THE IMPACT OF MOBILE FISHING GEAR ON BENTHIC HABITAT AND THE IMPLICATIONS FOR FISHERIES MANAGEMENT

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The Impact of Mobile Fishing Gear on Benthic Habitat and the Implications for Fisheries Management

by

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A major report submitted to the

School of Graduate Studies

in partial fulfillment of the

requirements for the degree of

Master of Marine Studies
Fisheries Resource Management

Fisheries and Marine Institute of
Memorial University of Newfoundland

May, 2001

St. John's Newfoundland

Abstract

Marine fisheries for demersal fishes, crustaceans and mollusks are commonly conducted using otter and beam trawls, dredges and rakes. The ecology and behavior of these commercially valuable species requires that such fishing gears, in order to be effective collectors, must come into contact, and often penetrate the seabed. Concern has long been expressed about the impact of bottom fishing activity on benthic environments and there is now a strong consensus within the scientific community that mobile fishing gear can alter the benthic communities and structures on the seabed. However, the short and long-term consequences of this disturbance and the implications for management of future fisheries are not well understood.

This paper attempts to examine the issue of fishing gear disturbances of the seabed from a holistic perspective. The mechanisms by which mobile gear impacts the seabed, are considered, as well as the spatial and temporal distribution of this impact in the context of natural disturbances. The selectivity, technical performance, environmental and socio-economic impact of otter trawls is contrasted with other non-bottom contacting fishing technologies. The seabed has long been protected by various national and international agreements and treaties, however these have rarely, if ever, been effective. Various management alternatives to mitigate the adverse effects of bottom contacting fisheries are therefore discussed.

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List of Abbreviations and Symbols

CPUE	Catch per Unit Area
DFO	Department of Fisheries and Oceans
FAO	Food and Agriculture Organization of the United Nations
GRT	Gross Registered Tons
MEY	Maximum Economic Yield
MPA	Marine Protected Area
MSVPA	Multi-species Virtual Population Analysis
MSY	Maximum Sustainable Yield
NMFS	National Marine Fisheries Service
PSI	Pounds per Square Inch
VPA	Virtual Population Analysis

Acknowledgements

The author wishes to express his gratitude to Dr. Paul Snelgrove for his expert guidance, comments and suggestions in completing this work. I would also like to acknowledge the unwavering support and encouragement of my friend and colleague, Dr. Stephen J. Walsh. Special thanks to Karen McCallum for painstakingly editing various versions of this document.

Finally, I acknowledge, with thanks, the Department of Fisheries and Oceans, Canada for financial support in completing the Masters of Marine Studies Program.

For Karen, Sarah and Laura

Chapter I: Overview

1.1 Introduction

Mobile fishing gear is classified as fishing gear that is towed above or in contact with the seabed in order to capture pelagic and demersal fishes, crustaceans and mollusks. Otter trawls, dredges, rakes and beam trawls are included within this definition of mobile fishing gear. Concern about the effects of towing fishing gear over the seabed date back to 13th century England where acts of parliament were passed to ban the use of trawls in order to protect young fish (de Groot, 1984). Despite the early recognition of gear impacts, this method of harvesting marine resources has become widespread, and the size and weight of fishing gear has increased as fishing vessels have become larger. Most recently otter trawling has been compared to the terrestrial practice of forest clear cutting (Watling and Norse, 1998) and has been described as "scorched earth fishing" in the popular press (Bjerklie, 1998). There is now a strong consensus within the scientific community that mobile fishing gear alters the seabed (Messieh et al., 1991; Anonymous, 1992; Jones, 1992; Dayton et al., 1995). However, there is far less agreement on the short and long-term implications of this disturbance on the marine environment and those species that inhabit it.

The growing concern over mobile fishing gear and the effect it may have on benthic environments has become a significant area of interest, not only because of the potential impact on marine biodiversity but also because of the potential impact on the long-term health of marine ecosystems and commercial fisheries (Botsford et al., 1997).

Although a number of management options remain open to fisheries managers, e.g., closed areas, gear modifications and fishing bans, all must be considered within the context of optimal sustainable use of the resource and the generation of economic returns from the common property resource. Unfortunately, failure to recognize the implicit link between the health of the ecosystem and the long term productivity of fisheries resources may see these management alternatives fail in favor of short-term, high levels of fishing activity typically found in mobile gear fisheries.

