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Impacts of Mobile Bottom Gears on Seafloor Habitats, Species, and Communities: A Review and Synthesis of Selected International Reviews

Effets des engins de fond mobiles sur les habitats, les espèces et les communautés du plancher océanique – Examen et synthèse des examens internationaux choisis

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Abstract

Since 2000, five major reviews of the impacts of mobile bottom-contacting fishing gears on benthic species, communities, and habitats have been conducted by international or independent science-based organizations. The bodies are the International Council for Exploration of the Seas, The US National Academy of Sciences, the National Marine Fisheries Service, the United Nations Food and Agriculture Organization, and the American Fisheries Society.

This paper first summarizes the mandate and approach taken in each separate review, and tabulated the conclusions and recommendations of each review separately. These review-specific conclusions are evaluated in terms of any qualifications placed on them in the original report, and their potential relevance for Canadian fisheries. Next the paper cross-tabulates similar conclusions and recommendations across the five source documents, looking for generalities across studies but paying special attention to contradictory conclusions across sources, and qualifications proposed by any one source which have relevance for similar conclusions drawn from other sources.

From this cross-tabulation, 27 specific general conclusions and recommendations are extracted in the final section of this document. These are partitioned into conclusions about effects of mobile bottom-contacting gears on physical features of the seafloor, effects of such gears on benthic species and communities, considerations in the application of adoption of mitigation measures, and recommendations for management of mobile bottom-contacting gears. Within each group, conclusions or recommendations are ordered by the strength and breadth of support across the five studies that were reviewed. The results of this evaluation of international studies and reviews need to be combined with the findings of Canadian studies, to provide a science basis for policy and management of these gears in Canada.

Résumé

Depuis 2000, des organismes à vocation scientifique internationaux ou indépendants ont mené cinq examens d'envergure sur les effets des engins de pêche mobiles qui entrent en contact avec le fond sur les espèces, les communautés et les habitats benthiques. Les organismes en question sont le Conseil international pour l'exploration de la mer, la National Academy of Sciences des États-Unis, le National Marine Fisheries Service, l'Organisation des Nations Unies pour l'alimentation et l'agriculture et l'American Fisheries Society.

Dans le présent document, on résume d'abord le mandat de chaque examen et l'approche adoptée pour les effectuer, et on présente séparément les conclusions et les recommandations formulées. Les conclusions de chaque examen sont évaluées en fonction des critères qualitatifs établis dans le rapport original ainsi que de leur pertinence potentielle pour les pêches canadiennes. Ensuite, on compare les conclusions et les recommandations semblables des cinq documents sources et on tente d'établir des notions générales d'une étude à l'autre. On prête toutefois une attention particulière aux conclusions contradictoires d'une source à l'autre ainsi qu'aux critères qualificatifs proposés dans les sources qui s'appliquent à des conclusions semblables tirées dans d'autres sources.

À partir de cette comparaison, 27 conclusions et recommandations générales particulières sont présentées dans la section finale de ce document. Elles sont divisées comme suit : conclusions au sujet des effets qu'ont les engins mobiles qui entrent en contact avec le fond sur les caractéristiques physiques du plancher océanique; effets de tels engins sur les espèces et les communautés benthiques; considérations relatives à l'adoption de mesures d'atténuation; recommandations pour la gestion des engins mobiles qui entrent en contact avec le fond. Dans chaque groupe, les conclusions ou recommandations sont classés en fonction de l'importance et de l'ampleur du soutien dans les cinq études passées en revue. Les résultats de cette évaluation d'études et d'examens internationaux doivent être combinés avec les résultats d'études canadiennes, et ce, afin de constituer une assise scientifique pour l'élaboration de politiques sur ces engins et pour la gestion de ceux-ci au Canada.

I. Introduction

DFO policy and management sectors have requested scientific information and advice to support development of policies and management measures to ensure impacts of mobile bottom gears on benthic communities and habitats are sustainable. Current policies and practices do take account of these impacts, but the science advice for a consistent and practical approach to this issue has not been consolidated in Canada. This Research Document is a science contribution to bringing about that consolidation.

In the early part of the 2000s, groups of science experts associated with three different non-partisan agencies or organisations (International Council for Exploration of the Seas – HQ in Copenhagen [ICES]; the US National Academy of Sciences - HQ in Washington DC [NAS]; and the US National Marine Fisheries Service – HQ Silver Springs, MD [NMFS] together with the New England and Middle Atlantic Fisheries Management Councils reviewed the scientific information on this issue. These reviews produced summary conclusions and management recommendations, following from their reviews of the scientific information available.

In 2005 the UN Food and Agriculture Organisation - HQ in Rome [FAO], and the American Fisheries Society – HQ Bethesda, Maryland [AFS]) have both published major documents on this topic as well. The FAO overview was prepared by a single contracted author rather than a team of experts, although it went through the standard FAO process of extensive internal review and external review by selected experts. As is standard practice with FAO reviews which are to be used as background for other Expert Meetings, that report summarizes findings and draws conclusions, but does not make specific management recommendations. The AFS "review" was actually the papers from a scientific Symposium, wherein individual authors provided specific conclusions and sometimes recommendations from their work. Standard journal peer review was applied to all papers, but the conclusions and recommendations cannot be taken as a consensus of the Symposium participants. Despite these differences in approach compared to the three reviews from 2001 and 2002, these two publications are included to make sure that the results summarized here include more recent findings. For the rest of this paper all five publications are referred to as "reviews", but it should be kept in mind that the AFS publication was not a "review" in the sense of the other four.

This Research Document first extracts the conclusions and recommendations from each of these five sources. The strategy was to quote conclusions and recommendations directly wherever possible, to reflect accurately the intended meaning of the original source. In the quotations strings of examples and references were deleted for sake of conciseness, but can be found, of course, in the original documents. The ICES and NMFS reviews were organized to provide scientific advice for specific areas (ICES - North Sea and Irish Sea; NMFS – New England and Mid-Atlantic States areas) so some of the conclusions and advice in these two reports is qualified relative to specific places. In those cases commentary is provided on whether the qualifications are thought to restrict the relevance of the conclusion or recommendation to Canadian contexts, or if the results are generalizable beyond the area of the initial request for advice. Otherwise the extracted material from each source is presented at face value as the views of the group of experts whose work is being cited.

The following five sections present the extracted information from each source separately. A final section provides a cross-comparison and synthesis of the material from all five. Here, discrepancies among the sources, when present, are accompanied by some interpretation of the likely causes and implications of the differences. The synthesis and tabulation of the results of the five separate reviews provides the basis for a final set of conclusions which reflect the consolidated views of the different groups of science experts who have reviewed the issue of impacts of mobile bottom gears on benthic populations, communities and habitats. Combined with a series of Research Documents being prepared on the specific information about Canadian benthic habitats, communities, and studies of gear impacts (Gordon et al. 2006, Gilkenson et al. 2006, Archambault et al. 2006), a scientific foundation is provided for Canadian policies and management practices.

II: ICES Advisory Committee on the Marine Environment (ACME) – 2000

Mandate of Review

The European Commission DG of Fisheries communicated to ICES that "ICES is requested to consider the report "The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems" (Lindeboom and de Groot, eds) and to formulate management advice as to how effects of the gears discussed in the report on benthic ecosystems could be measurably reduced, without unduly reducing the possibilities of catching commercially important species. ICES is invited to consider all possibilities, like establishing closed areas for bottom gears, reducing the weight of bottom gears, etc."

Context and Structure of their Review

The Lindeboom and de Groot report, referred to as IMPACT II, was the product of a three year research programme, funded by DG Research. The research reported in IMPACT II was conducted by over 40 scientists working in 13 research centres around the North Sea and Irish Sea. All studies focused on one or both of otter trawls and beam trawls, noting that each type of gear comprises a large class of fishing gears that may not be rigged and deployed the same way. The 404 page IMPACT II report was structured to begin with a series of research reports of the 9 component projects, which used a variety of research designs including designed experimental manipulations, comparative historical analyses, opportunistic comparisons of areas known to have different trawling histories, and literature reviews. These research reports were followed by a final section presenting 13 generalizations and conclusions, and 10 management and research recommendations (many quite broad, such as "Fisheries management should not only be based on management of fish stocks with commercial value, but also on ecosystem management").

The Regional Fisheries Management Agencies of the northeast Atlantic and DG Fish were prepared to adapt management plans to take account of the findings and recommendations of IMPACT II. However, they wanted an independent peer review of the report, to ensure that the conclusions and recommendations were supported adequately by the research findings. ICES was requested to conduct this peer review, and provide management advice as per the request quoted above.

The peer review of IMPACT II was conducted by the ICES Working Group on Ecosystem Effects of Fishing (WGECO), in December 1999. The WGECO meeting attracted 26 experts from 14 countries, covering the disciplines of benthic ecology, ecosystem dynamics, gear design and operation, fisheries population dynamics and management, and fish ecology. At least five scientists involved in IMPACT II research projects participated in the review, including both editors of the overall report. The report of WGECO was considered by ACME in its 2000 meeting. ACME, comprising one nominated expert from each of the 18 member countries of ICES plus an elected Chair, provided a second-level independent review of the WGECO review, conclusions, and recommendations, and formulated the management advice on behalf of ICES. Chairs of several Working Groups reporting to ACME, including the chair of WGECO, participated in the meeting as resource experts, but the advice was formulated by the ACME members.

