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Impacts of Fishing Gears other than Bottom Trawls, Dredges, Gillnets and Longlines on Aquatic Biodiversity and Vulnerable Marine Ecosystems

Impacts des engins de pêche autres que les chaluts de fond, les dragues, les filets maillants et les palangres sur la biodiversité aquatique et les écosystèmes marins vulnérables

Donaldson, A., Gabriel, C., Harvey, B.J., and Carolsfeld, J.
World Fisheries Trust, Inc.
434 Russell Road
Victoria, British Columbia, Canada

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ABSTRACT

This report summarizes the literature on the impacts of 16 different fishing gear types on biodiversity and marine ecosystems. These include pots and traps, beach seine, mid-water trawl, purse, Danish and Scottish seine, trap net, weir, troll, hand picking, diving, harpoon, hook and line, cast net, and fish wheel.

The impacts described range from the straightforward (e.g. bycatch and habitat damage) to subtle (e.g. promotion of new, learned behaviours in marine mammals). The main impacts include habitat damage by crushing or entanglement by pots and traps, entanglement by the same gear of mammalian bycatch, bycatch in non-selective seine gear, and localized habitat impacts of dive and hand-picking fisheries.

Potential impacts on Vulnerable Marine Ecosystems (VME) are damage of coral or sponge by pots and traps. Danish and Scottish seines and mid-water trawls can also have significant active effects on benthic habitats as they, or parts of the gear, contacts the bottom. These effects are localized and less than that caused by active bottom gear, but could be significant if applied to patchy VME and sensitive habitats. Hand-digging and dive fisheries can also affect sensitive habitats, but these effects are generally also quite localized.

Effects on biodiversity includes cetacean, shark, and other fish bycatch in nets, cetacean entanglement in more selective pots and traps, seal and fish bycatch in traps (including endangered fish species), and turtles on hand line gear. Mid-water trawls, while quite selective through their targeted deployment, also have a significant cumulative bycatch volume. Ghost fishing by abandoned or lost gear is often quoted as a concern, particularly for pot and trap fisheries.

The range of mitigation measures being reported is broad. Gear modifications are the most common, but operational mitigation through limits on the kinds of technologies and manners of their use, temporal and spatial closures, special techniques and strategies to permit live release of bycatch, and optimized strategies to retrieve lost gear and/or render it ineffective are also key strategies. Collaborative development and implementation of mitigating strategies with the fishing fleets has been shown to be a key element to successfully addressing these questions.

RÉSUMÉ

Le présent rapport se veut un résumé des publications scientifiques portant sur les impacts de seize types d'engins de pêche sur la biodiversité et les écosystèmes marins, notamment les casiers et les trappes, les sennes de plage, les chaluts pélagiques, les poches, les sennes danoises et écossaises, les trappes en filet, les fascines, les cuillers, la récolte à la main, la plongée, les harpons, les hameçons et les lignes, les éperviers et les tourniquets.

Les impacts décrits vont des effets directs (p. ex., prises fortuites et dommages à l'habitat) aux plus subtiles (p. ex., promotion de nouveaux comportements appris chez les mammifères marins). Parmi les principaux effets, mentionnons : les dommages causés à l'habitat par l'écrasement ou l'enchevêtrement des casiers et des trappes; l'enchevêtrement dans ces mêmes engins de prises fortuites de mammifères; les prises fortuites dans les sennes de pêche non sélectives; les répercussions localisées sur l'habitat causées par la pêche en plongée et la récolte à la main.

Les dommages causés aux coraux ou aux éponges par les casiers et les trappes figurent parmi les effets éventuels sur les écosystèmes marins vulnérables (EMV). Les sennes danoises et écossaises et les chaluts pélagiques peuvent également avoir des effets actifs considérables sur les habitats benthiques puisque ces engins, ou des parties de ces engins, sont en contact avec le fond de l'eau. Ces effets sont localisés et moindres que ceux causés par les engins de fond actifs, mais ils pourraient être importants s'ils touchaient des EMV épars et des habitats sensibles. La cueillette à la bêche et la pêche en plongée peuvent également nuire aux habitats sensibles, mais ces effets sont généralement très localisés.

Les effets sur la biodiversité comprennent : les prises accessoires de cétacés, de requins et d'autres poissons dans les filets; l'enchevêtrement de cétacés dans des casiers et des trappes de pêche plus sélective; les prises fortuites de phoques et de poissons dans les trappes (y compris des espèces en péril); les tortues pêchées à la palangrotte. Les chaluts pélagiques, bien qu'ils soient assez sélectifs grâce à leur déploiement ciblé, peuvent aussi représenter un volume de prises accessoires cumulatives important. La pêche fantôme (captures par des engins abandonnés ou perdus) est souvent citée comme étant une source de préoccupation, particulièrement en ce qui a trait à la pêche au casier et à la trappe.

On recense un vaste éventail de mesures d'atténuation. Les modifications apportées aux engins sont les plus répandues, mais les mesures d'atténuation opérationnelles – restrictions visant le genre de technologies et la manière de les utiliser, fermetures temporelles et de zones, techniques et stratégies spéciales pour relâcher les prises accessoires vivantes et stratégies optimisées visant à retrouver les engins perdus ou à les rendre inefficaces – constituent également des stratégies clés. L'élaboration et la mise en œuvre de stratégies d'atténuation avec la collaboration des flottilles de pêche se sont avérées un élément essentiel pour réussir à régler ces enjeux.

INTRODUCTION

Canada has an international obligation to manage its fisheries sustainably and to protect vulnerable marine ecosystems and marine biodiversity, from destructive fishing practices[1]. More specifically, Fisheries and Oceans Canada (DFO) is preparing to implement an ecosystem approach to fisheries management and other human activities in the aquatic environment that will assist in fulfilling these commitments. Therefore, there is a need to assess the effects of Canada's existing and exploratory fishing activities and to develop strategies for mitigating impacts. This report compiles and summarizes the international and domestic literature on the impacts of gear types (other than bottom trawls, gillnets, longlines and dredges) on biodiversity and vulnerable marine ecosystems. This report is intended to inform participants of a related Canadian Science Advisory Secretariat (CSAS) workshop (January 11-14, 2010; Ottawa) and will guide the development of Canadian policies addressing the effects of these gears on marine habitats and aquatic biodiversity.

The present report draws on the scientific literature as well as on unpublished reports and government or agency websites. Few comprehensive reviews exist, although the Ecology Action Centre, Living Oceans Society and Marine Conservation Biology Institute have reviewed the ecological impacts of Canadian fishing gear (Fuller et al. 2008). The conclusions of that review will be referred to in the present report. The ICES Working Group on the Effects of Fishing Activities (WGECO) has also explored the issue in its meetings, with an initial focus on developing systematic approaches to assessment of impacts. In 2007, a WGECO scoping report recommended assessment processes for European fisheries (the OSPAR region; ICES 2007). In 2008, the report dealt with creating a framework within which the efficacy of gear modifications for reducing environmental impact could be measured (ICES 2008a). Finally, in 2009, the report dealt with standardizing the use of terminology in policy formulation on ecosystem impacts and the ecosystem approach to management (ICES 2009). The Ad Hoc Working Group of Fishery Managers and Scientists on Vulnerable Marine Ecosystems (WGFMS) of the North Atlantic Fisheries Organisation (NAFO) also is dealing with the effects of fisheries on VME, with an immediate focus on developing appropriate indicators and their thresholds in identifying VME, initially in the north Atlantic (Canada is taking a significant lead in this endeavour) (NAFO 2008). Where appropriate, the results of these reports are incorporated in the present work.

BIODIVERSITY – A WORKING DEFINITION AND KEY ISSUES

Biodiversity has been defined as “the variability among living organisms from all sources, including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems” (Biodiversity Convention Office, 1995).

The level of aquatic biodiversity can be very high. For example, in the Gulf of Alaska, which includes the coastal shelf of British Columbia, marine macro-biodiversity includes 318 species of fish, 36 species of marine mammals (Sea Around Us, 2009), over 38 species of seabirds (Wahl et al., 1993), and numerous invertebrate and algal species. The area also contains eight seamounts, including the only seamount in Canadian waters (i.e. the Bowie seamount; Stocks, 2009) and recently-discovered glass sponge reefs. As described below in the section titled ‘Vulnerable Marine Ecosystems’, seamounts and sponge reefs possess particularly unique,

[1] United Nations General Assembly (UNGA) Resolution 61/105 and the Northwest Atlantic Fisheries Organization (NAFO)

diverse ecosystems. The Atlantic and Arctic coasts of Canada are equally rich in biodiversity. In addition to this better known megafauna biodiversity, Report A/59/62 to the UNGA estimates that 98% of known marine species live in benthic environments, with many additional ones still unknown.

Biodiversity is a key component in stable ecosystems (Heip et al., 2009). Aquatic organisms, unlike terrestrial ones, are still predominantly hunted and gathered from the wild, with fisheries the last major sector of human food production that relies primarily on wild production. Aquatic ecosystems and their biodiversity can thus be particularly affected by extractive activities.

BYCATCH

The main impact of fisheries on biodiversity, beyond simple removal of the target species, is generally considered to be bycatch, defined by the Food and Agricultural Organization of the United Nations (Appendix II) as “the part of a catch taken incidentally in addition to the target species." Generally, bycatch also includes individuals of the target species that are outside the permitted size range or of the wrong sex.

Bycatch can alter biodiversity by removing predator and prey species at unsustainable levels (Gilman et al., 2008). Bycatch has ecosystem-level effects by changing the abundance of non-target species and may also have effects on target species population dynamics. Bycatch becomes a particularly visible conservation problem when it involves threatened groups (e.g. sharks, albatrosses, sea turtles), even if they are not keystone species in an ecosystem. To protect these species and the biodiversity of aquatic ecosystems, several solutions are being explored by the global fishing industry, involving both gear modifications and other management measures.

Bycatch is either returned to the sea, where the chance of survival may be low (Hall et al., 2000) or landed if it has adequate commercial value. Bycatch has been described as "the most pressing issue facing the commercial fishing industry worldwide”, second only to the sustainability of the target species (Hall and Mainprize, 2005). Bycatch results from using fishing gear or strategies with “imperfect selection properties” (Cook, 2001) and totals millions of tons of unwanted fish and other biomass killed every year. Bycatch becomes a conservation problem when the catch levels are unsustainable or when endangered or threatened species are affected (Hall et al., 2000).

Bycatch levels vary among fisheries both in quantity and species caught (Revill, 2003). Cook (2001) states that over half the world's discards are from fisheries in the Northwest Pacific (including those for crab, shrimp, mackerel, cod, and pollock), as well as the Northeast Atlantic Roundfish and Flatfish fishery, and the West Central Pacific shrimp fishery. Damage can be disproportionate; trawl fisheries for shrimp and demersal finfish are responsible for over 50% of global discards, despite representing only 22% of global landings (Kelleher, 2005).

Bycatch not only unnecessarily removes fish and other biomass from ocean ecosystems; it also has significant collateral impacts on species and ecosystems (Cook, 2001). Overexploitation of undersized or immature individuals through bycatch, for example, can have serious implications for the sustainability of stocks, and the overall body size of individuals in a fished population may also change with intense fishing pressure on a single size (UNGA, 2006). In another example, the removal of one species in a predator-prey relationship is likely to cause a shift in community structure (Hall et al., 2000). Finally, discard of dead bycatch and fish offal can alter community structure by increasing local concentrations of scavengers and predators (UNGA, 2006).

Chuenpagdee et al. (2003) further describe bycatch as “economic bycatch”, “regulatory bycatch” and “collateral mortality,” referring to bycatch that has little value, is not permitted within the license conditions, and is killed by fishing but not brought on board, repsectively. Recent strategies promote the retention of bycatch to improve utilization, reporting, and avoidance. The terms “retained” and “unretained” catch have thus become relevant for bycatch in this context.

Bycatch of charismatic and/or endangered species has at times had an impact on fisheries development that is disproportionate to the apparent ecological significance. This reflects a public concern in aquatic resources and biodiversity beyond that of utilitarian management – now a significant force in fisheries management. *Ghost fishing* is arguably a special kind of bycatch – part of the “collateral mortality” described by Chuenpagdee et al. (2003). The term refers to the continuous, unpredictable and uncontrolled effects of lost or discarded fishing gear. Brown et al. (2005) refer to ghost fishing as causing “the mortality of fish and other species that takes place after all control of fishing gear is lost by a fisherman.” Ghost fishing most often happens with lost passive fishing gear such as gillnets and traps, rather than active gear like trawl nets and dredges. The lost gear continues to catch fishes, crustaceans, birds, marine mammals, and turtles of both commercial and non-commercial value, possibly indefinitely depending on the resistance of the component materials to degradation. In recent decades, concern about ghost fishing has increased because most modern fishing gear is made from synthetic, non-biodegradable materials (Brown and Price, 2005).

VULNERABLE MARINE ECOSYSTEMS (VME)

In the 2003 publication *Environmental Indicators*, habitat loss was identified as “the key threat to biodiversity in Canada” (Environment Canada, 2003). This statement is important to the Canadian and global fishing industry because fishing gear has been shown to have significant detrimental impacts on habitats. Rice (2006) reviewed the impacts of mobile fishing gear on seafloor habitats and concluded that fishing gear can “damage/reduce habitat structure and complexity, reduce/remove major habitat features and alter seafloor structure.” Active gears such as trawls and dredges have the greatest impacts, but passive gear such as demersal gillnets, longlines, and traps can also cause problems, for example through entanglement with branching corals (High, 1998) or abrasion and crushing of benthic fauna (Lewis et al., 2009). Impacts on habitat affect all species that use the damaged structures, which in turn affects the biodiversity of the ecosystem.

Vulnerable Marine Ecosystems (VME) are particularly sensitive to these impacts. The FAO defines VME as “areas that are easily disturbed by human activities, and are slow to recover, or will never recover.” While ecosystems meeting this definition are quite diverse, and specific definition remains adaptive, an updated series of characteristics for deepwater VME, published in 2008 (ICES, 2008b) include:

- uniqueness – including home to endemic species, rare or endangered species;
- critical feeding, spawning, or nursery habitat;
- fragility – high susceptibility to degradation by human activities
- long-life, late maturation, slow growth, low recruitment rate of component species
- low-levels of natural disturbance and/or natural mortality.

The FAO Code of Responsible Fisheries (FAO, 1995) refers to the protection of "vulnerable ecosystems." The term "vulnerable marine ecosystem" was subsequently adopted by the United Nations General Assembly (UNGA, 2006) that mandate their protection, and thus the term became part of signatory countries' legal responsibilities. Examples of VME cited by the UNGA resolution include: warm- and cold-water coral reefs, sponge fields, seep and vent communities, submerged edges and slopes, seamounts, polymetallic nodes, trenches, and canyons. Many of these are deep ocean features, in part reflecting the UN mandate to regulate the use of resources outside of national jurisdictions, but also dealing with areas that have particularly high species diversity (UNGA, 2006) and potentially subject to fishing impacts if fishing fleets move further offshore (Morato et al., 2006; UNGA, 2006). Animals in these deepwater ecosystems tend to be of "high longevity, slow growth, late maturity, and low fecundity" (Rogers, 2004; Morato et al., 2006; FAO, 2008a) and have limited mobility between habitat patches and they have poor recruitment from other sources (UNGA, 2006). This makes them not only vulnerable to exploitation but also slow to recover (decades or centuries). Prudent management should thus be risk-averse and protect enough of these habitats to ensure their continuing structure and ecosystem function.

A term that is similar in definition to VME is "sensitive habitat," also described in the UNGA (2006) resolution, and common in the literature (e.g. Tudelli & Sacchi, 2003), but not of the same international legal status as VME. Sensitive habitats include sea pen fields, burrowing mega-fauna communities, reefs and oyster beds, sea-grass beds, mangroves, and estuaries (UNGA, 2004 and 2006). Sensitive habitats have been described primarily for shallow waters (0 - 50 m), although some at depths of 200 m or more may also be included. These are thus largely under national jurisdiction and subject to impacts from land-based activities, in addition to fisheries (UNGA, 2006). However, according to a recent definition by UNGA (2004), sensitive habitats are also "easily adversely affected by human activity, and/or if affected are expected to only recover over a very long period, or not at all" (i.e. not very different from VME).

"Critical habitat" is another related concept that refers to areas that are essential for the survival of particular species. This is a common term in the endangered species literature, though it is also pertinent to other species. The current definition of potential VME includes such habitats, and capelin spawning grounds have been considered for VME status (NAFO, 2008).

RECONCILIATION OF TERMINOLOGY - ECOLOGICAL IMPACTS

The descriptions and examples of VME are clearly a mixture of physical substrates, biogenic substrates, and highly visible key species and not descriptions of discrete ecosystems. A variety of authors have commented on this. FAO (2008) suggests that most of the VME under discussion, despite their names, are ecotopes (small subsets of larger ecosystems) and warns about managers being misled by labels rather than recognizing the functioning ecosystem under consideration. Similarly, fisheries impacts on ecosystems have commonly been characterized as destruction of habitats, and impacts on biodiversity as bycatch. In reality, destruction of habitat will also have biodiversity impacts and the bycatch of biogenic substrates such as corals has habitat implications. Habitat and bycatch are actually two readily visible effects that are integrated with the effects of removal of the target species to result in holistic "environmental impacts," "ecological impacts", or "ecosystem impacts" (Hall, 2001; Fuller et al., 2008; Rice, 2006). Hall (2001) classifies the "ecosystem impacts" of fisheries as either direct or indirect. Direct impacts include:

- mortality of target and bycatch species, either through retained catch, collateral direct mortality (e.g. discards of undersize or unwanted catch), or making individuals more vulnerable to scavengers or predators,
- increasing the food available to other species by discarding unwanted catch; or
- disturbing and/or destroying habitats with the fishing gear.

Indirect impacts include changes in the abundance of predators, prey, and competitors of the target species resulting from reduced abundances of the target species and/or the provision of food in the form of discarded bycatch.

Fuller et al. (2008) likewise divide ecological impacts of fisheries into habitat and bycatch categories. While neither adequately describes the interplay of impacts on biogenic habitats such as coral reefs this reflects the structure of the literature and reports, and will be followed in this report as well.

The impacts of fishing gears on biodiversity outlined in the examples below can be through excessive direct or indirect removal of individuals of a species, even before they are reflected in reduced species richness. For example, the collapse of groundfish stocks in Atlantic Canada may have resulted from a combination of an intense, long-term commercial fishery and climatic conditions, manifested as a progressive decline in the energy flow through the benthic system, and a related decoupling of benthic and pelagic ecosystems (Choi et al., 2004). Substantial changes in biodiversity have no doubt accompanied and/or contributed to this process, but are not necessarily reflected in measures of species richness alone. In the groundfish case, population-level changes in morphological and physiological characteristics of target species and shifts in species abundance were documented (Choi et al., 2004).

STRUCTURE OF REPORT

This report describes the selected aforementioned fishing gears, summarizes evidence of the ecological impacts, and describes the Canadian context. Descriptions of these impacts are not always overtly expressed - in some case dispersed in reports of fisheries outputs and so at times need to be inferred. Depending on the fishery, the manner of applying the gear and/or the target species are important, and are dealt with separately. Specific reference to VME is very rare, as is reference to ecosystem impact characteristics outlined by the WGECO (ICES, 2007). These are extrapolated in a tabular form in the discussion.