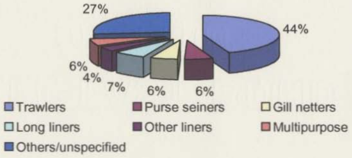
1.2 Global Trend in Mobile Gear Fisheries

Harvest of the world's marine resources increased dramatically in the latter half of the 20th century, reaching maximum production at approximately 122 million tons in 1997 (FAO, 1999). The FAO estimates that of the 200 major fisheries in the world, 35% are declining in catch rates, 25% are at maximum levels of exploitation and 40% are experiencing growth. While annual global fishery production has stabilized in the past decade, harvesting capacity is still 30% greater than what is required to harvest at MSY for high value species. Many believe we are at, or very near, the production limit of our global marine resources (Hall, 1999; Garcia & Newton, 1994).

Prior to the First World War, Russia, Japan, China as well as Southeast Asian and European countries participated in an annual production estimated to have been in the vicinity of 8-10 million tons (Sahrhage and Lundbeck, 1992). Fisheries development intensified after the Second World War as many countries pursued the rebuilding of their economies and by 1958 production had reached 28.4 million tons (Hall, 1999). Fleet expansions, driven by shipbuilding subsidies, placed unprecedented pressure on traditional fishing grounds. Many countries were forced to explore new opportunities in international waters, giving rise to distant water fleets. By 1982, world production had risen to 68 million tons and the distant water fleets of the world's fishing nations were targeting previously unexploited stocks in the Indian and South Pacific Oceans, the South-West Atlantic and many areas of the continental shelf.

By 1992, there were 21 million fishing vessels in the world. Although only 11%, or 127,600 of these vessels were classified as decked trawlers capable of using mobile fishing gear, they comprised close to 45% of the total GRT (Figure 1.1). Thus, mobile fishing gear was deployed from larger vessels capable of wide geographic range and great fishing power. By comparison, fishing vessels made up 30% of the world's merchant vessel fleet over 100 GRT in size. The mean GRT of trawlers in 1992 was 91.1 tons, compared with 62.3 and 18.5 tons for purse seiners and long liners respectively. The overall size of the global fishing fleet has increased from 600,000 to 1.1 million vessels during the period from 1970 to 1992 however, the number of trawlers has remained relatively constant during that period (FAO, 1994a). Approximately half of all groundfish and 40% of all shellfish landed in Atlantic Canada during 1998 were taken by mobile fishing gear, representing 40% of the $1.2 billion landed value for all species (Rivard, 1999).

Mobile gear fisheries, and trawling in particular, make a significant contribution to the world's annual harvest of seafood. The trawling fleet is composed of larger vessels capable of exploiting virtually any area of the world's continental shelf and beyond. Overfishing of traditional stocks and extended jurisdictional boundaries are forcing this harvest capacity to greater depths in search of new fisheries. Consequently, although most fishing still occurs on the relatively shallow continental shelf, only the deepest areas of the ocean lie beyond the reach of today's fishing technology.



Source: FAO, 1994

Figure 1.1 Composition of the World Fishing Fleet by GRT.

1.3 Environmental Concerns

Concerns about the detrimental effect of trawl gear on the environment were also expressed in 14th century Europe where small mesh gears such as the Dutch "wonderkuil" and the English "wondyrochoun" were known to capture small fish (Sahrhage and Lundbeck, 1992). Specific concern was expressed about the wondryochoun "pressing so hard on the ground when fishing that it destroys the living slime and the plants under the water..." (Anonymous, 1921; in de Groot, 1984). This quote is especially notable, as many believe that interest in fishing gear effects on benthic habitats is a relatively recent phenomenon.

Opposition to trawling was somewhat tempered by the scientific studies of Graham (1955), Arntz and Weber (cited in Jones, 1992) and Caddy (1973) which suggested that benthic disturbances were short term and that commercial species find increased foraging opportunities in the wake of trawl gear. It was not until the 58th ICES conference in 1970 that this topic came under widespread scrutiny by the international scientific community. In 1988, an ICES study group concluded that fishing activities may have some impact on marine habitat but that the existing research was mostly inconclusive. This, in turn, led to the establishment of an ICES working group in 1990 to investigate the impact of fishing on the marine ecosystem (Jones, 1992). A growing body of literature now exists describing the short-term impacts of fishing on different benthic habitats, but there has been very little study on the long-term effects (see excellent reviews by Dayton et al., 1995; Hall, 1999; Hutchings, 1990; Jennings and Kaiser, 1998; Jones, 1992; Watling and Norse, 1998).

Although early complaints about the detrimental effects of mobile fishing gear may have had more to do with economic competition between gear types than concern for the environment, there is now growing awareness and public support for the preservation of biodiversity. Overfishing, bycatch and habitat damage have been consistently identified as the most pressing issues in marine resource management today (National Research Council, 1995). This is reflected in recent legislation of many fishing nations. Among them are Canada's Oceans Act and The Sustainable Fisheries Act of the United States, both of which contain specific provisions for the protection of marine habitats and biodiversity.