The WGECO review first considered all studies in IMPACT II with regard to research design, appropriateness of analytical methods, and the strength of evidence which the studies provided for the conclusions drawn from each one. It then considered each overall conclusion and recommendation with regard to first its support from the IMPACT II component studies and then in the context of the wider scientific literature on impacts of trawl gears. From the results of that review WGECO prepared a cross-tabulation of the possible effects trawl gears could have on benthic populations, communities and habitats by the strength of evidence from IMPACT II and from other literature, and by the relative seriousness of the effect and corresponding need for mitigation. “Relative seriousness” was judged on three criteria:

- Temporal scale – permanent or enduring effects are of most concern;
- Spatial scale – the larger the area affected, the greater the concern;
- Direction of change – declines in abundances or features are of greater concern than increases.

In several cases more than one effect was given the same priority, reflecting ICES view that it was inappropriate to weight seriousness on one of the three criteria as necessarily of greater or lesser importance than other criteria, and that nuanced discriminations among effects of generally comparable seriousness would be artificial and possibly misleading.

Finally, WGECO considered the possible mitigation measures and provided judgments on the effectiveness of each type of mitigation measure for each type of potential effect.

From this scientific basis ACME built a series of management recommendations for reducing the impact of trawl fisheries on the benthos of the North Sea and Irish Sea. ACME stressed that application of most measures would require some scoping of specific problems before an effective package of measures could be developed for each case. It stressed that "**the advised Priority Management measures should not be viewed as universally applicable remedies, to be applied without further thought. They should be developed as well-planned mitigation programmes to address well-specified problems**" [bold in original]. It also advised some "Specific Immediate Actions" that should be actioned as quickly as problems could be adequately scoped. ACME also noted that the advice had been developed specifically for the types of otter trawls and beam trawls used in the North Sea and Irish Sea. However, detailed configurations of both of these gears were quite variable around the northeast Atlantic, and ACME warned that many of the advised measures would probably require some adaptation for other mobile gears used in other areas. However, in the advice that followed the caution, many of the advised measures were noted as likely to be generally applicable to a wide range of mobile gears and fisheries.

Findings and Recommendations:

The ICES advice on *possible* effects of trawl gears on seafloor habitats and communities is readily conveyed by repeating table 5.3.1.1 from their Advisory Report. This table has been modified only by reconfiguring columns reporting whether the scientific evidence for the effect came from the North Sea and Irish Sea or from other areas, and from experimental studies or from long-term monitoring. The information on the source of evidence was not influential in application of the advice since it was provided by ICES, and is not crucial to likely use in Canadian waters.

Table 1 –Summary of the information on evidence for the various possible effects of bottom trawling on species (macrobenthos and fish closely associated ecologically or spatially with the benthos) and habitats. Cell entries reflect ICES decisions on the weight of evidence. For many reasons related to study design, implementation, and analysis, or to true differences among specific situations, individual studies may differ in their conclusions regarding various effects of bottom trawling. In the table X means an effect can be present, but is rarely large. XX means that an effect is usually present, and can be large. "None" means no evidence is present from the type of study being considered. "Unclear" means that few studies have provided any information about whether the type of environment affects the likelihood or severity of effect. HPx refers to Habitat Priority x; SPx refers to Species Priority x.

Type of Effect	Strength of Evidence	Type of Evidence	Duration Of Effect	Environment Affected	
	N=North or Irish Sea G=Global	L=Long-term monitoring E=Experimental		High Energy	Low Energy
1. Removal of major habitat features - HP 1	N-Weak/mod G-Strong	L-XX E-None	Permanent	XX	XX
2. Reduction of structural biota – HP 1	N-Weak/mod G- Strong	L- XX E-XX	Years to decades	X	XX
3. Reduction of habitat complexity – HP 2	N – Weak G – Weak	L-None E-XX	Days to several months	Negligible	XX
4. Changes in seafloor structure – HP 3	N-Strong G –Strong	L-None E-XX	Days to several months	Negligible	XX
5. Reduction in geographic range –SP1	N-Mod* G-Strong*	L-XX E-none	Years to decades	XX	XX
6. Decrease in species with low turnover rates – SP 1	N-Weak/mod G-Mod/strong	L-XX E-XX	Years to decades	X	XX
7. Fragmentation of species ranges - SP 1	N-None G-Weak	L-XX E-none	Years to decades	XX	XX
8. Changes in relative abundance of species – SP 2	N-Strong* G-Strong*	L-XX E-XX	Days to many years	XX	XX
9. Fragile species more affected- SP 3	N-Weak G-Weak	L-None E-XX	Unclear	X	XX
10. Surface-living species more affected than burrowing species– SP 3	N-Weak G-Weak	L-None E-XX	Weeks to a few years	Unclear	Unclear
11. Sub-lethal effects on individuals – SP 4	N-Mod/strong G-Mod/strong	L-None E-XX	Weeks to a few years	X	XX
12. Increase in species with high turnover rates – SP 5	N-Moderate G-Moderate	L-XX E-None	Months to a few years	X	XX
13. Increase in scavenger populations – SP 5	N-Weak G-Moderate	L-XX E-X	Days to months	XX	XX

* Evidence for changes in population abundances and/or ranges is moderate or strong. However, because environmental conditions have changed over the period of fishing, and many stocks are exploited by several fisheries, it is usually difficult to unambiguously partition the contribution of a single factor, such as bottom trawling, to the quantified change.

The overall conclusions from the table are that:

"**ICES concludes that there is evidence for the occurrence of all the effects in [the table], and the evidence is strong for the two higher priority habitat effects, and all the higher priority effects on species effects except the fragmentation of populations**" [bold in the Advisory Document]. The ICES evaluation of impacts of trawl gears on benthic habitats and communities gave special attention to two considerations. First, it noted that effects are potentially more severe in low-energy environments with consolidated sediments (mud, gravel, boulders) than in high energy environments and habitats with unconsolidated sediments that are re-suspended frequently by natural events. Second, the impacts of bottom trawling on populations, communities and habitats may alter their ability to recover when fishing ceases. ICES noted that habitats are expected to undergo natural changes over time, so the concept of returning to a "pre-perturbation" state is not appropriate. Nonetheless fishing affects natural ecosystem processes in ways that differ from natural forcing factors, so the absence of a permanent natural equilibrium is not an excuse to ignore effects of fishing on seafloor habitats.

ICES also considered the effects of bottom trawling on food-web and ecosystem properties. It concluded that any effects would be indirect consequences of the direct effects listed above. It noted that there is much less scientific consensus on both the theory predicting the indirect effects, and on which data would constitute empirical evidence for or against the presence of these effects. It advised that because any ecosystem-scale effects would be indirect consequences of the direct effects, so any measures which reduced the direct effects would move the indirect effects in the correct direction. Hence the indirect effects increase the justification to address the direct effects of fishing, but do not suggest that completely different suites of corrective measures would be necessary.

In developing its advice on mitigative measures for the effects of bottom trawling, ICES began with several considerations which it labelled as "common sense". These included:

14. Recovery from a perturbation cause by trawling could take from weeks to centuries, and if recovery is desired, trawling must be reduced, and sometimes prevented, in the affected area for the duration of the recovery period. Thereafter, for the recovered conditions to persist, the reduced (or terminated) rate of trawling must be continued;
15. There is a generally monotonic relationship between intensity of trawling and degree of change in the benthos, with the greatest effects following the initial trawling events. The shape of the asymptotic curves depend on history of natural disturbances, type of gear, and characteristics of the species and habitats affected;
16. All technical measures intended to mitigate trawl impacts are specific to the species and habitats to which they are applied, and the scale and duration of their use. None are generic for all species and habitats;
17. Different technical measures may interact synergistically, so suites of measures should be considered for simultaneous application;

18. Economic incentives can be important for successful implementation of potentially beneficial mitigation measures;
19. Application of all mitigation measures requires case-specific analysis and planning.

These factors, and particularly the last one, all need to be taken into consideration, when drawing inferences from the tabulation of measures to potentially reduce effects of trawling by the specific effects of concern (table 5.4.1 in the Advisory Document). Two general types of measures were identified; those whose expected benefits are proportional to the extent of their implementation across a fleet, and those whose effects are inherently spatial, and therefore proportional to the area to which they are applied. Because of the inherent proportionality of effects of several of the tabulated mitigation measures, ICES made arbitrary assumptions of a scale of implementation in each case. ICES stressed that these assumptions were to allow comparative illustration of the potential effectiveness of different measures for various impacts of trawling, and did not endorse the assumed level of implementation, or any other one. Rather, ICES stressed again the need to address each specific case according to the information available on the particular circumstances.

Table 2. ICES judgements of the effectiveness of various possible mitigation measures in addressing the priority habitat and species impacts of mobile bottom gears. Adapted from ICES (2000).

