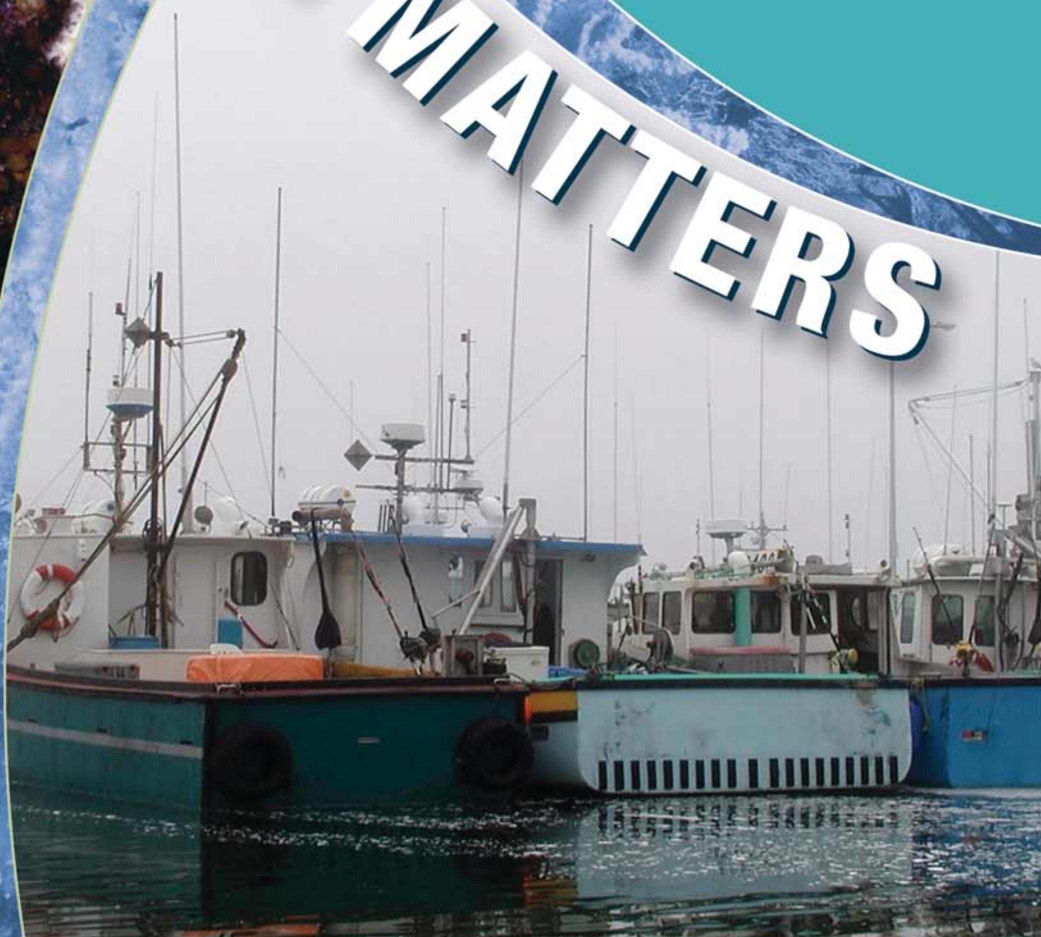
HOW WE FISH MATTERS

Addressing the Ecological Impacts of Canadian Fishing Gear

Susanna D. Fuller, Candace Picco,
Jennifer Ford, Chih-Fan Tsao,
Lance E. Morgan, Dorthea Hangaard,
Ratana Chuenpagdee



Seiners are used in the British Columbia salmon fishery. PHOTO: Dale Sanders.

Contents

The research, data synthesis and writing of this report were sponsored by the Gordon and Betty Moore Foundation.

COVER PHOTOS

Front cover: LEFT–Cold water corals are found on Canada's west and east coast, and are vulnerable to the impacts of bottom tending fishing gear. PHOTO: Dale Sanders. TOP RIGHT–Endangered porbeagle sharks are occasionally caught in bottom trawl fisheries for groundfish on Canada's east coast. PHOTO: H.R. Yao. BOTTOM RIGHT–Fishing vessels equipped with bottom longline gear on Canada's east coast. H: IStock. Back cover: TOP–Large catches of sponges occur in Canada's arctic and deep water fisheries. PHOTO: Fisheries and Oceans Canada. MIDDLE–LOBSTER traps piled high on wharves in Prince Edward Island. PHOTO: Shane McClure. BOTTOM–Herring fishery opening on the British Columbia coast. PHOTO: Bruce Burrows.

Canadian Cataloguing in Publication Data

Fuller, Susanna D. 1973-

How We Fish Matters: Addressing the Ecological Impacts of Canadian Fishing Gear

Susanna D. Fuller (Ecology Action Centre), Candace Picco (Living Oceans Society), Jennifer Ford (Ecology Action Centre), Chih-Fan Tsao (Marine Conservation Biology Institute), Lance E. Morgan (Marine Conservation Biology Institute), Dorthea Hangaard (Living Oceans Society), Ratana Chuenpagdee (Memorial University of Newfoundland)

All authors contributed equally to this report.

Includes bibliographic references.

ISBN 978-0-9734181-7-0

Printed in Delta, BC, Canada

Printed on paper made with 100% PCW recycled fiber content using non-polluting wind-generated energy. Certified SmartWood for FSC standards. Green Seal certified. Acid free. Using this stock, on this small print run, we saved: 3.77 trees; 4.94 lbs (10.89 lbs) of waterborne waste; 6063.7 L (1,603 gallons) of wastewater; 80.3 kg (177 lbs) of solid waste; 158.3 kg (349 lbs) of greenhouse gases; 2,672,400 BTUs of energy; 82.1 kg (181 lbs) of air emissions; 12.2 m^3 (432 ft^3) of natural gas. That's the equivalent to not driving 197 miles in an average car or planting 12 trees.

Acknowledgements

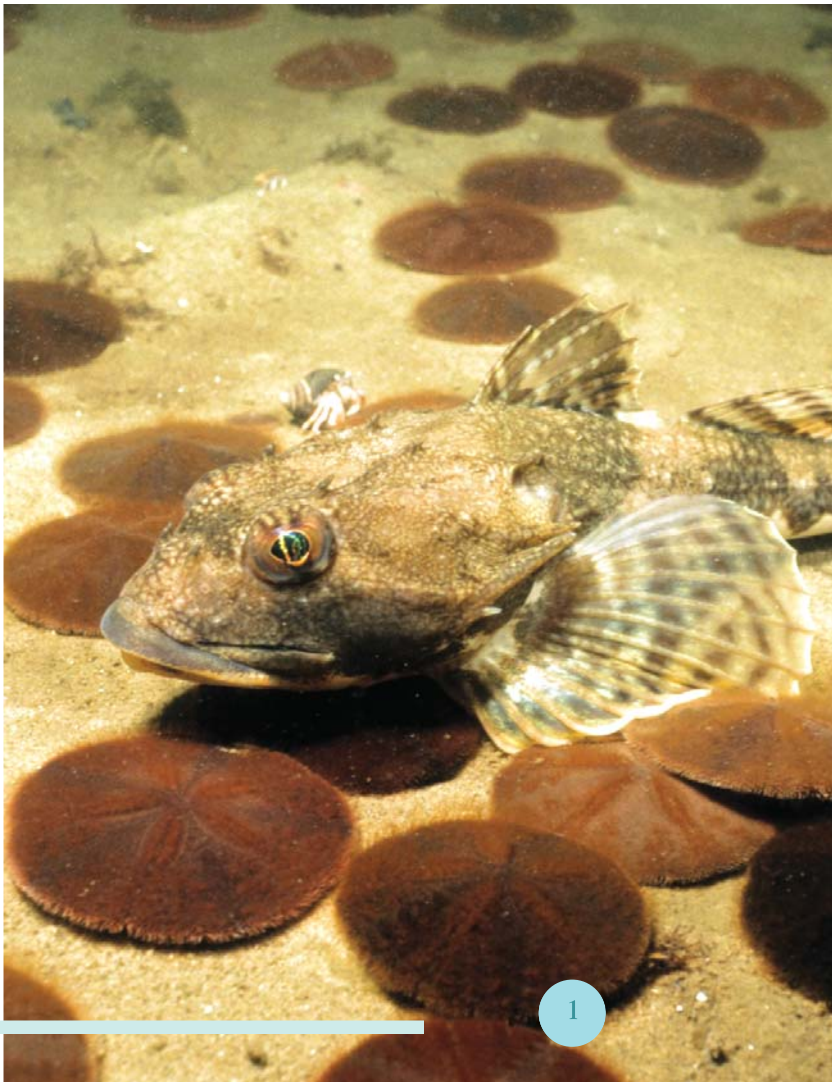
Inspiration for this study came from the **National Advisory Process on the Impacts of Mobile Fishing Gear** workshop held in Montreal in March 2006. At that meeting, the report *Shifting Gears*, authored by Lance Morgan and Ratana Chuenpagdee, was identified as an essential review of fisheries, fishing gear, and their relative impacts on the marine environment in the United States. In Canada, both the Ecology Action Centre and Living Oceans Society were conducting research on the impacts of fishing gear, and working to educate the public and policy makers on the issue. They recognized that a better understanding of the impacts of all fishing gears used in Canada is essential if the management of Canadian fisheries and the marine environment is to improve.

This project would not have come to fruition without the leadership and foresight of Jennifer Lash and Mark Butler. Nor could the study have been done without the participants at our **How We Fish in Canada** workshop or the fishermen, scientists, managers and conservationists who completed our survey. We would like to thank Sadie Beaton, John Guinotte, Elliott Norse, Elizabeth Rauer, Rachel Moffat, Rachel Antanacio and Susan Hollett, all of whom contributed to the project process and its successful completion. We also acknowledge the valuable comments of Scott Wallace and Martin Willison on this report and offer our thanks to the scenic and historic town of Lunenburg, Nova Scotia, which provided a topical setting for our consultative workshop.

Finally, the authors gratefully acknowledge the Gordon and Betty Moore Foundation, and specifically Meaghan Calcari, for providing funding and support.

Common Terms Defined

In this study, we use the term *fisherman* or *fishermen* to refer to men and women who make their livelihoods through fishing. We do not use the word *harvest* when referring to the capture of wild marine species, as the term has agricultural connotations, which are not relevant to the natural production of marine organisms. When referring to the action of fishing with bottom trawls, we use the word *trawling* throughout the report although we recognize that in the Atlantic Ocean, *dragging* is more frequently used. We define *habitat* as the physical seafloor and associated structure-forming species including but not limited to cold-water corals, sponges, hydroids, bryozoans and seaweed. *Bycatch* refers generically to all non-target species brought onboard during any fishing activity. Bycatch can be separated into bycatch that is kept and landed as part of the commercial catch and bycatch that is discarded. Unless otherwise stated, the term bycatch in this report refers to all species caught incidentally during a fishery, and this report deals specifically with the impacts of fishing gear on discarded bycatch.



Sandy habitats on Canada's east coast are home to clams, sand dollars and bottom feeding fish species. PHOTO: Andrew Martinez.

Executive Summary

The ecological impacts of fishing gear on seafloor habitat and the incidental catch of non-target marine species should play a significant role in fisheries management. Nevertheless, Canadian fisheries managers do not currently consider habitat impacts in management decisions, and only selected fisheries are managed with bycatch quota or with bycatch mitigation measures for non-target species. As a result, significant unrecorded discarding of marine species and damage to marine habitat are ongoing problems in a number of Canadian fisheries. The purpose of this study is to present a comprehensive analysis of the severity of habitat impacts and discarded bycatch resulting from major commercial fishing gears used in Canada.

The initial phase of this study consisted of a literature review of habitat impacts of fishing gear, and analysis of bycatch information where available, for all Canadian fisheries. We focused on experimental studies conducted in Canada on fishing gear impacts and international research conducted in adjacent or similar marine ecosystems to those found in Canada. Bycatch data were obtained from scientific reports on Canadian fisheries and wherever possible we analyzed data for individual fisheries, with catches greater than 1000 tonnes. The majority of the data compiled and synthesized in this review was from 2005, the most recent year for which comprehensive data was available. This information was presented at a multi-stakeholder workshop where we asked participants to review and comment on the data, contribute additional information on gear impacts and then rate those fishing gears according to their impacts. Their ratings became the basis of a survey comparing the severity of habitat and discard impact scenarios caused by 13 fishing gears used in Canada. Ninety-seven fishermen, scientists, marine conservation professionals and fisheries and marine managers across Canada completed the survey. Based on the survey results, we then ranked fishing gears according to their ecosystem impacts from most severe to least severe.

One of the most important results of this study is the agreement among stakeholders on the relative ecological impacts of fishing gear used in Canada. All respondent groups ranked the impacts associated with bottom trawls as the most severe. Canadian bottom trawl fisheries largely target groundfish in the Pacific, and shrimp and groundfish in the Atlantic and Arctic. Bottom gillnets were considered to be the second highest in the severity of habitat and bycatch impacts. Dredges, which include scallop and hydraulic clam dredges, were ranked third in overall ecological impact. Bottom longlines followed as having the fourth highest ranking in impact severity. Midwater trawls, pots and traps, pelagic longlines and purse seines followed with respectively decreasing levels of severity of ecosystem impacts. Hook and line gear, which included rod and reel for pelagic fishes, salmon trolling and groundfish hook and line, was considered to have low impacts on habitat and bycatch. The least damaging fishing gear was the harpoon, used in the North Atlantic swordfish fishery, which was considered to have no impact on habitat or bycatch, and only affected the target species. Based on an analysis of the volume of fish caught by fishing gear type, the gear used most extensively in Canada also has the highest ecological impact.