DESCRIPTION OF GEAR TYPES

POT AND TRAPS

A pot (also called a trap or barrel in some regions or applications) is a cage-like structure designed to catch crustaceans or fish. Shape and material (e.g. wood, wicker, metal rod, wire netting, etc.) reflect the target species, but the design and use of any pot (i.e. mesh size, escape devices, bait) affect both target and non-target individuals. Eel pots used in the Canadian Maritimes are often homemade, of variable design, and commonly constructed from wood lath or wire mesh (DFO, 2006a).

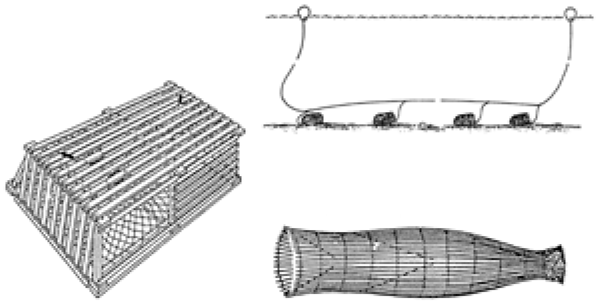


Figure 1. Examples of Pots (Source: http://www.fao.org/fishery/geartype/225/en).

Pots are usually set on the bottom at a wide range of depths, down to several hundred metres. They may contain bait, and can be laid singly or in rows on lines connected to surface buoys that show their position (FAO, 2008b). In Canada, numerous large fisheries are conducted with pots, but their ecosystem impacts are not fully understood (Troffe et al., 2005; Fuller et al., 2008). Pot fisheries include lobster, crab, whelk, spot prawn and Sablefish; in some cases, the "pots" used for the species are more commonly called "traps". Pots can cause habitat effects on benthic organisms, generally by dragging, and their surface lines can entangle marine mammals.

MID-WATER TRAWL

A mid-water trawl is similar to a bottom trawl, but does not have rollers on the footrope. Rectangular doors and a larger mesh in the mouth act to herd schools of fish toward the aft part of the net (FAO, 2008b; Fuller et al., 2008). The mid-water trawl is used not only in the mid-water region (where it can also be referred to as a pelagic trawl), but also in surface water and close to the bottom; it may even contact the sea floor. This occasional contact with the sea floor can damage fragile ecosystems such as those containing corals and sponges, however, the problem has been little studied (Morgan and Chuenpagdee, 2003; Zbicz and Short, 2007). The mid-water trawl is used mainly to catch pelagic and bentho-pelagic schooling species such as hake, Pollock, Herring, and Atlantic Mackerel (Morgan and Chuenpagdee, 2003; FAO, 2008b). In Canada, the mid-water trawl is most widely used in the Pacific hake fishery, which is conducted almost exclusively with this gear (Fuller et al., 2008; Hamel and Stewart, 2009).

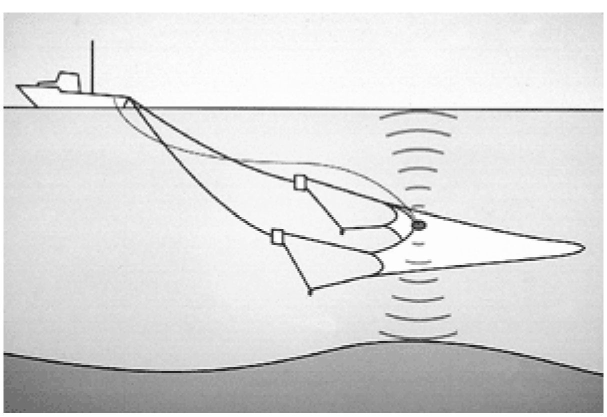
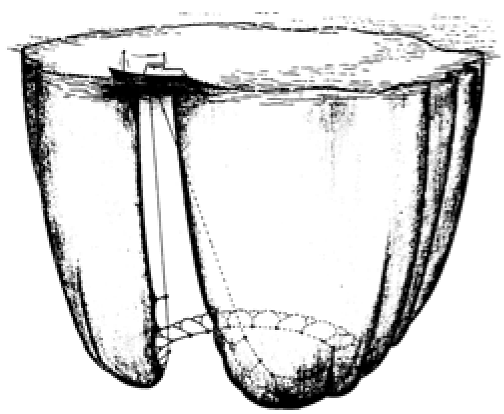


Figure 2. Pelagic Trawl (Source: www.fao.org/fishery/geartype/207/en).

SEINE

A seine is an active fishing system that traps fish by encircling or enclosing them in a net (Hayes, 1983). There are several different types of seine that target different fish and their varying habits.

A *purse seine* is a wall of netting framed with a floatline (above) and a leadline (below); a wire or rope purseline runs through purse rings hanging from the lower edge of the gear. The purseline allows the closing (pursing) of the net, usually accomplished mechanically by a power block or net drum. The purse seine is often the most efficient gear for catching large and small shoaling pelagic species, for example tuna or herring (FAO 2008b). On the Atlantic coast of Canada, it is used for mackerel, herring, and capelin.



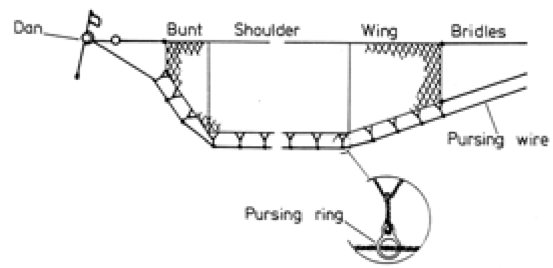


Figure 3. Purse Seine (Source: www.fao.org/fishery/geartype/249/en).

A *Danish* or *Scottish seine* consists of a conical body, two relatively long wings and a bag. An important component in its capture efficiency is the long ropes extending from the wings, which are used to encircle a large area. In Danish seining, the vessel remains in a fixed position while the gear is hauled along the bottom. Keeping the rope in contact with the bottom as long as possible during hauling confers a major advantage and special, heavy ropes are used. The action of the ropes on the ocean bottom stirs up a mud cloud and herds fish into the path of the net. Many such nets are very similar to trawl nets, but the wings of the latter are shorter (FAO, 2005). This fishing method, also known as "anchor seining", is the original seine netting technique from which "fly dragging" or Scottish seining was developed.

In Scottish seining, the net and ropes are towed along the ocean floor while they are closing. Scottish seining uses long lengths (up to 3 km) of seine rope to herd fish into the path of the net as the gear is hauled.

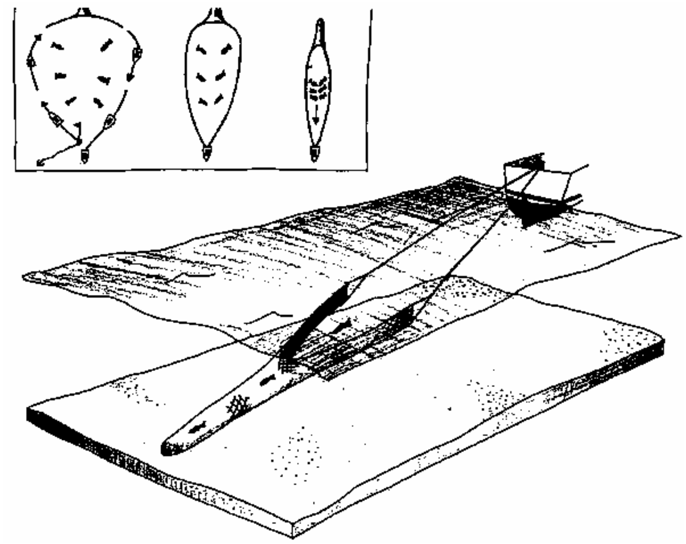


Figure 4. Scottish Seine (Source: http://www.fao.org/docrep/005/Y3427E/y3427e0a.gif).

A *beach seine* is operated from shore. The gear is composed of a bunt (loose netting) and long wings that are often lengthened with ropes for towing the seine to the beach. The float-equipped head-rope stays on the surface, while the foot-rope remains in contact with the bottom; the seine is therefore a barrier which prevents fish from escaping from the enclosed area. Beach seines are usually set from a boat with one towing line fastened to shore: the net and other towing lines are set out in a wide arc and brought back to the beach (FAO, 2008b). Since shallow waters close to the shore are often spawning or nursery grounds for many fish species, beach seining can disturb breeding and leads frequently to the capture of juveniles. For these reasons, the use of beach seines is regulated by law in a number of countries (FAO 2008b).

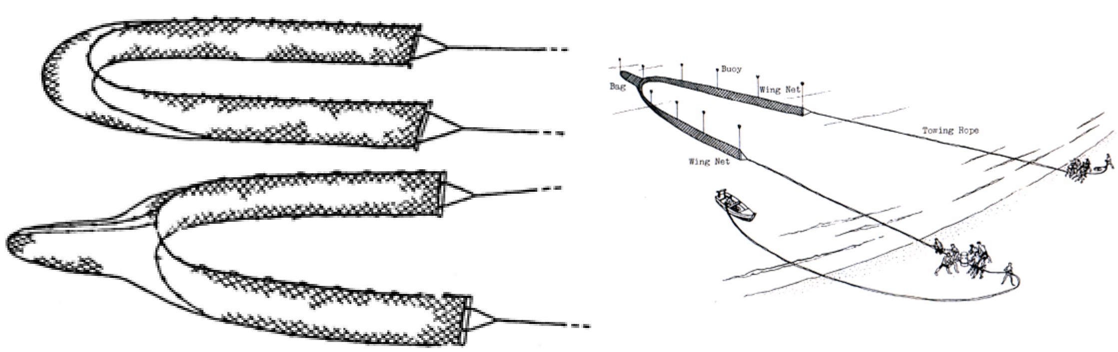


Figure 5. Beach Seine (Source: http://www.fao.org/fishery/geartype/202/en).

TRAP NET

A *trap net* is a large, stationary net that fish enter voluntarily but are unable to escape. Large guiding panels, made from netting, lead the fish into the catching chamber (FAO, 2008b). Variants include box, bag, fyke and square nets, Newfoundland cod trap, and Japanese cod trap. The entrance itself is a non-return device. Trap nets are most commonly used in tidal ponds, rivers, bays and estuaries.

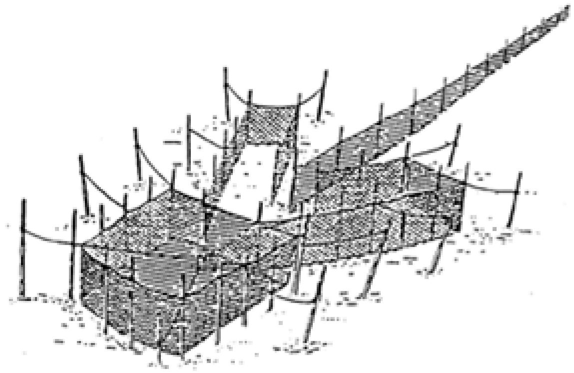


Figure 6. Trap Net (Source: http://www.fao.org/fishery/geartype/246/en).

Trap nets have historically been used in the Canadian smelt fishery. The most common trap net on the Atlantic coast is the Newfoundland cod trap, variations of which are used for herring, capelin and squid (Brothers, 2000; Brothers, 2002). The latter use small mesh and sometimes catch juvenile fish such as cod or protected species such as Atlantic Salmon. Trap nets have been known to catch marine mammals such as Harbour porpoise (Alverson et al., 1994).

Cod traps resemble open-topped box nets, measuring 11-22 m around the perimeter with a vertical opening on one side (Armour et al., 1991). The *Newfoundland cod trap* has four walls and a floor, all constructed of netting. Fish enter the trap through a doorway in the front wall. Extending outward from the centre of the doorway is a long leader of netting. The trap is kept upright in the water by floats along the top of the walls and lead weights at the bottom. The top of the trap might be at the surface or as much as 10 m below the surface. It is held in place by a system of corner ropes anchored to the sea bottom. The leader, likewise buoyed and weighted, is tied to the trap at one end and made fast to the shore, or to shoal-water rocks near the shore. When cod encounter the leader, they instinctively shift direction and swim through the open doors into the trap. Once inside, they tend to swim in circles to avoid the leader, and so fail to locate the doors. Traditional cod traps varied in size to reflect water depth, sea bottom, tide and wind. Mesh size varies from about eight inches (20.3 cm) in the leader and front wall, to 3 inches (7.6 cm) at the back (the smaller mesh at the back keeps the tightly enclosed fish from escaping through the net during hauling) (Armour et al., 1991).

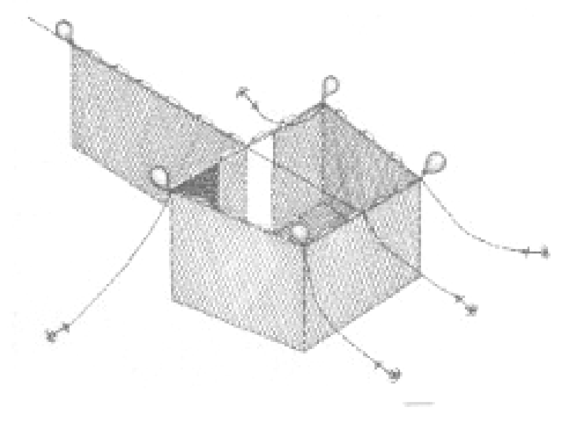


Figure 7. Traditional Newfoundland Cod Trap.

The *Japanese cod trap*, developed after consultation with Japanese fishing experts in the mid-1960s, was based on the Newfoundland cod trap but adds a roof that allows the trap to be set in much deeper water. Replacing the simple opening in the front wall is a funnel-shaped portion that reduces escape of trapped fish, and there is an additional room with outward-angled walls and a half-funnel type of door at the front of the main trap (Armour et al., 1991).

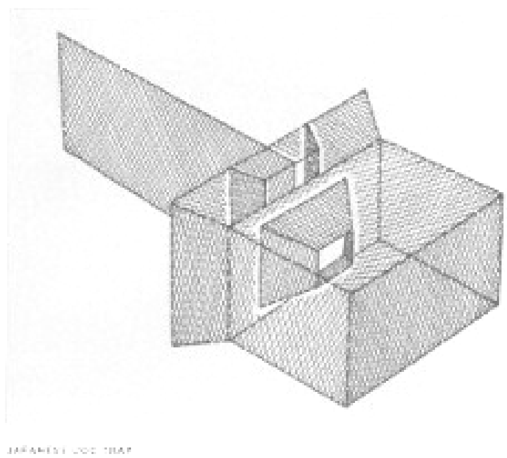


Figure 8. Japanese Cod Trap.

To reduce the cost of the more effective but also more expensive Japanese trap, a *modified Newfoundland cod trap* was developed, and combines aspects of the Japanese and Newfoundland traps by simply adding the half-funnel doorway from the front room of the Japanese trap to the traditional trap (Armour et al., 1991).

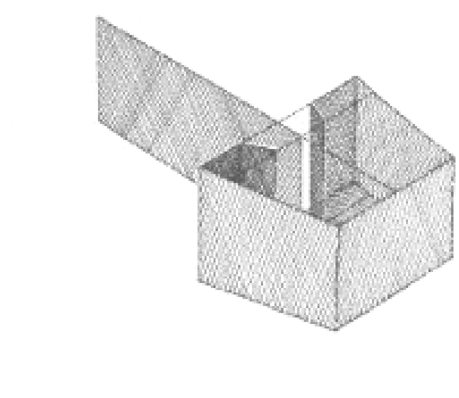


Figure 9. Modified Newfoundland Cod Trap.

A *box net* has a box-shaped trap and is usually set perpendicular to the shoreline, across the current, so that fish encountering the leader will follow it into the trap. Once inside, fish swim in circles to avoid the leader and fail to locate the open doors (DFO, 2006b). Box nets with one leader are used to fish a single tide, but double box nets consisting of adjacent boxes fitted with two leaders allow two tides to be fished (DFO, 2007a).

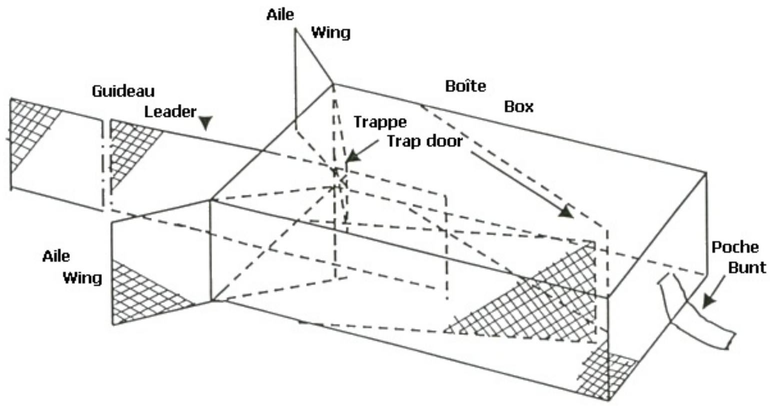


Figure 10. Box Net (Source: www.glf.dfo-mpo.gc.ca/fam-gpa/plans/nb/smelt-eperlan_2007_2011-e.pdf).

A *square net* also has a box-shaped trap, but has two leaders instead of one, and has differently configured trap doors. The net is set directly in the channel; the two leaders allow for a large opening and the trap door configuration prevents escapes (DFO, 2007a).

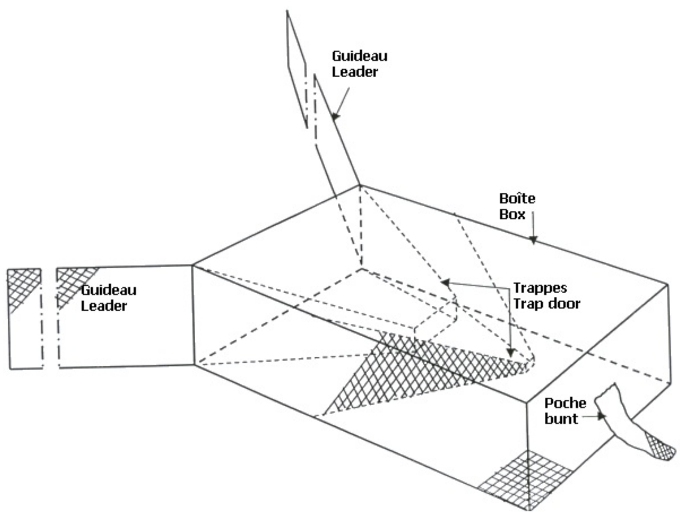


Figure 11. Square Net (Source: www.glf.dfo-mpo.gc.ca/fam-gpa/plans/nb/smelt-eperlan_2007_2011-e.pdf).

A *bag net* has a large opening and tapers to a close. It is most commonly deployed in tidal areas with the large "mouth" facing the current. Wing tips on the opening are attached to poles driven into the bottom of an estuary or bay. The deployment allows the net to catch fish as they move with the current both with the flood and ebb tide. Fish enter the large opening and continue through the smaller opening of the internal trap, and finally arrive at the "bunt," or tapered end of the bag net. At slack tide, the fisherman hauls up the foot line to shut off the mouth of the net, shakes the fish back towards the bunt, and hauls it out of the water (DFO, 2008a).