	Proportional to implementation in the fleet						Proportional to area of implementation			
Effect (see Table 1)	Reduce effort[1]	Gear substitu-tion[2]	Change gear usage[3]	Make gear lighter[4]	Make gear more selective[5]	Bycatch quota[6]	Spatial closure	Real time closures	Improve habitat	Species augmentation
Mitigating habitat impacts										
Physical (HP 1)	-	C	-	-	-	-	C	-	C	-
Biogenic (HP 1)	-	C	-	-	-	-	C	-	E	M
Complex (HP 2)	E	C	-	M	-	-	C	-	M	-
Structure (HP 3)	E	C	-	M	-	-	C	-	-	-
Mitigating species & community impacts										
Range (SP 1)	E	E	M	M	M	M	M	-	M	M
Low Turnover (SP 1)	E	E	M	M	M	M	M	-	M	M
Fragment (SP 1)	M	E	M	M	M	M	-	-	M	-
Relative (SP 2)	M/E	E	-	E	E	-	M/E	M	-	-
Fragile (SP 3)	E	C	-	M/E	-	M	M/E	M	M	-
Surface (SP -3)	E	C	M	M/E	-	-	M/E	M	-	-
Sub-lethal (SP 4)	E	C	M	M/E	E	-	M/E	M	-	-
Small species inc. (SP 5)	M/E	E	-	M/E	M	-	E	-	-	-
Scavengers Inc. (SP 5)	E	C	M	M/E	E	E	M	M	-	-

Key - -= no expected effect; M=moderate protection; E = effective protection; C = complete protection

[1] Assuming a 50% reduction in effort.
[2] Assuming full substitution of present demersal gears in enough areas to reduce seafloor impacts.
[3] Assuming are made in ways that reduce discard mortality.
[4] Assuming modifications to gear reduce their impact on the seafloor.
[5] Assuming modifications such as excluder devices which increase species selectivity and/or survivorship of fish not retained in gear.
[6] Assuming that bycatch quotas are set at an appropriate level to provide protection of valuable non-targeted populations.

Based on this table of effects, and the priorities assigned to the various effects of bottom trawling, ICES identified six priority management measures, and presented them in ranked order, with the most important measure first. These measures were:

20. Major reduction in fishing effort. ICES noted that almost all effects of fishing on benthic populations, communities, and habitats would be reduced by major reductions in fishing effort, particularly fishing with bottom gears. Benefits would be greater for species effects of trawling than for habitat effects of trawling. Reductions in fishing effort would interact synergistically with many of the other potential mitigation measures, and would be necessary for lasting benefits to be obtained from several of the other mitigation measures. ICES did discuss what would constitute a "major reduction", and concluded that it would be case-specific, but usually at least 30% below recent historical levels.

21. Closed Areas. ICES noted that closed areas can fully and effectively protect habitat features from harm, if the areas are sited correctly and implementation is effective. Sedentary species are expected to benefit much more from permanent closures than highly mobile species. The nature of the closure would depend on the objectives intended to be achieved, but for most habitat-related objectives, the closures would have to be year-round and permanent. Closing areas where fishing occurs would be expected to displace the effort to other areas, and careful planning would be needed to ensure that the displaced effort does not cause as many new problems as the closure was intended to address.

22. Gear substitution. Species-related benefits will depend completely on the differential mortality caused by the bottom gear and the gear substituted for it. Habitat-related benefits can be large, but only if the substituted gear has much less impact on the seafloor, and the new gear is used by a substantial portion of the fleet.

23. Gear modification. Effects will be case-specific but can be large, both for species and habitat effects of trawling. To be effective in mitigating effects of bottom trawling, the modified gear has to be used by a substantial portion of the fleet, and therefore cannot reduce the catching efficiency of the gear substantially (or else must be accompanied by substantial financial incentives). Gear modifications which substantially reduce catching efficiency are likely to lead to greatly increased fishing effort with the modified gear, possibly dissipating any potential benefits of the lesser impact per unit of fishing effort.

24. Habitat rehabilitation. ICES considered this method to be appropriate only in specific and local cases, where the habitat needs were well understood. However, for any benefits of habitat rehabilitation to persist, additional measures will be needed to protect the habitat from damage by the fishing methods which caused the habitat degradation to begin with.

25. Governance changes. ICES noted that the management of fishing in the northeast Atlantic was poorly integrated with management of other human activities in the same area, and agencies responsible for managing fisheries had limited interaction with agencies responsible for nature conservation. The situation is different in Canada – and now in Europe as well – as the ecosystem approach to fisheries has

been endorsed by the appropriate departments of governments on both sides of the Atlantic.

Finally, ICES recommended four immediate actions for the northeast Atlantic:

26. Prevent expansion of areas impacted by bottom trawls;
27. Prevent expansion of the number of bottom trawlers;
28. Strengthen the interactions of fisheries management agencies with agencies and groups working in marine conservation;
29. Improve ability to detect and measure impacts of fishing through improvements to instrumentation and monitoring.

These recommendations were made in the context of ICES repeated admonitions that all remedial actions should be matched to the specific circumstances of individual applications. Hence they should not be interpreted as globally appropriate immediate actions. Nonetheless, each warrants careful consideration for application in Canadian contexts as well, although the history of fishing effort, particularly bottom trawling, has been very different between the northeast Atlantic and the Canadian Atlantic and Pacific coasts over the past 15 years.

III. National Research Council – Effects of Trawling and Dredging in Seafloor Habitats

<u>Mandate of Review:</u>

"This first study will 1) summarize and evaluate existing knowledge on the effects of bottom trawling on the structure of seafloor habitats and the abundance, productivity, and diversity of the bottom-dwelling species in relation to gear type and trawling method, frequency of trawling, bottom type, species, and other important characteristics; 2) summarize and evaluate knowledge about changes in seafloor habitats with trawling and cessation of trawling; 3) summarize and evaluate research on the indirect effects of bottom trawling on non-seafloor species; 4) recommend how existing information could be used more effectively in managing trawl fisheries; and 5) recommend research needed to improve understanding of the effects of bottom trawling on seafloor habitats."

<u>Context and Structure of Report:</u>

In the 1996 reauthorization of the legislation under which federal management of fisheries in the US is conducted (*The Magnusson-Stevens Fishery Conservation and Management Act*, also known as *The Sustainable Fisheries Act*) several provisions were added or strengthened which gave greater focus to protection of "essential fish habitat". Implementation of the provisions to "minimize to the extent practicable adverse effects on such habitats caused by fishing" proved problematic. Consequently, the National Oceanographic and Atmospheric Administration (NOAA) contracted the Ocean Studies

Board of NRC to conduct several reviews of information on how fishing affects marine communities and habitats, and provide recommendations for management measures to minimize any detrimental effects. The first of those studies addressed the effects of bottom trawling on marine habitats, and is the focus of the rest of this section of this report. (The second study, underway at the time of writing this report, considers how fishing affects trophic relationships in the sea.) The review was restricted to otter trawling and bivalve dredging, which represent the major mobile bottom fishing gears in use in US waters.

The Ocean Studies Board appointed a panel of twelve experts; eight based at universities, three in marine research laboratories, and one consultant, of which two academics were from outside the US. The Panel was supported by three project officers from the OSB. The Panel reviewed the scientific literature, including their own research, conducted three open sessions where interested parties could present information, and their draft report was reviewed by six independent experts. The consensus report was released in 2002.

Report chapters address characteristics of fishing gear, effects of trawling and dredging, habitat mapping and distribution of fishing effort in the US, approaches to assessment of risk to seafloor habitats, management options, and findings and recommendations. For the purposes of the DFO review the chapters on effects of trawling and dredging and on findings and recommendations are most relevant.

<u>Report Findings and Recommendations:</u>

The report notes that "the acute, gear-specific effects of trawling and dredging on various types of habitat are well documented". However, to assess the risks that these types of fishing pose to seafloor habitats and communities also requires information on the spatial distribution of fishing effort and the distribution of habitats and benthic communities. Incomplete knowledge of the latter factors meant that general recommendations regarding trawl impacts and mitigation measures could be made, but few recommendations were possible regarding how specific fisheries should be managed in particular places.

Based on a literature review reported in their Chapter 3, the Panel concluded that the main potential effects of trawling and dredging included:

1. "Trawling and dredging reduce habitat complexity" – particularly the loss of erect and sessile epifaunas, smoothing of the seabed and reduction of bottom roughness.
2. "If the interval between trawls is shorter than the recovery time, the original benthic structure and species populations might not have the opportunity to recover."
3. "Repeated trawling and dredging result in discernable changes in benthic communities" – the changes include shifts to communities of taxa with smaller body sizes and shorter life spans. Very heavily trawled areas tend to have species richness reduced.

4. “Bottom trawling tends to reduce the productivity of an area.” Although there is a tendency to change towards species with higher productivity *per unit of biomass*, the reduction in standing biomass of benthic organisms in heavily trawled areas results in an overall reduction in productivity.
5. “The effects of mobile bottom gears are cumulative and depend on trawling frequency.”
6. “Fauna that live in low natural disturbance regimes are generally more vulnerable to fishing gear disturbance.” Exceptions were found in the literature, but in general ecological disturbance theory applies to fishing effects as well as natural disturbances.
7. “Fishing gears can be ranked according to effects on benthic organisms. … This ranking is consistent with the degree of bottom contact and sediment penetration of the different gears.”
8. “Benthic fauna can be ranked according to vulnerability. … vulnerability to mobile gear is predicated on the morphology and behaviour of the benthic species. Soft-bodied, erect, sessile organisms are more vulnerable … than are hard-bodies, prostrate organisms.”

Note that not all the numbered quotes above were listed as leading subheadings of paragraphs, so the number of generalizations extracted here from the Research Summary is greater than in the NRC report. The numbering of the generalisations is for use later in this document, and is not used in the NRC Report.