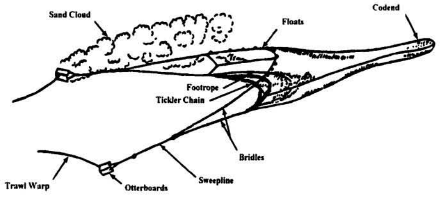
Chapter II: Mobile Fishing Gear

2.1 Introduction

The practice of towing fishing gear to capture or gather commercially valuable marine species is thought to have started in Western Europe during the 13th century. In an effort to increase the catch a traditional Roman "sagena" or seine, a gear normally deployed by hand from the beach, was modified to be towed behind sailing vessels (Sahrhage and Lundbeck, 1992). The conical-shaped seine was made of manila twine and kept open at the front end with a wooden beam. With its introduction into England in the 17th century, plates or "shoes" were added to the ends of the beam to raise it off the seabed. By the 19th century, the English version of what had now become known as the beam trawl was being used by other fishing nations around the North Sea and was used primarily to catch flatfish. Scarcity of fish inshore began driving fishing effort further out into the North Sea and as a result, vessels and gear began to increase in size. Without mechanization, trawl fisheries were generally limited to water depths less than 100 m with relatively light gear, and beam widths rarely exceeded 15 m.

The introduction of the steam engine to the fishing industry in the 1880's led to the rapid demise of the traditional sailing "smack", which was replaced by the steam trawler. Steam power now meant that larger beam trawls could be deployed and retrieved with winches from greater depths further from shore. Gear became heavier, chain mattes were added as protection on rough bottom and tickler chains that dragged across the seafloor were added to increase catches of flatfish. It has been estimated that steam technology increased catch rates by 6 to 8 times over traditional sail powered methods (Sahrhage and Lundbeck, 1992). In 1892, the beam was replaced by two wooden planks that were fastened at both wing-ends of the net. Water pressure acting against the face of the boards, and the resistance caused by the movement across the seabed, created a spreading force that opened the mouth of the trawl. Trawl size was no longer limited by the fishing vessel's ability to accommodate the length of the beam. Consequently, trawls became much larger for a given vessel size.

By the 1920's, the wooden planks, or otterboards, were being connected to the main body of the trawl by cables called sweep wires (Figure 2.1). This change effectively increased the area of bottom swept by the trawl, and improved its ability to herd fish into the mouth of the net. Further technological innovations during the early to mid 20th century focused on replacing wood with steel as construction materials, increasing fuel efficiency through reductions in drag and extending the geographical range of bottom trawl gear (i.e. over rougher bottoms and into deeper waters). In recent years, global resource shortages have motivated technological change in trawl design towards addressing conservation issues such as bycatch, size selectivity, and the destruction of bottom habitat and organisms.



Source: Gunderson, 1993.

Figure 2.1 A Typical Otter Trawl Rigged with a Tickler Chain.

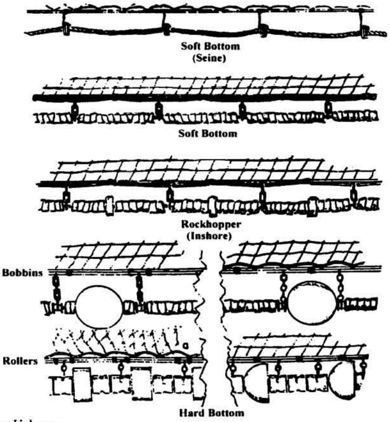
Like the beam trawl and otter trawl, dredges have evolved from the Roman "sagena". By replacing the footrope with a rigid bar fitted with teeth, "seines" could be used to excavate and gather bivalve molluscs such as oysters, clams and scallops. The size and weight of dredges has increased dramatically with the advent of mechanization, however, other than the use of modern construction materials, the form and function of dredges has not changed considerably in the last century, with the notable exception of hydraulic clam dredges.

2.2 Otter trawls and Seines

The otter trawl, in its most basic form, is a conical-shaped bag of netting that is towed across the seabed to scoop up fish in its path. The underside of the bag is fitted with a footgear designed to protect the vulnerable lower netting, while keeping the trawl firmly in contact with the sea bottom over all types of terrain. Floats are attached to the upper half of the bag to provide buoyancy, which opposes the weight of the footgear to keep the front of the bag open vertically. Otter boards are connected to the ends of each wing with cables called bridles, and provide a horizontal spreading force. Various mesh sizes are used in construction of the bag, depending on the species being targeted; the minimum mesh size in the end of the bag or codend is generally determined by regulation. Otter trawls rely on towing speed and reduced visibility resulting from the suspended sediment stirred up by the otter boards, ground cables, and footrope to herd fish into the mouth of the trawl, where they eventually tire and fall back into the codend.