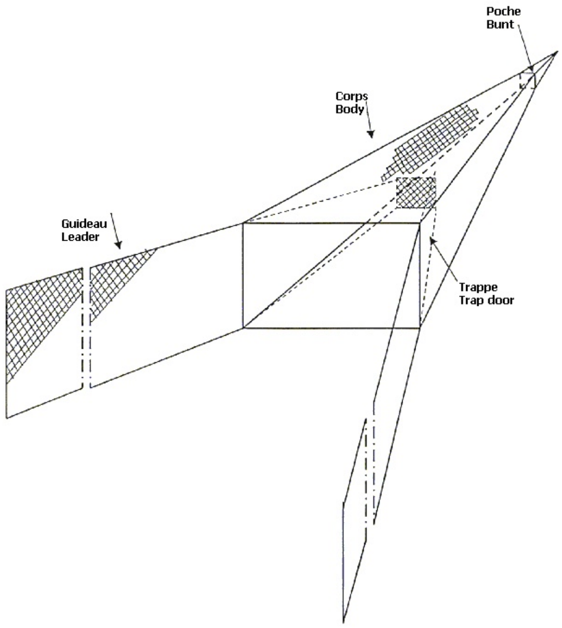


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Figure 12. Bag Net (Source: www.glf.dfo-mpo.gc.ca/fam-gpa/plans/nb/smelt-eperlan_2007_2011-e.pdf).

A *fyke net* is a cylindrical or cone-shaped bag slid over hoops or other rigid structures; net wings or leaders guide the fish toward the opening. Fyke nets are normally used in shallow water and are fixed to the bottom by anchors, ballast or stakes (FAO, 2008b); they are often used to catch Freshwater Eel *(Anguilla rostrata)* in Canadian waters.

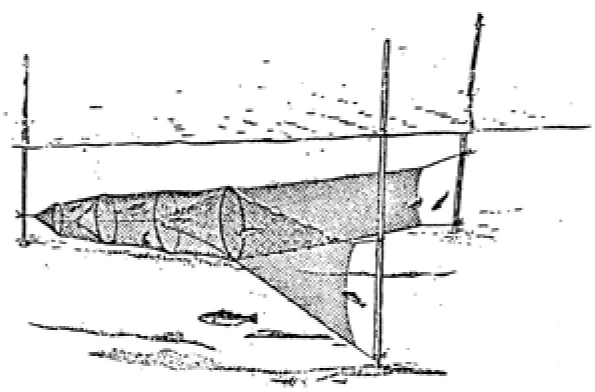


Figure 13. Fyke Net (Source: www.fao.org/fishery/geartype/226/en).

WEIR

A weir is a permanent or semi-permanent structure made of various materials (stakes, branches, reeds, etc.) and usually installed in tidal waters so as to intercept fish and guide them toward some kind of enclosure. A weir may thus be a barrier, fence or corral, and commonly ends in a narrow slit leading to an enclosed chamber that takes advantage of fish behaviour to prevent escape (FAO, 2008b).

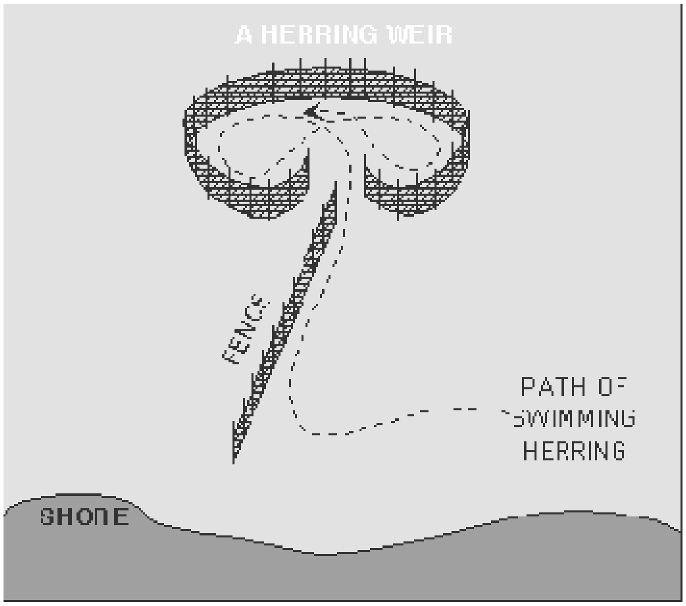


Figure 14. Herring Weir (Source: www.quoddyloop.com/weirillustration.htm).

In Canada, weirs are often used in the Bay of Fundy for herring (Gough, 2007). A herring weir is heart- or kidney-shaped and concentrates fish as they move along a shoreline at night. It is built from stakes driven into the bottom of an estuary or bay and enclosed with twine net. Herring first encounter a leader net running perpendicular to the shoreline and alter course to swim along the weir, whose curved shape directs fish away from the exit. A net can be raised over the exit to keep the fish inside until they can be removed. Captured herring are seined from inside the weir (GMWSRS, 2004).

TROLL

Troll gear consists of a fishing line with either a single hook/lure or numerous hooks/lures, trailed by a vessel at varying depths. Several lures or baited lines are often towed at the same time, using outriggers to keep the lines separated. Towing speed depends on the target species, and the lines are hauled by hand or with small winches (FAO, 2008b). Troll gear is well suited to pelagic fish close to the surface, especially valuable species where high quality is necessary (e.g. salmon or tuna). Troll gear is simple, requiring relatively little investment and less manpower than many other gears (FAO, 2003a).

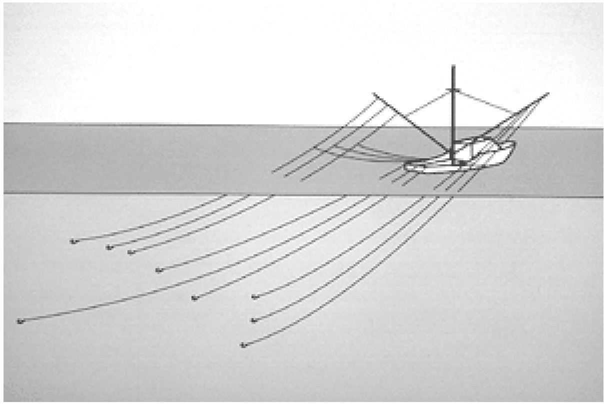


Figure 15. Trolling Lines (Source: www.fao.org/fishery/geartype/235/en).

HOOK AND LINE / HAND LINE / ROD AND REEL / JIG

Hook and line is a general term encompassing many types of gear (including longlines, which are not covered in this paper). *Hand lines* are single lines with one or more lures or baited hooks; they may be used with or without a pole or rod. For fishing in deep waters the lines are usually deployed and retrieved using reels. Hand lines are generally used on medium-sized vessels, but may also be used on small boats. They can be powered using reels or drums, and pole-lines can also be mechanized, e.g., for catching tuna, where the pole movement is entirely automatic (FAO, 2008b). Variations of hand lines represent the principal sport fishing gear.

A *jig* is a lure attached to a vertical line that is raised and lowered (jigged) by hand or mechanically to mimic prey movement. Jigging is a very efficient way to catch oceanic squid at night, when used in conjunction with powerful lights (FAO, 2001).

DIVING

Diving with the aid of SCUBA gear (i.e. self-contained underwater breathing apparatus) or surface-supplied air affords the freedom to remain underwater for long periods of time; other forms of diving include free diving and snorkelling. Diving gear may include swim fins to aid propulsion or use of an underwater vehicle or sled. Depending on the species being fished, various additional implements may be used, including spears, nets, sacs, and hand-held, manually operated high pressure water nozzles. In Canada, commercial dive fisheries include those targeting sea urchins, sea cucumbers, octopus, geoducks (large clams), scallops, and (illegally) abalone; sport diving fisheries are conducted primarily for spear-fishing, collection of crabs, scallops, lobster, and miscellaneous other species.

FISH WHEEL

Fish wheels consist of a set of baskets attached on a central axle that is suspended in the water on pontoons. The force of the current turns the wheel, with the baskets scooping up passing fish. In the most common application, migrating salmon are targeted as they travel upstream to their spawning grounds. As the migrating fish tend to travel close to shore, a fish-wheel can be appropriately placed to fish very efficiently. As the wheel rotates and the baskets reach the vertical, the trapped fish fall onto a slider, which directs them into holding tanks on the pontoons or a holding pen in the river. Fish are then usually removed by hand using dip nets, and either kept or returned directly to the river if they are not of the desired size or species (Link et al.

1996). Fish wheels are currently used in Canada in First Nations salmonid fisheries and monitoring programs on the Skeena, Fraser, and Yukon rivers.

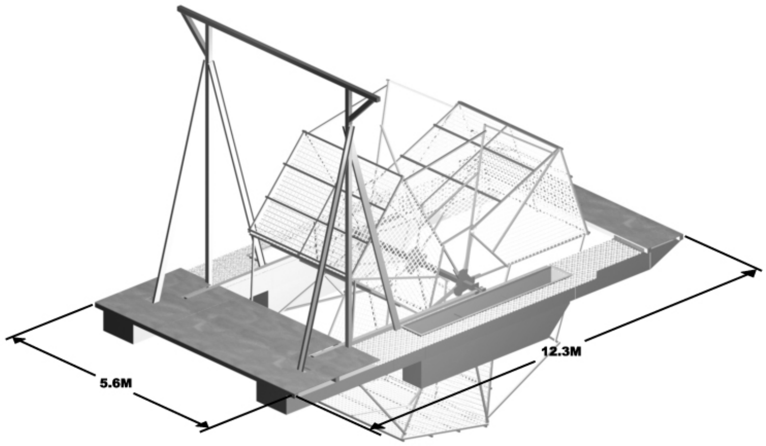


Figure 16. Fish Wheel (Source: http://fund.psc.org/2004/Reports/FRP_9_Whitehouse.pdf).

CAST NET

Cast netting, sometimes called throw netting, is done manually with conical weighted nets typically ranging from 1.2 to 3.6 metres in diameter. When thrown, the net opens to its full diameter, but as it sinks in the water it gradually closes at the bottom, enclosing any fish encountered. Cast netting generally takes place in shallow marine and fresh waters. It is the mainstay of artisanal fisheries in many developing countries, and is used to some extent for capturing bait for sport fishing in the United States and Canada.

HAND DIGGING / PICKING

Hoes, rakes and shovels are used in the intertidal zone to collect a variety of species including clams, cockles, oysters, lugworms, and algae. In some commercial operations, more sophisticated machinery may be used to harvest benthic invertebrates with small dredges or rakes in submerged areas or motorized mechanical harvesters in the intertidal.

SPEAR-FISHING/ HARPOON

The fishing spear may be the oldest fishing gear, dating back to prehistoric times. Spears range from pointed hardwood sticks to more complicated, many-pronged metal ones. FAO considers this gear to have no importance in commercial fishing. In Canada, it is used to some extent in Aboriginal fisheries and by recreational divers.

Harpoons are used for killing, wounding, or grappling fish, whales, and other marine mammals. The simplest harpoon is a wood pole with a steel point having one or more fixed or movable barbs. Harpoons are used in deeper waters than are spears, and differ from spears in that the point becomes separated from the shaft when it penetrates the target. The shaft floats to the surface but remains tethered to the point. Modern harpoons are fired by guns and may be attached to the vessel via a retrieving line. Harpoons used for whaling can be electrified or equipped with grenades. FAO also considers commercial fishing activities with harpoons to be of minor importance (FAO, 2008b). In Canada, harpoons are used commercially to harvest swordfish off the coast of Nova Scotia.

GEAR IMPACTS, MITIGATION AND CANADIAN EXPERIENCE

POTS

Impacts on biodiversity and ecosystems

There are few bycatch data for pot and trap fisheries, although it has been noted that bycatch can vary widely, depending on the target species and trap size, and often includes undersized individuals of the target species (Fuller et al., 2008). However, the catch is often alive and uninjured, allowing the survival of released bycatch organisms. Tagging studies indicate that lobster captured as bycatch but released from a trap fishery is very high (Tremblay and Eagles, 1997; Comeau et al., 1998), though survival of other released crustacean species may be lower (Stoner et al., 2008). Survival may be reduced by handling and decompression or thermal shock (Suuronen, 2005). Traps and pots can also be designed and used to increase selectivity and escape of non-target species or sizes significantly (Miller, 1996; Stevens, 1996, Winger and Walsh, 2007).

Pot fisheries for crustaceans and finfish are generally considered to have moderate ecosystem impacts. A damage schedule approach, drawing on the expert opinion of stakeholders, ranked the ecosystem damage caused by traps and pots as 38/100 for U.S. fisheries (Chuenpagdee et al., 2003) and 44/100 for Canadian fisheries (Fuller et al., 2008). These ratings represent a normalized scaling of responses, with 100 corresponding to “most severe damage”, and 0 corresponding to “no damage”. This result suggests that this gear is perceived to cause less damage than bottom trawling, gillnetting and dredging but more than hook and line and purse seining.

Bycatch discard, of target and non-target species, ranges from 3.51 kg/kg landed catch (e.g. Bering Sea Sablefish) to 0.36 kg/kg landed catch (e.g. East-Central Pacific Spiny Lobster) (Table 9a in FAO, 1994). Cook (2001) extrapolates these data to suggest that overall bycatch rates for pot fisheries are below bottom trawls but above seines, longlines, and pelagic trawls. Fish that escape traps appear to have a high survival rate, especially when compared to fish escaping from trawls (Kelleher, 2005).

Saila et al. (2002) suggest that bait used in the lobster fishery of the Gulf of Maine is a very substantial input of food to the benthic ecosystem as well, potentially contributing to the direct maintenance of ¼ to 1/3 of the lobster stocks in the fished area. Grabowski et al. (2009) indicate that about 70% of the local herring catch is sold as bait to the lobster fishery, and Harnish and Williston (2008) calculate that almost twice as much bait biomass is put into the ecosystem that is retrieved in effective lobster biomass. Grabowski et al. (2009) also cite results on nitrogen isotopic studies that indicate that lobster biomass is being subsidized significantly by pelagic oceanic production, consistent with input from the herring bait. However, these same authors also show that, based on comparisons of lobster growth in unfished regions, direct facultative maintenance of lobster stocks is unlikely other than in food-limited situations. Nevertheless, inputs from bait of pot and trap fisheries is likely an important impact on ecosystems wherever these fisheries are being prosecuted, the level of significance varying between individual situations.

A main concern associated with pots and traps is ghost-fishing (Brown et al., 2005; Matsouka et al., 2005; ICES, 2008a). The most common cause for losing gear is interaction with other fishery or aquaculture sectors (Brown et al., 2005, Matsouka et al., 1997). Matsouka et al. (1997) estimated a total of 639 lost traps, with 274 still actively fishing, from a small inshore pot fishery in Japan. The number of lost pots was ten times the number of pots actively fished in a day by local fishermen. Based on long-term observations, traps in shallow waters were sometimes able to maintain their capture function for more than three years (T. Matsouka & T. Nakashima, unpubl. data, 2002), but capture ability decreases with time due to breakage and fouling (Matsouka et al., 2005). In comparison, a recent study of lobster trap loss close to a shipping port in the Bay of Fundy (Fundy Engineering and Fundy North Fishermen's Association, 2009) indicated considerably lower levels of trap loss, despite the extra impact of loss through shipping traffic. The study estimated derelict trap densities on the order of 60/km^2, in an area where active fishing involves 100-200 traps/km^2. Average annual loss of traps per fisherman is less than 10% (M.J. Tremblay, pers. comm.). The study indicated that the derelict traps were up to 15 years old, with approximately 30% still fishing – primarily traps of less than three years of dereliction.

Deep water traps may continue ghost fishing for a longer time, because they are less affected by wave action and biological fouling (Matsouka et al., 2005). Ghost fishing in the Australian fishery for blue swimmer crabs using collapsible trawl mesh pots was found to catch 3-223 blue swimmer crabs/year after the bait had been consumed, while traditional wire pots caught 11-74 crabs/year; most fishermen use the former gear. Mortality due to ghost fishing was estimated to be as high as 111,811 to 670,866 crabs/year (Campbell and Sumpton, 2009); bycatch was also higher in the more modern trap.

Trap fishing is efficient, relatively low cost, and relatively easily practiced even in difficult bottom terrain. As such, it is creating concern about widespread use on coral reefs at intensities that could cause overfishing, biodiversity reduction and ecosystem alteration (Hawkins et al., 2007).

Habitat damage by traps depends on size, weight and trap material, as well as hauling depth and speed, ocean conditions, the number of traps set, and the substrate. Lobster traps move with the wind and can affect coral by scraping, fragmenting, and dislodging sessile fauna; because many traps are deployed and lost each season, such damage needs to be examined to protect coral reefs and fish habitat (Lewis et al., 2009). Benthic damage occurs when traps contact the bottom, and especially when they are dragged along the seafloor. Traps used for fish are larger and heavier than those used for invertebrates, and consequently cause more benthic damage (Fuller et al., 2008). In deep water, pots have only a small impact on the seafloor, but traps can have a greater impact than other lighter gear (e.g. longlines) when dragged over or entangling hard and soft corals (FAO, 2007).

Entanglement in fishing gear also causes injury and mortality to marine mammals and turtles throughout the world. These are largely unobserved fisheries, so our knowledge of such events relies on voluntary reporting (Picco et al., 2008). Johnson et al. (2005) studied the entanglements of 30 humpback whales and 31 right whales in the western North Atlantic, and were able to attribute 89% of them equally to pot and gillnet gear.

Mitigation

The global effects of using a particular kind of fishing gear can be remarkably indirect. In South America, for example, dolphins were killed in order to be used as bait for traps in a major crab fishery. It has been suggested that bait from slaughterhouses and fish plants be used to reduce the dolphin killings (Reeves et al., 2003); this kind of indirect mitigation could apply to many fisheries.

In 2002, the Northwest Straits Initiative (NWSI), in cooperation with the Washington Department of Fish and Wildlife (WDFW) and the Washington Department of Natural Resources (WDNR), started a derelict gillnet and crab trap removal program in Puget Sound, which continues today (June and Antonelis, 2009). This state-wide program includes a “no-fault” derelict fishing gear reporting system for fishers and the general public, survey techniques to find existing derelict gear, a database of known derelict fishing gear, a process for prioritizing derelict fishing gear removal, safe and environmentally effective removal protocols, and a science-based data collection system on the impacts of derelict fishing gear (NRCI 2007). More than 1,707 crab pots and 1,000 derelict nets have been removed since 2002, covering approximately 240 acres of seabed (June and Antonelis, 2009). Data indicate that one year after nets and pots were removed, habitat in Puget Sound was about 90% recovered (June and Antonelis, 2009). In a cost-benefit analysis study (NRCI, 2007) the cost-benefit ratio was positive and similar for the removal of both gear types. Costs of survey and removal of derelict pots/traps totalled $193/pot or trap, and $4,960/acre of net removed. Directly measurable monetized benefits of derelict fishing gear removal were based on the commercial ex-vessel value of species saved from mortality over a one-year period for derelict pots/traps, totalling $248/pot or trap and a ten-year period for derelict nets, totalling $6,285/acre (NRCI, 2007).