Several algebraic models presenting curvilinear but monotonic relationships between fishing and harm to benthic communities and habitats were presented in the report. All were conceptual, and none were parameterized.

Consequences of the changes in habitat structure for the fish community were listed as potentially increased predation risk for juvenile fish which used habitat complexity for cover due to both decreased prey abundance and increased exposure, and potential changes in species composition of the fish community as habitat suitability for various species changes. The report notes that these effects have rarely been quantified in the field, but this is due to difficulties in conducting long-term studies of adequate statistical power, not the absence of the effects.

Several other indirect of bottom trawling on fish and benthic communities and their habitats are reported, including:

9. Changes to nutrient cycling – could be either an increase or decrease, and pulses of re-suspended nutrients could occur outside the natural seasonal cycle of nutrient availability to which biological communities have adapted.
10. Changes to community structure and trophic linkages – the report does not differentiate clearly the degree to which such changes are a result of the direct mortality caused by encountering the fishing gear (whether retained as landed

catch or not) or are an indirect result of species abundances responding to changes to the seafloor habitats. To the extent that the community changes are consequences of direct mortality by fishing, the changes are a general effect of fishing, and not bottom trawling and dredging per se.

11. Changes to ecosystem processes – Bottom trawling and dredging can selectively remove “ecosystem engineers”; species that are particularly important for filtering the water column, providing three-dimensional habitat structure, and stabilizing substrates.
12. Increased susceptibility to other stressors – By simplifying habitat structure and forcing species to occupy suboptimal habitats, these species are exposed to other potential sources of mortality and stress, such as predation, hypoxia, and pollution.

Finally, with regard to recovery, the NRC Report notes the recovery from perturbation by trawling or dredging depends on a number of factors, including:

13. type and spatial extent (relative and absolute) of habitat alteration;
14. intensity and frequency of disturbance compared to ‘normal’ disturbance regimes;
15. habitat characteristics (sediment type, natural hydrodynamic regime);
16. species and life histories of the biotic community.

Some communities, such as biogenic structures (e.g. corals) and bottom-rooted plants and macro-algae may suffer major impacts and display very slow recoveries, whereas communities in mobile sandy sediments could withstand two or three trawl impacts per year with no marked changes.

The results in Chapter 3 are summarized in Chapter 7 (Findings and Recommendations) as:

“Stable communities of low-mobility, long-lived species are more vulnerable to acute and chronic physical disturbance than are communities of short-lived species in changeable environments”

“Habitat complexity is reduced by towed bottom gear that removed or damages biological and physical structures.”

“The extent of the initial effect and the rate of recovery depend on the stability of the habitat. The more stable biogenic, gravel, and mud habitats experience the greatest changes and have the slowest recovery rates.”

“Less consolidated coarse sediments in areas of high natural disturbance show fewer initial effects, …, recovery is also faster.”

These generalizations were the basis for a series of recommendations for management and research:

17. “Fisheries managers should evaluate the effects of trawling based on the known responses of specific habitat types and species to disturbance by different fishing gears and intensity of fishing effort, even when region-specific studies are unavailable.”

    This recommendation acknowledges that whenever possible, site specific information should be the basis for management actions. However, there is sufficient consistency between current ecological theory and the documented effects of fishing gears that predictions from general trends observed in similar areas would provide a sound basis for management.

18. “The National Marine Fisheries Service and its partner agencies should integrate existing data on seabed characteristics, fishing effort, and catch statistics to provide geographic databases for major fishing grounds.”

    This recommendation acknowledges that substantial relevant data exist of fishing effort and seafloor habitats, but the data are often scattered and not readily accessed together. Bringing these databases together in a common geo-referenced framework will facilitate effective management on local and regional scales. Nothing in the concepts underlying the recommendation restricts its applicability to the US NMFS.

19. “Management of the effects of trawling and dredging should be tailored to the specific requirements of the habitat and the fishery through a balanced combination of the following management tools:

    - fishing effort reductions; …
    - modification of gear design or restrictions on gear type; …
    - establishment of areas closed to fishing.”

    This recommendation acknowledges that no single management tool is universally the best for minimizing impacts of trawls and dredges on seafloor habitats and communities, but combinations of the three tools listed above should be sufficient to provide the necessary protection to benthic habitats.

20. “The Regional Fishery Management Councils should use comparative risk assessment to identify and evaluate risks to seafloor habitats and to rank management actions within the context of current statutes and regulations.”

    This recommendation acknowledges that risk-based management approaches are appropriate for choosing among management options. Further, it notes that even when data are inadequate to support full quantification of risks, suitable tools exist to apply risk-based approaches. Nothing in the concepts underlying the recommendation restricts its applicability to US Regional Fisheries Management Councils and US statutes and regulations.

21. “Guidelines for designating essential fish habitat (EFH) and habitat areas of particular concern (HAPC) should be established based on standardized ecological criteria.”

This recommendation stresses the importance of basing descriptions of the habitat requirements of aquatic organisms on knowledge of the species' biology and not just data availability. It is relevant to requirements under the *Species at Risk Act* (SARA) to protect critical habitat of Endangered and Threatened species, and to application of DFO habitat policies, but it is not unique to managing fisheries using mobile gears.

22. "A national habitat classification system should be developed to support EFH and HAPC designations."

    As with the preceding recommendation, this recommendation has relevance to general aquatic habitat management and application of an ecosystem approach to managing human activities in aquatic ecosystems. However, it is not unique to managing fisheries using mobile gears.

The report concludes with a number of recommendations for further research on gear impacts, habitat evaluation, and management mitigation. All of these recommendations address deficiencies in the global state of knowledge of impacts of mobile gears on benthic habitats and communities. Information needs are similar in Canadian marine jurisdictions, and it would be valuable to consider these recommendations in prioritizing marine ecosystem research in Canada as well.

IV. National Marine Fisheries Service Workshop (Northeast Fisheries Science Center Reference Document 02-01).

<u>Mandate of the Review</u>

The purpose of the review was "to assist the New England Fisheries Management Council (NEFMC), the Mid-Atlantic Fisheries Management Council (MAFMC) and NMFS with 1) evaluating the existing scientific research on the effects of fishing gear on benthic habitats; 2) determining the degree of impact from various gear types on benthic habitats in the Northeast; 3) specifying the type of evidence that is available to support the conclusions made about the impacts; 4) ranking the relative importance of gear impacts on various habitat types; and 5) providing recommendations on measures to minimize those adverse impacts".

<u>Context and Structure of the Review</u>

In the charge to the workshop by opening speakers from NMFS and the two management councils, it was made clear that "habitat" was to be interpreted in the context of "essential fish habitat" under the *Magnusson-Stevens Act* (1996). As such it only considered benthic species and communities in the narrow context of prey for commercially exploited fish stocks. Hence, although the workshop conclusions regarding impacts of mobile fishing gears on physical habitat features can be contrasted directly with the conclusions of the other reviews, the basis for comparing this study to the others with regard to impacts on biological properties of the benthos is very different. The review contains many observations on impacts of gears on benthic communities, but unlike impacts on physical habitat the review rarely specifies whether the observation is a consensus conclusion or a point made in discussion. Assuming that the report was reviewed by participants, so views highly divergent from the views of the majority were labelled as such, these observations are reported and tabulated here.

In that context, the workshop was given five explicit objectives (from Appendix C in that report):

1) Peer review background documents prepared by the workshop Steering Committee.

2) Evaluate the applicability of national and international fishing gear effects research to the Northeast.

3) Evaluate the strength of evidence regarding the effects of different types of gear and fishing practices on marine habitats in the Northeast.

4) Identify and evaluate types of management measures that could reduce the impacts of fishing gear on marine habitats in the Northeast.

5) Provide advice and recommendations to the New England and Mid-Atlantic Fisheries Management Councils for minimizing adverse effects of fishing gear on marine habitats in the Northeast.

For the workshop, 23 experts were invited, including 5 academics, two fishing masters, and two members of conservation advocacy groups. They were given 19 specific questions by the Steering Committee, which also provided background working papers as starting points for discussion. Some discussions were held in subgroups, but all conclusions were produced in plenary sessions. It was not possible for all participants to reach consensus on a number of the conclusions, and those cases are clearly identified in the report. The workshop considered several fishing gears, including several static gears. Only the results on otter trawls and scallop dredges are reported here, as those are the gears most similar to the ones being reviewed in the other documents.

Report Findings and Recommendations

For each gear type considered, the report summarizes the impacts in a table with the same structure for all gears. The table collapses all impacts on benthic populations, species and communities into the single row “changes in benthic prey”, which cannot be compared to the other reviews which differentiated effects on different types of benthic species, such as emergent and buried, long-lived vs. short-lived, etc. Occasionally, some specific type of organisms might be mentioned in the context of a particular type of impact. However, the format of the meeting and report did not make it possible to determine if such statements were consensus conclusions of the meeting or were just offered by a participant, nor if the absence of such statements in sections on other gears or for other types of organisms meant that the effects were not expected for those other types of gears or species. Hence, this report is not contrasted with the others in the context of impacts of gears on populations, species, and communities. On the other hand, the report consistently addresses the degree to which impacts may differ in high-energy and low energy environments, and among sand, mud, gravel, and hard-bottom habitats. These differences are brought out strongly in the review of the impacts of each gear type.