Wolffish, considered threatened under Canada's Species-At-Risk legislation are caught as bycatch in eastern Canadian groundfish fisheries. PHOTO: H.R. Yao.

Our results provide a clear direction for Canadian fisheries managers, scientists, and ocean policy makers, as well as a basis for a new fisheries management paradigm for how and where we should fish. As well, our results show that not all fishing gears cause the same level of damage, and that the use of less destructive fishing gear, wherever possible, will protect against further collateral damage to the Canadian marine environment. Based on the severity of fishing gear impacts reported in this study, we recommend the following to advance sustainable fisheries and resilient marine ecosystems in Canada:

1. *Fisheries managers should immediately implement ecologically risk averse strategies to minimize the impacts of fishing gear on habitat and bycatch. These strategies include habitat protection, and access to fishing grounds and quota allocations based on gear substitution.*

2. *Adequate monitoring, research and data collection on fishing gear impacts to habitat and non-target species must be undertaken, and made publicly available, to support ecosystem and spatial management practices.*

3. *Implement, inform and develop policies and management practices that prioritize the minimization of habitat destruction and incidental catch and discarding of target and non-target species.*

LEFT: Shallow water kelp forests and associated species in British Columbia. PHOTO: Dale Sanders.

Box 1

Gearing up:

Fishing gear and technology introductions in Canadian waters

For over a century, fisheries in the North Atlantic and North Pacific have been characterized by a continual "gearing up," where a low-impact gear is replaced with a higher-impact gear in efforts to catch more fish, more quickly and more efficiently. Each technological increase marks an increased pressure on the marine ecosystem.

1850	French fisheries replace handlines with bottom longlines (known as bultows) in the Newfoundland Grand Banks fishery.
1864	Drift nets introduced to the Fraser River salmon fishery on the west coast.
1870	Cod traps are introduced in Newfoundland.
1899	Long in use by First Nations, trolling is adopted by the commercial fishing industry.
1910-20	Otter trawl is introduced to the Northwest Atlantic and British Columbia.
1934	Last oar-powered Pacific halibut handliner fleet is replaced by bottom longliners.
1937	First salmon purse seines are used in British Columbia.
1940s	Spanish pair trawling is introduced to the Northwest Atlantic.
1950s	Refrigeration, acoustic fish finders, radar and synthetic nets are introduced to the Northwest Atlantic fishery following WWII.
1954	First factory freezer stern trawler is dispatched to the Grand Banks of Newfoundland.
1960s	Bottom trawling begins in Canada's Arctic.
1963	Pelagic longlines are introduced in the Northwest Atlantic, largely replacing the swordfish harpoon fishery.
2004	Last groundfish handliner in SW Nova Scotia switches to longline.
2004-05	Two largest trawlers in British Columbia history are added to the fleet, at 41m and 56m.
2008	Bottom trawling is the most prevalent gear type in Canada, targeting shrimp and groundfish populations.

The Challenge of Managing Our Fisheries

Fisheries in Canada have changed greatly since the time when humans first began living off the bounty of the sea. Canada's oceans were once richly endowed with marine life, supplying food for First Nations and Inuit communities on all three coasts. Now, most of our fish populations are in steady decline, with several populations considered collapsed. The shift from subsistence fishing to industrial fishing, which began in the late 1800's, has been accompanied by declines in targeted fish populations as well as significant impacts on fish habitat and non-target species.

The consequences of commercial exploitation of fish on the east and west coasts of Canada have followed much the same pattern, as once-abundant species have proven no match for fishing pressure. Since the collapse of the cod stocks in the early 1990s, Atlantic Canada has come to rely heavily on invertebrate species such as lobster, crab, scallop and shrimp to maintain coastal communities and viable fisheries. On the Pacific coast, the salmon populations are greatly depleted from historic levels. The Arctic Ocean is positioned as the next frontier for Canadian fisheries expansion, and little protection exists to ensure that Arctic marine species do not follow the pattern of decline seen in Canada's other oceans.

Canadian vessels on all of our oceans are now fishing farther north and in deeper waters to maintain the fishing industry. Historically, and continuing to the present day, as fish populations are depleted, vessels are forced to go farther offshore, to explore new areas and adopt fishing methods and gear with ever increasing capacity. These improvements in catch efficiency have often gone hand in hand with more destructive, less selective gear (see Box 1 for a history of fishing gear introductions in Canada).

Conventional single-species management has neglected important ecosystem impacts of fishing and does not take into consideration the growing number of scientific studies on the impacts of fishing gear on habitat or the incidental catch of non-target species. Increasingly, it is becoming clear that how and where we fish matters. The time has come for fisheries scientists and managers to recognize the impacts of fishing on the marine ecosystem as a whole and address the impacts of gear technology, not only on the target species, but on fish habitat and non-target species as well. Managing for habitat protection and reducing discards are key components of the ecosystem approach, which is increasingly being applied through fisheries management plans in Canada.

Our study examines the ecological impacts of the most common types of fishing gear used in Canada and assesses the relative severity of these impacts to seafloor habitat and discarded bycatch of target and non-target species.

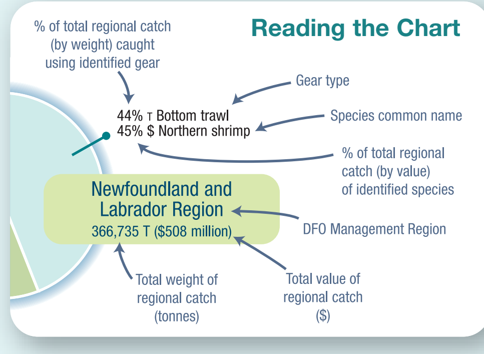
Fisheries in Canada

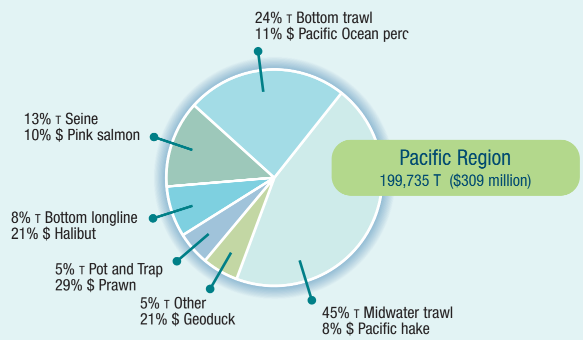
Figure 1

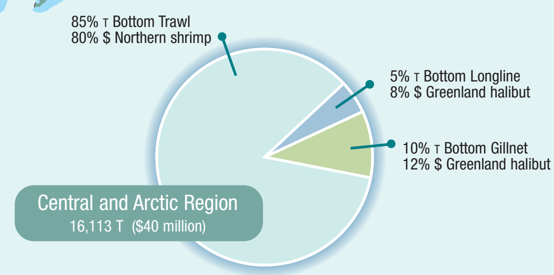
Size and Value of Catch

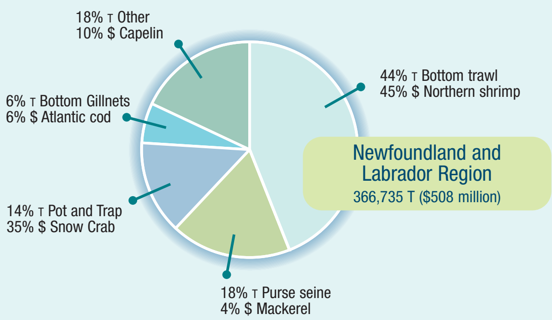
Landings (tonnes) and dollar value (millions) for fisheries >1000t in each DFO management region. Pie charts illustrate the landings by gear type and major species targeted.

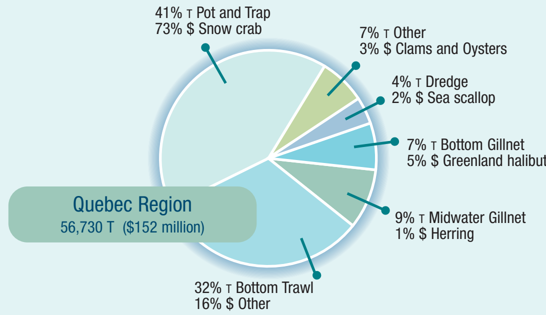
Data Sources: Data were synthesized from information provided by DFO Statistical Services.

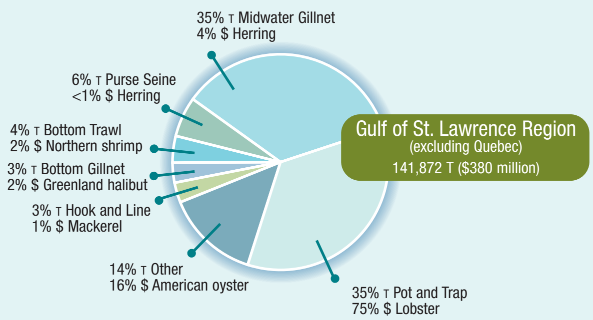


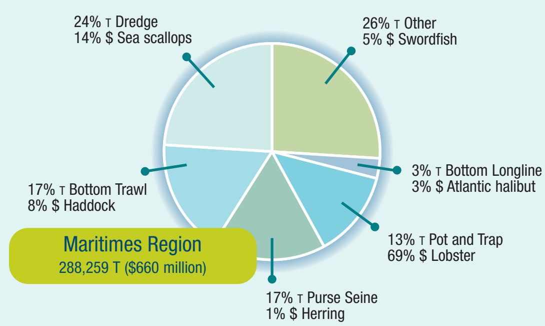












Bottom Trawl	$377.0	296,992 tonnes
Pot and Trap	$1,117.0	167,151 tonnes
Purse Seine	$63.0	149,017 tonnes
Dredge	$115.0	90,926 tonnes
Midwater Trawl	$25.0	89,014 tonnes
Midwater Gillnet	$32.0	76,582 tonnes
Bottom Gillnet	$48.0	32,864 tonnes
Bottom Longline	$97.0	32,130 tonnes
Hook and Line	$27.0	14,171 tonnes
Dive	$0.9	5,913 tonnes
Pelagic Longline	$14.0	2,203 tonnes
Harpoon	$1.6	214 tonnes

Figure 2

Catch volume and value (millions of dollars) aggregated by gear type for all Canadian fisheries greater than 1000t.
Bars represent tonnes caught.

Fisheries in Canada

A variety of fishing methods are used throughout Canadian waters, from lobster traps in the Atlantic Provinces to salmon drum seines in British Columbia. In order to assess the ecological impacts of Canadian fisheries we focused on those fishing methods with landings greater than 1000 tonnes (t) as of 2005 in the six Canadian fisheries management regions (Figure 1). For example, we did not include shore-based activities, such as clam digging or seaweed harvesting, or gears such as the Danish and Scottish seine or British Columbia shrimp beam trawls as they are not in large-scale use.

In total, we examined 13 different fishing gear types (Figure 3). In instances where gears were found to be similar in terms of their operation and general use, we collapsed the gears into one category. For example, the Atlantic side, stern, pair and shrimp trawl, along with the British Columbia and Atlantic groundfish otter trawls are all included under bottom trawls. Crab traps, lobster traps, shrimp traps and fish pots are grouped under pots and traps. We collected information on volume and landing value of fisheries and combined these across gear type in order to understand the relative magnitude of Canadian fisheries. Bottom trawls catch the largest volume of fish in Canada, while fisheries conducted using pots and traps are the most valuable (Figure 2).

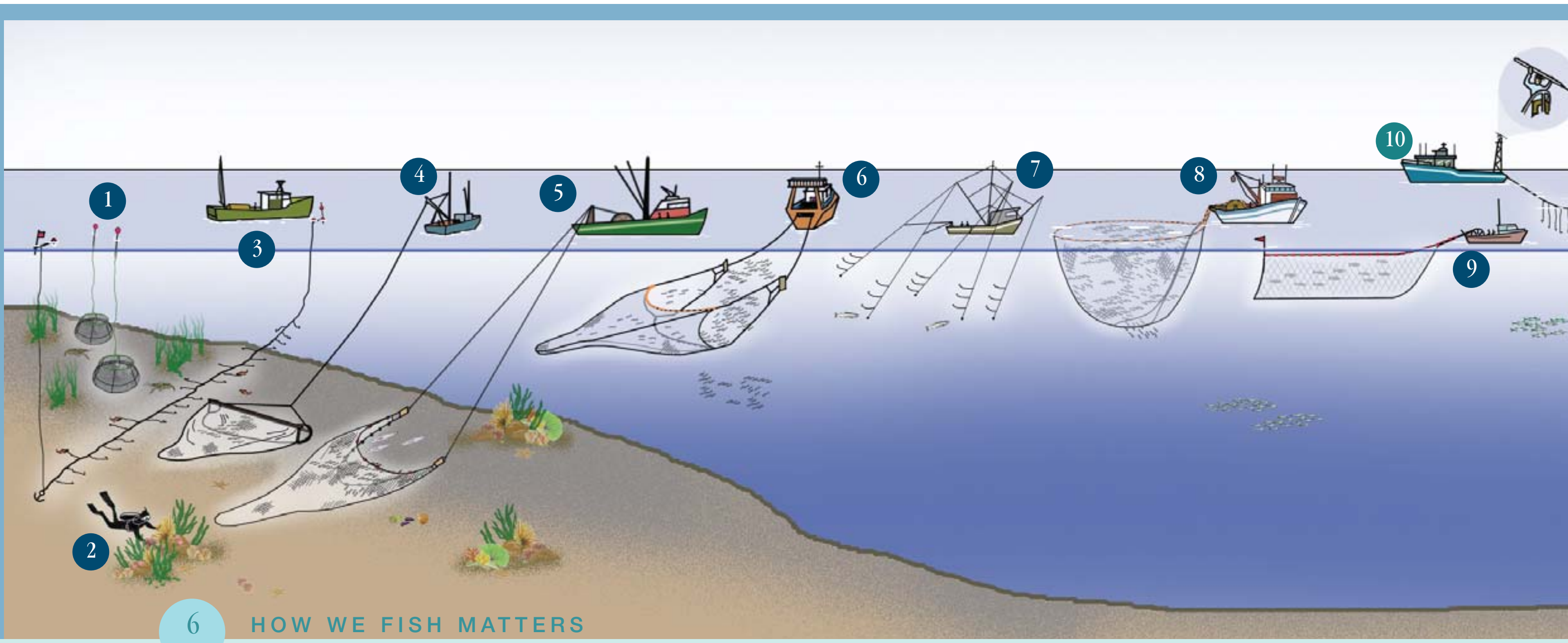
Assessing Ecological Impacts of Fishing Gear

For the purposes of this study, we define habitat as the physical seafloor and associated structure-forming species including cold-water corals, sponges, hydroids, bryozoans and seaweed. Bycatch refers generically to all non-target species brought onboard during any fishing activity. Bycatch can be separated into bycatch that is kept and landed as part of the commercial catch and bycatch that is discarded. Unless otherwise stated, the term bycatch in this report refers to all species caught incidentally during a fishery.