Traps can be designed to be more selective and to avoid bycatch. The use of escape gaps, larger mesh sizes, and options that allow for the deterioration of entrance funnels in collapsible trawl mesh pots would likely reduce ghost fishing and bycatch in the Australian blue swimmer crab fishery (Campbell and Sumpton, 2009). Ghost fishing is also a concern in deepwater fishing, and its effects could be minimized by using pots with degradable panels and other escape options (FAO, 2008b). The ICES Study Group on the Development of Fish Pots for Commercial Fisheries and Survey Purposes focused on two preventative mitigation measures: designing fish pots to promote conservation (see below); and minimizing loss of gear by avoiding conflict with other users (ICES, 2008c). Potential “conservation design” includes floating pots that minimize benthic impact; biodegradable construction materials that reduce ghost fishing and marine debris; and location aids and delayed release surface marker buoys that promote recovery of lost gear (ICES, 2008c). Spatial and temporal separation of different gear users is the most common and successful mitigation measure to reduce conflict between users, and can in turn reduce lost gear. Brown et al. (2005) suggest the following preventative measures for reducing ghost fishing with all types of static fishing gear:

- Reduce risks of conflict; e.g. zoning of different users
- Reduce risks of snagging; e.g. modification of gear and its deployment
- Reduce ghost fishing; e.g. biodegradable components
- Reduce fishing effort; e.g. net numbers, soak time
- Improve gear recovery; e.g. by attachment of transponders

Canadian experience

Over all of the fisheries management regions in Canada, pots and traps catch 167,151 tonnes of target organisms with an annual value of $1,117 million (Fuller et al., 2008). They are thus the most valuable fisheries in the country, despite the fact that bottom trawls catch the largest volume of fish. In the Pacific region, pots and traps are used for sablefish, crab, prawn and shrimp (DFO, 2009a,b,c). In Quebec and the Gulf of St. Lawrence, rock crab, snow crab, and lobster are targeted with this gear (DFO, 2000a; DFO, 2001; DFO, 2003; DFO, 2005a). Newfoundland and Labrador's snow crab fishery, also dependent on pots and traps, amounts to 14% of the total regional catch (DFO 2005b; Fuller et al. 2008). In the Maritimes, 13% of the total regional catch is obtained using pots and traps, equalling 69% of the total regional catch by value (Fuller et al., 2008). Baited pots are also allowed in the Maritime eel fishery (DFO, 2007b).

Several Canadian fisheries using pots and traps have observer or electronic monitoring coverage. The B.C. sablefish trap fishery has 100% electronic monitoring since 2006, the British Columbia Dungeness crab fishery has electronic monitoring, and the Nova Scotia snow crab fishery has between 9-30% coverage, depending on area (Fuller et al., 2008). All sablefish landings must also be validated through a dockside monitoring program (DFO, 2009a), as are pot fisheries in the Maritimes region, other than lobster.

Canadian lobster and crab fisheries are managed by limits on the number of licenses allowed, the number and size of traps, the duration of the fishing season, the minimum size of catch, and, other than Dungeness crab, year round quotas and total allowable catch (DFO, 2009d,e, f). There are also prohibitions on landing berried or V-notched females; it is illegal to land female crabs in Canada (DFO, 2009e). In the Pacific shrimp and prawn trap fishery, there can be a 300 or 500 trap per vessel limit depending on the license type, but there are currently no escape hatch requirements. Crab pots in the Atlantic are mostly cone-shaped with a volume of less than 2 m^2 and the bottom ring 135 cm or smaller. Each trap must have a degradable panel that will open if the trap is lost (Department of Justice, 1985). Lobster traps used in the Atlantic must have mesh size and/or escape mechanisms that release juvenile and sub-legal lobsters and crabs (Living Oceans Society et al., 2007), as well has having degradable panels to avoid ghost fishing by lost traps. It is noteworthy that a significant number of the derelict lobster traps retrieved in a project in the Bay of Fundy (Fundy Engineering and Fundy North Fishermen's Association, 2009) were non-compliant with the mandatory escape features.

There is no Canadian program for derelict gear recovery in the Strait of Juan de Fuca comparable to the one described earlier for Washington State. In 1987, 11% of the traps used in the Dungeness crab (*Cancer magister*) fishery of British Columbia were estimated to be lost annually in the Fraser River estuary, with a potential ghost-fishing catch of 7% of reported landing (Breen, 1987). There have not been more recent estimates published for this area. As cited above, derelict lobster traps were also removed around a liquid gas port in the Bay of Fundy, based on the belief that vessel traffic was primarily responsible for trap losses (Fundy Engineering and Fundy North Fishermen's Association, 2009).

Troffe et al. (2005) found that prawn (*Pandalus platyceros*) trapping may cause more damage to sea whips (*Halipteris willemoesi*) than does beam trawling, including acute mortality through uprooting of the colonies. Similar traps to those used by Troffe et al. (2005) are also used in the fishery for humpback shrimp, but there are no bycatch data on sea whips available for this fishery. Dungeness crab traps are larger and heavier than prawn traps, and may therefore cause more damage to sea whips. Eno et al. (2001) have observed that flexible sea pens in Great Britain appeared relatively unaffected by fishing with lobster and crab pots.

The North Atlantic right whale (*Eubalaena glacialis*) was designated by COSEWIC as endangered in 2003 (COSEWIC, 2003a), and in 2005 was added as a SARA schedule 1 species (SARA, 2005). Principal risks for the species are high mortality from collisions with ships and entanglement in fishing gear, predominately pot and gillnet gear (Johnson et al. 2005, Johnston et al., 2007). Lobster traps, however, are no longer part of this problem, as the fishery has been voluntarily closed during the period of whale presence - an example of multi-stakeholder community management (DFO, unpublished).

The cusk, a cod-like Lotid fish (*Brosme brosme*) is regularly caught in lobster traps and crab pots and was also designated threatened by COSEWIC in 2003 (COSEWIC 2003b). The spotted and Northern wolffish (*Anarichas minor* and *Anarchias denticulatus*), are injured by, and captured in, a variety of traps (DFO, 2004b), and both are threatened species (COSEWIC, 2001a and b; SARA, 2001a and b).

Pots are the main gear type used in the sablefish fishery on the Pacific Coast of Canada and were responsible for 78% of all sablefish landings in Canada from 1994-2004 (Haist et al., 2005). The rest of the sablefish catch was fished from seamounts with long-lines. In 2000, the sablefish fishery was one of the most economically important in B.C. with a value of $29 million (B.C. Ministry of Environment, 2006). The pots used in the Pacific fishery are a Korean conical design with a bottom hoop diameter of 48 or 54 inches (121.9 -132.1 cm), and are generally deployed about 46 m apart in strings of 50 to 80 (Haist et al., 2004). By regulation, traps must have a section of mesh closed with a single length of thin, untreated natural fibre that will deteriorate if the trap is lost. Beginning in 1999, two side-wall escape openings with an inside diameter of at least 8.9 cm were required to reduce the catch of juvenile sablefish and other species (Haist et al., 2004). Traps may not be left in the water more than four consecutive days. Vessels leaving unattended trap gear in the water for more than four consecutive days are required to take an observer at the vessel's expense for the remainder of the season (DFO, 2009a, c).

MID-WATER TRAWL

Impacts on biodiversity and ecosystems

A U.S.- based survey of fishers, managers, scientists, and conservationists on the relative severity of bycatch and habitat damage caused by fishing gear rated mid-water trawl as 4 on a scale of 1 to 100 (with 100 being the most severe), which makes the gear comparable to purse seines and hook and line (Morgan and Chuenpagdee, 2003). Although ghost fishing can be caused by nets and cod ends discarded at sea (despite regulations), lost trawl gear has a low potential for ghost fishing unless it is suspended by floats, in which case the gear can attract pelagic fishes and invertebrates, which in turn attract sea turtles and seals. Lost mid-water trawl gear can also cause seafloor damage if it sinks as a result of encrusting organisms and dying animals (Morgan and Chuenpagdee, 2003).

There are no data on the impact of mid-water trawls when the gear contacts the sea floor during Canadian fisheries (Fuller et al., 2008). In the Alaskan pelagic trawl fishery, data on gear contact with the seafloor are similarly lacking (NOAA and NMFS, 2005). However, some data exist for such effects in the Bering Sea pollock fishery. Like the pollock fishery in the Gulf of Alaska, this fishery is solely pelagic. Nevertheless, footropes of mid-water trawls often contact the seafloor for up to 85% of tow duration (Enticknap, 2002). Mobile organisms or those attached to light substrates may pass over the footrope, and the mesh size in the forward sections of the net must be large enough that any benthic organisms that actively swim upward in it will not be retained (NOAA and NMFS, 2005). However, sessile organisms, which may be part of biological habitat structures, may become dislodged by the footrope, and non-living habitat components can be damaged (NOAA and NMFS, 2005).

Even if a gear type such as the mid-water trawl is found to have relatively low bycatch or habitat impact per tonne of target catch, the cumulative impacts on ecosystems can be large if the fishery is extensive, as has been seen in the Bering Sea pollock fishery (Morgan and Chuenpagdee, 2003). Mid-water trawls are thought to have low bycatch percentages, but the actual numbers of individuals can be quite high (Morgan and Chuenpagdee, 2003; SeaChoice no date). For example, discard rate for the Pacific hake fishery (the largest fishery on the B.C. coast) is reported to be just 1%; however, this small percentage represents 900 tonnes of marine organisms discarded every year (Picco et al., 2008). In the U.S. factory-trawler hake fishery, bycatch (less than 3% of the total catch by weight), consists primarily of yellowtail rockfish, widow rockfish, Pacific Ocean perch, jack mackerel and chub mackerel. The chinook salmon bycatch of 4,000-6,000 fish per year is a low absolute number, but still a concern due to the listing of several chinook salmon runs under the U.S. Endangered Species Act (Dorn, 1998). In Finnish lakes, Jurvelius et al., (2000) found mid-water trawling to be far more lethal to pike-perch than surface trawling.

Marine mammals, including cetaceans and pinnipeds, are caught in large, high-speed pelagic trawl fisheries (Lewison et al., 2004; UNGA, 2006). In the Northeast Atlantic, eleven pelagic trawl fisheries operated by four countries were studied by Morizur et al. (1999). Three species of marine mammals were caught as bycatch, including white-sided dolphin, common dolphin and grey seal. In four of the eleven fisheries, dolphins were caught as bycatch at night (Morizur et al.,1999). It has also been suggested that cetacean strandings can be caused by interactions with pelagic trawling in the Northeast Atlantic (Morizur et al., 1999).

Mitigation and Canadian experience

Mid-water trawl gear was used historically in the Gulf of St. Lawrence for schooling fish such as herring and mackerel (FRCC, 2009). Opposition to mid-water trawling for herring and mackerel in the Gulf of St. Lawrence was based on evidence from New England, Gulf of Maine, and Scotia Fundy Regions that the fishery was non-selective, and on the concern that the fishery reduced the availability of forage fish for large migratory pelagic fish such as bluefin tuna (FRCC, 2009). In 2006, a freeze was placed on new mid-water trawling for Atlantic mackerel, based on these concerns and unreliable catch reporting (DFO, 2008c).

In Canada, mid-water trawl is currently widely used only in the Pacific Region, where 45% of the total catch is hake (Fuller et al., 2008; SeaChoice, no date). The hake fishery is the largest, by volume, on the coast of B.C., landing nearly 90,000 tonnes in 2005 (Picco et al., 2008). In 2007, the fishery was carried out by 34 vessels making 760 trips for a total of 2,115 sea days (McElderry, 2008). Discard data in this fishery must be registered in logbooks, with a dockside monitoring program recording weight and species of the landed catch. There is also 10% at-sea observer coverage of the fishery (Wallace 2006). Under the Coastal Fisheries Protection Regulations, all mid-water trawl nets used for Pacific hake and licensed to deliver to a foreign fishing vessel must have an escape panel for unwanted fish (Living Oceans Society et al., 2007).

In addition to jig fisheries for squid, Canada participates in the North Atlantic mid-water trawl fisheries for squid, targeting the short-finned squid (*Illex illecebrosus*). This once large fishery is now very reduced (DFO, 2008e) and is managed in collaboration with NAFO (Hendrickson 2006). We did not find information for bycatch in this fishery, but expect that it is significant, comparable to that of the trawl fishery for *Loligo pealei* in the mid-Atlantic and American Eastern seaboard (King et.al., 2009).

There is also a euphausiid (krill) fishery that uses mid-water trawl gear in Georgia Strait, on the southern B.C. coast. Given the important role of krill as a critical food source to many vertebrates in the aquatic ecosystem this is a “sensitive fishery that requires careful management” (Nicol and Endo, 1997). In Canada, this fishery has limited entry licensing, periodic openings, conservative harvest quotas, and a dockside monitoring program. The annual total allowable harvest is 500 tonnes (DFO, 2007c). However, there is minimal information on the krill fisheries, nor is there much information available on bycatch. The DFO 2007-2012 Euphausiid Integrated Fisheries Management Plan (IFMP) states that vessels in Canada “are requested to cease trawling in any location if the catch of larval or juvenile fish exceeds 10 per litre drained catch”. Information about the location, date and level of catch is to be reported to DFO so that “appropriate action can be taken to prevent any fishing of larval or juvenile fish” (DFO, 2007c).

DANISH & SCOTTISH SEINES

Impacts on biodiversity and ecosystems

Danish and Scottish seines rely on disturbance of the seabed sediment to herd fish into their path, suggesting a direct effect on benthic invertebrates within the circle of the gear (ICES, 2006). In terms of seabed impact, the effect of mobile fishing gears is a function of the frequency with which an area is fished and the type of seabed (Johnson, 2002; ICES, 2006; Arkley, 2008). There is still discussion on the quantitative effect of these seine nets on marine habitats (Arkley 2008), but effects are considered to be less than those of beam and otter trawls (ICES, 2006). In a study focusing on fishermen’s perspectives, most respondents considered the habitat effects of Scottish and Danish seines to be negligible since areas fished are smooth and already quite flat (Fuller and Cameron, 1998).

Accurate estimates of the environmental impact of these seine nets require more and better quality information on seabed types and habitat. Such studies are currently being conducted by the Institute of Marine Research (Arkley, 2008). The rapid recovery of bivalve molluscs after deep dredging in seabed sediment has been extrapolated to the effects of seine rope contact with the seabed sediment, and is considered minimal (Arkley, 2008).

The main impact of Danish seining is bycatch of both undersized individuals of the target species and individuals of non-target species (FAO, 2008b). In one European study, Danish seine, along with diving, pole and line, pot, traps, purse seine, pelagic trawl, and jigging was ranked as “most responsible” means of fishing, while beam trawls, bottom trawls, and dredges were ranked “least responsible”. Franco (2007) considered the effects of Danish seines on the sea bed to be limited, with bycatch resulting primarily from the use of a large, small mesh nets in shallow waters. Because Danish seine gear is tended while in use and is in the water for a short period of time, the risk of right whale entanglement is limited (Johnson et al., 2005).

Scottish seining is efficient for slow-swimming bottom-dwelling species such as flatfishes. Selectivity is better than that of an otter trawl, but its ability to release fish unharmed is unknown. The seine affects the seabed less than does the trawl due to the absence of otter boards, slower towing speed and shorter tow time. There is negligible ghost-fishing potential because the chances of losing the entire gear are low (FRCC, 1994). Potential impacts of Scottish seine include the removal of and damage to sedentary marine organisms, the capture and removal of bycatch species and undersized target species (Seafood Scotland, 2009). In the waters around Ireland, one-quarter of the catch of Scottish seiners is discarded, amounting to about 2158 tonnes from 50 species (Borges et al., 2005). In the Southern Gulf of St. Lawrence, the winter skate (*Leucoraja ocellata)* has been listed as "endangered" (COSEWIC, 2005) most catches are reported from bottom trawl and demersal Scottish or Danish seine fisheries (DFO, 2008b).

Mitigation

The impact of Danish seining can be mitigated by using larger meshes in the bag, and/or devices installed on the seine to reduce capture of small, unwanted organisms (FAO, 2005). Danish seines are used around Iceland, using this kind of mitigation. The minimum mesh size in Iceland is 135mm to 155 mm depending on the fishing area, but 120mm is allowed in the witch flounder, *Glyptocephalus cynoglossus,* fishery as long as a selectivity device is also used (Icelandic Ministry of Fisheries and Agriculture, 2008).

Mitigation of impacts of Scottish seining is similar to that for Danish seining. In the Scottish seine fisheries in Canada and Scotland, minimum mesh size of the cod end is regulated. Structural options that are readily available to enhance the size- and species-selectivity in these seines include square mesh cod ends, cod ends with lastridge ropes, Nordmore grates; net liners and adjustments to net geometry can also reduce selectivity. Fishery closures are also applied when bycatch limits have been exceeded, as indicated by dockside monitoring, on-vessel observers or research vessel sampling (FRCC, 1994). In the Scottish seine fishery in Scotland, fishermen have also implemented other measures such as using lighter gear that has low impact on the seabed. Regulations in this fishery include square mesh panels with a minimum mesh size, and specification of maximum twine thickness (Seafood Scotland, 2009).

Canadian experience

There are small fisheries in Atlantic Canada that use Danish and Scottish seines to catch cod, American plaice (*Hippoglossoides platessoides*), witch flounder or grey sole (*Glyptocephalus cynoglossus*), and redfish or ocean perch (*Sebastes* spp.). In a 1997 study to reduce cod bycatch in the Gulf of St. Lawrence, traditional and experimental designs of Scottish seines were tested (Fisheries and Aquaculture N.B., 1998). The best reduction of cod bycatch with minimal loss of American plaice was achieved with two diamond-shaped holes on the top centre line of the cod-end (the closed bag at the end of the seine). The extent to which this design is used today is unclear.

The Canadian fishery for cod was carried out mainly by longliners and handliners, but otter trawlers and Danish seiners also took substantial portions of the catch. The 1993 cod moratorium remains in effect, but management of cod bycatch in other fisheries in the area has become an important regulatory issue. To address this issue, government and industry in Newfoundland and Labrador have implemented conservation measures over the past decade which include an increase in mesh size of Danish seines from 130 mm diamond to 155 mm square (DFO, 2005c). In the 4VW area of the Maritimes Region, Danish seiners normally fish for flatfish with a 145mm diamond mesh, but if high cod bycatch is encountered (>5% daily or >2% annually) they are required to switch to 155 mm square mesh (DFO, 2006c).

PURSE SEINE

Impacts on biodiversity and ecosystems

Although purse seines are presently considered to have relatively low impact on ecosystems, it is unclear if this conclusion simply reflects a lack of data (Fuller et al., 2008). Purse seining takes advantage of the target species' schooling behaviour, but when juveniles, undersized individuals, or other species are mixed in with the targeted aggregation they are also often caught in the purse. Determining the species and size composition of the school, as well as the actual amount of catch when setting a purse seine, are not precise practices. The accuracy of such information also depends on the fishery and species, and may be affected by oceanographic or meteorological factors (Hall, 1996).

Purse seining of tuna

Public awareness of the need for mitigation of fisheries bycatch was provoked initially by the bycatch of charismatic species like dolphins in purse seine fisheries for yellowfin tuna (*Thunnus albacares*) in the Northeast Pacific (Hall, 1996).

Industrial tuna seine fleets are very mobile, consisting of large boats (over 70 m) that can fish the west Indian Ocean, then return to the eastern Atlantic Ocean to continue fishing off the West African coast, or to the Pacific and the east Indian ocean to fish off Japan or in the EEZ waters of the Pacific island nations (FAO, 2003b). Regulation of the activity for both fisheries management and bycatch mitigation is thus an international challenge. There are five regional fisheries management organizations responsible for the global management of tuna stocks: the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Indian Ocean Tuna Commission (IOTC), the Inter-American Tropical Tuna Commission (IATTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Western and Central Pacific Fisheries Commission (WCPFC). Regulations for onboard observer coverage vary between the different commissions, but the trend is moving toward 100% coverage.