The otter boards, ground cables and footrope are in partial or full contact with the seabed for most or all of the tow, depending on bottom conditions and towing speed. Footropes vary in design, depending on the nature of the seabed and the species targeted (Figure 2.2). Where wire wrapped in rope may suffice for flat sandy bottoms, heavy steel spherical rollers or "bobbins" strung on wire may be used for an uneven bottom populated with large boulders. Unlike traditional bobbin footgear, which is free to roll, the "rockhopper" is dragged over the seabed. A relatively recent innovation, the "rockhopper" is constructed of large rubber disks separated with rubber spacers packed tightly on chain such that the individual components cannot turn. In some fisheries, such as those for flatfish, a "tickler chain" is attached to the wingends such that it runs ahead of the footrope, digging into the bottom to stir-up buried animals. The degree of bottom contact is determined by the weight and length of the footrope, and the spacing between the individual components. The Engel 145, a popular groundfish trawl used in Atlantic

Canada from 1950-1980, used a steel bobbin footrope 31 m long constructed of 23 steel bobbins, ranging in diameter from 35 to 60 cm, spaced at approximately 1.0 m intervals, and weighing 470 kg in seawater (McCallum & Walsh, 1997).

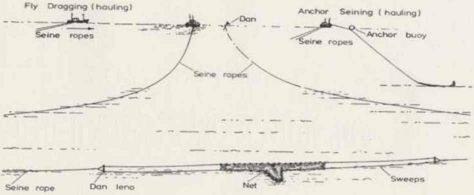


Source: Unknown.

Figure 2.2 Various Footrope Configurations used on the Otter Trawl.

Otter boards are essentially flat or curved plates made of wood or steel, which use hydrodynamic and ground shear forces to spread the trawl. The bottom or "shoe" runs over the seabed and is ballasted to provide stability and resist the upward pull of the towing warps. Otter boards can weight up to 6500 kg each. Modern designs, such as the popular oval, exploit hydrodynamic features such as camber and slots to increase efficiency and reduce reliance on ground contact. The degree to which an otterboard disturbs the seabed will depend on the length and weight of the shoe as well as its angle of attack (i.e. projected frontal area). Gilkinson et al. (1998) have shown that an otterboard with a 165-cm long shoe, operating at a 30 degree angle of attack, will create a scour path approximately 53 cm in width. Side-scan sonar records collected on the Grand Banks of Newfoundland show otterboard scours marks 60-90 cm in width (Parrot, pers. comm., cited in Gilkinson et al., 1998). Penetration depth is heavily dependant on the amount of shoe in contact with the bottom and the nature of the substrate, but generally ranges from 10-30 mm (de Groot, 1984; Main & Sangster, 1979; Riemann and Hoffman, 1991; Brylinsky et. al., 1994). Crewe (1964) estimated that 30% of an otterboard's weight in water comes to bear on the seabed and that ground shear forces can reach 50% of this value depending on bottom type.

Seines are similar to trawls in construction except that they have much larger wings and do not use otterboards. The seine net is connected in the middle of a long warp, which is laid-out along the bottom, such that an area of seabed is surrounded (Figure 2.3). The warps are gathered back at the vessel and, in the process, fish are herded into the seine. Warps are most often constructed of synthetic propylene or polyethylene with lead cores to aid in sinking. As with the otter trawl, seines are configured with footropes appropriate for the bottom conditions. During the retrieval process, the fishing vessel can be either stationary (Anchor or Danish Seining) or towing and hauling simultaneously (Scottish Seining or Fly Dragging). In either case, it is estimated that seining sweeps approximately the same area of seabed per hour as otter trawling (Sainsbury, 1996).

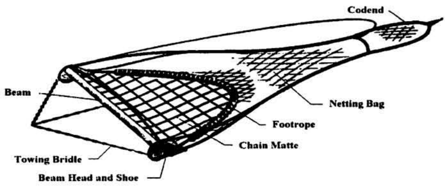


Source: Bridger et al., 1981.

Figure 2.3 Illustration of Bottom Seining and the Hauling Procedures used in Fly Dragging (Scottish Seining) and Anchor Seining (Danish Seining).

2.3 Beam Trawls

The beam trawl differs from the otter trawl in that the front of the net is held open horizontally by a steel beam. The beam is suspended off the bottom on either end by two triangular plates of steel called beam heads, which are fitted with sole plates designed to run over the seabed. The top of the netting bag is fastened to the beam and the lower section is fitted with a footrope connected to the back ends of the beam shoes (Figure 2.4). The top section of netting immediately behind the beam is left open to allow finfish and non-target species to escape. The trawl is towed from a 2 or 3 chain bridle and a single warp at speeds of 3.0-5.0 kts. Beam trawls vary in size depending on the size and horsepower of the fishing vessel but can be up to 12 m in width and have a vertical opening of 1 m. These trawls are especially effective when targeting bottom dwelling species such as sole and plaice.