To assess the ecological impacts of fishing gear, we first conducted a literature review of scientific studies on fishing impacts and compiled available data on bycatch. We then held a workshop, bringing together fishermen, scientists and conservation professional to discuss reports of fishing impacts from previous studies and existing data, as well as add more information based on their experience with different types of fishing and fishing gear in Canada. We combined all information during the workshop, and asked participants to rate the relative impacts of a range of fishing gears through a series of exercises. Based on the workshop results and further validation, we conducted a survey of stakeholders in the fishing industry asking them to compare sets of ecological impacts.

Habitat Impacts, Bycatch and Discards

To date, relatively few studies have been conducted in Canada on the ecological impacts of fishing methods. For the 13 fishing methods covered in this report we collated the available habitat impact information from national and international scientific studies, and analyzed discard data from those Canadian fisheries where data are available. We focused on studies in Canadian waters or nearby jurisdictions with similar ecosystem characteristics. Bycatch and discard data came mainly from Fisheries and Oceans Canada (DFO), while other information was found in research documents. Bycatch is primarily assessed through independent observers. Coverage ranges



from 0 to 100% of trips, depending on the fishery, but many fisheries had less than 1% of the catch observed.

In many cases, observers are required to only report on commercial species that are discarded and non-commercial discards are often ignored. For some fisheries, we found a considerable lack of published information or primary data on ecosystem impacts (Box 2).

Despite the lack of information for some fisheries, there have been improvements in fisheries monitoring in recent years. For example, observers in the Northwest Atlantic fisheries are now required to record corals and sponges as well as other non-commercial species. Selected scallop fisheries also require that observers record all species caught, including those retained and discarded. In western Canada, the three-year Groundfish Pilot Integration Program implemented in 2006, has improved commercial bycatch management in all groundfish fisheries; it requires individual quotas for all commercial bycatch (transferable between all commercial groundfish fisheries), and 100% at-sea electronic monitoring or on-board observers. Most fisheries research surveys quantify the non-commercial catch, which can also be used to assess the impact of a particular gear type used in the survey.

In reviewing information we did not attempt to analyze the scale or "footprint" of a fishery or the status of a bycatch species in terms of the Species At Risk Act or listing by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). These are important to consider when assessing gear impacts, but they are not necessarily inherent in the selectivity or habitat impacts of a specific gear type, and so did not influence the bycatch and habitat impact rating of fishing gears in this study.

A description of each gear type assessed in this study as well as a synthesis of bycatch and habitat information collected during the literature review and data synthesis is presented in Table 1.

Box 2

Data gaps

In gathering information to assess the impacts of fishing gear types on habitat and bycatch, it was evident that several fisheries are data deficient. For example, there is relatively little available research survey or observer data on the commercial and non-commercial bycatch of scallop or hydraulic clam dredge fisheries, both of which have a high impact on the seafloor.

Most pot or trap fisheries in Canada, with the exception of snow crab in some areas on the east coast and the British Columbia sablefish fishery, exhibit a complete lack of data on bycatch or habitat damage, and there is relatively little available information on the ecosystem impact of fisheries using midwater gillnets and purse seines. Although these gear types are considered relatively low impact, it is unclear if this conclusion is simply a result of the lack of data.

West coast salmon fisheries in general tend to have little available bycatch data, as do fisheries targeted with hook and line gear, including handline and rod and reel. When it comes to bycatch in Canadian groundfish fisheries on both coasts, the presence of some observer coverage means that data tend to be better than in other fisheries. Overall, however, significant gaps remain in our understanding of the bycatch impacts of many fisheries in Canada, even when their effort and spatial extent are large.

Figure 3 **Illustration of common fishing gears used in Canada** (gear and vessels not drawn to scale)

1 Prawn Trap
2 Dive
3 Groundfish Bottom Longline
4 Shrimp Beam Trawl
5 Groundfish Otter Trawl
6 Midwater Trawl
7 Hook and Line
8 Salmon Purse Seine
9 Midwater Salmon Gillnet
10 Pelagic Longline (swordfish longline)
11 Harpoon (swordfish harpoon)
12 Purse Seine (herring seine)
13 Groundfish Otter Trawl
14 Offshore Hydraulic Clam Dredge
15 Dredge (scallop dredge)
16 Pot and Trap (lobster trap)
17 Bottom Gillnet (groundfish gillnet)
18 Groundfish Bottom Longline
19 Pot and Trap (crab pots)
20 Dive

Key: West coast gear type; East coast gear type

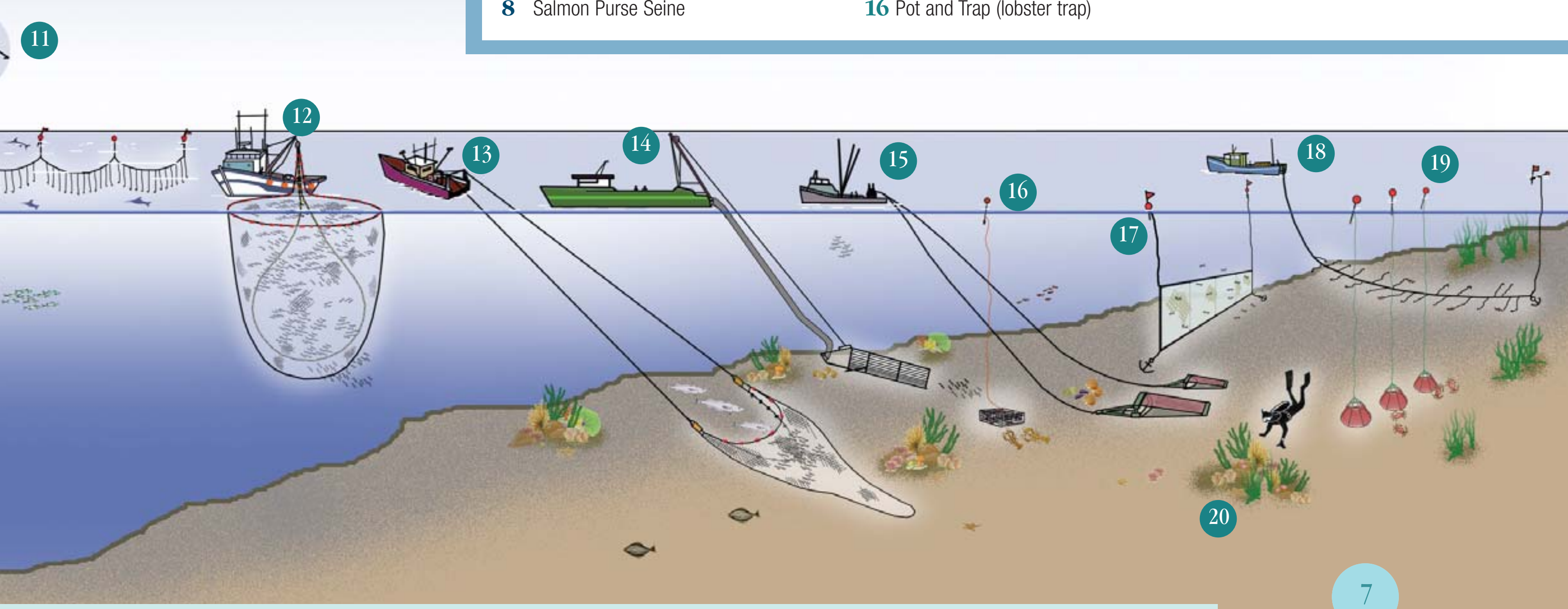
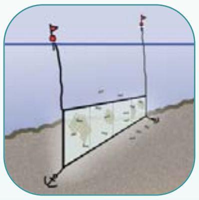


Table 1

Overview of fishing gear and associated ecological impacts

Information in this table is a synthesis of published studies and analysis of bycatch and discard data available from Fisheries and Oceans Canada.



Bottom Gillnet

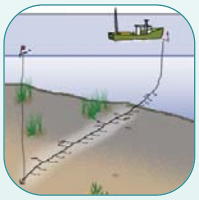
Bottom gillnets hang vertically in the water column and catch fish in their mesh. Anchors or weights are attached to the gillnet, securing it to the seafloor. Bottom gillnets are only used in Atlantic Canada.

Bycatch

Observer coverage is very low and little bycatch information is available for the bottom gillnet fisheries. For bottom gillnet fisheries targeting Greenland halibut in the Atlantic, discards account for 3% of the total biomass caught, though significant bycatch of snow crab have been reported in some areas [1]. Incidental marine mammal catch is an issue in some fisheries: the lumpfish fishery off Newfoundland caught an estimated 5000 harp seals in 2003 [2] while the cod fishery off southern Newfoundland caught as many as 1500–3000 harbour porpoises in 2002 [3]. It is also estimated that between 3000 and 14,000 common murres were caught in bottom gillnets targeting Atlantic cod off the northeast coast of Newfoundland in 2001–2003 [4].

Habitat Impact

Bottom gillnets contact the seafloor, although the area impacted is assumed to be less than that of mobile gear such as trawls and dredges. Cold-water corals have been caught in bottom gillnet fisheries in Atlantic Canada, with coral caught in 27% of bottom gillnet sets targeting Greenland halibut [5].



Bottom Longline

Bottom longlines consist of a single mainline to which hundreds of shorter lines are attached armed with baited hooks. Anchors attached to the longline secure the gear to the ocean floor.

Bycatch

There is a lack of fish discard data for the Atlantic Canada bottom longline fisheries. On the Pacific coast fishermen's logbook data for 2005 show minimum discard rates in this fishery of 0–15% by weight (based on fishermen's logbook data submitted to DFO). In the Pacific halibut fisheries, 44% of the catch was discarded in 2006, with undersized halibut constituting the majority of discards (DFO Fishery Operations System database). Bottom longlines in the Pacific also catch seabirds, the species of greatest concern being the black-footed albatross. In 2002/2003 mitigation measures became part of the bottom longline license conditions: depending on vessel size and area fished, electronic monitoring and bird scaring devices must now be used. Despite these measures, 30 albatross were caught in the Pacific halibut fishery in 2006 (DFO Fishery Operations Systems database) and the seabird bycatch in the rockfish bottom longline fishery was estimated at up to 70 birds [6].

Habitat Impact

Habitat damage from bottom longlines depends on the gear configuration including weights, number of hooks and type of line as well as hauling speed and technique. Habitat damage is also dependent on bottom type, with documentation of damage to corals and sponges. In one study, 4% of corals along a transect had been damaged by bottom longlines [7]. Thirteen percent of bottom longline sets deeper than 125 m off Newfoundland and Labrador contained some coral, although the amount of coral taken was not available [5].

Bottom Trawl

Bottom trawls consist of large nets dragged along the seafloor. The net may be held open by a pair of heavy metal doors (otter trawling) or by a beam (beam trawling). In Canada, beam trawling only occurs in the west coast shrimp trawl fishery, which was not assessed in this study.

Bycatch

Observer coverage in bottom trawl fisheries in Canada ranges from less than 10% to 100%, depending on the target species, region and boat size. In fisheries where complete bycatch information is available, discard rates vary from 2% to 15% of the catch [1, 8, DFO PacHarvTrawl database]. Discarded bycatch reported in these fisheries is primarily non-target and undersized groundfish, though small pelagic fish are recorded in several bottom trawl fisheries. In the Atlantic, the introduction of haddock separator trawls, where the net is split in two, with the upper net capturing the haddock that swim upwards and the lower net with an open end that allows the cod to escape, has greatly reduced cod bycatch in haddock fishing on Georges Bank.