The Eastern Pacific tuna purse seine fishery is managed by the IATTC, with an extensive on-vessel observer program. Nevertheless, the annual number of trips of vessels with carrying capacities of more than 363 tonnes during 1993-2007 has ranged from 475 to 907; only 26 of those trips have not been accompanied by observers (IATTC, 2009). Sea turtles caught in this fishery include olive ridley (*Lepidochelys olivacea*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), and loggerhead (*Caretta caretta*). These species are considered to be endangered or threatened, but virtually all turtles in this study were released in viable condition. The average estimated annual discard and bycatch of tunas and bonito for 2003-2007 was 20,964 tonnes, and of billfishes was 4,745 tonnes. For sharks and rays, marine mammals, sea turtles and all other fish an estimated 35,857; 1,167, 25; and 1,262,844 individuals respectively were either caught as bycatch or discarded annually over the same time period (IATTC, 2009).

The predominant tuna species in the Eastern Pacific Ocean tuna purse seine fishery are now skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), and yellowfin (*Thunnus albacares*), captured mainly with use of man-made fish-aggregating devices (Harley and Suter, 2007)—a practice that has increased since the mid 1990s. These aggregating devices (FOB) attract many kinds of fish and other aquatic organisms. Purse seines, depending on how they are used, are not very selective for species or fish size, so bycatch can be substantial, particularly if the net is set around FOB (FAO, 2003b), so there are concerns about the indirect impacts of this fishing method on the ecosystem (Hall 1998; FAO 2003b; Watson et al. 2008). With regard to the tuna fishery itself, the FOB fishery has had no noticeable effect on skipjack tuna abundance (Maunder, 2002a) and little effect on yellowfin tuna (Maunder, 2002b). However, the FOB has led to a considerable increase in fishing mortality of juvenile bigeye tuna (Maunder and Harley, 2002).

Purse seining of small pelagics

Pelagic purse seines do not generally come in contact with the sea floor, so do not directly impact the benthos. However, if a seine set is lost and the fish do not survive, there may be considerable localized harm to the benthos through organic enrichment and disturbance (ICES, 2006). Inshore or demersal purse seines may also make direct contact with the bottom, with impacts similar to those of light otter trawls, which "disturb the benthos occasionally". However, ICES (2006) considered this impact to be relatively insignificant, given its occasional nature and focus on dynamic habitats with a high level of natural disturbance.

In many purse seine fisheries, including the Norwegian offshore pelagic fisheries, gear is relatively non-selective for species, size, or quality (Gezelius, 2006). In the purse seine fisheries of southern Europe, especially Spain, low value or small size are the main reasons for discarding bycatch (CEC, 1992). Sometimes the entire catch or part of it is released before the net is closed or brought on board ("slippage"). The mortality of fish released in this fashion is determined by the fish density and time spent in the net before release (Lockwood et al., 1983; Suuronen, 2005; Marcalo et al., 2008). In trials with confined mackerel at a stocking density of 30 fish/m^3 (6.5 kg /m^3), it was found that 50% of the fish died after 48 hours (Lockwood et al., 1983). When mackerel were held at stocking densities for periods comparable to a "dried up" purse seine prior to slipping, trials showed that up to 90% of slipped fish died within 48 hours of release (Lockwood et al., 1983). Physical damage, such as skin loss, is the main cause of mortality after release (Lockwood et al., 1983). Physiological stress, including osmoregulation difficulties, also causes behavioural impairment which may lead to greater susceptibility to predation (Marcalo et al., 2008). Initial studies on effects of crowding on herring prior to slipping produced varied results: 27.9% mortality after 5 days in one trial, and only 1.8% mortality in another (Vold et al., 2009).

According to a number of demersal purse seine skippers, the bycatch of sharks, sea turtles and marine mammals is rare in their fishery, mainly because the fishing grounds are close to shore and at depths of less than 25 to 30 m (Goncalves et al., 2008).

Mitigation

Reducing the bycatch of dolphins in purse seine tuna fisheries has been accomplished in two ways. Medina panels, or dolphin-safety panels (DSP) of fine mesh webbing sewn into the upper part of the net keep dolphins from becoming entangled. The "back down" technique, in which the top of the seine is pulled underwater to allow dolphins to jump out, increases the chance that encircled dolphins may be released alive (FAO, 2008b).

The use of fishery closures to reduce bycatch is often complicated by spatial overlap of target and bycatch species. A closure designed to reduce bycatch may thus be considered too costly (Harley and Suter, 2007). For example, time-area closures in the Eastern Pacific purse-seine fishery to conserve bigeye tuna may not be possible without a large reduction in the catch of skipjack tuna (Harley and Suter, 2007). A focus on the costs of conservation allows managers to identify policy options that may increase the likelihood of compliance with a particular closure. This kind of pragmatic and transparent assessment of the trade-offs, though not without shortcomings, can be applied to different fisheries, regions, or species (Watson et al., 2008). Resolution C-09-01 on the Conservation of Tuna in the Eastern Pacific Ocean in 2009, for example, contains provisions for one of two possible time closures, depending on vessel size.

Bycatch reducing devices (BRD) have also been developed for demersal purse seine fisheries. In Portugal, for example, seines usually target high value demersal species such as sea bream (e.g., *Diplodus* spp., *Pagellus* spp., *Sparus aurata*) and the European sea bass (*Dicentrarchus labrax*), while discarding pelagic species and juveniles. In this case, the BRD consists of a panel of diamond-shaped 70 mm netting in the posterior part of the purse seine. Results of trials with this BRD have been promising, with an average of 49% (± 24%) of the potential bycatch species escaping from each set (Goncalves et al., 2008). In attempts to improve the purse seine selection by use of sorting grids, there was relatively high mortality (> 40%) for mackerel that escaped through a sorting grid with a bar spacing of 40 mm (Misund and Beltestad, 2000). Mackerel suffered severe stress and skin injuries during the selection process, and Misund and Beltestad (2000) concluded that the mortality rate was too high for sorting grids to be recommended for commercial purse seine fishing.

Reduction of damage to fish is also possible. Once fish are captured in the seine and ready to be brought on board, the traditional method (bringing the net and its contents onto the deck) can compress fish and expose them to air, both of which contribute to high stress and mortality. Methods which minimize air exposure and compression include use of large dipnets (“brailers”) or fish transfer pumps to bring fish on board, followed by wet sorting (Plate et al., 2009). Brailers are mandatory in the Pacific salmon seine fishery (DFO, 2009g and h).

Canadian experience

Small pelagic

There are purse seine fisheries on the Pacific and Atlantic coasts for small-bodied pelagic fish species. On the West coast, the Pacific herring (Clupea pallasii) roe fishery, including the spawn on kelp (SOK) fishery, produces the highest purse seine landings and value (Appendix 1). The herring from the SOK fishery are released after spawning, but potentially have a high rate of mortality due to handling (DFO, 2009i). The opal squid (Loligo opalescens) are also fished commercially by seine net on the West Coast of Canada in a small, opportunistic, fishery. The squid are mainly used as bait in the crab, sablefish (black cod), and halibut fisheries, not competing well with California’s low priced food product. Bycatch in this squid fishery is known to occur, but no data is available (DFO, 2007f).

On the East coast, Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus* L.) and capelin (*Mallotus villosus*) fisheries all have purse seine components. The "tuck" seine, used since 2005, is now the second most important gear, in terms of catch, on the west coast of Newfoundland for Atlantic herring and Atlantic mackerel (Grégoire and Gendron, 2009). A tuck seine is a small purse seine used to catch pelagic fish in shallow, near-shore waters. In all of these fisheries, the impacts on biodiversity and marine ecosystems from purse seining are more related to removal of pelagic forage species from the ecosytem and alteration of predator-prey interactions than to any direct gear effects (Chuenpagdee et al., 2003; Read and Brownstein, 2003).

Pacific salmon

The Pacific salmon seine fishery captures pink (Oncorhynchus gorbuscha), chum (Oncorhynchus keta), sockeye (Oncorhynchus nerka), coho (Oncorhynchus kisutch) and chinook (Oncorhynchus tshawytscha) salmon. Approximately 40% of the total salmon catch on this coast is harvested by purse seine, with the remainder taken by troll or gillnet (DFO, 2009g and h).

The incidental catch of non-targeted salmon species is a concern in these fisheries (Ryall, 1994). While sorting and release of chinook, chum, coho, and steelhead from Northern B.C. purse seines is mandatory, information on compliance or on the survival rate of released fish is deficient. For example, in 2006 there was less than one per cent observer coverage for *all* Pacific salmon fisheries, regardless of gear type. Based on voluntary reporting and observer coverage, 2% of the purse seine catch was discarded (Picco et al., 2008).

BEACH SEINE

Impacts on biodiversity and ecosystems

Knox (2008) considers beach seines to be very selective – in part because non-target individuals are adequately healthy for effective release. However others point out that beach seine nets are relatively non-selective, catching a wide range of species and sizes (Lamberth et al., 1995; Gray and Kennelly, 2003; Mangi and Roberts, 2006). For example, on Kenya's coast, beach seine fishermen landed more juvenile fish than any other artisanal fishing method, and discarded 6.5% of their total daily catch (Mangi and Roberts, 2006). Most of the discards were juveniles of commercially important fin-fish, and their survival rate was probably low (Mangi and Roberts, 2006). Sites with high frequencies of beach seining had significantly smaller corals and a lower density of coral colonies than those where beach seines were not used. Coral colonies were broken or removed through dragging nets and trampling (Mangi and Roberts, 2006).

In beach-seine fisheries in South Africa (Lamberth et al., 1995) and Australia (Gray et al., 2001; Gray and Kennelly, 2003), discards contain juveniles of most of the primary target species. Estuarine beach seiners in New South Wales discard large quantities of bycatch—between 57 and 59% of the total catch (Gray and Kennelly, 2003). In Lake Macquarie and St. Georges Basin, more species were discarded than retained, with all individuals of many species being discarded regardless of size because they were of little value. Most of the primary species captured in southeastern Australian beach-seine fisheries are also targeted in other commercial and recreational fisheries, causing significant conflict with other users and concerns over wastage. Mortality in Australian estuarine beach seine discards was examined by Broadhurst et al. (2008), who reported seined-and-discarded mortality of 20.3% for yellowfin bream (*Acanthopagrus australis*), 30.0% for sand whiting (*Sillago ciliata*), and 72.2% for silver biddy (*Gerres subfasciatus*).

In central Portugal, species composition of beach seine catch varies seasonally, so the percentage of fish discarded also varies according to haul and season (Cabral et al., 2003). This fishery catches around 60 different fish species, but chub mackerel (*Scomber japonicus*), Atlantic horse mackerel (*Trachurus trachurus*) and Senegal seabream (*Diplodus bellottii*) represent the great majority (90%) of the catch. For most other species caught, the discard rate was around 100% (Cabral et al., 2003).

Mitigation

The use of larger-sized mesh to allow juveniles to escape is basic and effective mitigation (Kennelly and Gray, 2000). For example, in Benin, West Africa, the FAO Sustainable Fisheries Livelihood Program supported research into use of a two-inch mesh beach seine instead of one-inch mesh, which caught large quantities of juveniles. Juveniles could escape through the larger mesh, leaving more room for mature fish. The new nets also proved cheaper and easier to pull in, since less drag was created (Lowery, 2003).

In Australia, seasonal and area closures mitigate the amount of bycatch in beach seine fisheries (Australian Department of Fisheries, 2005). In researching the impact of closed areas and beach seine exclusion on other kinds of inshore artisanal fishing, McClanahan and Mangi (2001) found that closing an area often reduces total fishing area, while the exclusion of beach seines can lead to greater use of other gear types. In Australian estuarine beach seines, modifying the transparent mesh panels on either side of the bunt improved the size selection of targeted commercial species (primarily sand whiting, *Sillago ciliata*) and reduced the bycatch of other species (Gray et al., 2000).

Canadian experience

Beach seines have historically been used on both the Pacific and Atlantic coasts, but today there remain only small beach seine fisheries for herring (*Clupea harengus*), mackerel (*Scomber scombrus*), and capelin (*Mallotus villosus*) on the Atlantic coast (Appendix 1). There are also small, selective First Nations fisheries on the Skeena River and elsewhere that target sockeye salmon (*Oncorhynchus nerka*).

TRAP NET

Impacts on biodiversity and ecosystems

Despite the large size of some trap nets, there is little literature on their expected impacts on habitat or local oceanography. References focus more on the bycatch of marine mammals, such as seals, who follow fish into the traps.

Smelt (*Osmerus mordax*) trap-net fishermen in P.E.I. report that seals commonly patrol the leaders, and can follow fish into the traps. Harbour seals typically drown in the traps, but the larger grey seals can break through (Cairns et al., 2000). In the northern Baltic Sea, seal interaction with the traditional salmon trap-net fishery is widespread; seals enter the gear and eat and/or damage the catch and net (Kauppinen et al., 2005; Suuronen and Sarda, 2007). In 2001, an estimated 462 grey seals, 416 harbour seals, and 53 ringed seals drowned in Swedish commercial fisheries, most of which occurred in fixed gear (trap nets) set for salmon and eel (Lunneryd and Konigson, 2005). Nevertheless, Swedish seal populations have continued to grow (Lunneryd and Konigson, 2005).

In comparison with many other fishing methods, trap nets offer the potential for low bycatch mortality of fish. Fyke or trap nets often catch non-target fish species, but trapped fish are normally alive and uninjured, so bycatch can in many cases be released with a good chance of survival if handled properly and the nets regularly monitored (Siira et al., 2006; Suuronen and Sarda, 2007). Bycatch from trap nets can be minimized by good gear design, including appropriate mesh size and material, size, shape, location and design of entrances and escape openings, and incorporation of excluder devices (Suuronen and Sarda, 2007).

Mitigation

An important strategy in reducing bycatch in trap nets is to restrict the duration of deployment. When interactions cannot be managed that way, other measures are taken. For example, in the Baltic Sea, studies on the use of acoustic harassment devices (AHD) in the salmon trap net fishery showed an initial drop in seal/trap interactions, but late season damage to the catch was still significant (Fjalling et al., 2006). Scaring marine mammals away can also harm them: many seals became accustomed to the sound, even at very high intensity, but there is a risk of causing a permanent hearing-threshold shift after prolonged exposure to an AHD (Fjalling et al., 2006).

In Swedish and Finnish salmon fisheries, substantial progress in reducing seal bycatch and net damage from seals has been achieved with improvements to the pontoon trap. The net material has been made stronger, a grid fitted across the chamber entrance, and the fish bag made of double-layer netting under tension (Suuronen and Sarda, 2007). Because this arrangement is awkward to handle, submersible pontoons have been added, which can be filled with air from a compressor and the whole assemblage easily brought to the surface for emptying (Hemmingsson et al., 2008). Variations of this arrangement are used for herring, capelin and squid. However, the trap fishery for squid uses small mesh and sometimes also catches juvenile fish such as cod or Atlantic salmon. The gear has also been known to catch marine mammals such as harbour porpoise. In Newfoundland, mitigation of interaction or bycatch of whales and basking shark in cod traps involved non-fatal release with a protocol developed by Dr. Jon Lien of Memorial University (H. Lear, pers. comm. 2009).

Canadian experience

Atlantic cod

The inshore cod fishery of Newfoundland has traditionally used a variety of gear including cod traps. Prior to 1993, thousands of traps averaging 100 meters in circumference and 18 meters deep were operated around Newfoundland to catch Atlantic cod (Brothers, 2000). During 1990, there were about 4000 of these traps in operation (H. Lear pers. comm. 2009).

In the 1960s, the Newfoundland design accounted for 80 per cent or more of the traps in the inshore fishery, declining to about 40 per cent by the early 1990s, by which time the Modified Newfoundland was the predominant trap design (the Japanese trap design then accounted for 21 per cent of all traps). However, the excess catch of undersized cod (more than 15% of the catch of fish less than 43 cm in size) and bycatch of Atlantic salmon resulted in the closure of the cod trap fishery in some areas (Brothers, 2000; FRCC, 1996). Of 15 inshore fishers interviewed in the early 1990s, more than half recommended reduction in fishing capacity to limit the impact on juvenile cod populations. Specific suggestions included limiting the number of traps per crew and eliminating Japanese traps. One offshore trawler favoured the elimination of all traps. The other main recommendation was to increase the mesh size used in the bunts of the traps and in the leaders that guide the fish into the traps (Neis and Felt, 2000). A moratorium was placed on the trap fishery in 1992, and continues in some areas (DFO, 2007d). Modified traps with square mesh panels to reduce the bycatch of small fish have also been tried in several locations on the coast of Newfoundland. Brother (2000) found that, in the majority of traps with 117 mm square mesh, the percentage of fish under 43 cm was less than 15%; with 102 mm square mesh panels, only one trap had less than 15% small fish.

Minke whales and harbour porpoise mortality have both been attributed to cod traps (Alverson et al. 1994). Five minke whales were caught and died in Newfoundland cod traps during 1989. Efforts to reduce interaction included use of several types of sound emitters, and it was concluded that low frequency (3.5 kHz) 'beepers' reduced by nearly half the frequency of capture of large whales (Lien et al., 1990; Jefferson and Curry, 1996). Later tests with louder, low frequency whale alarms greatly reduced the collision rate of humpback whales (*Megaptera novaeangliae*) with cod traps (Lien et al., 1992).

<u>Capelin</u>

In 2008, the capelin fishery had the highest landings of all trap net fisheries in Canada (Appendix 1). No recent quantitative bycatch data are available for either the purse seine or trap net capelin fisheries in Canada, although management has prohibited discarding male and juvenile capelin (Trenor and Danner, 2008). The capelin’s role as a keystone species of the local marine ecosystem (it is the preferred prey for a variety of fish and mammals) has raised concern about this fishery (Grégoire and Gendron, 2009).

<u>Smelt</u>

The small fishery for Eastern New Brunswick smelt (Osmerus mordax) uses gillnets, box and bag nets. Landings are largely unreported, which has led to a reduced effort to manage this fishery in a scientific manner (DFO, 2007a). The ecosystem effects of this fishery are not known. Bycatch of striped bass (Morone saxatilis), winter flounder (Pleuronectes americanus), and white hake (Urophysis tenius) in box nets is a major problem in this fishery, especially in Miramichi Bay and the Richibouctou River. Bycatch of striped bass is the most concern, because stocks of this species in the Gulf of St. Lawrence are very reduced, and all spawn in the Miramichi River (the northern limit for striped bass reproduction in North America) (DFO, 2007a). The Southern Gulf of St. Lawrence population of striped bass (Morone saxatilis) has also been designated as threatened by the COSEWIC, which may result in management changes to reduce bycatch (COSEWIC, 2004; DFO, 2007a).

<u>American Eel</u>

The American eel (*Anguilla rostrata*) was designated as a “species of concern” by COSEWIC in 2006 (COSEWIC, 2006). Commercial and recreational fisheries on the species were ended in Ontario in 2004, but continue in Quebec, Newfoundland, Labrador and the Maritime Region with fyke nets, supplemented by baited setlines, pots, box nets, electro-fishing and weirs in some locations. For example, the inland fisheries of Quebec use box nets, while the estuarine fishery of the St. Lawrence River uses weirs (Anon, 2009a). Bycatch in eel traps has been studied in Newfoundland and found to include two other species of concern – the Atlantic salmon, in the fyke nets, and the banded killifish (*Fundulus diaphanous*) in fyke nets and baited pots. Regulations implemented in 1995 require a salmon exclusion device (generally a rubber band on the door to the end funnel) and an area of mesh that allows small, non- target fish to escape through the netting (Newfoundland and Labrador Fisheries and Aquaculture, 2001), but the bycatch study by Gallant (2006) suggests that bycatch of 23 species continues. However, mortality of bycatch is very low (3%) and primarily of abundant flounder or sole (Gallant, 2006). In the Maritimes Region, DFO encourages the use of exclusion devices - such as mesh or screen across the front of a trap – to help reduce bycatch of fish, mammals, and birds (Quigly, S., pers. comm., 2009) .