Source: Lindeboom and de Groot, 1998.

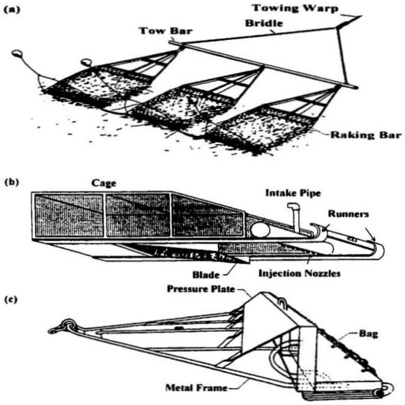
Figure 2.4 A Flatfish Beam Trawl Fitted with a Chain Matte.

Beam trawls can be fitted with either "tickler" chains or a chain matte, depending on bottom conditions. Mattes are particularly effective on rough rocky bottom because they ride over large boulders. Both are connected to the beam head and are rigged to lie ahead of the footrope such that they excavate the top layer of substrate, disturbing fish buried in the bottom. It has been estimated that a beam trawl rigged with tickler chains will gather approximately 10 times more benthic material than an otter trawl (de Groot, 1984). As with the otter trawl, sediment penetration depths vary with tow speed and bottom type but depths up to 8 cm have been recorded (Bergman, 1992; Lindeboom, 1998). Bridger (1972) observed that a beam trawl rigged with 15 tickler chains penetrated the substrate between 10 to 30 mm, depending on the nature of the bottom. This type of trawling is not common in Atlantic Canada, although a modified beam trawl is being considered for the inshore shrimp fisheries in Newfoundland.

2.4 Dredges

A simple dredge is constructed of a metal frame formed into a basket shape covered with a sheet of steel rings on the bottom and synthetic webbing on the top (Figure 2.5). The lower lip of the basket is fitted with a raking bar, which is designed to dig into the seabed and lift the target organisms (e.g., scallops, oysters, clams, sea urchins) into the trailing bag. The raking bar may be equipped with "teeth", the length of which will depend on the depth of the species being targeted, with typical lengths ranging from 5 to 10 cm. Dredges vary in size and sophistication depending on water depth, vessel size and fishing grounds. Although most rely on their own mass to penetrate the seabed, some offshore scallop dredges use the hydrodynamic force generated by a pressure plate mounted above the ranking bar to increase cutting depth. The hydraulic dredge was developed to increase catch rates and uses a series of nozzles to inject high-pressure water into the seabed just ahead of the cutting bar. The 125 psi pressure fluidizes the sediment, thereby reducing towing resistance and increasing penetration depths.

In Atlantic Canada, dredges are used to harvest scallops on the Scotian Shelf, Georges Bank and in the Bay of Fundy. Inshore dredges can be from 0.5 to 1.5 m in width and are towed in gangs of one or two where each gang may be composed of up to 7 dredges. Offshore dredges can be up to 3.8 m in width and weigh 650-700 kg (Messieh, 1991). The Arctic surf clam (*Mactromeris polynyma*) is harvested on the Grand Banks and Banquereau Bank using hydraulic dredges of up to 4.0 m in width. Side-scan sonar records of the Scotian Shelf show evidence of scallop rakes scouring 10 to 15 cm deep into silty, very fine sand. Penetration appeared to be relatively consistent regardless of seabed texture (Jenner, 1991), and the hydraulic dredge, in particular, create a distinct trench up to 20 cm deep with sharply angled shoulders and a relatively flat floor.



Source: Bridger et. al., 1981. Messieh et. al., 1991.

Figure 2.5 Inshore Scallop Dredge (a), Hydraulic Clam Dredge (b) and a Offshore Scallop Dredge (c).

2.5 The Spatial and Temporal Distribution of Fishing Effort

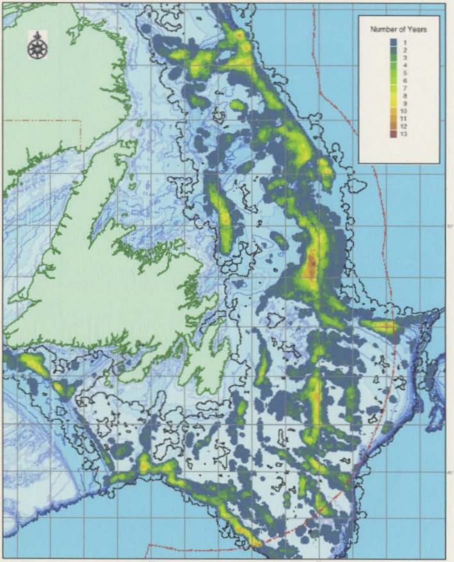
In considering the effects of mobile gear on the marine environment, it is important to understand the spatial and temporal distribution of the disturbance over the seabed. Fishing effort is rarely, if ever, homogeneously distributed over a geographical area but is directed on the basis of historical knowledge of fish location and/or use of technology such as echosounders. It is more economically viable to target aggregations of fish, which are typically found in areas of high biological productivity and favorable habitat, than it is to randomly scrape the bottom. Although fishing effort can be somewhat geographically restricted to areas of favourable bottom, this is less true with newer fishing gears such as the rockhopper. Management measures such as seasonal and area closures, as well as environmental factors, such as weather and winter ice cover, can restrict access to fishing grounds both spatially and temporally.