Greenland sharks are the highest-volume discarded bycatch species in the Greenland halibut otter trawl fishery in the Arctic [1]. Bycatch data for the northern shrimp fishery in Scotia–Fundy indicate that 96% of the catch is northern shrimp, with discards mainly consisting of juvenile groundfish and small pelagic fish [8]. As of 1996, the Pacific groundfish trawl fishery has had 100% observer coverage. In 2005, discards from bottom trawling in the Pacific largely consisted of undersized target species and species which cannot be retained under current regulations. Mortality estimates of fish caught in trawls and discarded, or that contact trawls but are not caught, range from 0 to 100%, depending on the species and the conditions [9].

Habitat Impact

Multi-year studies of the impacts of groundfish otter trawling carried out in the Atlantic by DFO [10-12] show short-term disruption of benthic communities, including reductions in the biomass and diversity of benthic organisms. Some previously fished seafloor habitats showed recovery within one to three years but frequently trawled habitats remain in an altered state. Destruction of glass sponge reefs from groundfish otter trawling in British Columbia has also been documented [13, 14].

The otter trawl fishery for shrimp differs from traditional groundfish otter trawling because shrimp are targeted primarily on muddy substrate. In addition, the net is fished higher in the water column, attached to the footrope along the ground by a series of chains. Studies on the impacts of shrimp trawling on seafloors are fewer, but muddy seafloor communities are generally more resilient to disturbance than are those on hard, rocky seafloors [15].

Large catches of corals and sponges have been recorded, particularly when groundfish otter trawls enter new areas. For example, in Greenland halibut fishing in Newfoundland and Labrador from 1997 to 2002, the mean catch of sponges per fishing set was 18 kg, although the maximum caught in one set was 5000 kg (DFO Observer Database). Additionally, it is thought that 50% of the glass sponges off the west coast may already have been destroyed by bottom trawling when they were discovered there in the 1980s [16].

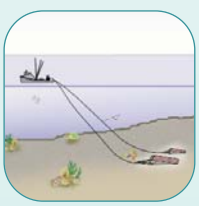
Dive

Bycatch

There are no known bycatch concerns in the dive fishery.

Habitat damage

In general, habitat damage from dive fisheries is minimal. However, hydraulic tools used in the Pacific geoduck fishery can disturb sediment and infauna (burrowing animals). Even careful and gentle handling by divers has the potential to destroy kelp and invertebrates living on or near the seafloor.



Dredge

Scallop dredges consist of metal baskets that are dragged along the seafloor to capture scallops. A clam dredge uses a hydraulic jet to liquefy the sediment and then catches any solid objects in its path. There is a small dredge fishery in the Pacific but only dredging in Atlantic Canada was considered in this study.

Bycatch

Relatively little information is available about bycatch in the inshore and offshore scallop fisheries in Atlantic Canada. In 2006, however, an estimated 479 t of yellowtail flounder, Atlantic cod and haddock were recorded as discarded bycatch for 2700 t of scallops landed in the Georges Bank fishery [17]. In assessments of scallop discards, 261 species have been recorded in the Bay of Fundy (Atlantic Canada) [18] while observers in the South West Nova Scotia scallop fishery have recorded 113 species (DFO Maritimes, unpublished data). Observed sets of the 2006 hydraulic clam fishery show that 7% of the catch was discarded. Discards consisted of sand dollars and other small invertebrates (DFO Maritimes, unpublished information), but a large portion of the retained bycatch is propeller clam, for which there is no official total allowable catch (TAC) or management plan.

Habitat Impact

Specific impacts of scallop dredging documented in Canada include damage both to scallops not caught in the dredge and to other non-target shellfish [19]; changes to physical habitat such as movement of boulders [20]; and, in one study, a change in community structure from long-lived sessile species to short-lived mobile species [21]. In an international review of experimental studies of fishing impacts, scallop dredging had the highest impact on seafloor ecology of any mobile fishing method [15]. Hydraulic clam dredging is less widely used in Canada, but in a study conducted on the Scotian Shelf (Atlantic Canada) the community remained altered two years after dredging ceased [22, 23].

Harpoon

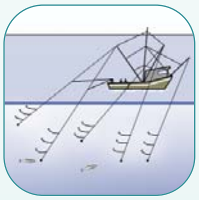
Harpooning involves sighting a swordfish that is basking or finning at the sea surface, then spearing it with a 4–5-metre-long harpoon attached to a line. The line is usually attached to a buoy or floating drum to allow the swordfish to tire before being hauled onboard [24]. Harpoons are only used in Atlantic Canada.

Bycatch

There are no known bycatch concerns in the harpoon fishery.

Habitat Impact

There are no known concerns of habitat damage from the use of this gear.



Hook and Line

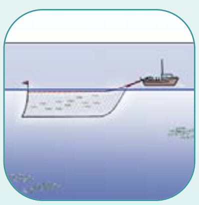
In this study, hook and line refers to fisheries that have a single or only a few hooks on a line. Examples of hook and line fisheries include troll, jig, handline and rod and reel.

Bycatch

There are no available published data on bycatch for hook and line fisheries in Atlantic Canada. On the Pacific coast, bycatch information has been collected since 2006 for all groundfish species because of mandatory 100% observer coverage or electronic monitoring. At the time of publishing, however, technical difficulties with the DFO database mean that the data are not yet available. There are also few data from the British Columbia salmon fisheries; voluntary reporting in 2006 from 3% of the salmon troll fishery showed a 10% discard rate, mostly of other salmon species (DFO Pacific Region, unpublished information). There is no bycatch information for the British Columbia albacore tuna jig fishery.

Habitat Impact

Though suspended in the water, groundfish hook and line fisheries can come into contact with the seafloor, snagging or entangling structures such as corals and sponges [25]. Otherwise, associated habitat damage is low.



Midwater Gillnet

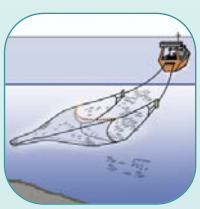
Midwater gillnets consist of nets that hang vertically in the water column. The depth at which nets are set depends on the target species, and they are not intended to contact the seafloor.

Bycatch

In the Atlantic, bycatch information from midwater gillnets is only available from a small study on the Atlantic herring bait fishery where bycatch amounted to 24% of fish caught [26]. In the Pacific salmon gillnet fishery, all bycatch information is reported voluntarily so information is only available for a small percentage of the fishery. Reported discards were only 2% in 2005 and consisted almost entirely of other salmon species (DFO Pacific Region, unpublished information) Extrapolated bycatch from a test fishery in British Columbia estimated seabird discard mortality at 16,000 common murres and 5000 auklets per year [6]. Porpoise and seal bycatch have been reported on the west and east coasts [27, 28].

Habitat Impact

There are no known concerns of habitat damage in these fisheries.



Midwater Trawl

The midwater trawl is similar to the bottom trawl except it lacks rollers on the footrope, and has rectangular doors and a larger mesh in the mouth of the trawl. Midwater trawls are often fished near the seafloor and in Canada are widely used only in the Pacific.

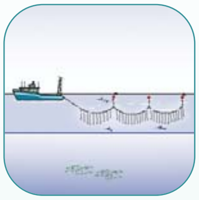
Bycatch

This Pacific fishery has 10% observer coverage and bycatch information is reported by fishermen. The midwater trawl in British Columbia has a discard rate of 1%, equaling 900 t of discarded marine life in 2005. The discard largely consists of undersized Pacific hake and groundfish (DFO PacHarvTrawl database).

Habitat Impact

When on occasion a midwater trawl contacts the seafloor, it can cause benthic disturbance [29]. There were no available data on impacts of midwater trawls in Canadian fisheries.

Pelagic Longline



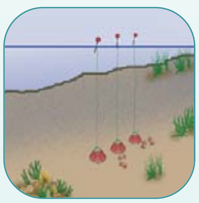
Pelagic longlines consist of a long "backline" from which thousands of smaller lines hang, each with a baited hook. The line is suspended in the water column by a series of floats. Mainlines are typically 64 km long and baited with 1000–3000 hooks at a time [30]. Pelagic longlines are only used in Atlantic Canada.

Bycatch

Information on bycatch for this fishery comes mainly from DFO observer coverage, where there has been ~5% coverage in recent years. Since 2001, the proportion of discards in the pelagic longline fishery in Nova Scotia has been approximately 50% (DFO Observer Database). The majority of the discarded bycatch (>80%) was blue shark, but leatherback and loggerhead turtles, juvenile swordfish, and other sharks were also caught. In this fishery, discards may be released alive, depending on how long the animals have been caught. Of 104 blue sharks caught in the Atlantic Canada pelagic longline fishery, 38% were healthy when released, 44% were injured and 18% were dead [31]. In 2006, approximately 13 leatherback and 32 loggerhead sea turtles were recorded in 17 observed trips, approximately 5–10% of the total fishery (based on estimated weights in DFO observer data). The majority of sea turtles were released alive (97% in 2001), but their survival after release is unknown, as is the case for other discard species, such as sharks.

Habitat Impact

We have no data on habitat damage from this gear but it is generally thought to be low.


Pot and Trap

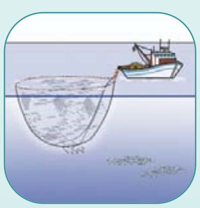
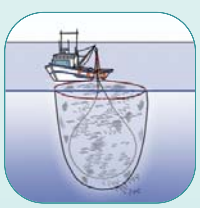
A number of different retrievable pots and traps are used in Canada. For this study, we focused on retrievable pots and traps because there is no bycatch information for fisheries using weirs or fish traps that are attached to the shoreline.

Bycatch

Bycatch rates are not available in most pot and trap fisheries in Canada as trap fisheries generally do not have observer coverage. Two notable exceptions are the British Columbia sablefish fishery, which has had mandatory 100% electronic monitoring since 2006 and the snow crab fishery in Nova Scotia, which had 9 % coverage overall, but up to 30% in some areas. For 2005, when the sablefish fishery was only partially observed, fishermen logbook data show an 8% discard rate consisting mostly of undersized sablefish. In the observed part of the snow crab fishery in Nova Scotia, discards were 0.01% of the fishery [32]. In areas of the inshore lobster fishery in Atlantic Canada that have been observed, groundfish bycatch including cod and cusk has been reported [33]. Bycatch in pots and traps varies widely and depends on the target species and size of the trap, though often bycatch consists of undersized individuals of the target species.

Habitat Impacts

Habitat damage from pots and traps can depend on many factors: size, weight and material of the trap; hauling speed and ocean conditions; depth of haul; number of traps set; and the substrate where the trap is placed. When traps make contact with the seafloor, they cause benthic disturbance, especially during hauling when they may be dragged over the seafloor. Fish traps are often larger and heavier than invertebrate traps so can cause more damage than lighter gears such as inshore lobster pots.

Purse Seine

The purse seine, the most commonly used seine, employs large sections of net with floats along the top edge and weights along the net bottom. Purse seines are set in the water in a circle using a small boat called a skiff. Once the fish are encircled, the bottom is pulled together to close the net around the fish.

Bycatch

Seine fisheries on both coasts have little or no observer coverage or bycatch information. The Scotia–Fundy herring fishery and the Pacific salmon fishery have information for a small percentage of each fishery and both show relatively low discard rates [34].

Habitat Impacts

Habitat damage in the seine fishery is minimal unless it touches the seafloor. Contact with the seafloor can damage the seafloor and re-suspend sediment.

Rating Fishing Gear Impacts

Following the literature review, we invited individuals with knowledge of the fisheries on the Atlantic and Pacific coasts of Canada to participate in a two-day facilitated workshop held in Lunenburg, Nova Scotia. Participants were selected on the basis of their experience in fisheries, and included fishermen, marine and fisheries scientists and marine conservation professionals (Appendix 1). Participants were asked to discuss and review the information on fishing gear impacts collected during the literature review, summarized in Table 1, and to share their relevant knowledge and experience, and to assess the severity of gear impacts. Workshop participants also discussed approaches to mitigation, such as altering fishing seasons, modifying gear and changing the behaviour of individual fishermen.

We then reviewed the information gathered during the workshop, revisited available data, and further consulted with experts specializing in areas where we had little knowledge and/or where there were information gaps. The workshop participants were in general agreement about the level of impacts of the fishing gears on discarded bycatch and habitats. The exception was the impacts of midwater gillnets on seabird and marine mammal bycatch. Upon further consultation with seabird experts and based on additional information gathered from the available literature on seabird [6] and marine mammal bycatch [28, 35], the rating for this gear was adjusted. Yet, because of this discrepancy, we did not use midwater gillnet impact scenarios in developing our ecological impact survey. The final severity ratings for each fishing gear considered in this study by discarded bycatch and habitat impact category, as confirmed by the workshop participants, are shown in Figure 4.

Figure 4 **Rating of ecological impacts of fishing gears used on the west and east coasts of Canada.**
Ratings are based on expert consultations, available DFO data and reviews of the scientific literature.