Alewife/Gaspereau

Alewife/Gaspereau (Alosa pseudoharengus and Alosa aestivalis) represent the largest landings for any species caught in trap nets in the Gulf of St. Lawrence region (gillnets are also used to a minor degree for these species). In Eastern New Brunswick, for example, landed value in 2004 was $728,000, and fishing effort of up to 337 trap nets and 700 fathoms of gillnet (DFO, 2007e).

Smelt, trout, salmon and striped bass are bycatch in both trap nets and gillnets; as a license condition, DFO stipulates the location of trap nets in the various ecosystems in order to reduce bycatch (DFO, 2007e). A five-year experiment with mandatory logbooks was discontinued in 2006 due to poor compliance; alternative ways of obtaining landing data may be implemented in order to ensure the effective management of this fishery, including its ecosystem effects (DFO, 2007e).

WEIR

Impacts on biodiversity and ecosystems

Although weirs permit the release of non-target species, little is known about their bycatch impact (Fuller et al., 2008; Pitcher and Chuenpagdee, 1994; Sawada and Tautz, 1994). There is no ghost fishery with weirs, and their footprint is highly localized; however, they tend not to be size-selective (FRCC, 2009).

Mitigation and Canadian experience

Over the past two decades, selective salmon fishing methods have been tested in the Fraser River to minimize the mortality of non-target fish species. In tributaries, weirs are believed to have this potential. Weirs inflict little harm on the fish and excess catch can be released. Their efficiency depends upon location and the experience of the operator (Plate et al., 2009). It has been suggested that some populations of the West Coast salmon should be fished entirely with non-lethal weirs. This method would allow accurate live counts of salmon and steelhead needed for each stream's spawning grounds; any surplus could be harvested commercially and for First Nations food and ceremonial purposes (Taylor and Dickie, no date).

Weir fishing has a long history in Atlantic Canada (Wong et al., 2001; FRCC, 2009). The present herring fishery uses several gear types (gillnet, purse seine, weir), with weir harvesters regarding their long history of stable landings as an indication of a sustainable fishery (FRCC, 2009). In Scotia-Fundy, juvenile herring are caught mainly in 70 or so active weirs in coves and bays, and sold as sardines (Gough, 2007). Atlantic mackerel is also caught using weirs, and in 2004 there were 16 weir-license holders in the Eastern New Brunswick eel fishery. Eel weirs typically have V-shaped walls, opening upstream, which block off a portion of the river and force the water through a trap at the apex of the "V" (DFO, 2006b).

In the herring fishery, bycatch includes salmon, pollock, mackerel, tuna, sharks, Minke, right and humpback whales and porpoises; all can be released alive (FRCC, 2009). In 1991, the

Grand Manna Whale and Seabird Research Station in New Brunswick began the Harbour Porpoise Release Program to help operators of herring weirs remove harbour porpoises safely without loss of herring. Staff members of the Grand Manna Whale and Seabird Research Station check local weirs every morning for trapped porpoises. Between 1991 and 2001, the program released over 350 harbour porpoises from local weirs, and guidelines for the release of all species caught as bycatch in weirs have been published (Wong et al., 2001). Striped bass is also amongst the bycatch in weirs. The incidental catch in the trap/ weir operations in the Bay of Fundy, for example, has contributed to this population being listed as “threatened” by COSEWIC (COSEWIC, 2004).

All Scotia-Fundy herring weirs operate with Conditions of License that require reporting and monitoring in accordance with the provisions of an industry-funded Dockside Monitoring Program (DFO, 1999a).

TROLL

Impacts on biodiversity and ecosystems

Trolling is considered to have low impact on habitat and biodiversity because of the selective nature of the gear (Fuller et al., 2008). Release of non-target species is commonly practiced, but their actual survival is difficult to determine (Parker et al., 1959; Wertheimer, 1988; Farrell et al., 2001). Survival of non-target species in troll fisheries depends on the type of hook, hook removal method, and handling time (Wertheimer, 1988; Farrell et al., 2001). Depredation of catch by marine mammals can also be a concern in some troll fisheries. For example, a 20% depredation rate by bottlenose dolphin (*Tursiops truncatus*) was observed in the Florida king mackerel (*Scomberomorus cavalla*) commercial troll fishery (Zollett and Read, 2006). Depredation of troll-hooked salmon by killer whales (*Orcinus orca*) in the Pacific troll fishery is an issue of increasing concern (DFO, 2009b). Depredation is a learned behaviour that is quickly adopted by whale social groups; once established it appears impossible to eliminate (DFO, 2009g). This increases the likelihood of whale injury or mortality, and/or loss of natural foraging behaviours or seasonal movements. Killer whales that take chinook salmon from troll lines may also shift their food choices to engage in depredation of other economically important species like halibut, sablefish or lingcod (DFO, no date a).

Mitigation

Barbless hooks reduce damage to fish (including non-target fish) and are mandatory in the Pacific salmon troll and jig fisheries. Nevertheless, use of barbed hooks was still observed by fishery officers in the Northern Pacific salmon troll fishery in 2008 (DFO, 2009h). Specific troll “plugs” or bait can also be used to reduce catch of non-target species. Orsi et al. (1993) found that large plugs caught significantly larger chinook salmon, fewer sub-legal sized chinook, and fewer coho compared to other lures such as smaller plugs, hootchies, and painted spoons. They suggest that in a quota-limited chinook fishery the use of large plugs could reduce bycatch of coho and sub-legal chinook.

Canadian experience

The B.C. tuna troll fleet for Pacific albacore (*Thunnus alalunga*) operates in both Canadian and international waters. In 2008, the fleet landed 3,373 tonnes in Canada with a value of $10.8 million (DFO, 2008d). According to a co-author of the 2002 DFO working paper “Update of

Canadian tuna fisheries in the North and South Pacific Ocean", bycatch in this fishery is considered minimal with a "very small catch of skipjack tuna" (Bill Shaw, pers. comm., 2009). There is a similar small troll fleet on the east coast, fishing for swordfish and tuna other than the bluefin.

The salmon troll fleet's historically important role on the BC coast is now much reduced. Along the Southern coast of B.C. there are trolling quotas for sockeye, pink, and chum salmon, with a directed quota for chinook in one area only (DFO, 2009g). In the Northern Pacific region of coastal B.C. there are quotas for sockeye, pink, chinook, and coho (DFO, 2009h). Non-target species (steelhead in both regions, coho and chinook for most of the Southern area, and chum in the Northern area) must be released.

In 1998, DFO required that all B.C commercial salmon fishing vessels use fish-recovery boxes to reduce mortality of released non-target species. The thinking behind the new regulation was that salmon revived prior to release would have a better chance of survival and would escape predation. In older studies, the delayed mortality rates for non-target salmon released directly into the water after being caught on troll gear was estimated at 34-52% for coho and 23.5-80% for chinook (Parker et al., 1959; Wertheimer, 1988). The first recovery boxes had flaws (Farrell et al., 2000), but techniques such as submerging cages beside the vessel reduced 24 hour post-capture mortality of troll-caught coho to zero (Farrell et al., 2001). Unfortunately, compliance continues to be a problem within the entire salmon fishery (Plate et al. 2009). In 2008, fishery officers spent 0.2% and 1.6% of their total effort in monitoring the Southern and Northern Pacific salmon troll fisheries respectively (DFO, 2009g and h).

HOOK AND LINE (HAND LINE / JIG / ROD AND REEL)

Impacts on biodiversity and ecosystems

Hook and line is a general term encompassing many types of gear (including longlines, which are not covered here). As already noted for troll gear, hook and line gear has high selectivity for the target species. Biodiversity and ecosystem impacts depend largely on the type of hook and bait/lure used, the number of hooks and lines deployed, and the depth of deployment. These parameters vary widely between fisheries. FAO indicates that, in general, pole and line gear has no potential negative impact on species, though hand-lining for tuna in some areas can take incidental bycatch, in particular sharks (FAO, 2003c).

In the Pacific Ocean, Indian Ocean, Red Sea, Mediterranean and Atlantic, hand lines are used to catch different species of tuna, frequently around fish aggregation devices (FADs). Although hand lines have been reported to be selective (FAO, 2003c), high levels of incidental capture and mortality of birds have been reported. For example, in Brazil, avian bycatch includes endangered species such as spectacled petrel (*Procellaria conspicillata*) and Atlantic yellow-nosed albatross (Cuthbert et al., 2003; Ryan et al., 2006). High avian mortality in the Brazilian Itaipava Fleet fishery may have been influenced by use of small hooks which are easily swallowed by birds (Bugoni et al., 2008). The hook and line category, however, is quite diverse and statistics are often combined with those of longlines (see below).

The impacts of lost hook and line fishing gear on sessile organisms are poorly documented. In the Florida Keys National Marine Sanctuary, lost or abandoned rod and reel gear is widespread, but the percentage of individual sessile invertebrates damaged by this gear appears to be low (0.2% of total estimated densities; Chiappone et al., 2005). Much research still needs to be done on the impacts of derelict rod and reel gear on other marine fauna, on the rate of migration of lost gear, on the proportion of commercial to recreational gear, and on how the impacts of lost gear are influenced by oceanographic conditions (Chiappone et al., 2005).

Discard rates and the fate of discarded fish have been little studied for commercial handline, rod and reel or jig fisheries (Rudershausen et al., 2007). An example of the incomplete state of knowledge is the coral reef finfish fishery in most tropical countries, where hand lining is the dominant fishing method. Coral reef fisheries typically target several species. Where they are regulated by size limits, species exclusions or catch quotas, discard rates may be substantially higher than the global average of 2% reported by Kelleher (2005). Welch et al. (2008) note that, for coral trout and red throat emperor fished on the Great Barrier Reef, fleet-wide estimates of total annual discards from 1989 to 2003 were 292-622 tonnes and 33-95 tonnes respectively. Estimated discard rates for coral trout in some regions on the Great Barrier Reef were higher than for most other non-trawl fisheries and comparable to many trawl fisheries. Discard rates were, however, highly variable among regions, as were harvest and underlying population size structure. Meaningful data on discard rate and harvest need to be collected regionally, along with post-release survival, if we are to have a realistic idea of the likely impacts of discarding in this fishery. The same authors noted that discard rates from line fisheries might be expected to vary widely among species.

Mitigation and Canadian experience

Groundfish

In the Pacific region, the groundfish fisheries are classified as “hook and line” gear fisheries, including longline, troll, and jig. Ling cod is the only species where catch by longline is prohibited. Catch statistics that distinguish these different hook and line gears are currently unavailable.

In the Pacific region, a three-year pilot plan for integrating management of commercial groundfish fisheries began in 2006, and is continuing until evaluation is completed (DFO, 2009a). The objective is "to improve stock management through bycatch monitoring, reduced discarding, and requiring harvesters to be accountable for all catch.” New monitoring standards for groundfish hook and line fisheries require 100% at-sea and dockside monitoring (DFO, 2009a). Monitoring can be accomplished either through at-sea observer coverage or through the use of an Electronic Monitoring (EM) system. Other measures include individual vessel quotas (IVQ) for lingcod and dogfish, and individual quotas (IQ) for rockfish fisheries; a temporary quota reallocation process between the various commercial groundfish sectors will also address bycatch (DFO, 2009a). The integrated management plan appears to be contributing to conservation and sustainable use. We now have:

- comprehensive, timely data, acquired through a much improved catch monitoring system, on all fish caught (both landed and released) in all seven groundfish fisheries;
- certainty that current catch levels are being maintained within allowable limits for all species, and;
- evidence that there is substantial reduced waste of fish in fishing operations.

However, the program imposes a supplementary cost on fishers, which has been controversial. Some offset may come through improvements in fleet efficiency, but there is no evidence for this yet. Social impacts on operators of smaller vessels and First Nations need to be addressed (Fraser, 2008).

In Atlantic Canada, the collapse of groundfish stocks in the early1990s initiated a strong movement for conservation-based management. Initially, measures focused on fisheries closures, reduced total allowable catch, license buyback and early retirement of fishermen. Limited fishery reopenings in 1999-2001 came with strict management measures including surveillance, gear selection, and catch monitoring in all Atlantic groundfish fisheries (DFO, 2007d). Sentinel fisheries were conducted to provide information concerning stock abundance, and tighter controls were introduced in the recreational food fishery (licenses, tags, and log books) to control harvests and provide DFO with an estimate of how much cod was being harvested annually through this sector (DFO, 2007d). There is a mandatory requirement for various groundfish fleets in Atlantic Canada to be equipped with a Vessel Monitoring System (VMS), which can improve compliance with fisheries regulations and contribute to increased accuracy and timeliness of fishing information (DFO, no date b). In the Maritime Region Groundfish Management Plan, all fixed gear vessels greater than 45 feet and all mobile gear vessels operate under Individual Transferable Quotas (ITQ) or Enterprise Allocations (EA) (DFO, 2004b). There is a competitive fishery with quotas for various stocks, divided among 10 geographically-based community management boards for fixed gear vessels less than 45' (DFO, 2004b). A Dockside Monitoring Program (DMP) to verify and report landings exists across the Atlantic region for groundfish.[2]

<u>Tuna</u>

In Canada, Atlantic bluefin tuna are fished over the Scotia Shelf, in the Gulf of St. Lawrence, in the Bay of Fundy, and off Newfoundland. The number of license holders eligible to land bluefin tuna increased to 777 in 2004 and has remained constant since then (ICCAT, 2008). The number of vessels active in the fishery has varied from year to year: in the Gulf of St. Lawrence there was a high of 350 vessels in 2004, dropping to around 250 in 2007 (ICCAT, 2008).

This fishery primarily employs rod-and-reel gear or tended lines. 2007 landings by gear type were: 389 tonnes by rod and reel, 23 tonnes by tended line, 17 tonnes by harpoon, 58 tonnes as longline bycatch, and 4 tonnes by trap (ICCAT, 2008). Vessels are restricted to a maximum of four lines and one hook per line. A portion of the Canadian harvest, as indicated above, is taken as bycatch in the longline fisheries for swordfish and other tunas (DFO, 2009j).

<u>Atlantic mackerel</u>

The Canadian Atlantic mackerel fishery is highly competitive. In recent years in the southern Gulf of St. Lawrence, large numbers of mackerel below the minimum legal size or the size accepted by processing plants are being discarded in the hand line fishery. Mortality of discards is not known. However, given the predominance of the hand line fishery in the southern Gulf, discards are a major concern. There is a 10% allowed bycatch of herring in the mackerel fishery (DFO, 2008c).

[2] In contrast to other species management plans, current management plans for cod or other groundfish in Atlantic Canada appear not to be available online.

Atlantic cod

The 1993 moratorium on Atlantic cod allows for modest commercial directed fisheries in some areas. Fishermen handlining for cod landed 1,124 tonnes in Newfoundland/Labrador in 2008 (Appendix 1).

Squid

Jigging for short-finned squid (*Illex illecebrosus*) is mostly confined to Newfoundland. The inshore bait fishery for squid in Newfoundland has operated for more than a hundred years and, until the mid 1960s, contributed at least 90 per cent of Atlantic Canada's squid catch (DFO, 2008e). In 2008, 514 tonnes were landed in Newfoundland/Labrador (Appendix 1). No data on by-catch is available.

On the Pacific coast, jig fisheries for the opal squid are recreational. This activity has been prohibited in Rockfish Conservation Areas (DFO, 2007f). It is unclear if this is out of concern for bycatch, difficulty in policing different jigging activities in the area, or concern about snagging biogenic substrates. Commercial jig fisheries have also been experimented with for the flying squid (*Ommastrephes bartrami*) (DFO, 1999b) as a more responsible alternative to the experimental driftnet fishery that was notorious for excessive bycatch levels (McKinnon and Seki, 1998).

DIVING

Impacts on biodiversity and ecosystems

Some insights on impacts from scuba fishing can be gained from the literature on recreational diving. Although scuba diving has been perceived as compatible with conservation, there are recent concerns that some heavily dived sites may have visitation rates exceeding the limits of ecological sustainability (Hawkins and Roberts, 1996; Treeck and Schuhmacher, 1998). Impacts can be concentrated spatially, as divers choose certain sites over others (Shivlani and Suman, 2002). While environmental research on diving has primarily been conducted in the tropics (Medio et al., 1997; Rouphael and Inglis, 1997), recent studies of diving in temperate waters have highlighted the potential for cumulative impacts. This may be especially true for Marine Protected Areas (MPA), which are known to attract divers (Harriott et al., 1997; Schaeffer et al., 1999). Divers can have a wide range of impacts, including the harvest of natural resources, direct physical damage to habitat—either by divers or from anchoring—and indirect impacts, such as increased sediment and nutrient loads associated with dive-tourism infrastructure (Hawkins and Roberts, 1992; Harriot et al., 1997; Nickerson-Tietze, 2000). In places where the harvest of marine organisms using scuba equipment is prohibited (for example, in New South Wales), physical damage to habitat is the most pressing concern (Lynch et al., 2004).

Despite these potential concerns, Fuller et al (2008) rates diving as having the lowest impact among the most common fishing gears. Bycatch in the dive fishery (which includes geoduck, horse clam, sea urchins, sea cucumbers and other species) is unknown. In general, habitat damage from dive fisheries is minimal, although the Pacific geoduck fishery disturbs the sediment and infauna (burrowing animals) with hydraulic hand tools (DFO, 2009k). Even careful handling by divers can dislodge kelp and invertebrates living on or near the seafloor.

Mitigation

Many dive fisheries in the world can be described as small scale or artisanal. Centralized monitoring, assessment, and control of these fisheries are unrealistic. In many countries, problems created by dive fisheries are hard to control. A good example is the widespread use of cyanide in dive fisheries for aquarium fish in southeast Asia (Wabritz et al., 2003).

Canadian experience

Canadian commercial dive fisheries on the Pacific coast, except for octopus, are species-specific limited entry, individual quota fisheries, generally managed co-operatively and conservatively with the license holders. Many are quite lucrative, well beyond the artisanal level of fishing effort. First Nations communal licences are fished similarly. In the Maritime Region, the only dive fishery is for sea urchins, managed differentially in different areas.

Geoduck (*Panopea abrupta*)

Geoducks are harvested commercially by divers using high pressure water delivered through a nozzle. Geoducks are usually delivered live to Asian markets. The commercial dive fishery for geoduck and horse clam (Tresus capax and T. nuttallii) in B.C. began in 1976 and expanded rapidly until 1979, when the number of licenses was limited and harvest quotas were set for conservation reasons (DFO, 2009k).

In 1989, at the request of the commercial industry, a geoduck management program with individual vessel quotas (IVQ) was initiated (DFO, 2009k). As part of this initiative, area licensing and a three-year area rotation period for the fishery were established. Geoduck IVQ were set at 1/55 of the annual coast-wide quota, and vessel owners were required to select one of three license areas in which to fish. Commercial fishery openings are scheduled to allow for a year-round supply of geoducks to the market. Horse clams, generally harvested incidentally to geoducks, were not included in the IVQ system (DFO, 2009k). First Nations non-commercial harvest is limited to the shellfish gear specified in their communal license. The recreational fishery is limited to hand digging methods.

Very little is documented on the effects of harvesting geoduck or horse clam on nearby eelgrass beds or other habitats. Activities are unlikely to impact eelgrass beds if they extend at least 10 metres, and harvesters are urged to avoid eelgrass beds when anchoring and dragging air hoses (DFO, 2009k).