Otter trawls sweep an area of seabed equivalent to the distance between the otter boards multiplied by the distance towed. Rakes, dredges and beam trawls sweep an area the width of their raking/cutting bar or beam multiplied by the distance of the tow. An accurate assessment of total fishing effort as it relates to benthic disturbance, requires data on the location and duration of each tow conducted by each vessel in the fishing fleet.

Various methods have been used to estimate seabed disturbances by mobile gear. In analyzing Geological Survey of Canada side-scan sonar records of the Continental Shelf off Nova Scotia, Jenner et al (1991) estimated that less than 2% of the surveyed seabed showed evidence of disturbance by either otter trawls, scallop rakes or clam dredges. Similar records suggest that less than 10% of the surveyed area of the Grand Banks has been disturbed by otter trawls (Schwinghamer cited in Prena et al, 1999). Side-scan observations of heavily fished Kiel Bay in the western Baltic showed evidence of trawl door scouring over 30 % of the survey area (Krost, 1990). Twitchell (1981) reports a high density (20 per 100 m^2) of trawl door tracks seen on side scan sonar images taken in 100 m of water along the outer shelf of the Mid Atlantic Bight. Submersible observations of the seabed on the north side of Chaleur Bay, New Brunswick showed at least 3% of the area covered by tracks made by trawl doors (Caddy, 1973). Relying on evidence of physical interaction such as scour marks or tracks can be problematic, given that these tracks tend to have short life spans in high-energy environments. Detectable trawl door scours last approximately 1 year on the Grand Banks and have been observed to last anywhere from 37 hours to 18 months in the North Sea. (Schwinghammer et al, 1998; Lindeboom, 1998)

Commercial fishing effort data for the Grand Banks and Labrador shelf (1980 to 1998) suggest highly localized areas of intense fishing activity (i.e. approximately 25 % of an area of seabed disturbed annually) (Figure 2.6). While some of these high activity areas could be trawled up to 7.4 times annually, and often much less, they generally represent less than 5 % of the total fishing grounds (D. Kulka, personal communications). Using NMFS (National Marine Fisheries Service) data and estimates of door spread and towing speed, Churchill (1989) was able to estimate fishing effort expressed as total swept area within 30' latitude by 30' longitude boxes for the Middle Atlantic Bight. He concluded that some regions (coastal Nantucket and Nantucket Shoals) were swept an equivalent of three times the area of the box while some areas went un-trawled. Swept area estimates have been used to conclude that some areas of the North Sea experience up to 321% (percentage area swept) and as low as 0.3% exposure to fishing activity by beam trawls (Anonymous, 1992). Alternatively, crude assumptions about global fishing capacity have been used to estimate total mobile gear swept area as a percentage of the world's continental shelf. These vary widely depending on assumptions made about effort. McAllister (1995) estimated 5.6 % of the world's continental shelf is trawled annually whereas Slavin (1981) suggested a figure of 53% based on global shrimp harvesting capacity.

Although these studies illustrate the large scale of physical disturbance presented by mobile fishing gear, they lack the fine-scale resolution required to quantify the concentration of fishing effort typically found on productive fishing grounds. Hall (1999) has suggested that the absence of such data could very well be the single most important issue impeding further progress on this subject.



Source: Anonymous, 2000.

Figure 2.6 **Spatial and Temporal Distribution of Intense (i.e. 25 % of an area disturbed annually) Commercial Fishing Effort on Grand Banks from 1980 to 1998.**

Chapter III: The Impact of Mobile Fishing Gear on Benthic Habitat

3.1 Introduction

Benthic structures can be defined as those features of the seabed, both physical and biological, that co-exist in a highly interdependent manner to form the habitat for benthic communities. The sedimentary topographical features of the seabed and the biogenic structures created within and on top of it are the essential components of marine habitat. Infauna (organisms that live below the sediment surface) and epifauna (organisms living on the seabed surface) tend to associate with specific sediment types and bottom features such as sand waves and crevices, creating a wide range of habitats (Langton et al., 1995). Both groups of organisms are vulnerable to fishing gear; epifauna occur at the interface between the ocean bottom and the water above it, and most infauna are concentrated in the upper few centimeters nearest the sediment-water interface. Some species of mobile megafauna demonstrate a preference for specific seabed types and the habitat structure provided by the resident infauna and epifauna (Auster et al. 1998).

