportion of the total area.

6.5 Multiply the results of Step 6.4 by the impact matrix (Step 4) to yield the total historical lethal and non-lethal impact of each gear component or scenario on each vulnerable taxa.

6.6 Sum across all gear components and scenarios (Step 6.5) to yield cumulative total historical impact for each VME taxa, expressed as a percentage (e.g. x% of taxa A in the fishable area has been lethally impacted at the scale of the fishery, y% of taxa B in the fishable area has been sub-lethally impacted at the scale of the fishery etc.).

Results

When the NZ Workshop applied the impact assessment framework described above to data from the New Zealand Ross Sea fishery, the resulting calculations suggested that the cumulative impact on VME organisms of all historical New Zealand fishing effort has been very small. For example, when applied to the most vulnerable VME group (stony corals) at the scale of the entire Ross Sea fishery (all fishable depths in Subareas 88.1 and 88.2) the calculations suggested that approximately 0.0008% of stony corals within fishable depths of the Ross Sea region have been lethally impacted by New Zealand fishing gear in the history of the fishery. Within the most heavily fished 1° x 1° area, an estimated 0.008% of stony corals have been lethally impacted. Note however, that these calculations assume no relationship between the impacted areas and the spatial distribution of VMEs; the validity of this assumption is unknown.

These calculations are subject to considerable uncertainty and are likely to change as new data become available. One such change has already been considered, illustrating a major strength of the impact assessment approach, i.e. the ease with which it can incorporate new information and reveal the implications of altered assumptions. Sensitivity analysis in the original NZ workshop revealed that perhaps the most critical assumption of the assessment was that the standard set does not involve significant lateral movement of the backbone after the line has settled on the sea floor. Research to test this assumption, e.g. using tethered or remotely operated cameras, was identified as a high priority (New Zealand, 2008). Subsequently Welsford and Kilpatrick (2008) presented tethered camera observations in which the backbone did settle and remain stationary on the sea floor even in the presence of strong lateral currents prior to retrieval, but in one of five sets was seen to drift laterally up to 24 m in contact with the sea floor during retrieval. If valid, this result has significant implications for the impact assessment. Taken at face value, this new evidence suggests the need (in Step 3) for a new non-standard deployment 'Scenario 5' involving lateral movement during hauling. The available evidence is sparse ($n = 1$) but in the absence of further data, an event frequency = 0.20 (1 of 5 observed lines) and footprint width = 24 m can be assigned. Impact estimates (Step 4) within this footprint arise from the slow sideways drift of the backbone (with hooks) prior to being lifted free of the ocean floor. Effects on VME taxa are largely unknown because the camera footage only observed a single section of line interacting with a single VME species (stalked crinoids); nonetheless, from first principles, impacts can be assigned that are higher than for the standard set (which involves minimal line movement) but lower than for non-standard Scenario 1, which involves substantially faster movement of more and heavier fishing gear. The addition of Scenario 5 using these assumptions results in total impact estimates that are an order of magnitude higher than previously, but nonetheless still minor at the scale of the fishery: estimated total lethal impact increases from 0.008% to 0.088% in the most heavily fished 1° x 1° area, and from 0.0008% to 0.008% at the scale of the entire fishery (see Table 1). These results illustrate the ease with which the impact assessment framework incorporates new information. The estimates themselves remain highly uncertain in the absence of further research to understand the true frequency and nature of possible line movement in contact with the sea floor.

Discussion

Strengths of the impact assessment approach

The described impact assessment framework provides a useful template that could be productively applied to other fisheries, informing ERAs, prioritising impact mitigation and allowing cross-fishery comparisons to encourage best practice. The framework offers the following strengths.

Consistent applicability

The adoption of a single consistent impact assessment framework greatly facilitates objective comparisons between fisheries utilising different fishing gears and/or operating in different areas. Individual estimates of footprint size (Steps 2–3) and of vulnerability/impact for particular VME taxa/fishing gears (Step 4) still depend on the application of expert knowledge and remain subject to some unavoidable uncertainty due to the inherent difficulty of directly observing benthic impacts. But by utilising expert knowledge within an open and systematic framework, the influence of personal biases is minimised (e.g. Maguire, 2004; Kerns and Ager, 2007). Within the framework even subjective estimates are nonetheless quantitative – *hence testable and objectively scalable relative to one another* – and the rules by which particular estimates are combined to yield cumulative impact estimates at the scale of the fishery (Step 6) are mathematically logical and involve the objective application of available fishery data (Step 5).