The most concise presentation of the conclusions from this review are tables 4 and 5 from that report on scallop dredges and otter trawls, respectively. These are copied directly as tables 3 and 4 of this report:

Table 3 Impacts of scallop dredges on benthic habitat

Type of Impact	Degree of Impact	Duration	Type of Evidence	Comments
MUD				
Removal of Major Physical Features	N/A			
Impacts to Biological Structure	N/A			
Impacts of Physical Structure	N/A			
Changes to Benthic Prey	N/A			
SAND				
1. Removal of Major Physical Features	Unknown			
2. Impacts to Biological Structure	XXX(L) X	(H)Months-Years	PR,GL,PJ	
3. Impacts of Physical Structure	XXX(H,L)	Days-Months	PR,GL,PJ	Cut shell provides additional structure
4. Changes to Benthic Prey	Unknown			Disposal of shucked scallop viscera may alter local food sources – impacts unknown
GRAVEL				
5. Removal of Major Physical Features	Unknown			
6. Impacts to Biological Structure	XXX (H) N/A(L)	Several Years (H)	PR,GL,PJ	(L)=deepwater banks, gravel ridges in GOM; fishery is not prosecuted here.
7. Impacts of Physical Structure	XXX (H) N/A(L)	Months – Years (H)	PR,GL,PJ	(L)=deepwater banks, gravel ridges in GOM; fishery is not prosecuted here; Cut shell provides additional structure.
8. Changes to Benthic Prey	XXX (H) N/A(L)	Months – Years (H)b	PR,GL,PJ	(L)=deepwater banks, gravel ridges in GOM; fishery is not prosecuted here
KEY: X=Effect can be present, but is rarely large; XX = Effect is present and moderate; XXX= Effect is often present and can be large; (H) = High energy environment; (L) = Low energy environment; PR=Peer reviewed literature; GL= Grey literature; PJ = Professional Judgment. [Other notes included re definitions].				

The report included the findings of a number of published studies that were considered applicable to other similar habitats. However, these may not be consensus conclusions of the workshop, or else the effect may not have been linked to the dredges:

9. "disruption of amphipod tube mats and decline in dominant megafauna species in sand"
10. "increased epifauna on cobble/shell bottom in a closed area"
11. "disturbance of storm-created coarse sand ripples"
12. "increased abundance of emergent sponges inside a sandy area closed to dredging"
13. "redistributed gravel, pebbles, and boulders, flattened sand and mud bedforms, and resuspended fine sediments"
14. "reduced epifaunal community, smoother bottom, and disturbed and overturned boulders in a gravel area"
15. "reduced densities, biomass, and species diversity of megabenthic organisms in disturbed gravel habitats"

From their discussions, other points that were included in the report include:

16. "higher percentage cover of emergent colonial epifauna in undisturbed gravel habitats"
17. "The panellists also agreed that the first pass of a dredge over an undisturbed area is expected to have more significant effects than subsequent passes."
18. "Structure-forming biota that are present in sandy habitats are just as vulnerable to scallop dredging as in gravel habitats, but the biological impacts of dredging on emergent epifauna are less significant in high energy sand environments …"
19. The possibility of nutrients and contaminants being resuspended was discussed, but it was noted most studies were done in inshore coastal and estuarine habitats, and could not be the basis for generalisations.
20. With regards to Management options, the report includes statements that effort reduction, gear modification and area management could all contribute to reducing impacts of scallop dredges on benthic habitats, with spatial management getting particularly strong support.

Table 4 – Impacts of Otter Trawls on Bentic Habitat

Type of Impact	Degree of Impact	Duration	Type of Evidence	Comments
MUD				
21. Removal of Major Physical Features	XXX (H) N/A (L)	Permanent	PJ	(H) in Mud refers to clay in all cases
22. Impacts to Biological Structure	Unknown (H) XX* (L)	Months - Years	PJ	(L) opinions ranged from X-XXX
23. Impacts of Physical Structure	XXX* (H) XX* (L)	Months - Years	PR,GI,PJ	(L) opinions ranged from XX-XXX and unknown
24. Changes to Benthic Prey	Unknown			
SAND				
25. Removal of Major Physical Features	N/A	N/A	N/A	
26. Impacts to Biological Structure	XX* (H,L)	Months - Years	PR,GI,PJ	(H) opinions ranged from X – XXX (L) opinions ranged from XX – XXX
27. Impacts of Physical Structure	X* (H) XX* (L)	Days - Months	PR,GI,PbJ	(H,L) opinions ranged from X - XXX
28. Changes to Benthic Prey	XX* (H,L)	Months - Years	PR,GI,PJ	(H) opinions were XX or unknown (L) ranged from X-XXX and unknown
GRAVEL				
29. Removal of Major Physical Features	XXX (H,L)	Permanent	PR,GI,PJ	
30. Impacts to Biological Structure	XXX (H,L)	Months - Years	PR,GI,PJ	
31. Impacts of Physical Structure	XXX (H,L)	Months- Years	PR,GI,PJ	Rocks altered or relocated
32. Changes to Benthic Prey	Unknown			
KEY: X=Effect can be present, but is rarely large; XX = Effect is present and moderate; XXX= Effect is often present and can be large; (H) = High energy environment; (L) = Low energy environment; PR=Peer reviewed literature; GL= Grey literature; PJ = Professional Judgment. [Other notes included re definitions]. * This does not represent a consensus among the panel.				

The report discussed several indirect effects of otter trawling that are reported as "potential effects". However, these may not be consensus conclusions of the workshop, or else the effect may not have been linked to the otter trawls. These effects include:

33. "1) altered trophic function of benthic communities primarily caused by a reduction or change in large biota, a reduction or change in predators, or a reduction or change in epiphytes, and 2) altered demersal communities, primarily caused by loss of structure-forming biota and an alteration of physical features."
34. "The most significant potential effects of otter trawls … included changes to bottom structure and long-term changes in benthic trophic function or ecosystem function. … these changes may result either from a reduction of organisms or the replacement or organisms."
35. There was discussion of effects on scavengers and sediment dispersion, but no clear conclusions.
36. The panel did agree that "the effects of otter trawls are believed to vary by the specific configuration used, by the intensity of the trawling activity, and by the type of habitat in which the gear is used".
37. With regard to Management the panel listed effort reductions, area restrictions, and gear improvements as all appropriate. Strongest support was given to area closures as offering the most permanent protection to habitat features, but the three measures could be used together for best overall effects

V. Impacts of trawling and scallop dredging on benthic habitats and communities" – FAO Technical Paper 472.

The scientific basis for both the ICES and the National Academy advice was research completed in the 1990s or very early in this decade. There have been two major overviews published in 2005, which bring the scientific basis for managing trawl fisheries in the context of impacts on seafloor species and habitats up to date. Neither report includes formal management advice, but the scientific content can be considered for consistency with the ICES and National Academy advice.

The first document is "Impacts of trawling and scallop dredging on benthic habitats and communities" – FAO Technical Paper 472, released in September 2005. It reviewed more than 35 studies of trawl and dredge impacts published since 1990. The review focused particularly on critical evaluation of the methodologies used in impact studies, finding many shortcomings in published works. Although there are many kinds of design problems in trawl impact studies, the review concludes that the net tendency is for studies to often overestimate short-term effects of trawling by including natural variation in the treatment effect but to underestimate long-term effects through the limited time span of many studies.

Despite these common tendencies, the FAO report does contain a number of conclusions regarding physical and biological effects of trawl gears and scallop dredges. (As with previous sections, the numbering of conclusions is internal to this report, for comparative purposes across sections. In the quoted text, lists of examples or references have been deleted to save space, and these deletions are marked with three dots.)

Conclusions regarding physical effects include:

1. Particularly for beam trawls and scallop dredges "the most conspicuous physical impact is flattening of bottom features such as ripples and irregular topography";
2. "features such as bioturbation mounds and polychaete tubes are shown to be eliminated in the tracks of beam trawls and scallop dredges";
3. "The physical impacts on the sea bed caused by otter trawling are likely to be different from those caused by beam trawling and scallop dredging. As the latter two gear types penetrate into the sediment …";
4. "The ecological impacts of eliminating natural bottom features on the benthic community are not clear and have not been adequately addressed in the studies on trawling disturbance published to date.";
5. "Furrows and berms created by the trawl doors are the most conspicuous physical impacts from otter trawls. The trawl doors …. create an irregular bottom topography rather than flattening natural features."
6. For otter trawls "The area disturbed by the trawl doors comprises only a small proportion of the total area swept by the trawl. … Because no or only faint marks are created by the other parts of an otter trawl, the physical impacts on the sea bed are likely to be marginal in most otter trawl fisheries. An exception may be intensively trawled fishing grounds in sheltered areas or in deep water, where trawl marks may last a long time."
7. "The longevity of these effects [of all three gear types] is determined by sediment type and natural disturbances, …, and has been shown to last from a few hours to more than a year."
8. "Data are too scarce to allow a clear relationship between persistence of trawl marks and bottom type/natural disturbance to be made."
9. Importantly this report concluded that "the tools and methods used to determine physical impacts … are rough and crude ways of describing seabed characteristics." A study using "very high-resolution acoustics were able to determine small-scale structural changes in the upper 4.5 cm of the sediment, at a scale of resolution that is relevant to the benthic biota. This is the scale at which the physical impacts of trawling should be investigated."