Organisms living on and in the seabed create structures. Bryozoans, corals, worms and mollusks create calcium carbonate shells, and mobile species such as polychaete worms, amphipod crustaceans, bivalve mollusks, sea urchins and some fishes create burrows and tubes in the sediment (Watling & Norse, 1998). Physical and biological structures are important in that they provide relief from the otherwise flat seabed. For example, some benthic suspension-feeders use structures as points of attachment and to extend above the seabed where water currents are generally faster moving, allowing access to a greater flux of food particles suspended within the flow. Benthic structures may also provide a means by which organisms extend themselves above the bottom into oxygenated waters during hypoxic events. The construction of burrows and tubes is important as the process provides oxygen to the sediment (Aller, 1988; Meyers et al., 1988 cited in Watling & Norse, 1998).

The distribution of sediments and the creation of sedimentary topographical features are also influenced by physical processes such as glacial deposition, currents, tides and iceberg scour. Specific seabed features provide ideal habitat for epifauna. The cracks and crevices provided by a cobble bottom provide shelter as well as a surface to which epibenthic life can attach (Auster, 1998). The troughs created by sand waves and ripples provide shelter from fast moving bottom currents, facilitating ambush predation on drifting demersal zooplankton (Auster, 1998).

Habitat structure offers protection from predators. Many fishes, especially juveniles, demonstrate a preference for specific habitat features such as depressions, shells and burrows (Auster et al., 1996; Langton et al., 1995). Tupper and Boutiller (1995) found that the survival rate of juvenile cod (0+) was higher in more structurally complex habitats as a result of increased shelter availability and decreased predator efficiency. Juvenile cod prefer the gravel habitat of eastern Georges Bank exclusively during July and August, suggesting they are best able to avoid predators and find food on a gravel seabed (Collie et al., 1997).

The benthos is an important source of food for many marine organisms and its critical role in trophic relationships and transfer may rival that of plankton. While varying annually, it has been estimated that half of all benthic production is consumed by commercial species and the remainder by non-commercial species and predatory benthos (Laevastu et al., 1996). The juveniles of many demersal and semi-demersal fish feed partly on the benthos after settlement to the bottom. However this reliance diminishes with age for some fauna as adults become more piscivorous. In the North Sea the macrobenthos is considered to be the main source of food for demersal fish (Steele, 1974). Unfortunately, estimates of total benthic production are based on very limited data and are often at odds with predicted consumption rates for most species.

Because habitat structure and complexity are increased by living organisms, a reduction in complexity through the deleterious actions of fishing activity could result in the loss of habitat for harvested populations, a reduction in their growth rates, alteration of benthic species composition, and a loss in overall ecosystem productivity. It is therefore critical to examine the impacts of fishing activity in the context of the highly interdependent nature of the ecosystem.

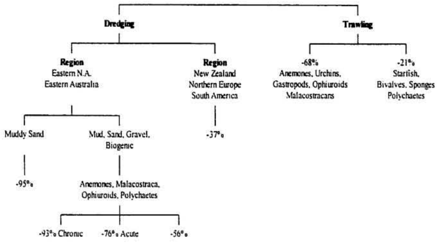
3.2 Physical Alteration of the Seabed

The degree to which mobile fishing gear affects the seabed depends on the type of gear, its weight, the speed with which it is towed and the nature of the sediments over which it is towed (Lindeboom & de Groot, 1998). The predominant physical effect of bottom trawling is the tracks created in the sediment by the trawl doors. Trawl doors scour the upper layer of seabed and can displace rocks and large boulders. In simulating the scour made by a trawl door on substrates typical of that found on the Northeastern Grand Banks of Newfoundland, Gilkinson et al. (1998) found that up to 70% of buried bivalves were completely or partially exposed as they were caught up in spoil pushed ahead of the door. Increased stress levels were recorded in the sediment below the visually observable furrow. This pattern suggests an impact to the sediments and biological organisms below the immediate area of the furrow. The bridles and footrope have a less obvious impact on the bottom, however for footgears that roll, compression of the sediment is more likely than scouring (Brylinsky, 1994).

Most bottom fishing gear will tend to flatten surficial topography, however hydraulic clam dredges will create, deep wide furrows. A heavy beam trawl towed over densely packed fine sand and silt will remove the upper 1cm of sediment, resulting in the bottom becoming harder and less rough (Lindeboom & de Groot, 1998). Caddy (1973) observed that scallop rakes towed over gravel overlaying sand will redistribute the gravel below the sand and lift and overturn large boulders from the sediment.