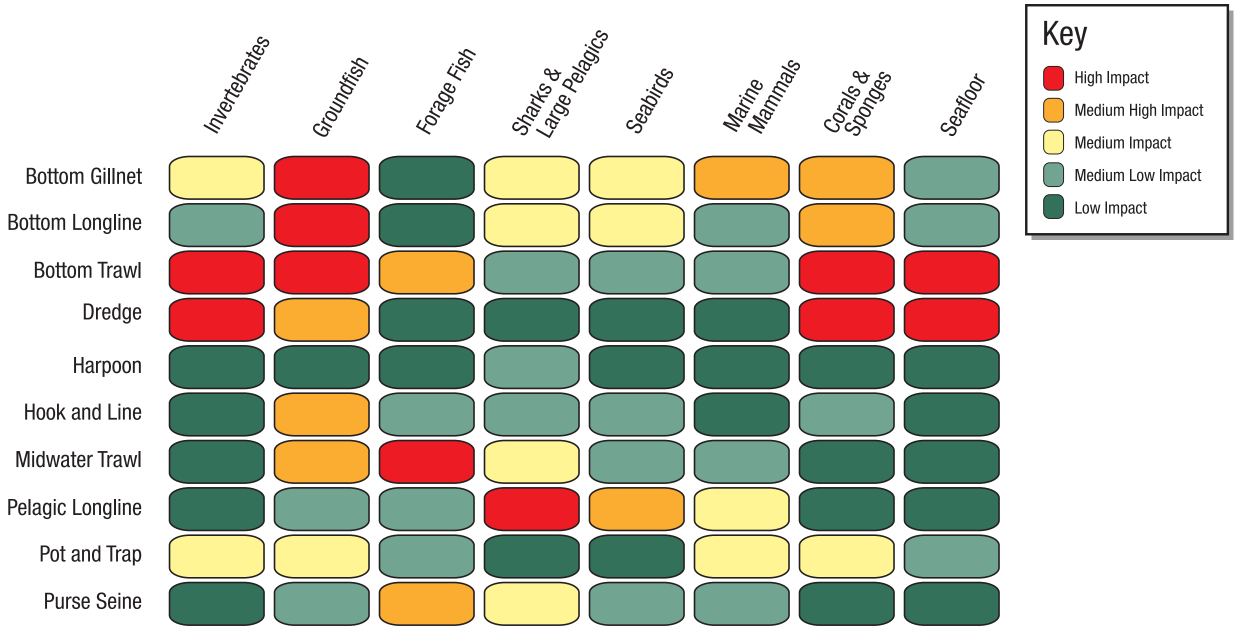
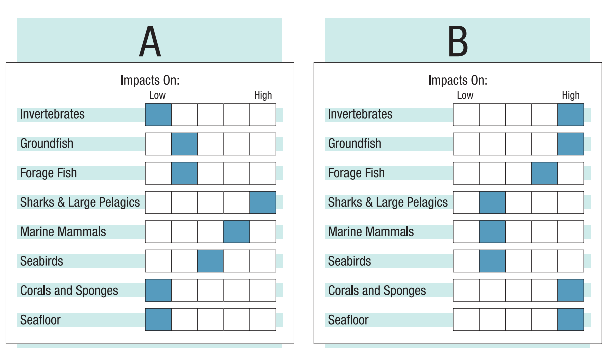


Figure 5

An example of a paired comparison from the survey.
Participants were asked which set of impacts, A or B, they considered to be more ecologically severe.



Survey Ranking of Fishing Gear Impacts

The final part of our study was a paired-comparison survey of five stakeholder groups to obtain their assessment of the relative severity of fishing impacts [see 36]. Identified stakeholder groups included east coast fishermen, west coast fishermen, fisheries and marine scientists, marine conservation professionals, and fisheries and marine managers. Survey participants were randomly selected from lists compiled through professional contacts, staff lists, fishing associations and personal recommendations.

Each survey page contained two ecological impact scenarios based on the ratings obtained in the previous step (Figure 4 and see sample question in Figure 5). Each survey included 32 pairs of impact severity comparisons in randomized order such that each survey was unique. The impact scenarios were presented without the names of the fishing gear to enable survey participants to judge the ecological impacts and not the gears that cause them (survey materials can be viewed at www.howwefish.ca).

The survey also included a series of demographic questions to gather information on each participant's age, profession and length of time in the profession. Participants were additionally asked to rank which bycatch and discarded species they deemed more ecologically important and to comment on what influenced their decision when choosing impact scenarios (i.e., discard, habitat impact, or both equally). We also asked them to list the gears for which they had experience.

Sponge reefs found in Hecate Strait on Canada's west coast. PHOTO: Pacific Geological Survey of Canada.

Ranking Fishing Gears

A total of 262 individuals with experience in some aspect of Canadian fisheries or the marine ecosystem were contacted, of whom 70% agreed to fill in the survey. The return rate of completed surveys was 61%. Of the 97 surveys completed, 38% were by fishermen, 27% by scientists, 25% by marine conservation professionals, and 10% by managers. Participants had a range of experiences with different gear types, with all fishermen having used more than one gear type during their career (Table 2). Returned surveys were analyzed to obtain the impact scores, i.e., number of times each scenario was considered more severe. Within each stakeholder group, scores from individual respondents were aggregated and normalized on a scale of 0 to 100, with 0 being low severity and 100 being high severity of impacts. Impact scenarios were then ranked according to these aggregated scores.

When given the choice between habitat and bycatch, the top ecological concern of the respondents was habitat damage, and participants consistently ranked scenarios with "high" seafloor impacts as most severe. Though most respondents

Table 2

Expertise and experience of survey participants

	East Coast Fishermen	West Coast Fishermen	Managers	Marine Conservation Professionals	Scientists
Total	20	17	10	24	26
Average # years in occupation	33	36	22	9	12
% with commercial fishing experience	100	100	20	46	26

Percent respondents with experience with various categories of commercial fishing gear or impacts related to specific gear types.

	East Coast Fishermen	West Coast Fishermen	Managers	Marine Conservation Professionals	Scientists
Benthic fixed gear	75	82	10	17	27
Benthic mobile gear	45	18	0	8	27
Pelagic gear	70	53	10	12	12

indicated that they were equally concerned about habitat and bycatch, their survey responses showed a greater concern with habitat impacts than with bycatch (Table 3). All groups were most concerned with groundfish, except for fishermen on the east coast, who considered impacts on invertebrates their top concern. This may reflect the value of the invertebrate fisheries (i.e., lobster, crab, shrimp, scallops) on the east coast, while on the west coast groundfish are still of greater economic value.

One of the notable results of this survey was the consistency with which survey participants ranked the different impact scenarios (Figure 6). The similarity between groups was very high (Kendall's Tau rank correlation ranged from 0.78 to 1). Our results show that the impacts of bottom trawling are consistently considered the most ecologically damaging (Figure 7). The high correlation found in the survey enabled the aggregation of scores from all respondents into one scale as shown in Figure 7. The impacts of bottom gillnets and dredges are considered only slightly less severe than bottom trawls. Gears considered to have moderate levels of impacts are bottom longlines, followed by midwater trawls, pots and traps, pelagic longlines and purse seines. Hook and line gear including rod and reel for pelagic fishes, salmon trolling, and groundfish hook and line are all considered to have lower impacts on habitat and bycatch, and harpoons are judged to have the lowest impact of all. Because the fisheries and hence fishing gears used in Canada's oceans vary, we identified specific ratings for gear types used on the west coast and the east coast, with the latter including fishing gears used in the Arctic, as the vast majority of Arctic fisheries are an extension of east coast fisheries, both in species targeted and fishing gear used.

The ranking of fishing gear according to the severity of their ecological impacts indicates that the gears we use most extensively in Canada have the highest impact. In order to address these impacts on a broad scale there should be a movement to gear substitution and using the least destructive fishing gear wherever possible.

Table 3

Importance of fishing gear impacts according to survey participants

Percentage of participants selecting the impact category as important.

Impact category	East Coast Fishermen	West Coast Fishermen	Managers	Marine Conservation Professionals	Scientists
Bycatch	6	0	0	9	13
Habitat	44	50	33	31	35
Equal consideration	50	50	67	60	52

Figure 6

Gear rankings by survey participant group

Kendall's Tau rank correlation analysis shows that the rankings are not signifiantly different between groups (at p=0.01 level).

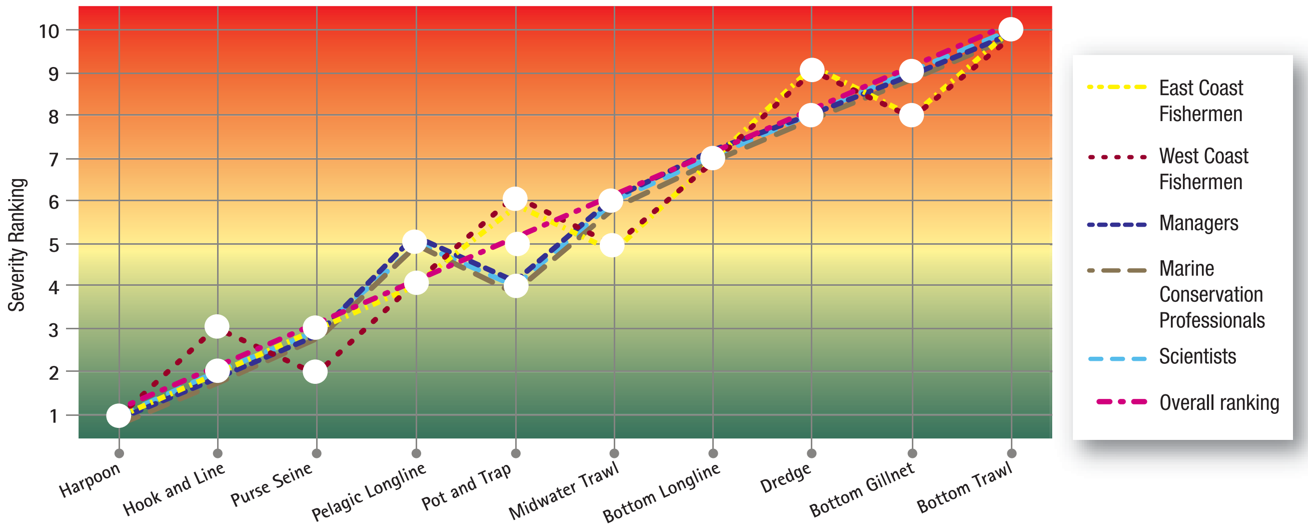
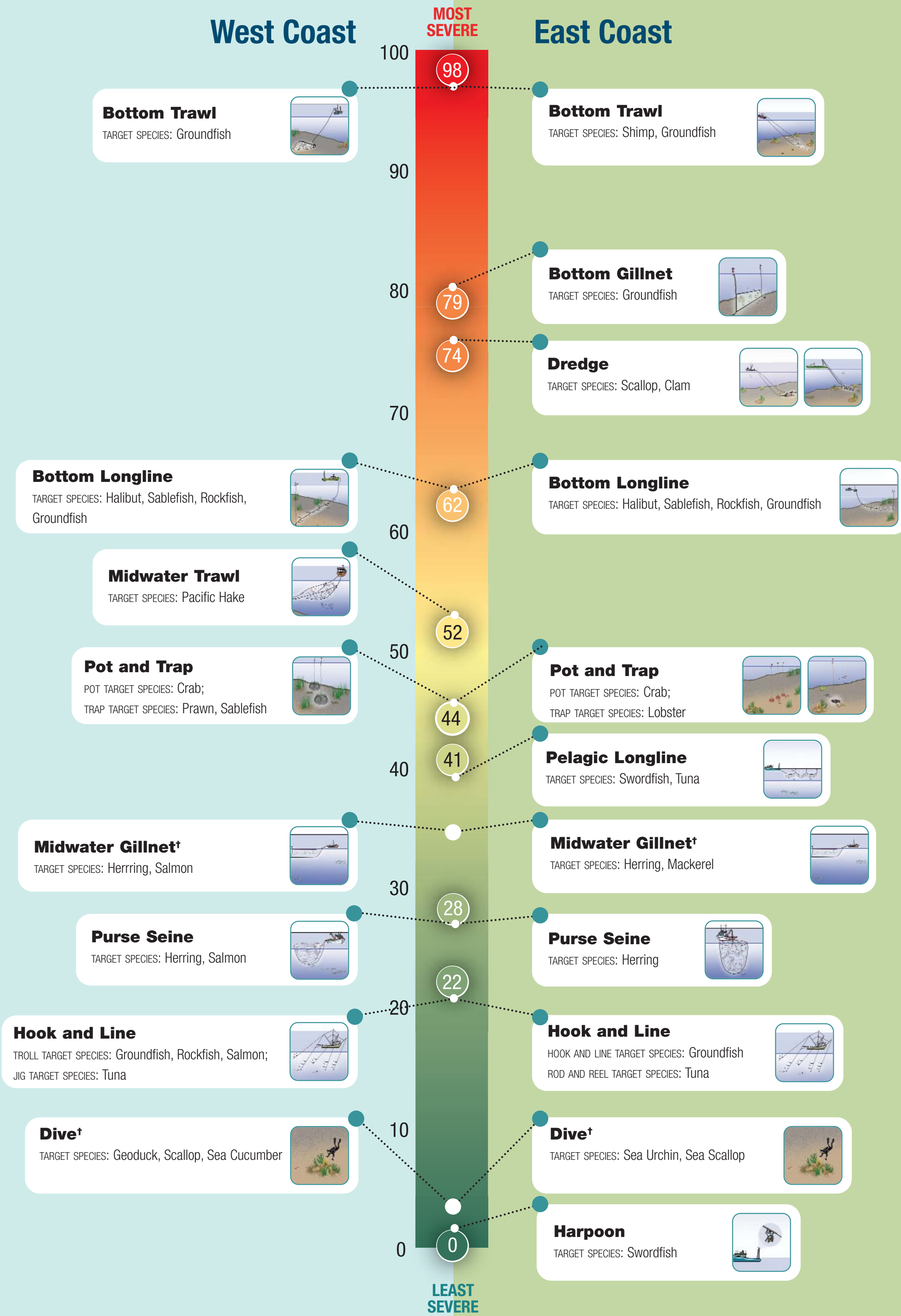


Figure 7

Severity ranking of fishing gears normalized on a scale of 100



† *See Box 3.*

Box 3

Ranking fishing gears not incorporated in the survey

As previously stated, there was not sufficient information or consensus reached at the workshop on some gear types to include their impacts in the survey. Yet, we can make an inference about the level of severity of these gears from the final ranking scheme if we are able to generate an impact rating for each bycatch and habitat category (similar to those shown in Figure 4). This set of impact ratings can then be compared with the existing ones on the overall severity scale (Figure 7) and inserted accordingly. The same approach can be applied to incorporate other gears such as those employed in specific areas or new gears.