Sea urchin

Sea urchins play an important ecosystem role, and their removal through over-fishing would be expected to destabilize ecological equilibria (Scheibling, 1996; Sumi and Sheibling, 2005).

There are commercial fisheries for red sea urchins (*Strongylocentrotus franciscanus*) in British Columbia (DFO, 2009l) and green sea urchins (*Strongylocentrotus droebachiensis*) in both B.C. and Atlantic Canada (DFO, 2000b; Lopuch, 2008; Miller and Nolan, 2008; DFO, 2009m) (Appendix 1). Both are caught for their roe, for which the main market is Japan. On the west coast, urchins are fished with individual transferable quotas. On parts of the East Coast, however, green urchins have also been fished on a habitat-based management scheme with exclusive area rights that appear to value habitat/ecosystem function (Miller, 2008).

The Pacific stocks are considered to be moderately healthy, with further research ongoing (Lopuch, 2008; DFO, 2009m). Atlantic stocks have not recently been assessed. Both species are inherently resilient because they mature quickly (less than 5 years), and have a high reproductive potential (Lopuch, 2008).In the Canadian urchin fisheries, precautionary management has resulted in more stable population trends and a lower probability of overfishing (Lopuch, 2008). All the Canadian urchin fisheries have limited entry licensing, a minimum size limit, and area licensing, while B.C. and New Brunswick urchin fisheries also have harvest quotas and individual quota (IQ) programs (DFO, 2000b; Miller et al, 2008; DFO, 2009l and m). If urchins are hand- collected there is considered to be minimal impact on habitat, and bycatch is negligible (Lopuch, 2008).

<u>Octopus</u>

In Canada, octopuses are harvested by scuba divers, who drive the animals out of their dens using an irritant. Harvesters are not permitted to use deleterious substances as an irritant, or sharp implements. The octopus dive fishery is classified as an experimental fishery, occurring primarily in south coast areas. The majority of octopuses are landed on the East Coast of Vancouver Island (DFO, 2009o).

Octopus landings increased briefly in the late 1980s in response to a demand as bait in the halibut fishery; this demand has now subsided. Since 1996, there has been some interest in the octopus fishery for food products.

As with the sea urchin dive fishery, impacts of the octopus fishery would appear to be limited to effects of removing numbers of the target animal, rather than to any gear considerations, as long as restrictions on the types of gear and the use of noxious chemicals are adhered to (DFO, 2009o).

FISH WHEEL

<u>Impacts on biodiversity and ecosystems</u>

The fish wheel is an historic gear that has made a small comeback mainly as a fisheries management tool, with little impact on the overall catch in the commercial salmon fisheries in those parts of B.C. and Alaska where it is used. In studies on effects of fish wheel capture and handling in the Yukon River in Alaska, mortality associated with capture and handling appeared to be the most likely cause for a reduction in mark rates at upriver locations (Underwood et al., 2004; Bromaghimn et al., 2007). Bromaghimn et al. (2007) found that holding fish in submerged pens at the marking site reduced their ability to migrate, at least for some time after release. These authors suggest that fish wheels may have more effects on released fish than was previously thought.

Fish wheel ecosystem impacts depend on location and size. Historically, fish wheels could be up to 30 metres in diameter and harvest as much as 35 tonnes a day (Sturhahn and Nagtegaal, 1999). Today’s designs are portable and are usually only in operation during salmon migration runs, so they are likely to cause little to no habitat impact. Unfortunately, there is no literature in this area.

Mitigation

In the course of monitoring salmon runs with fish wheels in Alaska, Daum (2005) developed an event-triggered video system that eliminated the handling and holding of fish associated with live-boxes. Fish were recorded during capture, then immediately released. In evaluations of reliability and accuracy over 14,000 hours of operation and 262,000 fish images, the system failed only once.

In a long-term monitoring project for chinook abundance in the Cooper River, Alaska, vertical-slot "escape panels" were developed for the fish wheel live tanks, which allowed the much more abundant sockeye salmon to escape while retaining chinook salmon (Smith et al., 2005). This modification allowed for reduced handling of non-target fish.

Canadian experience

Fish wheels were used for commercial harvest of salmon in B.C. rivers from the late 1870s to the mid 1930s, when excessive catch threatened the livelihood of traditional net fishermen (Sturhahn and Nagtegaal, 1999; Whitehouse et al. 2005). In 1934, fish wheels were banned from B.C., partly as a result of successful lobbying from the net fisheries (Sturhahn and Nagtegaal, 1999). In the early 1990s, however, fish wheels were brought back as a tool for fisheries managers and biologists who were tagging migrating salmon stocks (Link et al. 1996). Fish wheels are now used on the Yukon, Taku, Nass, Skeena and Fraser Rivers for First Nations' harvesting and escapement monitoring programs (Whitehouse et al., 2005).

CAST NET

Impacts on biodiversity and ecosystems

Manual cast nets, when employed intensively, may be harmful to fish populations depending on mesh size. A small mesh can catch immature fish living in schools or swarms. In intensive use on spawning aggregations or migrating schools, a cast net may also affect populations by overfishing, particularly in restricted freshwater environments. Bycatch can be reduced by banning cast nets with exceedingly small meshes, and effects on reproductive aggregations can be alleviated by area or time closures (FAO, 1994).

Cast nets are not inherently selective, except as determined by their user that target their catch. They are particularly useful for fish that are schooling in shallow water, close to shore, or at the surface. Bycatch can theoretically be released with little mortality, as the net is retrieved immediately.

Cast netting/ thrownetting continues to be a traditional gear of choice for coastal or freshwater artesenal fisheries in many countries (where it has not been replaced by gillnets), but in developed countries it is used exclusively for bait fisheries for recreational use. Concerns include the impact on juvenile fish and spawning fish that aggregate in areas particularly good for cast netting. In some places regulations exist for maximum net size, minimum mesh size, and season or location of use. In Pennsylvania, for example, nets of up to 20 feet in diameter and minimum 3/8 inch mesh are allowed (Pennsylvania Fish and Boat Commission, 2009) and used to capture gizzard chad and alewives (Cimbaro, 2006). In Hawaii, where traditional reef fisheries use cast nets, regulations on the use and mesh size of cast nets are much more stringent. It is unlawful to use or sell nets with mesh size of less than 2 inches. (Hawaii Division of Aquatic Resources, no date). In general, however, there is very little literature on the use of this gear and its potential environmental impacts.

Mitigation and Canadian experience

In Canada, cast nets are permitted on the Pacific coast for recreational fishing of herring, mackerel, anchovy, sandlance, sardines, and squid with no net or mesh size stipulations (Anon, 2009b). Specific reference to castnets was not found for other regions. We found no data on levels of use or mitigation measures.

HAND DIGGING OF INVERTEBRATES

Hand digging, picking and spear fishing are examples of artisanal, and usually small scale, fisheries. As the examples below will show, they can still have significant impacts, whose cumulative effect depends on the number of enterprises in a given area. The problem of isolating gear effects from simple over-harvesting is particularly acute for such fisheries.

Impacts on biodiversity and ecosystems

An example of where the effects of hand-digging have been studied is the collection of the lugworm *Arenicola marina* for bait. In Maine, collection not only reduces target species density for as long as six months (Cryer et al., 1987), it also affects non-target species including the soft-shell clam, *Mya arenaria*, causing shell damage and increased susceptibility to epibenthic predators such as gulls (Ambrose, 1986; Beukema, 1995; Ambrose et al. 1998). Brown and Wilson (1997) also demonstrated that clam and baitworm digging in Maine reduced population densities of the polychaetes *Heteromastus filiformis*, *Streblospio benedicti*, and *Tharyx acutus* and reduced overall species richness (Brown and Wilson, 1997).

In Dutch coastal waters, lugworm harvesting is done both mechanically and by hand. Because several other zoobenthic species are disturbed and a significant proportion of the benthos dies as a consequence of lugworm digging, local effects are expected to be considerable (Van den Heiligenberg, 1987). So far, only results of short-term and small-scale studies have been reported. Van den Heiligenberg (1987) reports higher death rates in lugworms and other benthic animals from mechanical harvesting than from hand digging. However, the areas that were fished were small, and several species rapidly returned, with the abundance of most species completely recovered after six months. On the other hand, Jackson and James (1979) report a drastic decline in the cockle (*Cerastoderma edule*) population as a result of harvesting lugworms and, six months after lugworm harvesting on a tidal flat in the Wadden Sea, total zoobenthic biomass was still well below control values at most sites (Van den Heiligenberg 1987). Physical disturbance associated with collection of the benthic ghost shrimp, (*Callianassa kraussi*) decreased densities not only of the target species, but also of associated benthic macrofauna.

Mechanical intertidal harvesting of another bivalve, the cockle, also causes high mortality in non-target benthic fauna (Hall and Harding, 1997), and clam harvesting in North Carolina decreased densities of both clams and oysters in comparison to undisturbed sites (Lenihan and Micheli, 2000). Griffiths et al. (2006) demonstrate that recreational clam digging reduces clam densities and overall biodiversity.

In general, short- term disturbances such as intertidal hand-digging or trawling include reduction in the abundance of benthic species and their biomass (Hall, 1999, cited in Logan, 2005). Distinct benthic community compositions have been observed for these physically disturbed sites (Wynberg and Branch, 1997; Logan, 2005).

Mitigation

In general, commercial and recreational harvest on intertidal public land appears to be limited to hand tools to minimize deleterious impacts on the clam beds. The Clam Diggers Association of Oregon state has also published best-practices guidelines for recreational clam digging, which include reference to minimizing damage during digging, filling in dug holes and trenches, replacing unwanted clams in species-specific fashions, and avoiding eelgrass (Lackner, 2005). We found no data on what extent these kinds of practices are implemented.

Canadian experience

In the Maritime Provinces oysters are harvested from natural beds and leased areas using rakes, tongs and dredges, as well as by handpicking at low tide in shallow waters. Raking and tonging are done by hand, operated in depths of up to 7.6m (25 ft.) and 5.4 m (18 ft), respectively. Hand- or small boat-operated dredges can be used in deeper water, but are only allowed on oyster leases and some restricted public areas (DFO, 2008f). Predators taken incidentally, such as starfish and rock crabs, are often destroyed by their collectors (DFO, 2008f). We could not find any assessment of this bycatch, nor the effects of their disposal.

In the case of clams, that live within the interstitial habitat that is disturbed by harvest, it can be difficult to separate effects of overfishing from habitat damage that affects recruitment. Intensive commercial harvesting and repeated digging may affect survival and growth rates of the clams left behind (bycatch) and potential for recruitment, even with minimum legal size limits set above the size of reproductive maturity (DFO, 2009n). Management measures thus often combine concerns on habitat and bycatch impacts with those of stock maintenance. In the case of clam digging in Quebec, collection is limited to hand tools (clam digging fork and shovel), a minimum shell size (51 mm), a harvesting season and a participation clause. The management plan calls for “controlling harvesting mortality and mitigating fishery bycatches” to maintain stocks and reproductive potential. Strategies employed include permitting only hand tools, advising against collection when temperatures are below freezing, and dissuading “disturbance of coastal habitats, particularly the sediment.” (DFO, 2008e). The plan reports that significant impact on stocks by exploitation only exists in a few locations.

On the Pacific coast, clams are harvested for commercial, recreational and traditional use by hand digging. Four species of intertidal clam (butter, littleneck, Manila, and razor) make up most of the landings in commercial and recreational fisheries (DFO, 2009n). Manila clam, an introduced species, is the most widely sought species. Bingham (2007) discusses a variety of potential impacts of clam digging on non-target species, including disruption of the benthic ecosystem and reduced biodiversity (Griffiths et al., 2006), uprooted or trampled eelgrass (Boese, 2002), infaunal mortality from trampling (Rossie et al., 2007), and changes in food availability or foraging opportunities for birds (Jamieson et al., 2001). The Management Plan for harvesting Razor Clams warns against the use of motor vehicles on beaches to avoid damage to clams in the lower intertidal and juvenile clams in the mid-intertidal (Council of the Haida Nation and DFO, 2009), but in general management regulations do not deal with impacts on species other than clams.

HAND PICKING OF SEAWEED

Impacts on biodiversity and ecosystems

Harvesting of attached and drifting seaweed is done using small hand tools. Some commercial operations use mechanized tools to assist with large harvests. In Northern Ireland, hand tools are believed to be the least damaging ecologically, while mechanical harvesting could threaten the marine ecosystem, undermining the sustainable use of the seaweed resource (McLaughlin et al., 2006). However, data on ecosystem effects of harvesting are often lacking. For example, there is limited information on the biomass, distribution and productivity of living seaweed and drift weed around the Northern Ireland coastline, and little research has been carried out on the direct and indirect effects of harvesting on biodiversity and coastal processes. There is also little known about the carrying capacity of marine ecosystems to support seaweed harvesting and mariculture. Harvest of wild seaweeds on a large scale occurs in some countries (McLaughlin et al., 2006), but much of the research has not been published in the scientific literature, having been done by harvesting companies or by government.

Canadian experience

On the east coast of Canada, *Chondrus crispus* (Irish moss), *Ascophyllum nodosum*, and species of *Laminaria* (a kelp) are the few economically valuable species harvested (Sharp and Pringle, 1990). Stands of *C. crispus* house up to 36 animal species and 19 major species of algae, which are vulnerable to removal as bycatch (Sharp and Pringle, 1990). In some areas of Atlantic Canada, long-term harvesting has altered the population structure and population ecology of *C. crispus* and *A. nodosum*; however, both target species and associated communities are resistant to perturbation in general (Sharp and Pringle, 1990). In British Columbia, various kelp species are harvested in a specialized fishery for production of herring roe-on-kelp. Species of *Porphyra* (nori) are also harvested occasionally by fishermen, First Nations, and the public, and a few individuals have licenses to harvest *Laminaria* (Chambers et al., 1999). These algal fisheries are regulated by the Provincial Government, and though once considered of considerable potential for economic development are not currently exploited significantly.

A 1990 review of the ecological impact of marine plant harvesting in the northwest Atlantic concluded that, while macrophyte communities were resistant to long-term damage by current commercial harvesting techniques, there remained considerable room for improved resource management plans to permit optimization of environmentally sustainable annual yields (Sharp and Pringle,1990).

SPEAR-FISHING AND HARPOON

Impacts on biodiversity and ecosystems

FAO considers commercial fishing activities with harpoons to be of minor importance (FAO, 2008j). Spear and harpoon fishing are highly selective and produce little bycatch. However, along with beach seines, spear guns have been described as the most destructive fishing gear used in Kenya's reef lagoons. Spear guns are not themselves destructive, but selection of target species alters their population size and composition, especially by removing large animals; spears can also damage corals (Mangi and Roberts, 2006).

Groupers are apex predators often caught by spear fishing. They are thought to play important roles in ecosystem function. Their loss or reduction from coral reef communities can affect local biodiversity and ecosystem stability (Dulvy et al., 2004; Campbell and Pardede, 2006). In Micronesia, survey findings show a fishery dominated by night-time spearfishing that largely removes juveniles and small adult grouper (Myers, 1999; Allen, 2005). While spear fishing will have local impacts on population dynamics and structure, particularly in the more accessible shallow inshore waters, previous research has been limited to the larger "trophy" species. The dynamics of the recovery of these impacted populations are poorly understood (Pollard et al., 1996).

Mitigation

Management of fisheries in developing countries is complicated with multi-species fisheries, numerous types of gear, and different levels of governance. In a survey of fishers and managers in Kenyan coastal small-scale fisheries, respondents generally agreed on which gears that the government and traditional leaders discourage. There were, however, differences in opinion as to which gear is believed to sustain fish catches, particularly for fishers that use gears discouraged by their leaders. Beach seines and spear guns were the two gears most often listed as discouraged, with most other gear receiving only scarce mention (McClanahan et al., 2005).

Canadian experience

In the early 1960s, the Atlantic swordfish fishery shifted from a harpoon to primarily a longline fishery. There were still 1,242 harpoon-only licences Atlantic-wide in 2004; only 188 harpoon-only licenses were recently active according to DFO records (DFO, 2004c) (Appendix 1). Harpooning involves sighting a swordfish at the surface and spearing it with a 4–5-metre harpoon attached to a buoyed line. There are no known bycatch or habitat damage concerns in the harpoon fishery (Fuller et al., 2008).

DISCUSSION

The impact of commercial fishing on marine ecosystems is determined by factors that include gear type, gear design, timing, duration and frequency of use, as well as operator competence and knowledge (Revill, 2003), oceanographic conditions and bottom types. In general, the impacts of fishing gear can include:

- habitat modification, degradation or destruction,
- decline of the target population, at times leading to collapse from over-fishing,
- decline of non-target populations and species due to bycatch or other ecosystem impacts, and
- shifts in species composition (Environment Canada, 1996; Hughes et al., 2005).

Mounting evidence of these impacts has led to an increasing recognition of the need for fishing practices that are more sustainable both in terms of maintaining productivity and minimizing environmental impacts, as well as new or updated legislation that supports these practices. There are two main factors that have driven this recognition:

- reduced stocks of target species with a direct economic impact on fisheries, and

- greater public interest in impacts on non-target species, ecosystems, and/or local stocks.

Both drivers lead to formal and informal investigation, a sometimes raucous discourse and, ideally, mitigation. This report investigates the current status of the field as reflected in the scientific literature, focusing on selected gear types. Separating or quantifying the two main drivers was, however, beyond the purview of the report.

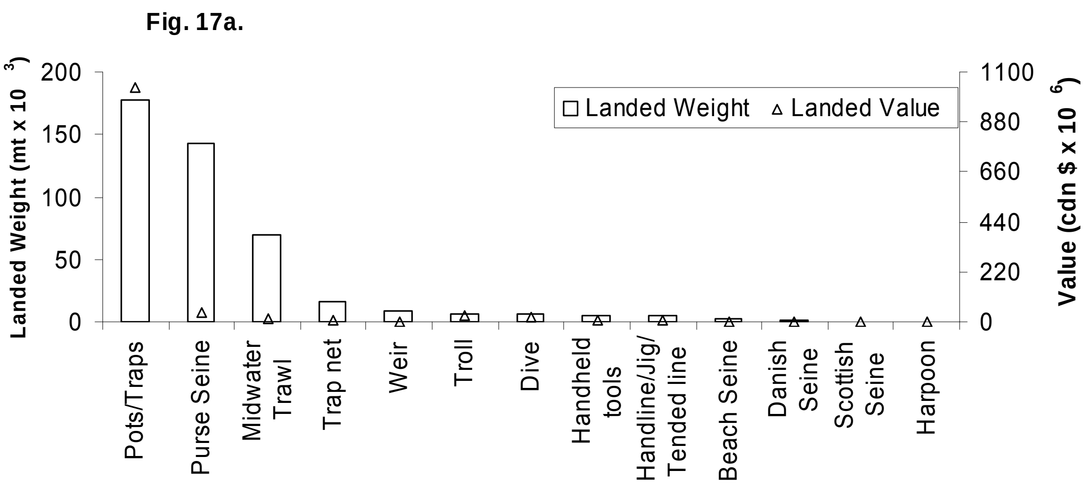
The “miscellaneous” fishing gear described in this review represents a substantial contribution to Canadian fisheries, both in quantity and value (Figure 17 and Appendix 1). Pots and traps are the dominant category by far, primarily represented by lobster and crab fishing. Fraser et al. (2008) rated fisheries gear by a survey of the opinions of fisheries stakeholders and literature (Table 1). Our review did not find substantially different results. They are summarized in Table 2, with current mitigation strategies. This table also includes an indicator of potential impact on VME. Reports on interactions with VME are few, with the potential impacts of large numbers of pots and traps being the greatest threat. Specific data on the current impact is not great, though in some cases pots and traps have been promoted as a better option on seamounts relative to more destructive trawl fisheries (DFO, 2009a). Potential effects on sensitive habitats are also included in this table, though the current scale of these impacts is not well documented. The potential effects on seagrass and benthic communities is a recurrent theme, including effects by dive and hand-collecting fisheries that are slipping under the radar. However, while these effects probably change targeted ecosystems on an ongoing basis, they appear to be quite localized impacts.