Transparency and testability

Despite persistent uncertainty, a major strength of the proposed impact assessment framework is that the assumptions and logic by which total impact estimates are generated are stated explicitly and expressed quantitatively at every stage, and are therefore testable. Completed assessments of this kind can be subjected to sensitivity analyses using rigorous Bayesian methods to represent the degree of uncertainty associated with input data and with each subjective estimate and assumption (Fox, 2006). The importance of various inputs and assumptions adopted in the assessment can then be examined with regards to the magnitude of their effect on the final outcome, guiding the prioritisation of research to test the most important inputs and assumptions. In contrast, assessment processes that express risk or impact in terms of qualitative ratings rely on subjective processes but tend to conceal the logic by which those ratings were generated, such that conclusions become difficult to test objectively.

Ease of modification

The proposed framework is deliberately designed to readily incorporate change. As new data become available, particular numerical estimates can be refined; the consequences for overall impact estimation then arise logically as defined by the framework. Where initial assumptions are shown to be invalid, these can be modified or new scenarios can be defined, without the need to repeat the entire impact assessment process or revisit other assumptions. Impact assessments under this framework are thus amenable to constant incremental improvement, avoiding the institutional burden of repeating the entire assessment process at regular intervals (as in Hobday et al., 2007). In contrast, qualitative risk or impact labels do not lend themselves to easy modification (e.g. in the absence of a quantitative impact metric it is unclear at what point a ‘moderate’ risk becomes ‘high’, and any such modification will likely only be possible by repeating the entire assessment process).

Utility in a data-poor setting

The described impact assessment process *does not require spatially resolved knowledge of the distribution and abundance of various VME taxa* in order to calculate the likelihood that the fishing gear will interact with them. Instead, the assessment calculates the *proportion* of VME taxa affected in a particular area as a function of spatial fishing effort patterns and the nature of the physical disturbance, irrespective of VME presence or abundance. Spatially explicit knowledge of Southern Ocean VME taxa distributions is not presently available at scales useful for management; existing benthic data are sparse, unevenly distributed, and collected using a wide variety of sampling tools that confound comparisons between data from different locations. This situation is likely to persist for the foreseeable future due to: (i) the extreme size of the Southern Ocean; (ii) the high cost and technical difficulty of directly observing benthic communities *in situ* (i.e. using cameras), often at extreme depths; and (iii) the poor and variable efficiency of typical sampling methods.

The overall evaluation of risk associated with fishing impacts on VMEs and the formulation of management responses will still require that attempts be made to map the probable distributions of VME organisms. One proposed alternative to large-scale direct observation of the sea floor is to devise models predicting benthic community composition on the basis of available proxy variables. The modelling approach faces considerable obstacles of its own, namely: (i) the complex and scale-dependent nature of the relationship between physical habitat variables and benthic communities (e.g. see Thrush et al., 2006; Cummings et al., 2006); (ii) insufficient data and/or ecological knowledge to reliably model this relationship at scales big enough for management, yet small enough to be taxa specific; and (iii) the unavailability of key physical habitat data layers (e.g. benthic substrate) with which to build such a model. The application of innovative new statistical methods to model spatial patterns of community composition using both physical and biological datasets shows considerable promise in meeting these challenges (Elith et al., 2006; Ferrier and Guisan, 2006); spatial modelling of Ross Sea benthic communities using these methods is currently under way. In the meantime, application of the impact assessment framework alone empowers decision-makers to prioritise research, manage relative impacts, and design effective impact mitigation even in the absence of spatially resolved knowledge of benthic community composition.

Impact mitigation

Impact assessment empowers and encourages impact mitigation. A standardised impact assessment approach allows objective comparison of the relative impacts of different fishing methods and different gear configurations, encouraging the adoption of minimum-impact fishing practices. Transparent and quantitative impact estimates provide tangible metrics by which to measure incremental improvements, providing incentives for fisher-led innovation in the development of codes of conduct or technical gear modifications to reduce impact further (e.g. Robertson et al., 2006; Hobday et al., 2007; NPFMC, 2009). Assessments that itemise impacts separately for different gear components and different fishing scenarios (i.e. see Table 1, column I) are a valuable tool to help focus mitigation efforts in areas where they are most needed or are likely to yield the greatest reduction in impact.