For example, in the post-workshop exercise, we were able to estimate the level of impacts of midwater gillnet by incorporating the advice of an east coast seabird expert and available literature on seabirds [6] as well as marine mammal bycatch [26, 32]. These ratings were 'low' for all bottom-dwelling bycatch groups, seafloor, and corals and sponges, which are consistent with the literature and workshop ratings of other pelagic gears (Figure 4). If we were to incorporate midwater gillnets on the severity scale, they would be expected to rank similarly to other pelagic gears (Figure 7).

A second example was the Canadian dive fishery, which was not adequately discussed due to the lack of expertise among workshop participants, and thus was excluded from the survey. When rating the impact of dive fisheries on the seafloor, workshop participants referred most often to the Pacific geoduck clam fishery. The geoduck fishery in British Columbia disturbs seafloor below the surface, sometimes with hydraulic tools significantly disturbing the sediment. In contrast, other benthic dive fisheries remove target species such as the scallop, sea urchin and sea cucumber dive fisheries. Despite the impacts associated with the geoduck fishery, dive fisheries have an overall relatively low impact when compared with other habitat damaging fisheries, which would place them near harpoon fisheries on the severity scale (Figure 7).

Implications of Results for Fisheries Management, Science and Policy

The relative severity of fishing gear impacts on bycatch and habitat in Canadian waters supports the establishment of new mechanisms to reduce the impact of fishing on the marine ecosystem. We recognize that many initiatives, from gear technology changes to fisheries closures and changes in fishing strategies have been implemented over time to address ecosystem impacts of fishing (Box 4 includes some notable examples in Canadian fisheries). Nevertheless, there is room for significant improvement, as indicated by the lack of available information on habitat impacts and bycatch data for many fisheries. We recommend changes in fisheries management, science and policy to address the range of risks to the marine ecosystem posed by fishing gear used in Canada as identified in this study.

Box 4

Fishing gear modifications

In recognition that fisheries have incidental impacts on aspects of the marine ecosystem other than the target species, there have been improvements in fishing gear used in Canada. In addition to technological improvements, fishermen also engage in behaviour that can reduce the impact of fishing gear on both habitat and bycatch. The focus on technological changes has been primarily to reduce bycatch of non-target commercial species or species at risk.

Nordmore Grate

The Nordmore grate has been used in the Atlantic Canadian northern shrimp fishery since 1992 specifically to reduce the bycatch of groundfish species. The Nordmore grate has been seen to be successful in reducing bycatch, particularly for adult groundfish. There continue to be catches of juvenile fish, which are small enough to pass through the grate, mainly cod, redfish and Greenland halibut [52]. There are no good estimates of the mortality of adults that are captured, but not caught in the net as a result of the Nordmore grate.

Haddock Separator Trawl

The need to reduce fishing mortality on cod stocks in the Northwest Atlantic has stimulated gear changes to lessen the rate of bycatch in fisheries where cod is often caught. As the haddock stocks on Georges Bank have increased, haddock separator nets have been introduced in the bottom trawl fishery, where a panel separates the net. Cod tend to swim downwards, while haddock swim upwards, so the bottom net is open, allowing cod to swim through while the top net is closed, and catches the haddock. Bycatch of cod was reduced to 3.9% of the total catch while haddock was 91% of the total catch in the observed portion of the haddock fishery on Georges Bank in 2007. This likely reflects a combination of higher haddock abundances than cod, and the selectivity of the separator trawl.

Circle Hooks and Gangion Lines Lengths

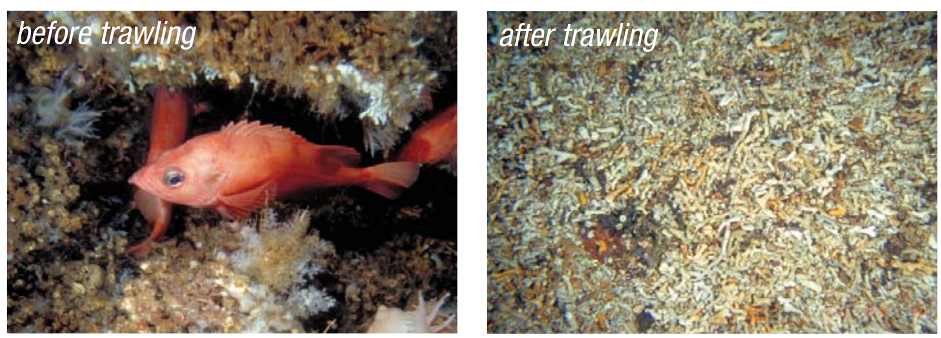
In many pelagic longline fisheries, circle hooks are mandatory as they reduce the catch of shark and turtle species, and increase the likelihood that hooked and released animals will survive. Also, in the US fishery it is mandatory that the gangion line (the line leading from the main line to the hook) be long enough to reach the surface, in all sets of 50 m depth or less. This is to ensure that hooked turtles can reach the surface to breath. These gear modifications are voluntarily practiced in much of the Canadian longline fishery, but are not mandatory. They are mandatory in US pelagic longline fisheries, where gear modifications and bycatch limits have led to a significant reduction in turtle bycatch.

How and Where We Fish Matters

Our results show significant differences in the impacts of fishing gear on the marine environment (Figure 7). These impacts can be mitigated in part by closing sensitive habitats as well as areas of high bycatch to gear types with significant impacts on these ecosystem components. Access to fishing grounds can also be regulated by creating gear exclusion areas that will minimize impacts on habitat and bycatch. Replacing gear that poses a high risk to the marine ecosystem with fishing gear that is known to be low risk to habitat and associated species can also mitigate ecosystem impacts of fishing.

Our results support the need for spatial management as part of fisheries management, where sensitive and unique habitats are protected from destructive fishing gears and bycatch mitigation measures include spatial considerations. Ocean zoning, area-based fisheries management, fisheries closures and designation of marine protected areas are all spatial management measures that can be used to reduce the impacts of fishing on both habitat and non-target species. Opportunities for Canada to implement spatial planning exist through current integrated management initiatives in Large Ocean Management Areas (LOMAs), of which there are currently five in Canada's three oceans. The existing LOMAs include the Pacific north coast, the Beaufort Sea, the Gulf of St. Lawrence, the Eastern Scotian shelf and Placentia Bay / Grand Banks on the Atlantic Coast.

How we fish and where we fish matters not only to marine species and habitat, but also to the people who depend on a healthy marine ecosystem for their livelihoods. As gear with greater catch capacity has been introduced, coastal communities on both the east and west coasts of Canada have been greatly impacted (Box 5). Fisheries quota allocations to low-impact gear types frequently benefit small-scale fishermen, in turn helping to maintain and restore vibrant coastal communities. Where there are opportunities for gear substitution, fisheries should be conducted using the gear type that causes the least amount of impact possible. For example, where a fishery has a high bycatch rate, such as in the pelagic longline fishery for swordfish in Atlantic Canada, efforts should be made to transfer fish quota to more sustainable fishing methods such as harpooning.



90% of *Lophelia* coral on Canada's east coast has been destroyed by bottom trawling: intact coral provides protection for redfish and other species and coral rubble following fishing activity. PHOTO: Fisheries and Oceans Canada.

Monitoring, Research and Data Availability for Ecosystem-Based Management

In this study we use existing and available information to assess the impacts of fishing gears. For some fisheries, however, we found a considerable lack of information on the ecosystem impacts (Box 2). Given that many fisheries in Canada use research surveys to develop population estimates, these surveys should increase collection of information on discarded bycatch and benthic species. Without recording species that are incidentally caught, there is no way of measuring change in these species, which can be a proxy for seafloor community change [21]. Monitoring is important in existing fishing areas, but is also of even greater importance in areas that have had relatively little fishing activity in the past (Box 6). Research surveys can be used to create habitat maps of the seafloor, which are key components to spatial management plans.

In addition to improved data collection, there is a need for transparency, disclosure and public access to data on Canadian fisheries. Without adequate and timely reporting, the ecosystem impacts of fishing cannot be adequately assessed. In addition, reporting and transparency of fishing information allows for adaptive management, which is a component of ecosystem-based management.

With publicly available survey information, logbook data as well as fisheries observer data, mapping of marine habitats, fishing effort and areas with high bycatch and discard rates can then take place. This can provide the basis for spatial management of Canada's fisheries.

Fisheries Policy and Management

To date, there are very few restrictions on bottom tending gears aimed at protecting habitat in Canada. Fisheries management currently does not apply a risk averse strategy to avoiding ecosystem impacts of fishing. A few existing closures have been put in place, and serve to protect British Columbia's globally unique glass sponge reefs [13], two areas on the Scotian Shelf to protect cold-water corals [44] and a coral habitat on the southwest slope of the Grand Banks of Newfoundland.

A policy and legal framework exists in Canada and internationally for protecting the marine environment. The first step in mitigating impacts of fishing gear to habitat and bycatch from a policy perspective would be to implement existing tools. As Canadian fisheries law and policies are revised and adapted to reflect and provide for a comprehensive ecosystem approach to fisheries management, our results can be used to inform these changes. For instance, the Canadian Fisheries Act states that it is illegal to harm fish habitat. Additionally, in 1986, DFO adopted the Policy for the Management of Fish Habitat with the mandate of "no net loss of fish habitat." Unfortunately, neither fisheries law nor habitat policy currently applies to or addresses the impacts of commercial fishing on seafloor habitat and there is no assessment of the impacts of different fishing gears on fish habitat included in scientific advice or fisheries management plans. Future revisions to the Fisheries Act must address this oversight.

Additionally, Canada has three government agencies, including Fisheries and Oceans Canada, Parks Canada and Environment Canada, who have mandates to establish protected areas in the marine environment. Implementing existing legislation that enables the establishment of fisheries closures, marine protected areas, national marine conservation areas and national wildlife areas would be a major step in mitigating the impacts of fishing gears on habitat and bycatch as identified in this report.

New policies for fisheries management are being developed. For instance, the Impacts of Fishing on Sensitive Benthic Areas policy, a component of the newly developed Sustainable Fisheries Framework (still in draft form as of November 2008), will be of great significance, particularly as fisheries (including Arctic fisheries) expand to new and deeper areas (Box 6). In 2006, the Canadian government convened a national review of the impacts of fishing gear, and accepted the findings of several

Box 5

Sustaining fishing communities with low impact fishing gear

West Coast

The number of jobs associated with the commercial fishing industry in British Columbia has been halved since 1984 [37]. The majority of job losses occurred in small coastal communities which depended heavily on the fishery [38]. Both job reductions and license buybacks were intended to improve the long-term sustainability of Pacific fisheries [37] but despite these measures, many fish populations continue to decline.

As the remaining fishermen and fishing companies strive to achieve economic efficiencies, fish habitat is increasingly exposed to more destructive fishing gear. For example, in the 2006-2007 British Columbia groundfish fisheries, 63% (1.8 million t) of all groundfish quota was allocated to the trawl sector [39]. The remaining 37% was divided between the bottom longline, hook and line and trap fleets.

Parallels to the trawl versus passive gear allocations in the groundfish fishery can also be found in the herring fishery. The herring roe fishery in British Columbia is done using purse seines and gillnets (both with 100% herring mortality) and the spawn-on-kelp (SOK) method. In SOK, herring are released alive to spawn another season. In 2007, license allocations to the herring roe fishery strongly favoured purse seines and midwater gillnets as opposed to SOK, despite the abundance predictions for 2008 that three out of the five assessment regions would be unable to support herring fisheries, up from two regional closures in 2007 [40]. In a fishery with drastically declining populations, methods with the lowest rate of unnecessary mortality are the obvious choice, where they are commercially viable.

East Coast

In Atlantic Canada, the face of the fishing industry has changed rapidly and extensively over the last 20 years. Across the region, the shift from a groundfish-based fishery to an invertebrate-based fishery has increased the overall value of fisheries [41]. However, fishery-related employment trends have varied across the region. The number of people employed by fishing in Nova Scotia, for example, has remained fairly steady from the mid-1980s until 2002, at around 14,000 people (full- and part-time), while the value of the catch has doubled (without correcting for inflation) [42]. This is primarily a result of the independent owner-operator lobster fishery.

In Newfoundland, the value of the catch has also increased recently, from $285 million in 1990 to $478 million in 2007 [43]. However, fisheries employment has shown an opposite trend in Newfoundland, decreasing from 26,564 fishermen in 1985 to 12,725 fishermen in 2007 [43]. This opposing trend in fishing employment and value reflects shifts to fisheries that are higher value but require either small crews (such as lobster) or large offshore vessels, which have very high catch rates for the number of people employed (such as offshore clam fishing vessels).