Conclusions regarding biological impacts include:

10. "Several studies … state that trawling is the most disruptive and widespread anthropogenic disturbance on benthic habitats and may substantially alter benthic communities". By considering the deficiencies in many studies, "this review ... has shown that the evidence for such statements is not well documented or convincing."

11. However, with regard to studies that have concluded that there are few documented benthic impacts of fishing, at least on the scale of commercial fisheries "it is difficult to conduct studies that give clear and unambiguous results, and such statements should be avoided. … The chance of detecting potential changes caused by trawling can be low because the power of the statistical tests in some studies has been shown to be very low."

12. Of the few otter trawl studies considered scientifically sound in this report "The comprehensive experiment conducted on the Grand Banks showed a 24 percent decrease in total biomass of megabenthic species", but this may "represent an overestimate of the real effect of the disturbance. … This decline seemed to recover within a year, and very few community indices or taxa showed any long-term effect from trawling."

13. With regard to shrimp trawling, "The four experiments on shrimp trawling provide no clear evidence of disturbance effects on benthic soft-body communities, with the exception of a decrease in the abundance of echinoderms."

14. "Studies on the impacts of trawling on hard bottoms are few, but the three studies reviewed here all showed effects on large, erect sessile invertebrates. … tall sessile invertebrates such as sponges are damaged to a large extent when hit by the ground gear and, depending on the proportion of the fishing ground that is touched by this part of the trawl, habitats dominated by large sessile fauna may be severely affected by trawling."

15. For scallop dredges, with two exceptions "effects on community structures were demonstrated in all the studies … The most common effects demonstrated were a decrease in the number of species and reduced abundance for certain species."

16. The few studies of "Recovery of the benthic community after [scallop] dredging disturbance … showed that few effects lasted beyond eight months after dredging".

In the final overall conclusions this report notes:

17. "Although current knowledge of the linkage between benthic habitat complexity and the dynamics of fish populations is rudimentary …some effects on the fish community have been demonstrated, e.g. higher juvenile survivorship in more complex habitats … and changes in the abundance of different fish general following alteration in the abundance of epibenthic fauna."

18. "Several studies have demonstrated that anthropogenic impacts have a negative effect on longer-lived benthic species, but a positive effect on small opportunistic species."

19. "the knowledge of how towed fishing gears affect different habitat types is still rather rudimentary. The main reasons … is [sic] that such studies are very complicated and demanding to conduct and that benthic communities show large natural variability that is not well understood."

VI. Benthic Habitats and the Effects of Fishing" edited by Barnes and Thomas (2005)

The other major recent publication is the Proceedings of an American Fisheries Society Symposium entitled "Benthic Habitats and the Effects of Fishing" edited by Barnes and Thomas (2005). Although the Symposium was held late in 2002, the editing process for the publication resulted in many of the 59 full papers and 99 abstracts containing more recent information. As a scientific symposium, the format did not allow challenge and debate of the content of most presentation, and no management advice or consensus conclusions were produced. Several of the book sections were on overarching policy issues, technologies for measuring impact, and social issues, which are outside the purview of this Research Document. However, for many of the papers in the sections on Linking Fisheries ... to Benthic Habitat Character and Dynamics, Effects of Fishing: Assessment and Recovery, Comparison of Effects of Fishing with Effects of Natural events and Non-Fishing Anthropogenic Impacts on Benthic Habitats, Extrapolation of Local and Chronic Effects of Fishing …, and Minimizing the Adverse Effects of Fishing on Benthic Habitats: Alternative Fishing Techniques and Policies, the factual information in many of the presentations is relevant to the deliberations at this meeting. The key conclusions of selected papers are presented below, and as in the other sections, numbered for comparative uses in the Synthesis and Discussion section.

1. Linking Fisheries to Benthic Habitats at Multiple Scales: … (Anderson et al.). Quantification of habitat preferences of haddock becomes more specific as the spatial resolution of the data analyzed becomes finer. From the range of habitats available on various banks, haddock consistently were at higher densities in more rugged areas.
2. Combining Scientific and Fishers' Knowledge to Identify Possible Groundfish Essential Fish Habitats (Bergmann at al.). Fishers and scientific surveys provided generally compatible indications of preferred habitats for groundfish, and cod, haddock and whiting seem to be fairly general in their habitat usage.
3. Delineating Juvenile Red Snapper Habitat … (Patterson et al.). Habitat characterisation required fairly fine-scale (less the tens of km, and possible less than km) data, and snapper consistently reach highest densities in areas with small-scale (cm to m) spatial complexity.
4. Living Substrate in Alaska: Distribution, Abundance and Species Associations (Malecha et al.). Bycatch data from research surveys allowed the spatial distribution of sponges, sea anemones, etc. to be characterised, and areas with high densities of such "living habitat" features also tended to have high densities of several commercially important fish and invertebrates.
5. Effects of Fishing on Gravel Habitats: Assessment and Recovery … (Collie et al.) A comparative study of lightly and heavily trawled areas on Georges Bank found that the lightly trawled area had significantly higher numerical abundance and biomass of benthic megafauna. The undisturbed area also had more fragile species that live in the complex habitats presented by the epifauna. When a

heavily trawled area was closed to bottom gears, over 5 years there was a 4-fold increase in abundance, an 18-fold increase in biomass, and a 4-fold increase in productivity. There was also a change in species composition with increases in crabs, molluscs, polychaetes, and echinoderms, and larger animals came to dominate the fauna in the closed area.

6. Effects of Area Closures on Georges Bank (Link et al.). After a 5 year closure of portions of Georges Bank, there were few differences in nekton or benthic species composition and richness between paired areas inside and outside the closure. However, larger individuals of many species of fish were found inside the closed areas. Additionally, habitat type strongly influenced the distribution, abundance, biomass, size, and feeding ecology of many species. The areas of higher habitat complexity and lower natural disturbance ("low energy environment") had higher values of many of the biotic variables, and showed greater differences in benthic faunas between areas opened and closed to fishing.

7. Effects of Fisheries on Deepwater Gorgon Corals (Mortensen) – Using underwater video, signs of fishing impacts were found on three species of deepwater corals in waters off Nova Scotia, in an area fished intensively by otter trawls, gill nets, and long lines. Damage included broken, tilted, and scattered skeletons of corals, with less brittle corals showing less damage. 4% of the coral colonies examined were damaged, and damage was present in nearly 30% of the transects.

8. Susceptibility of the Soft Coral … to Hydraulic Clam Dredges ... (Gilkinson et al.) – Using underwater video, in an experimental study no statistically significant effects of dredging were observed on soft corals normally attached to shells and gravel. However, the study had a low power to detect differences, and coral-bearing shells may have been displaced out of the path of the dredge by dredge-generated turbulence. Larger effects might occur in areas of greater shell and coral density.

9. Effects of Experimental Otter Trawling on Feeding of Demersal Fish … (Kenchington et al.) – In an area closed to fishing for more than a decade, intensive experimental trawling was conducted in selected study area. Following the first trawl event the density of species such as cod, haddock and winter flounder increased markedly. The diets of cod haddock and several flatfish showed significant changes after trawling, with an increase in amount of prey consumed, an increase in diversity of taxa eaten, and increased in consumption of some particular prey species, including horse mussels and polycheates.

10. Summary of the Grand Banks Otter Trawl Experiment … : Effects on Benthic Habitat and Macrobenthic Communities (Gordon et al.) – A 3-year trawl experiment on a relatively high-energy sandy-bottom ecosystem found short term (< 1 year) effects on habitat structure, and an average of a 24% reduction in mean epibentic biomass immediately after trawling. The species showing greatest effects were snow crabs, several echinoderms, and soft corals. Immediate effects on infauna were small and limited to a few species of polychaetes. The biological

community appears to recover in < 1 year, and no effects were recorded 3 years after the experimental trawling.

11. Effects of Chronic Bottom Trawling on the Size Structure of Soft-bottom Benthic Invertebrates (McConnaughey et al.). Comparing adjacent heavily trawled and untrawled high-energy, sandy-bottom areas, three years after trawling ceased, for 15 of 16 benthic taxa examined mean sizes of individuals were smaller in the heavily trawled area than in the untrawled area. For the remaining species, the larger size was due to a rarity of small crab, not an increase in abundance of large crab.
12. Effects of Commercial Otter Trawling on Benthic Communities in the … Bering Sea (Brown et al.) An area closed to fishing for 10 years was contrasted with an adjacent recently reopened area in a shallow, high-energy sandy area. The fished area had lower macrofauna density, biomass, and richness than the unfished area. Sessile taxa were more common in the closed area and scavengers were more common in the open area. Fragile taxa were rare but appeared unaffected by fishing.
13. Effects of Bottom Trawling on Soft-bodies Epibentic Communities in the Gulf of Alaska (Stone et al.). Benthic communities on adjacent low or moderate energy areas open to fishing and closed to fishing for 11-12 years were compared using video methods. In the areas open to fishing species richness tended to be lower, and biogenetic structures, low mobility taxa, and prey taxa for commercially harvested species were less abundant.
14. Biological traits of the North Sea Benthos: Does Fishing Affect Benthic Ecosystem Function? (Bremner et al.) – Trends in 18 biological traits representing morphology, life history, feeding and habitat use of benthic species were examined over a 30 period of increasing fishing pressure. Opportunistic species dominated the communities, and increased with initial increases in fishing effort, thereafter maintaining relative stability. Traits expected to be associated with vulnerability to fishing decreased proportionately to increasing fishing effort. Species with high regeneration potential and asexual reproduction also declined. Traits related to feeding and habitat usage remained relatively stable.
15. The Impact of Trawling on Benthic Nutrient Dynamics… : Implications of Laboratory Experiments (Percival et al.) – Nutrient concentrations and fluxes under simulated trawling at moderate and high rates were compared to control rates. Trawl impacts affected all the nutrient measurements and flux rates, and elevated levels of ammonium and phosphate persistent more than 48 hours. This suggests regular trawling may have altered benthic nutrient fluxes widely, with impacts on coastal nutrient dynamics and productivity.
16. Potential Impacts of Deep-Sea Trawling on the Benthic Ecosystem along the Northern European Coastal Margin (Gage et al.) – In a review of scattered information, it is reported that trawl scour marks on soft sediments persist longer than in shallower areas. Many other implications of results from elsewhere were extrapolated to deep-sea continental marginal areas.