These results are sometimes counter-intuitive, revealing mitigation options that would otherwise be missed. For example, the original New Zealand assessment (i.e. before the inclusion of Scenario 5) revealed that the cumulative impact of Scenario 1 events (in which the floats, downline and anchors on the end of the fishing line are captured and dragged by moving ice) was estimated to be of comparable magnitude to the cumulative total impact of all standard sets despite the infrequent occurrence and much smaller total footprint for Scenario 1 events. This is because this was the only scenario that involved significant movement of heavy fishing gear across the sea floor. To the extent that it is valid, this result suggests that major impact reductions are possible merely by reducing the frequency of Scenario 1 events.

Process error and uncertainty

The impact assessment process is not without its weaknesses. Although the estimates used are explicit, testable and derived by experts, they are based on working hypotheses and published data from other regions, sometimes in dramatically different environments, with very little use of quantitative information and no direct observation of impacts. As multiple inputs are incorporated, there is no cumulative assessment of estimate uncertainty. Also, as illustrated, the scaling-up process can serve to magnify the effects of uncertainty, such that alteration of key assumptions in the early stages of the impact assessment can result in major changes in the impacts estimated for a given scenario. It is therefore important that uncertainty be considered when interpreting impact estimates, especially where uncertainty varies between different gear types or in different gear performance scenarios. Future applications of this, or any, impact and risk assessment framework should include explicit estimates of uncertainty, with data inputs and quantitative assumptions expressed as ranges rather than point estimates, if possible using rigorous Bayesian methods to track uncertainty through interim calculations to final estimates of impact (and subsequently risk) (Fox, 2006).

Spatio–temporal considerations

Consistent with current knowledge of life history of vulnerable groups, such as corals and sponges (Rogers et al., 2008; Lumsden et al., 2007), the NZ Workshop included ‘slow recovery time’ as a criterion for the selection of VME taxa. However, temporal recovery dynamics were not included in the subsequent impact assessment; cumulative impact estimates essentially treat every impact as if it were permanent. This is a fundamentally conservative (i.e. impact-maximising) assumption. Furthermore, in the context of the Ross Sea fishery, this is a reasonable simplification because the fishery is effectively less than 10 years old; expected recovery times for most vulnerable taxa will be substantially longer than that.

The impact assessment arising from the NZ Workshop also does not address the more complex spatio–temporal nature of historical impacts in the Ross Sea fishery arising from the overlap of multiple-impact footprints in the same location. The assessment effectively assumes that every impact occurs on a previously un-impacted track of the seabed. This is a conservative (impact-maximising) assumption, and also a reasonable approximation of reality for the Ross Sea fishery. For example, note that within the most heavily impacted 1° x 1° area of the Ross Sea fishery, the cumulative total spatial footprint of all New Zealand fishing effort covers less than 0.5% of the ocean floor, even when the assessment is modified to include the much larger footprints of 'Scenario 5' events involving lateral line movement (see Table 1). Assuming random footprint orientation, this implies that only 0.0025% of the seabed has been impacted twice. It is clear then that for impact assessments conducted at these large scales, ignoring areas of overlap between multiple footprints will introduce negligible error to the total impact estimate. It is important though that spatio–temporal considerations be retained in a generalised impact assessment framework. As impact assessments are conducted at finer scales (e.g. to estimate impacts on particular VMEs), or in fisheries where cumulative effort is greater, or where impact footprints are wider, it may become necessary to conduct more sophisticated temporally explicit impact assessments in which the effects of multiple impacts are calculated within the areas of overlap and the average interval between subsequent impacts is assessed relative to the estimated recovery rate of the vulnerable taxa.

Impact assessment does not equal risk assessment

Although the quantitative nature of impact assessment is useful in managing relative impacts, and therefore risks, impact assessment is still a component of a full risk assessment, not a replacement. Spatial impact assessment under this framework cannot determine the level of actual mortality experienced by a given taxon without knowledge of the distribution of that taxon. It cannot describe the nature of the ecological consequences arising from the impact, or the likelihood that these will be 'significantly adverse' (UNGA, 2005) without knowledge of the broader ecological context in which the impact occurs.