There are many fisheries in which different gears are used to target the same species in some or all of the area fished in Atlantic Canada, creating opportunities to switch from high-impact gears to low-impact gears. For example, groundfish are targeted with bottom longlines, which have a lower overall impact than bottom trawls (Figure 6). Similarly, both harpoons and pelagic longlines are used to target swordfish. Pots can be used rather than trawls to catch shrimp in inshore areas, and there are many other examples.

international reviews [45]. The Sensitive Benthic Areas policy could direct fisheries managers to assess the impact of bottom tending gear on seafloor habitat, as suggested by our results, when developing management plans.

There are management measures for addressing commercial bycatch, particularly through new management programs in selected fisheries as well as fishery specific gear modifications (Box 4). The 2006 Groundfish Pilot Integration Program in western Canada has improved the management of commercial bycatch for all groundfish fisheries; it requires individual quotas for all commercial bycatch (transferable between all commercial groundfish fisheries), and 100% at-sea electronic monitoring or on-board observers. In Atlantic Canada, several groundfish fisheries are considered multi-species fisheries, with a quota for the target species as well as for bycatch species. Despite these initiatives, the Sustainable Fisheries Framework does not include a policy on bycatch in Canadian fisheries — a clear gap when it comes to addressing the impacts of fishing gear on non-target species, as identified in this report.

Recommendations

1 *How and Where We Fish Matters*

Fisheries managers should immediately implement ecologically risk averse strategies to minimize the impacts of fishing gear on habitat and bycatch.

- Use variation orders under the Fisheries Act to protect known areas of vulnerable marine ecosystems from destructive fishing practices.
- Develop and implement a spatial plan or zoning scheme that considers gear type and its impact on habitat and bycatch and apply this system in all three oceans.
- Allocate quotas preferentially to low impact gears and provide incentives for fishing gear substitution wherever possible.

2 *Monitoring, Research and Data Availability for Ecosystem-Based Management*

Adequate monitoring and research on fishing gear impacts to habitat and non-target species must be undertaken, and made publicly available, to support ecosystem and spatial management practices.

- Implement comprehensive and consistent monitoring and assessment programs on the quantity and type of non-target and non-commercial species and habitat damage for all fisheries and make data publicly available.
- Complete comprehensive seafloor maps for all coasts.
- Complete comprehensive maps of existing fishing grounds and areas of discarded bycatch on all coasts.

3 *Fisheries Policy and Management*

Implement, inform and develop policies and management practices that prioritize the minimization of habitat destruction and incidental catch and discarding of target and non-target species.

- Establish a comprehensive network of protected areas and fisheries closures, using existing legal tools, to provide resilience against the impacts of fishing on habitat and bycatch.
- Pending final public consultation, adopt and implement the draft Impacts of Fisheries on Sensitive Benthic Areas Policy as part of the Sustainable Fisheries Framework.
- Include management provisions to reduce the risk of impacts of fishing gear on habitat and incidental catch in Integrated Fisheries Management Plans.
- Develop and implement a national bycatch and discard policy that includes bycatch limits for commonly caught commercial and non-commercial species, as well as for species at risk.

Box 6

Threats to new fisheries and frontier areas

New Fisheries

In 1996, Canada instituted an Emerging Fisheries Policy that lays out how new fisheries will be developed. Included are fisheries for species that have not traditionally been fished, the introduction of new gear types, and new fishing areas for species that have traditionally been fished elsewhere. These emerging fisheries include a wide range of species and gear types, though low-trophic invertebrate species have tended to dominate new fisheries development in Canada in recent years [46].

While some new fisheries have used low-impact fishing methods like diving (e.g., sea urchins) or pots (e.g., whelks), new trawl and dredge fisheries have also been developed. For example, a dredge-based sea cucumber fishery has been under development in Atlantic Canada [47]. In the Pacific, where sea cucumber fisheries have existed for decades, diving is the only permitted method of targeting sea cucumbers.

Fishing Deeper

In Atlantic Canada, trawling below 600 m was quite rare until the early 1990s, but since then substantial fishing effort has occurred at depths of 1000–1500 m. Similarly, a fishery for the longspine thornyhead developed during the 1990s in British Columbia, exposing a large area at depths between 500 and 1200 m to trawling disturbance for the first time. The greatest damage to long-lived, habitat-providing species such as corals and sponges comes from the first trawl pass, as this often removes or destroys these fragile animals [48]. Observer data show a very large increase in sponge bycatch in Atlantic Canada during the period between 1992 and 2001, as trawling in deeper water and at higher latitudes disturbed new areas for the first time [49].

The Arctic Frontier

Expansion of trawling into previously untrawled areas continues on all coasts of Canada, with the most rapid expansion occurring in the eastern Arctic Ocean. Arctic ecosystems have low levels of natural disturbance and have historically been largely inaccessible to commercial fishing because most areas are covered by multi-year sea ice. Ecosystems that evolve with minimal disturbance can be less resilient to fishing pressure, as the rate of natural disturbance is low [50].

The Canadian federal government's 2008 budget allocations dedicated $10 million to support commercial fishery infrastructure development in the Arctic to take advantage of "untapped inshore fishing opportunities" (DFO budget announcement). This development augments a decade of offshore Arctic fishery expansion that now generates $50 million annually, almost entirely from destructive fishing methods such as bottom trawling.

Despite the existence of still pristine and unfished areas of the seafloor in the Arctic Ocean, there is no legislation that protects the seafloor or its inhabitants in these waters.

Fishing vessels at the dock in Sointula, British Columbia. PHOTO: Bruce Burrows.

Conclusion

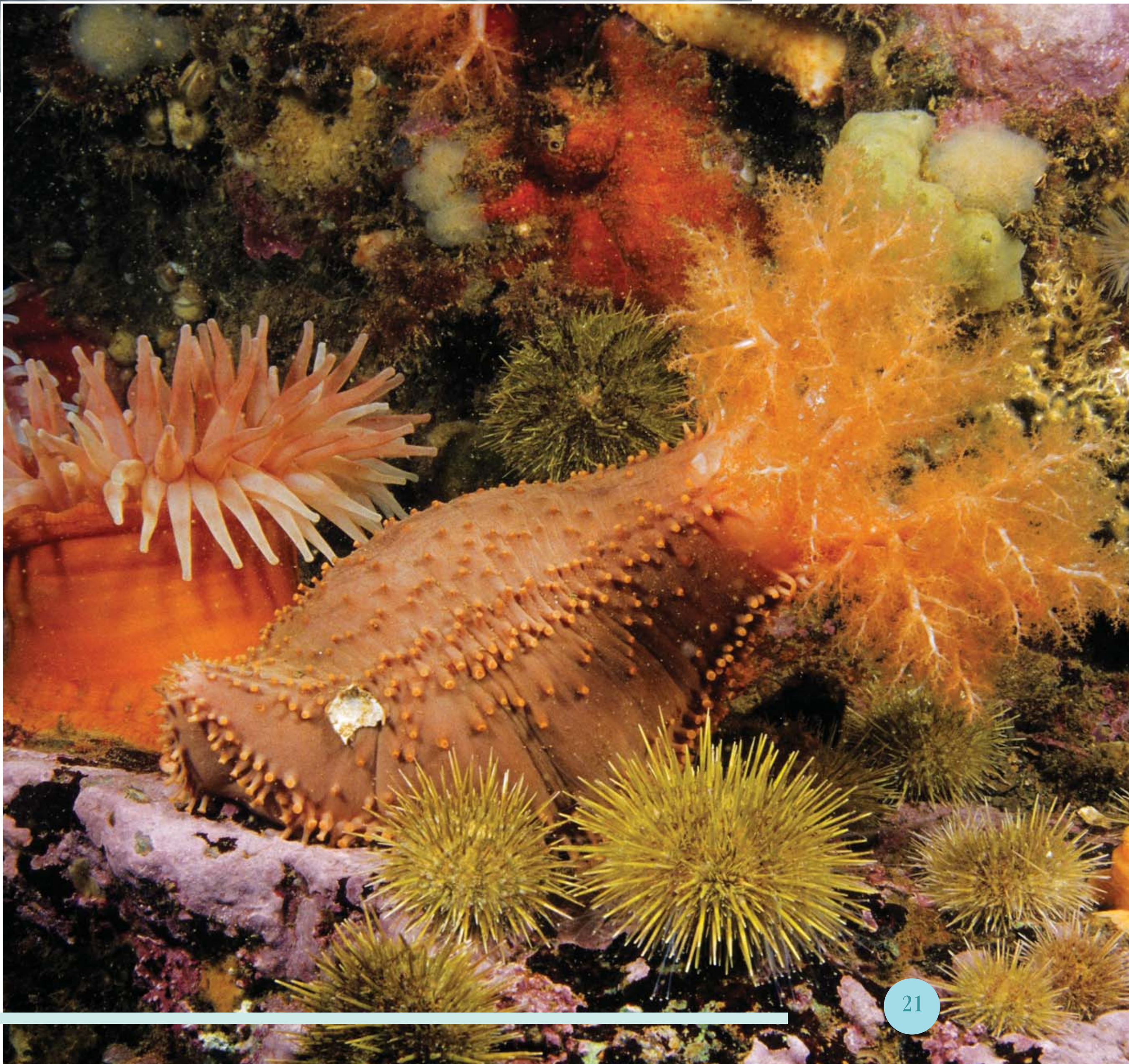
Our study corroborates the results of a similar study done in the United States [51], confirming that the destruction of habitat is considered the most important ecological impact of fishing gear. There are also significant concerns about discarded bycatch of both commercial and non-commercial species in certain fisheries. There is a link between habitat impacts and bycatch as many habitat impacts are detected only through bycatch data, such as catches of cold water corals, sponges and other habitat forming species.

The severity rankings presented here provide a basis for the development and implementation of new policies to address the impacts of fishing gear on Canadian marine ecosystems, specifically those impacts related to habitat damage and discarding of non-target species. Considering that the gears with the highest impact ranking are also the gears most widely used in groundfish fisheries, a new vision for fisheries management that incorporates the impacts of fishing on the marine ecosystem must be adopted. It is clear that when developing new fisheries, using a new gear type, targeting a new species, or fishing in a new area, ecological impacts must be part of the management discussion. The ranking of fishing gear impacts presented here can become the basis for new policies and provide a regulatory framework for ecosystem-based management in Canada.

One of the most significant findings of this study is that despite the frequently contentious nature of fisheries management decisions, fishermen, scientists, marine conservation professionals, and fisheries managers share similar attitudes regarding the impacts of fishing gear on habitat and the amount of discarded bycatch. This provides a common place from which to begin building a new vision for Canada's oceans. By considering how and where we fish, and shifting from high- to low-impact gears, we will avoid following the trends of the previous century. Repeated stock collapses, expansion into frontier areas, and fishing down the food web could become past mistakes and a new day could dawn on Canada's fisheries, bringing hope of sustainable fisheries and fishing communities.

LEFT: Loggerhead sea turtles caught in the pelagic longline fishery are released but often retain the hook in their mouths. PHOTO: H.R. Yao.

BELOW: Sea cucumbers on Canada's east coast are harvested by modified scallop dredges. PHOTO: Andrew Martinez.



Herring are caught by purse seines and inshore weirs in Atlantic Canada. PHOTO: H.R. Yao.

Appendix 1

Workshop Participants

Jim Boutillier
Fisheries Scientist
Fisheries and Oceans Canada
Nanaimo, British Columbia

David Boyes
Fisherman
Vancouver Island, British Columbia

John Brajcich
Fisherman
Capilano Fishing Limited
Vancouver, British Columbia

Ghislain Chouinard
Fisheries Scientist
Fisheries and Oceans Canada
Moncton, New Brunswick

Jean Guy D'Entremont
Scotia Harvest Seafoods
South Shore, Nova Scotia

Don Gordon
Fisheries Scientist (Emeritus)
Fisheries and Oceans Canada
Dartmouth, Nova Scotia

Gilbert Devine
Fisherman
South Shore, Nova Scotia

Pat Gallaugher
Professor
Centre of Coastal Studies
Simon Fraser University
Vancouver, British Columbia

Joseph Gough
Researcher and Writer
Ottawa, Ontario

Jason Hall-Spencer
Marine Scientist
Marine Institute, University of Plymouth
Plymouth, United Kingdom

Roger Hunka
Executive Director
Maritime Aboriginal Aquatic Resources Secretariate
Truro, Nova Scotia

William Lee
Fisherman
Petty Harbour, Newfoundland

Dave MacLellan
Fisherman
British Columbia

Danial Smith
Fisherman
Alert Bay, British Columbia

Tucker Soltau
Fisheries Observer
Vancouver Island, British Columbia

Scott Wallace
Scientist
David Suzuki Foundation
Vancouver, British Columbia

Paul Winger
Fisheries Scientist
Memorial University
St. John's, Newfoundland

Boris Worm
Professor
Dalhousie University
Halifax, Nova Scotia

Afterword

—Callum Roberts, University of York

> *The trawl is still suffered to be employed in all its baneful tendencies without restraint or limitation… Dragged along with force over considerable areas of marine bottom, it tears away promiscuously, hosts of the inferior beings there resident, besides bringing destruction on multitudes of smaller fishes, the whole of which, be it observed, are the appointed diet of those edible species sought after as human food… An interference… of such magnitude, and of such long duration, will hereafter bring its fruits in a perceptible diminution of those articles of consumption for which we at present seem to have so great necessity.*

So wrote J.C. Bellamy in 1843. For the reasons presented in this report, bottom trawling has been highly controversial since its invention in 14th century England. In the process of catching fish it causes immense damage to marine habitats and gnaws at the productive foundation of fisheries.

Scallop dredging on Canada's east coast can capture over 200 species which are all discarded. PHOTO: Susanna D. Fuller.