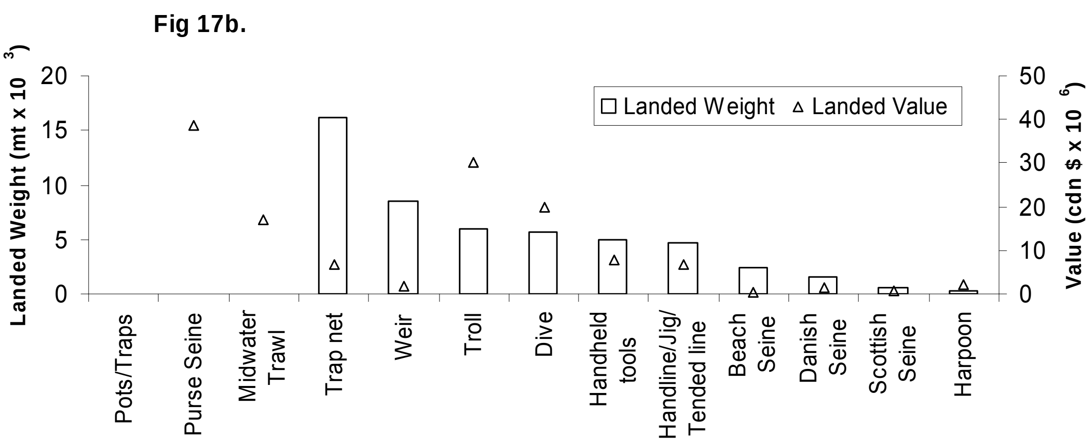
The WGECO also identified a series of criteria for assessing ecosystem impacts of fishing activities – including a variety of biodiversity-related impacts (ICES, 2007). Ghost fishing by traps is perhaps of greatest concern in this analysis, as well as entanglement by this gear of charismatic and endangered species.

Mitigation measures encountered in the literature include gear modifications such as degradable escape hatches to reduce ghost fishing of traps and special net panels in seining, traps and weirs to reduce mammalian bycatch. Operational mitigation measures are, however, key elements in mitigating most impacts – including special techniques for releasing bycatch live, and avoiding bycatch with temporal or spatial fisheries closures.

Table 1. "Ecological impact ratings 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; 1 = low impact, 5 = high impact. Figure adapted from Fuller et al. (2008, Figure 4).

	Habitat			Bycatch				
Gear type	**Corals & Sponges**	**Seabed**	**Inverte-brates**	**Ground -fish**	**Forage fish**	**Sharks & large pelagics**	**Marine mammals**	**Seabirds**
Bottom Gillnet	4	2	3	5	1	3	3	4
Bottom Longline	4	2	2	5	1	3	3	2
Bottom trawl	5	5	5	5	4	2	2	2
Dredge	5	5	5	4	1	1	1	1
Harpoon	1	1	1	1	1	2	1	1
Hook & Line	2	1	1	4	2	2	2	1
Midwater trawl	1	1	1	4	5	3	2	2
Pelagic longline	1	1	1	2	2	5	4	3
Pot & trap	3	2	3	3	2	1	1	3
Purse seine	1	1	1	2	4	3	2	2





N.B. See fig. 17a for catch values for Pots/traps, purse seine, and midwater trawl

Figure 17. Total landed weight and value of Canadian fisheries according to gear type, 2008. (a) All gears in report; (b) same as (a), but with smaller scale and excluding landed weights of larger fisheries.

Table 2. Summary of ecological impacts of fishing gear researched in this report.

Gear Type	Impact: Habitat	Biodiversity	VME impacted	Sensitive habitat impacted	COSEWIC threatened species	Charismatic species	Mitigation measures
Purse/ Tuck Seine	Insignificant benthic impact from occasional contact; smothering of habitat by lost gear or catch	Bycatch potential substantial with high mortality			Leatherback sea turtles	Dolphins; other sea turtles	Mesh size, operator skill, season & geographic controls; dolphin safety panels & bycatch reducing devices; brailers to transfer catch and permit live release of bycatch
Scottish Seine	Low if used on flat, smooth bottoms	Bycatch of sedentary organisms, undersized, and non-target species			Winter skate (Gulf of St. Lawrence pop'n)		Minimum mesh size; gear modifications; area closures
Danish Seine	Low if used on flat, smooth bottoms	Bycatch of non-target species & undersized target species					Minimum mesh size; area restrictions
Beach seine	Benthic disturbance from dragging & trampling	High bycatch potential due to low selectivity - undersized fish and low value fish	Corals (shallow water)	Estuaries			Seasonal & area closures; gear modification; mesh size regulations; bycatch released live
Mid-water Trawl	Low potential through bottom hits, dragging footrope & ghost fishing	Bycatch rate low, but cumulative total high				Dolphins, seals	Escape panel; logbooks; dockside monitoring; observer coverage; limited entry, openings & quota
Cast net		Possible change in fish use of an area					Mesh size; area and seasonal restrictions
Trap net		Fish & mammal bycatch; striped bass & Atlantic salmon			Striped bass (St. Lawrence pop'n); eel (target species in fishery); Atlantic salmon	Seals; capelin (keystone species); Atlantic salmon	Ttime & area restrictions; salmon exclusion device, mesh size, seal avoidance panels, live release of bycatch, acoustic deterrents

Table 2.(Cont'd) Summary of ecological impacts of fishing gear researched in this report.

Gear Type	Impact: Habitat	Biodiversity	VME impacted	Sensitive habitat impacted	COSEWIC threatened species	Charismatic species	Mitigation measures
Weir		Fish & mammal bycatch				Seals	Time & area restrictions; dockside monitoring, training for live release of mammal bycatch; entry panels to avoid seal bycatch
Trolling		Minimal bycatch; mammal depredation					Operational to avoid training mammals; hook design and permit live release; quotas; recovery boxes
Handline/ Jigging/ Tended line		Minimal bycatch, but rockfish of concern in squid jigging (?)		Coral reefs		Sharks (on tuna lines); albatross; petrels	Vessel Monitoring Systems; quotas; gear design & restrictions; live release of bycatch
Harpoon/ Spear	Corals			Coral reef lagoons			
Pots/ Traps	Entanglement; coral & benthic damage;	Ghost fishing; bycatch	Seamounts; coral reefs		North Atlantic right whales; cusk; spotted and Northern wolffish	Humpback whales	Degradable escape hatches; mesh size; soak time; area controls; license limits; trap limits; quotas; size limits; observer coverage
Dive	Benthic & structural disruption	Minimal		Eelgrass beds; MPAs			Limited entry; quotas; area restrictions; size limits; avoid eelgrass
Handheld tools	Benthic, localized disruption	Target & non-target species densities & diversity; Forage opportunities for birds		Eelgrass beds			Size limits; seasonal closures; gear limited to hand tools
Fish Wheel		Bycatch potential					Bycatch released live

Table 2 (Cont`d) Ecosystem impacts of gillnets and longlines

Gear Type	Impact						Mitigation measures
	Habitat	**Biodiversity**	**VME impacted**	**Sensitive habitat impacted**	**COSEWIC threatened species**	**Charismatic species**	
Pelagic Gillnet		Bycatch potential			NA Right whale	Birds, whales	Operational[1], mesh size, coloured top panels, trot-lines, bycatch revival tanks; pingers
Bottom Gillnet	Entanglement	Bycatch potential, ghost fishing	Seamounts, *Lophelia* reefs			Turtles, cetaceans, other mammals, birds	Operational, mesh size; pingers, reduced fleet size (# joined nets); taut rather than saggy nets; reduced buoy lines; acoustic tags;;
Pelagic Longline		Bycatch potential			Leatherback turtle	Birds, sharks, turtles	Gear and operational modifications, bycatch revival
Bottom Longline	Entanglement	Bycatch potential	Seamounts, *Lophelia* reefs		Leatherback turtle	Depredation by whales	Regional restrictions, gear and operational modifications, bycatch revival

[1] “Operational” Includes avoiding areas and times of high concentrations of potential bycatch species, protocols for raising or deploying gear, etc.

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APPENDIX 1. CANADIAN CATCH SUMMARY

Canadian catch summary for 2008 of gear covered in this report. Landed weights and value of species with 5 tonnes or more of catch only are shown. Data from preliminary DFO statistics.

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
Danish Seine	American Plaice	*		Gulf	10	9
	American Plaice		*	Gulf	34	29
	American Plaice		*	Newfoundland/Labrador	48	34
	American Plaice		*	Quebec	5	4
	Cod	*		Gulf	13	15
	Cod		*	Gulf	39	48
	Cod		*	Newfoundland/Labrador	26	42
	Cod	*		Quebec	230	299
	Greenland Halibut/Turbot		*	Maritimes	21	34
	Greysole/witch	*		Gulf	311	358
	Greysole/witch	*		Maritimes	164	110
	Greysole/witch	*		Newfoundland/Labrador	472	333
	Hake		*	Newfoundland/Labrador	6	4
	Redfish	*		Maritimes	91	65
	Redfish		*	Newfoundland/Labrador	29	17

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Shrimp	*		Gulf	57	30
	White Hake		*	Gulf	7	4
Pair Danish Seine	American Plaice	*		Gulf	23	22
Danish Seine Total					**1586**	**1,457**
Scottish Seine	American Plaice		*	Quebec	8	5
	Cod	*		Gulf	107	148
	Cod		*	Gulf	14	24
Scottish Seine	Cod		*	Quebec	5	8
	Greenland halibut/turbot	*		Gulf	24	53
	Greenland halibut/turbot		*	Gulf	9	18
	Greenland halibut/turbot		*	Quebec	7	13
	Greysole/witch	*		Gulf	57	55
	Redfish	*		Gulf	75	72
	Redfish	*		Quebec	141	125
	Unspecified groundfish			Quebec	111	133
Scottish Seine Total					**558**	**655**
Pots/Traps	Crab (unspecified)	*		Pacific	6437	36,483

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Crab, jonah	*		Maritimes	385	311
	Crab, rock	*		Gulf	4481	3,615
	Crab, rock		*	Gulf	386	209
	Crab, rock	*		Maritimes	339	160
	Crab, rock	*		Newfoundland/Labrador	85	65
	Crab, rock	*		Quebec	1778	1,546
	Crab, snow	*		Gulf	18526	85,597
	Crab, snow	*		Maritimes	8870	40,566
	Crab, snow	*		Newfoundland/Labrador	52740	179,483
	Crab, snow		*	Newfoundland/Labrador	9	30
	Crab, snow	*		Quebec	13464	45,505
	Crab, spider/toad	*		Gulf	53	46
	Crab, spider/toad	*		Newfoundland/Labrador	362	284
	Eel	*		Newfoundland/Labrador	22	80
	Hagfish	*		Maritimes	1242	1,242
	Hagfish	*		Newfoundland/Labrador	207	343
	Lobster	*		Gulf	17450	171,604

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
Pots/Traps	Lobster		*	Gulf	70	691
	Lobster	*		Maritimes	33411	364,812
	Lobster	*		Newfoundland/Labrador	2807	26,412
	Lobster		*	Newfoundland/Labrador	174	1,610
	Lobster	*		Quebec	3451	36,991
	Octopus		*	Pacific	16	51
	Prawn	*		Pacific	1677	18,479
	Rockfish (Rougheye, Shortraker, Shortpine thornyheads)		*	Pacific	26	est. 31
	Sablefish	*		Pacific	1427	est. 9,441
	Shrimp	*		Pacific	27	221
	Unspecified crustaceans			Quebec	1256	1,288
	Whelk	*		Newfoundland/Labrador	5911	6,507
Pots/Traps Total					**177087**	**1,033,705**
Midwater Trawl	Cod	*		Quebec	10	13
	Euphausiid	*		Pacific	17	23
	Hake	*		Pacific	69530	16,862
	Sea Scallop	*		Maritimes	123	164

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
Midwater Trawl Total					**69680**	**17,062**
Purse Seine	Capelin	*		Gulf	66	5
	Capelin	*		Newfoundland/Labrador	15854	4,112
	Chinook Salmon	*		Pacific	30	177
	Chum Salmon	*		Pacific	857	1,512
	Coho Salmon	*		Pacific	16	28
	Herring	*		Gulf	4213	758
	Herring	*		Maritimes	53231	10,077
	Herring	*		Newfoundland/Labrador	19063	3,555
Purse Seine	Herring		*	Newfoundland/Labrador	191	36
	Herring	*		Pacific	54	38
	Herring (roe)	*		Pacific	6559	5,640
	Mackerel	*		Newfoundland/Labrador	20824	5,651
	Mackerel		*	Newfoundland/Labrador	8	2
	Pink Salmon	*		Pacific	188	103
	Sockeye Salmon	*		Pacific	466	1,797
Tuck Seine	Capelin	*		Newfoundland/Labrador	10314	2,646

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Herring	*		Newfoundland/Labrador	5208	967
	Herring		*	Newfoundland/Labrador	100	19
	Mackerel	*		Newfoundland/Labrador	1719	467
	Mackerel		*	Newfoundland/Labrador	28	8
	Capelin	*		Newfoundland/Labrador	3694	944
Purse/Tuck Seine Total					**142680**	**38,540**
Beach & Bar Seine	Herring	*		Newfoundland/Labrador	2224	413
	Mackerel	*		Newfoundland/Labrador	186	51
	Unspecified, otherfish			Quebec	54	8
Beach & Bar Seine Total					**2464**	**472**
Trap net (trap net)	Alewives/Gaspereau	*		Gulf	2900	1,428
(trap net)	Capelin	*		Newfoundland/Labrador	7685	1,968
(trap net)	Cod	*		Newfoundland/Labrador	26	38
(fyke net)	Eels	*		Gulf	138	691
(fyke net)	Eels	*		Newfoundland/Labrador	23	92
(trap net)	Herring	*		Maritimes	235	44
(trap net)	Herring	*		Newfoundland/Labrador	1426	268

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
(trap net)	Herring	*		Quebec	307	41
(trap net)	Mackerel	*		Maritimes	886	703
Trap net …... (trap net)	Mackerel	*		Newfoundland/Labrador	247	67
(trap net)	Mackerel	*		Quebec	20	6
(trap net)	Silversides	*		Gulf	425	389
(box net)	Smelt	*		Gulf	540	352
(trap net)	Smelt		*	Gulf	6	5
(box net)	Tom cod	*		Gulf	10	3
(trap net)	Tuna	*		Maritimes	23	561
(trap net)	Unspecified, other fish			Quebec	1257	181
Trap net Total					**16152**	**6,837**
Weir	Herring	*		Maritimes	8534	1,606
	Mackerel	*		Maritimes	26	21
Weir Total					**8560**	**1,627**
Trolling	Albacore tuna		*	Maritimes	5	56
	Albacore tuna, Can. waters	*		Pacific	93	283
	Bigeye tuna		*	Maritimes	14	161

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Bluefin tuna	*		Gulf	135	2,701
	Bluefin tuna	*		Maritimes	212	5,176
	Chinook salmon	*		Pacific	700	7,253
	Chum salmon	*		Pacific	78	145
	Coho salmon	*		Pacific	319	1,709
	Pink salmon	*		Pacific	44	49
	Tuna (species not identified), U.S. & International waters	*		Pacific	3373	10,800
Trolling or Jigging	Lingcod	*		Pacific	925	1,836
Trolling Total					**5897**	**30,168**
Jigging	Squid	*		Newfoundland/Labrador	514	219
	Mackerel	*		Gulf	250	152
Handline	Cod	*		Gulf	98	144
	Cod	*		Maritimes	35	72
	Cod	*		Newfoundland/Labrador	1124	1,774
	Cod	*		Quebec	20	27
	Dogfish	*		Maritimes	11	4
	Mackerel	*		Gulf	1401	905

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Mackerel	*		Maritimes	90	58
	Mackerel	*		Newfoundland/Labrador	27	7
	Mackerel	*		Quebec	875	463
	Pollock	*		Maritimes	34	31
Tended line	Bluefin tuna	*		Gulf	124	2,452
	Bluefin tuna	*		Maritimes	20	491
Handline/Jigging/Tended line Total					**4623**	**6,800**
Dive	Geoduck	*		Pacific	606	11,523
	Green Sea urchin	*		Maritimes	1311	2,903
	Green Sea urchin	*		Newfoundland/Labrador	47	53
	Green Sea urchin	*		Pacific	63	213
	Red Sea urchin	*		Pacific	1704	1,736
	Sea Cucumber	*		Pacific	1460	2,713
	Unspecified items			Quebec	428	722
	Bar clams	*		Gulf	70	74
Dive Total					**5688**	**19,937**
Handheld tools	Dulse	*		Maritimes	136	279

Gear Type	Species	Target	Non-target	DFO Region	Landed Weight (metric tonnes)	Landed Value ($ 000's)
	Mussels	*		Gulf	3253	4,294
	Periwinkles	*		Maritimes	12	24
	Quahaugs	*		Gulf	395	601
Handheld tools	Soft shell clams	*		Gulf	410	847
	Unspecified crustaceans			Quebec	14	16
	Clams	*		Pacific	696	1,763
Handheld tools Total					**4916**	**7,824**
Spear/Harpoon	Bigeye tuna	*		Maritimes	5	54
	Swordfish	*		Maritimes	255	1,624
Electric Harpoon	Bluefin tuna	*		Maritimes	22	541
Harpoon Total					**282**	**2,219**

APPENDIX 2. LIST OF ACRONYMS

AHD	Acoustic Harassment Devices
BRD	Bycatch Reducing Devices
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CEC	Commission of the European Communities
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CSAS	Canadian Science Advisory Secretariat
DFO	Department of Fisheries and Oceans Canada
DMP	Dockside Monitoring Program
DSP	Dolphin-Safety Panel
EA	Enterprise Allocation
EEZ	Exclusive Economic Zone
EM	Electric Monitoring
FAD	Fish Aggregating Devices
FAO	Food and Agricultural Organization of the United Nations
FRCC	Fisheries Resource Conservation Council
FOB	Floating object
GMWSRS	Grand Manan Whale & Seabird Research Station Inc.
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IFMP	Integrated Fisheries Management Plan
IOTC	Indian Ocean Tuna Commission
IQ	Individual Quota
ITQ	Individual Transferable Quota
IVQ	Individual Vessel Quota
NAFO	Northwest Atlantic Fisheries Organization
NWSI	Northwest Straits Initiative

SARA	Species at Risk Act
SOK	Spawn on Kelp
TAC	Total Allowable Catch
UNGA	United Nations General Assembly
VME	Vulnerable Marine Ecosystem;
VMS	Vessel Monitoring System
WCPFC	Western and Central Pacific Fisheries Commission
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WGECO	ICES Working Group on Ecosystem Effects of Fishing Activities
WGFMS	Ad Hoc Working Group of Fishery Managers and Scientists (NAFO)