Research is currently under way by multiple countries to develop spatial models of benthic community distributions in the CAMLR Convention Area, with an emphasis on VME taxa. As knowledge of the environmental factors influencing benthic community composition improves, and spatial estimates of VME occurrence become available, the intersection of these data with spatially explicit impact assessments, as represented in Figure 1, will provide a powerful tool to inform spatial management responses to avoid and mitigate risks to VMEs. Combined with knowledge of likely ecological consequences at different levels of impact, they will also form the basis of full ecological risk assessments. However, because the requisite ecological knowledge to complete assessments of this kind is sparse with respect to Antarctic benthic habitats, for the foreseeable future the determination of acceptable risk will be made with a large degree of uncertainty, and must therefore be appropriately conservative.

Conclusion

The adoption more widely within CCAMLR of an impact framework, such as that proposed here, would potentially yield immediate benefits. By facilitating objective comparisons between fisheries and regions, a consistent impact assessment framework would identify high-impact fishing practices and encourage the more widespread adoption of lower-impact methods. A spatially comprehensive impact assessment would identify potential impact hotspots at the regional or circumpolar scale and serve to focus subsequent research and mitigation efforts. By providing transparent and quantitative impact estimates, such a framework would provide a basis for the development of tangible incentives to encourage mitigation, and would help to focus mitigation efforts. More long term, pursued in parallel with spatial modelling of VME distributions, an impact assessment framework of this kind would provide essential input to a full ecological risk assessment that considers spatial patterns of fishing impact and benthic community vulnerability simultaneously.

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Liste des tableaux

Tableau 1: Exemple de structure d'évaluation de l'impact, 6^e étape : Calcul de l'impact cumulatif de la pêche de fond sur un échantillon de taxon de VME (corail pierreux) pour tous les palangriers automatiques néo-zélandais dans toute l'histoire de la pêcherie de la mer de Ross (sous-zones 88.1 et 88.2, 1997–2008). Un tableau de l'évaluation exhaustive de l'impact comprendrait des colonnes séparées pour la vulnérabilité à l'impact et l'impact total (colonnes H–I, par ex.) pour chaque taxon vulnérable.

Liste des figures

Figure 1: Effort de pêche cumulatif de la Nouvelle-Zélande dans la pêcherie de la mer de Ross (sous-zones 88.1 et 88.2, 1997–2008). Le secteur de 1° x 1° du plus important effort de pêche cumulatif (176–177°E, 71–72°S) est indiqué. Les profils bathymétriques tracés sont ceux de 1 000 et 2 000 m. Noter que la résolution spatiale des données d'effort a été brouillée pour protéger les informations confidentielles.

Список таблиц

Табл. 1: Пример ступени 6 системы оценки воздействия: расчет кумулятивного ретроспективного воздействия донного промысла на образец таксона УМЭ (каменный коралл) для всех новозеландских судов с автоматическим ярусом при промысле в море Росса в предыдущие годы (подрайоны 88.1 и 88.2, 1997–2008 гг.). Таблица подробной оценки воздействия будет включать отдельные столбцы для уязвимости к воздействию и общего воздействия (т. е. столбцы H–I) по каждому уязвимому таксону.

Список рисунков

Рис. 1: Кумулятивное промысловое усилие Новой Зеландии при промысле в море Росса (подрайоны 88.1 и 88.2, 1997–2008 гг.). Показан район 1° x 1° наивысшего кумулятивного усилия (176–177° в. д., 71–72° ю. ш.). Контуры показывают глубину 1 000 и 2 000 м. Заметьте, что пространственное разрешение данных об усилии дано нечетко с целью защиты конфиденциальной информации.

Lista de las tablas

Tabla 1: Ejemplo de la Etapa 6 del marco metodológico para evaluar el impacto: Estimación del impacto acumulado en un taxón representativo de EMV (corales pétreos) de la pesca de fondo efectuada por todos los barcos neocelandeses que pescaron con palangres de calado automático en las pesquerías del Mar de Ross (Subáreas 88.1 y 88.2) desde 1997 hasta 2008. La tabla de una evaluación detallada del impacto incluiría columnas separadas para la vulnerabilidad al impacto y el impacto total (es decir, las columnas H–I) para cada taxón vulnerable.

Lista de las figuras

Figura 1: Esfuerzo de pesca acumulativo de Nueva Zelandia en la pesquería del Mar de Ross (Subáreas 88.1 y 88.2) desde 1997 hasta 2008. Se muestra el área (1° x 1°) de mayor esfuerzo acumulativo (176–177°E, 71–72°S). Las líneas de contorno indican una profundidad de 1 000 y 2 000 m. Nótese que la resolución espacial de los datos del esfuerzo ha sido desdibujada, para proteger la información de naturaleza confidencial.