Despite widespread condemnation in the 19th century, bottom trawling was allowed to prosper. The economic arguments in its favour overwhelmed opposition. Only trawling appeared able to supply explosive growth in demand as human populations increased and markets expanded with the spread of railways.

Bottom trawling, as this report confirms, is not the only fishing method that inflicts significant collateral damage in our pursuit of fish. Most gears kill species that are not the intended targets and many disrupt habitats and aquatic food webs. For most of history, the fate of habitats and bycatch species has barely furrowed the brows of scientists, fishers or fisheries managers. We have assumed, unwisely it is now obvious, that habitats of sufficient quantity and quality would always be there to underpin the production of our quarry. But there are big differences between now and the 19th century. Today, the footprint of fishing has expanded to fill seas and oceans, leaving few refuges for sensitive habitats and species. As groundfish stocks have declined, the ecological shift to prawn domination has led us to sieve the seas with fine mesh nets that afford no prospect of recovery for depleted stocks of other species.

Unless we embed a respect for habitats and wider ecosystems at the heart of fisheries management we will lose much of what we take for granted from the sea: clean, safe water, productive fisheries, and a richness of life that can fascinate and inspire us, to name four. While economic arguments in the 19th century favoured a disregard for anything other than fish landed, today they weigh in favour of greater environmental protection. Fisheries management is no longer about just fish, but must serve the wider interests of society, safeguarding diverse, healthy and productive ecosystems for the full range of benefits they bestow.

The next time you sit down to a seafood meal, spare a thought for how it was caught. Contemplate for a moment the ghostly heap of bycatch on your plate, a side of coral, sponge and goby perhaps, or a garnish of albatross. This important report serves as a reminder of the wider costs of fishing, and is starting point for long overdue reform.

References

1 Treble, M., T. Siferd, B. Brodie, and P. Richard, 2007. Canadian research report for 2007, part 2. Central and Arctic Region. Scientific Council Meeting - June 2007. NAFO SCS Doc. 07/12 Part 2 Serial No. N5368.

2 Sjare, B., D. Walsh, G.B. Stenson, and S. Benjamins, 2005. An update on harp seal (*Pagophilus groenlandicus*) by-catch estimates in the Newfoundland lumpfish fishery. DFO CSAS Research Document 2005/049.

3 Lawson, J., S. Benjamins, and G. Stenson, 2004. Harbour porpoise bycatch estimates for Newfoundland's 2002 nearshore cod fishery. DFO CSAS Research Document 2004/066.

4 Davoren, G.K., 2007. Effects of gill-net fishing on marine birds in a biological hotspot in the Northwest Altantic. Conserv Biol, 21(4): p. 1032-1045.

5 Edinger, E., K. Baker, R. Devillers, and V. Wareham, 2006. Coldwater corals off Newfoundland and Labrador: distribution and fisheries impacts. World Wildlife Fund Canada (Atlantic Region). Available from: http://wwf.ca/coral.

6 Smith, J.L. and K.H. Morgan. 2005. An assessment of seabird bycatch in longline and net fisheries in British Columbia., Canadian Wildlife Service, Editor, Pacific and Yukon Region Technical Report Series No. 401.

7 Mortensen, P.B., L. Buhl-Mortensen, D.C. Gordon Jr, G.B.J. Fader, D.L. McKeown, and D.G. Fenton, 2005. Effects of fisheries on deepwater gorgonian corals in the Northeast Channel, Nova Scotia. Am Fish Soc Symp, 41: p. 369-382.

8 Koeller, P., M. Covey, and M. King, 2007. An assessment of the Eastern Scotian Shelf shrimp stock and fishery in 2006 and outlook for 2007, including an estimate of bycatch and evaluation of alternative fishery independent abundance indicators. DFO CSAS Research Document 2007/XXX.

9 Broadhurst, M.K., P. Suuronen, and A. Hulme, 2006. Estimating collateral mortality from towed fishing gear. Fish Fish, 7: p. 180-218.

10 Gordon, D.J., K. Gilkinson, E. Kenchington, J. Prena, C. Bourbannais, K. MacIsaac, D. McKeown, and W. Vass, 2002. Summary of the Grand Banks otter trawling experiment (1993-1995): Effects on benthic habitat and communities. Can Rep Fish Aquat Sci, 2146: p. 72pp.

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

12 Kenchington, E.L.R., K.D. Gilkinson, K.G. MacIsaac, C. Bourbonnais-Boyce, T.J. Kenchington, S.J. Smith, and D.C. Gordon, 2006. Effects of experimental otter trawling on benthic assemblages on Western Bank, northwest Atlantic Ocean. J Sea Res, 56(3): p. 249-270.

13 Ardron, J.A., 2005. Protecting British Columbia's corals and sponges from bottom trawling. Living Oceans Society.

14 Conway, K.W., M. Krautter, J.V. Barrie, F. Whitney, R. Thomson, H. Reiswig, H. Lehnert, G. Mungov, and M. Betram, 2005. Sponge reefs in the Queen Charlotte Basin, Canada: controls on distribution, growth and development in Cold-Water Corals and Ecosystems, A. Freiwald and J.M. Roberts, Editors, Springer Berlin Heidelberg. p. 605-621.

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

16 Austin, W.C., Conway, K.W., Barrie, J.V. & Krautter, M . . 2006. Growth and morphology of a reef-forming glass sponge, *Aphrocallistes vastus* (*Hexactinellida*), and implications for recovery from widespread trawl damage. in 7th International Sponge Symposium: Armação de Búzios (Rio de Janeiro, Brazil).

17 Van Eeckhaute, L. and S. Gavaris, 2006. Estimation of cod, haddock and yellowtail flounder discards from the Canadian Georges Bank scallop fishery for 2005. Transboundary Resource Assessment Committee Reference Document 2006/04.

18 Fuller, S. and P. Cameron, 1998. Marine Benthic Seascapes: Fishermen's Perspectives. Marine Issues Committee Pulication No. 2, Ecology Action Centre: p. 69p.

19 Caddy, J.F., 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J Fish Res Board Can, 30: p. 173–180.

20 Fader, G. and S. Pecore, 1988. Surficial geology of the Abegwait Passage area of the Northumberland Strait, Gulf of St. Lawrence. Alantic Geoscience Centre, Open File No. 2087.

21 Kenchington, E.L., T.J. Kenchington, L.-A. Henry, S. Fuller, and P. Gonzalez, 2007. Multi-decadal changes in the megabenthos of the Bay of Fundy: The effects of fishing. J Sea Res, 58: p. 220-240.

22 Gilkinson, K., E. Dawe, B. Forward, B. Hickey, D. Kulka, and S. Walsh, 2006. A review of Newfoundland and Labrador Region research on the effects of mobile fishing gear on benthic habitat and communities. DFO CSAS Research Document 2006/055.

23 Gilkinson, K.D., D.C. Gordon Jr., K. MacIsaac, D. McKeown, E.L.R. Kenchington, C. Bourbonnais, and P. Vass, 2005. Immediate impacts and recovery trajectories of macrofaunal communities following hydraulic clam dredging on Banquereau, eastern Canada. ICES Journal of Marine Science, 62: p. 925-947.

24 Von Brandt, A. 1984. Fish catching methods of the world. Third Edition ed, Surrey: Fishing News Books.

25 Chiappone, M., D.W. Swanson, and S.L. Miller, 2005. Spatial distribution and benthic impacts from hook-and-line fishing gear in the Florida Keys National Marine Sanctuary in Benthic habitats and the effects of fishing, proceedings of the American Fisheries Society Symposium 41, Tampa Florida 2002, P.W. Barnes and J.P. Thomas, Editors, American Fisheries Society: 592: Bethesda MD,.

26 Reddin, D.G., R. Johnson, and P. Downton, 2002. A study of by-catches in herring bait nets in Newfoundland, 2001. DFO CSAS Research Document 2002/031.

27 Cairns, D.K., D.M. Keen, P.-Y. Daoust, D.J. Gillis, and M.O. Hammill, 2000. Conflicts between seals and fishing gear on Prince Edward Island. Can Tech Rep Fish Aquat Sci, 2333.

28 Hall, A., G. Ellis, and A. Trites, 2002. Harbour porpoise interactions with the 2001 selective salmon fisheries in southern British Columbia and license holder reported small cetacean by-catch. Selective Salmon Fisheries Science Program Report. Fisheries and Oceans Canada.

29 NRC. 2002. Effects of trawling and dredging on seafloor habitat. Washington, DC: National Academies Press, National Research Council.

30 Fitzgerald, G., 2000. The decline of the Cape Breton swordfish fishery: an exploration of the past and recommendations for the future of the Nova Scotia fishery. Marine Issues Committee Special Publication No. 6, Ecology Action Centre.

31 Campana, S., L. Marks, W. Joyce, and N. Kohler, 2004. Influence of recreational and commercial fishing on the blue shark (*Prionace glauca*) population in Atlantic Canadian waters. DFO CSAS Research Document 2004/069. 67 pp.

32 Choi, J. and B. Zisserson, 2007. An assessment of the snow crab resident on the Scotian Shelf in 2006. . DFO CSAS Research Document 2007/017.

33 DFO, 2007. Recovery potential assessment for cusk (*Brosme brosme*). DFO CSAS Science Advisory Report 2007/xxx. In press.

34 Stephenson, R., M.J. Power, K.J. Clark, G.D. Melvin, F.J. Fife, S.D. Paul, L.E. Harris, and S. Boates, 1999. 1999 Evaluation of 4VWX Herring. DFO CSAS Research Document 99/64.

35 Lesage, V., J. Keays, S. Turgeon, and S. Hurtubise, 2003. Incidental mortality of harbour porpoises of the estuary and Gulf of St. Lawrence in 2000-2002. DFO CSAS Research Document 2003/069.

36 Chuenpagdee, R., L.E. Morgan, S.M. Maxwell, E.A. Norse, and D. Pauly, 2003. Assessing collateral impacts of fishing methods in US waters. Front Ecol Environ, 1(10): p. 517–524.

37 BCME, 2007. British Columbia's Fisheries and Aquaculture Sector, 2007 Edition. British Columbia Ministry of Environment.

38 Ecotrust Canada, 2004. Catch-22: conservation, communities, and the privatization of B.C. fisheries. Ecotrust Canada and Ecotrust. Available from: http://www.ecotrustcan.org/catch-22.shtml.

39 DFO, 2008. Pacific Region Integrated Fisheries Management Plan - Groundfish. March 8, 2008 to March 31, 2009. Fisheries and Oceans Canada.

40 Schweigert, J. and V. Haist, 2007. Population assessment for British Columbia herring in 2006 and forecasts of the potential catch in 2007 DFO CSAS Research Document 2007/002.

41 DFO, 2008. DFO Statistical Services. [cited March 2008]; Available from: http://www.dfo-mpo.gc.ca/communic/Statistics/main_e.htm.

42 Gardner Pinfold, 2005. Economic value of the Nova Scotia ocean sector. prepared for Nova Scotia Office of Economic Development.

43 Newfoundland and Labrador. 2008. 2007 Seafood industry year in review. Department of Fisheries and Aquaculture, Newfoundland and Labrador.

44 Breeze, H. and D.G. Fenton, 2007. Designing management measures to protect cold-water corals off Nova Scotia, Canada. Bull Mar Sci, 81 (11, Suppl. 1): p. 123-133.

45 Rice, J., 2006. Impacts of mobile bottom gears on seafloor habitats, species, and communities: a review and synthesis of selected international reviews. DFO CSAS Research Document 2006/057.

46 Anderson, S. 2006. How sustainable are emerging low-trophic level fisheries on the Scotian Shelf? in BSc Honors Thesis, Biology Department, Dalhousie University: Halifax, NS.

47 Therkildsen, N.O. and C.W. Petersen, 2006. A review of the emerging fishery for the sea cucumber *Cucumaria frondosa*: Biology, policy, and future prospects. Secretariat of the Pacific Community Beche-de-mer Information Bulletin #23. Available from: http://www.spc.int/Coastfish/News/bdm/bdm.htm, (#23).

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

49 DSF, 2007. Dragging our assets: toward an ecosystem approach to bottom trawling in Canada. David Suzuki Foundation. Available from: http://www.davidsuzuki.org/files/reports/DSF_DraggingAssets.pdf.

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

51 Morgan, L.E. and R. Chuenpagdee, 2003. Shifting gears: addressing the collateral impacts of fishing methods in U.S. waters. Pew Science Series.

52 Orr., D.C, P.J. Veith and D.J. Sullivan 2004. An update of information pertaining to Northern Shrimp (*Pandalus borealis* Kroyer) and Groundfish in NAFO Divisions 3LNO. NAFO SCR Doc. 04/86.

LEFT: Cold water corals and associated species off Canada's east coast. PHOTO: DFO.

Ecology Action Centre

Ecology Action Centre
2705 Fern Lane
Halifax, Nova Scotia Canada V3K 4L3

t 902-429-2202
f 902-405-3716

www.ecologyaction.ca

Living Oceans Society

Healthy Oceans. Healthy Communities.

Living Oceans Society
135 First Avenue, Box 320
Sointula, BC Canada V0N 3E0

t 604-696-5044
f 604-696-5045

www.livingoceans.org

MCBI
MARINE CONSERVATION BIOLOGY INSTITUTE

Marine Conservation Biology Institute
2122 112th Ave NE, Suite B-300
Bellevue, WA 98004
USA

t 425-274-1180
f 425-274-1183

www.mcbi.org