17. Immediate Effects of Experimental Otter Trawling on a Sub-Arctic Benthic Assemblage inside … a Fishery Protection Zone ... (Kutti et al.) – Experimental trawling seemed to affect the community mainly through resuspension of surface sediments and relocation of shallow burrowing infauna species. At 1 day of post-trawling, there was an increase in the biomass and abundance of the majority of the infauna bivalve taxa. No dramatic changes in composition of the fauna due to trawling was found.

18. Preliminary Results on the Effects of Otter Trawling on Hyperbenthic Communities. (Koulouri et al.). Although the analyses of results were incomplete, an experimental investigation of the effect of otter trawl ground-ropes showed significant perturbation of small benthos living at the sediment-water interface. Effects persisted at least a week post-trawling, and reflected a likely in-migration of small organisms to feed on an increased food supply. Several groups of hyperbenthos did not show changes in abundance after trawling.

19. Trawl Fishing Disturbance and Recolonization Dynamics (Pranovi et al.) – Medium-term (~9 months) recolonization of an area experimentally trawled a single time was studied with a number of ecological indices. Scavengers increased for ~ 7-30 days, then decreased, depending on the substrate type. Complete recovery required approximately 9 months in both sand and mud habitats. The benthic communities in heavily trawled areas resembled the community in the experimental area soon after the trawl treatment.

20. Short-term Effects of the Cessation of Shrimp Trawling (Sheridan and Doerr) – In a shallow, high-energy sandy environment, after a 7-month experimental closure to shrimp trawling, there were no differences in sediment rates or characteristics compared to an adjacent area which was open to fishing. Densities and biomasses of most small epibenthic and infauna invertebrates did not differ between the areas.

21. Comparison of Effects of Fishing and Effects of Natural Events and Non-Fishing Anthropogenic Impacts … (Lindeboom). A review article presents few new data. However, it highlighted the very complex interactions among natural changes and various human activities. It concluded that effects of fishing on benthos are several orders of magnitude greater than effects of sand and aggregate extraction, or oil and gas development.

22. Spatial and Temporal Scales of Disturbance to the Seafloor … (Thrush et al.) – This paper included few new data, but developed a heuristic model applying ecological theory of disturbance rates and magnitudes to fishing effects. It concluded that many effects of fishing may be difficult to reverse if the rates of disturbance by fishing were much more frequent than rates of natural disturbance. Recovery potential also depends importantly on the spatial extent of fishing relative to the mobility of species affected by fishing.

23. Muddy Thinking: Ecosystem-based Management of Marine Benthos: (Frid et al.) This paper developed a conceptual framework for managing human activities that affect the benthos. It stressed the value of performance metrics and decision rules, and concluded that few currently used metrics of ecosystem status,

particularly community metrics, provide a robust foundation for evaluating performance of management or for guiding decision-making.

24. Spatial and Temporal Distributions of Bottom Trawling off Alaska … (Rose and Jorgensen) This paper highlighted the difficulties of providing accurate estimates of total area exposed to trawl gears during a fishing season. It concluded that spatial overlap of repeated trawl events is high in the fisheries studied, and given the spatial scale of reporting commercial effort, most analysis methods will over-estimate the total area exposed to trawling and underestimate the frequency with which the most preferred grounds are fished.
25. Impacts of Fishing Activities … : Approaches to Assessing and Managing Risk (Fogarty) – This paper is primarily about reference points and multi-criterion management strategies. In the context of evaluating trawl impacts it does highlight that recovery of depleted populations may be intimately tied to recovery of altered habitats. It also noted that the management tactics available to address habitat impacts are combinations of effort controls, changes in gear configuration or usage, and spatial management strategies which restrict use of bottom gears in selected areas.
26. An alternative Paradigm for the Conservation of Fish Habitat … (DeAlteris) – This is another largely conceptual paper about management strategies. It proposed to have degree of protection of areas from bottom gears depend on vulnerability of the substrate (with sand substrates less vulnerable than muddy ones) and rarity of the habitat type.
27. Habitat and Fish Populations in the Deep-Sea *Oculina* Coral Ecosystem … (Koenig et al) - These structurally complex and fragile habitats support particularly high densities of many fish. They have been protected from trawling since 1984, but there is evidence that the protection has been far from completely effective. Less than 10% of the *Ocalina* stands examined with video appeared to be undamaged, with the source of the damage inferred indirectly to be most likely fishing.
28. The Impact of Demersal Trawling on … The Darwin Mounds (Wheeler) – Several parts of this field of deep-water (<1,000 m) small coral-topped mounds was shown by acoustic and video methods to be extensively impacted by trawling, despite their depth and the comparative recency of deep-water trawl fisheries in the Northeast Atlantic. There is evidence of heavy trawl activity in some areas, where dead coral and coral rubble are common, and trawl marks are clearly visible.
29. Fishing Impacts of Irish Deepwater Coral Reefs (Grehan et al.) – In an area of large, complex, and fragile coral reefs in the deep-sea off Ireland video methods showed no evidence of trawl damage, but gill nets and long-lines were entangled in coral branching in some areas. These areas are not thought to have been trawled, but expanding deep-water fisheries were considered a threat, and they were recently identified as a priority habitat conservation area. This situation is considered a test of the effectiveness of EU marine habitat conservation policies and practices.

VII. Synthesis and Overall Conclusions

There are many similarities in the conclusions of the five review sources with regard to impacts of bottom trawling and effectiveness of mitigation measures. Only the ICES advisory report has comprehensive management advice, although both the National Academy and the NMFS reviews do have management recommendations as well as research recommendations.

The conclusions and management recommendations of the five studies are tabulated in Table 5 (using the numberings in the preceding sections and not from the original reports). The table begins with the ICES list, both because it was the first of the reviews to be published, and because it had the most explicit mandate to provide management advice. The other reviews are tabulated chronologically, so the phrasings of the conclusions and recommendations (column 1) are shortened paraphrases of the wording used in the first report where the conclusion or recommendation occurs.

Many judgement calls were needed in preparing this tabulation, as different reports often came at the same issue from different perspectives so the wordings used were different. However, where it was judged that the same basic conclusion was being drawn, they are tabulated as the same. In a few cases a particular conclusion was not drawn explicitly, but for some other conclusion to have been drawn the corresponding conclusion would have to have been drawn as well. In these cases the corresponding number is in parenthesis (). Moreover, in only a few cases were findings or conclusions of one report contradictory with the findings or conclusions of another report. These cases are noted in **bold** type.

Table 5 – Synthesis and tabulation of the conclusions and recommendations in each of the four reviews. Numbers refer to the numbered conclusions or papers from the previous sections of this Research Document. Symbols used are explained in the preceding paragraphs.

Types of Effects of Mobile Bottom Gears	**ICES**	**NAS**[1]	**NMFS**[4]	**FAO**[2]	**AFS**[3]
Removal of major habitat features	1	1, 18	21, 28		10
Reduction of structural biota	2	1, 11, 18	2, 6, 22, 26, 30, 31	2	10, 13, (28), (29)
Reduction of habitat complexity	3 (weak)	1, (11), 18	3, 7, 23, 27	1	10, 13
Changes in seafloor structure	4		11, 13, 14	5	10, 17
Reduction in geographic range	5				
Decrease in species with low turnover rates	6	3, (6), 17		14, 18, **13**	12, 14
Fragmentation of species ranges	7 (weak)				
Changes in relative abundance of species	8	3, (6), 8, 10, 17	8, 9, 14, 15, 16, 28, 33, 34	**10,** 12, **13**, 14, 15, 17	5, 6, 9, 11, 12, 13, 14, 18, **19, 20,**
Fragile species more affected	9 (weak)	3, 8, 19		14	5, 7, **8, 12**
Surface-living species more affected than burrowing species	10 (weak)	1, 8, 17	9, 10, 12, 16	14	5, 10, 12, 13, **17**
Sub-lethal effects on individuals	11				
Increase in species with high turnover rates	12	3, (6), 17		18	5, 14, (17)
Increase in scavenger populations	13		**35**		5, (9), 12, 18, 19
Decrease in productivity &/or changed nutrient cycling & sedimentation		4, 9	**19?**		5, 15, **20**
Types of Effects of Mobile Bottom Gears	**ICES**	**NAS**[1]	**NMFS**[5]	**FAO**[2]	**AFS**[3]
Impacts greater in low disturbance (energy) regimes than high ones	(All of Table)	6, 19, 20	2-8, 21-28		6
Increased susceptibility to other stressors		12			

Continued…

[4] Effects numbered 1, 4, 5, 24, and 32 are reported as "unknown" and hence not tabulated

[5] Effects numbered 1, 4, 5, 24, and 32 are reported as "unknown" and hence not tabulated

Table 5 (Continued)

Mitigation and Management Issues					
Recovery can take weeks to centuries, and measures to facilitate recovery must continue in the long term	14	2, 13-16	2-8, 21-28	13, 16 (<1 yr)	10 (<1-3 years) 18 (~1 wk), 19 (~9 mo),
Monotonic relationship between effort and impact, with greatest impacts from the first few exposures	15a	5	17, 36	8	14, 21, 22
Shape of the relationship depends on history of area, gear, and features of species and habitats affected	15b	5 ,7, 8, 13-16, 20	18, 37	6, 7	6, 16, 21, 22, 24, (26)
Effectiveness of all technical measures will be case-specific	16		(17), (36)	(20), (22)	(22)
Technical measures can act synergistically, so suites of measures should be considered	17				
Economic incentives can be important to successful implementation	18				
Application of all mitigation measures requires case-specific planning and analysis	19	(20), 21			(22)
Management Recommendations					
Major reductions in fishing effort needed	20, (27)	23	20, 36		25
Implement Closed areas	21, (26)	23	20, 36		25, (27)
Gear substitution	22	23	20, 36		25
Gear modification	23	23	20, 36		24
Habitat rehabilitation	24				
Governance changes	25, (28)				
Apply comparative risk assessment		24			

[1]22 and 26 are research recommendations; 25 is not trawl impact issue
[2]3,4,9,11,and 19 are research recommendations or recommendations about methodologies for studies.
[3]1-4 are about fish use of different types of habitats; 11 is about sizes of organisms, which could be related directly to fishing, and 22 is about the management performance of various benthic indicators.

Based on this table, a number of conclusions about impacts and mitigation measures receive consistent support. These are listed in an order reflecting their relative breadths and strengths of support.

Impacts of Bottom Gears on habitats:

1. Mobile bottom gears can damage/reduce structural biota - All reviews, strong evidence or support.
2. Mobile bottom gears can damage/reduce habitat complexity - All reviews panel, variable evidence or support.
3. Mobile bottom gears can reduce/remove major habitat features (boulders etc.) – Some reviews, strong evidence or support.
4. Mobile bottom gears can alter seafloor structure – Some reviews, conflicting evidence for benefits or harm.

Other emergent conclusions on habitat impacts included:

5. There is a gradient of impacts, with greatest impacts on hard, complex bottoms and least impact on sandy bottoms – All reviews, strong support (with qualifications).
6. There is a gradient of impacts, with greatest impacts on low energy environments and least (often negligible) impact on high-energy environments – All reviews, strong support.
7. Trawls and mobile dredges are the most damaging of the gears considered – Three of the reviews considered other gears, all drew this conclusion, often with qualifications.

Impacts of Bottom Gears on benthic species and communities:

8. Mobile bottom gears can change the relative abundance of species – All reviews, strong evidence or support.
9. Mobile bottom gears can decrease the abundance of long-lived species with low turnover rates – All reviews, moderate to strong evidence or support.
10. Mobile bottom gears can increase the abundance of short-lived species with high turnover rates – All reviews, moderate to occasionally strong evidence or support.
11. Mobile bottom gears affect populations of surface-living species more often and to greater extents than populations of burrowing species – All reviews, weak to occasionally strong evidence or support.
12. Impacts of mobile bottom gears are less in high-energy / frequent natural disturbance environments than in low energy environments where natural disturbances are uncommon - 4 reviews (one did not address the factor) – strong evidence or support.
13. Mobile bottom gears affect populations of structurally fragile species more often and to greater extents than populations of “robust” species – All studies, variable evidence and support.
14. Abundance of scavengers increases temporarily in areas where bottom trawls have been used – 3 reviews, variable support or evidence, all argue for only transient effect.

15. Rates of nutrient cycling and/or sedimentation are increased in areas where bottom trawls have been used – 2 reviews, mixed views on magnitude of effects and conditions under which they occur.

Scattered and inconsistent support was found for other conclusions on biological effects of mobile bottom gears. For example, no group found moderate or strong evidence for considerations 5, 7, and 9 of ICES.

Considerations in the application or adoption of mitigation measures:

16. The impact of mobile fishing gears on benthic habitats and communities is not uniform. It depends on:
    a. the features of the seafloor habitats, including the natural disturbance regime - All reviews and NMFS panel, strong evidence or support;
    b. the species present - All reviews, strong evidence or support; Not mentioned by NMFS panel
    c. the type of gear used and methods of deployment; - All reviews and NMFS panel, moderate to strong evidence support; and
    d. the history of human activities (particularly past fishing) in the area of concern - All reviews, strong evidence or support.
17. Given the above considerations, the impact of mobile bottom gears has a monotonic relationship with fish effort, and the greatest impacts are caused by the first few fishing events – (All reviews, moderate to strong evidence or support).
18. Recovery time from trawl-induced disturbance can take from days to centuries, and depends on the same factors as listed in conclusion VII-16. (All reviews, strong evidence or support).
19. Application of mitigation measures requires case specific analyses and planning; there are no universally appropriate fixes - Three reviews, moderate to strong evidence or support. The issue of implementing mitigation was not addressed in the FAO review. It is also stressed in the US National Academy of Sciences review and discussed in the ICES review that extensive local data are not necessary for such case-specific planning. The effects of mobile bottom gears on seafloor habitats and communities are consistent enough with well-established ecological theory, and across studies, that cautious extrapolation of information across sites is legitimate.
20. Conclusions regarding the potential synergy of technical mitigation measures, and the value of economic incentives in facilitating implementation and compliance were only discussed in the ICES review and the NMFS panel report. However, nothing in the other reviews directly contradicts these conclusions.
21. The same is the case for the ICES admonition that in cases where benthic communities or habitats have recovered due to application of some mitigation measures, the benefits of the recovery can be quickly dissipated unless either the measures are continued in the long term or the fishery is otherwise managed in ways the prevent a resumption of the detrimental impacts.

Recommendations for management of mobile bottom gears:

The FAO review and the Barnes and Thomas book did not include management recommendations, so there are only three reviews to tabulate in this case. Moreover, only the ICES review and the NMFS Panel ranked their management recommendations in order of importance. The ICES ranking was labelled as specific to the North Sea and Irish Sea, the areas for which science advice was requested. However, the considerations which led to their ordering are generally applicable, and consistent with the lines of reasoning in the National Academy of Sciences review as well. The ranking of the NMFS panel was also labelled as specific to the US Northeast, and noting that there had already been an effort reduction of more than 50% in the area. Also, although recommendations contained in papers published in the AFS Symposium are tabulated here, it should be noted that the recommendations are those of individual authors, not the Symposium participants as a whole. No attempt was made to consolidate possibly redundant recommendations of different authors in the book nor to be comprehensive in matching to coverage of recommendations to the full range of fisheries impacts on benthic populations, communities, and habitats.

22. The impact of mobile bottom gears on seafloor habitats and species can be reduced through major reduction in effort in fisheries using those gears – All reviews, strong support.
23. The impact of mobile bottom gears on seafloor habitats and species can be reduced through implementation of areas where use of those gears is not permitted – All reviews; strong support for habitat features, especially by NMFS, support for species and communities qualified in all cases to depend on the characteristics of the species of concern.
24. The impact of mobile bottom gears on seafloor habitats and species can be reduced through substitution of another gear or modification of the trawl gears to reduce contact with the benthos and seafloor – All studies, moderate to strong support.
25. Only the ICES review considered habitat rehabilitation, to which it gave qualified support under specific circumstances.
26. Only the ICES review discussed the need for governance changes as a part of the strategy to reduce the detrimental effects of fishing activities in general, as well as the impacts of mobile bottom gears. However, much of the argumentation in the National Academy of Sciences review, and many of the papers on social sciences in the American Fisheries Society Symposium publication are consistent with this recommendation from ICES.
27. Only the National Academy of Sciences review considered risk assessment tools explicitly, and recommended use of comparative risk assessment methods in planning mitigation measures. Nothing in the other reviews would contradict this recommendation.

Finally, at different points all the reviews highlight that benthic habitats are themselves dynamic, and undergo changes for many reasons other than impacts of fishing gears. This does not mean that the impacts of fishing gears are unimportant, or that mitigation is unnecessary. However the natural variability of benthic systems does mean that studies to link fishing to impacts on benthos cannot be expected to provide simple and unambiguous results within great care in design and execution, and sometimes even very good studies will produce results open to multiple interpretations.

These overall conclusions on impacts and mitigation measures, and recommendations for management action form a coherent and consistent whole. They are relevant to the general circumstances likely to be encountered in temperate, sub-boreal, and boreal seas on coastal shelves and slopes, and probably areas within Canadian jurisdiction beyond the continental shelves. They allow use of all relevant information that can be made available on a case by case basis, but also guide approaches to management in areas where there is little site-specific information. Augmented by the specific Canadian information in the other Research Documents cited earlier, they provide a scientifically sound and practical basis for developing Canadian policies and management programmes.

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