In comparing experimentally trawled verses non-trawled corridors on the Grand Banks of Newfoundland, Schwinghamer et al. (1998) used high-resolution acoustics to determine that trawling increased seabed hardness and altered biogenic sediment structure to depths of 4.5 cm. Disturbance of the bottom mixes sediments, which can result in the burial of metabolized organic matter, thereby altering biological organization within the seabed (Mayer et al., 1991). A shift from aerobic respiration at the seabed/water interface to anaerobic respiration below the surface of the seabed could alter the benthic ecosystem and change the types and availability of food for other species (Snelgrove et al., 1997).

In summary, bottom contacting fishing activity changes the physical characteristics of the seabed, altering habitats and reducing surficial and sub-surface sediment structure (Auster et al., 1996; Schwinghamer et al., 1995, 1998; Tuck et al., 1998). The loss of biogenic structure formers, through the scraping, digging and plowing action of fishing gear, results in reduced structural complexity of marine benthic communities. Collie et al. (2000) used meta-analysis techniques on fishing impact studies published in the scientific literature to conclude that, on average, fishing removes half the benthic population. Using regression analysis they were able to predict the likely response of particular taxa to different fishing gears on various habitats (Figure 3.1). Structure formers contribute to overall biodiversity of the ecosystem and provide critical habitat and cover from predators for the post-settlement juveniles of commercially important species. Of equal concern is the role of benthic organisms in maintaining ecosystem stability by regulating global carbon, nitrogen and sulfur cycles, aiding trophic transfer, absorbing marine pollution and stabilizing bottom sediments (Snelgrove et al., 1997).



Source: adapted from Collie et al., 2000

Figure 3.1 The relative impacts of fishing, predicting that trawling would remove 68% and 21 % of the anthozoans and Asteroids respectively whereas chronic dredging on biogenic habitats would remove up to 93% of the anthozoa, malacostraca, ophiuroidea and polychaeta.

3.3 Re-suspension of Sediments

Fishing gear that comes in contact with the seabed will cause sediment to become mixed and temporarily suspended in the water column. The amount of material and the time to re-settle depends on the weight of the fishing gear, its penetration depth and, most importantly, the nature of the substrate combined with fishing patterns (e.g. frequency and intensity). Sediment-covered bottoms tend to be the least resistant to disturbance. Generally, silts and clays accumulate in low-flow environments such as deep water and sheltered bays. Underwater observations have shown that trawl doors create trailing clouds of suspended sediment, which can grow to many times the height of the otter board before settling to the bottom (Main & Sangster, 1981). Trawl doors observed fishing on Canso Bank created a suspended sediment cloud < 1.8 m high on coarse rippled sand and up to 2.0 m high on fine, rippled silty-sand (Jenner et al., 1991). Pilskaln et al. (1998) suggested that sediment dwelling polychaete worms found in time-series sediment traps placed 25-35 m above the seabed in the Gulf of Maine, resulted from the re-suspension of sediments caused by trawling. Caddy (1973) found that the sediment plume created by a scallop dredge towed on a gravel/sand bottom reduced visibility in the immediate area from 4-8 m to less than 2 m, covering the dredge track with a layer of fine silt.

Sediment resuspension can result from natural processes such as currents, tides and especially storms. It is important to distinguish these effects from the results of fishing activity. Riemann (1991) found that dredging and trawling in the shallow Limfjorden, Denmark increased the amount of suspended material in the water column above normal background levels by 1361 % and 1000 % respectively. Dredging resulted in the re-suspension of up to 1470 grams of particulate material per square meter of bottom dredged. It has been estimated that 9.08 kg/m^2 of sediment is re-suspended annually in the Gulf of Maine as a result of bottom trawling (Pilskaln et al., 1998). Models of fishing effort and sediment transport have suggested that trawling can be the primary source of re-suspended bottom material over the Mid Atlantic Bight outer shelf (Churchill, 1989).

The time it takes a sediment plume to dissipate is a function of substrate type and water velocities in the immediate area (de Groot, 1984). Riemann (1991) found that significant sediment plumes created by dredging and bottom trawling had completely dissipated within 1 hour in a high current area. In contrast, transmissometer measurements taken after trawling activity in the Mud Patch region of the Mid Atlantic Bight have shown that it took approximately 24 hours for water clarity to return to pre-trawling levels (Churchill, 1989). The Mud Patch is an area dominated by a silty (> 25%) clay bottom and characterized by relatively weak bottom currents.

Sediment plumes affect water clarity, oxygen content and nutrient concentration, potentially impacting biological life living at the seabed interface and in the water column above it. Consistently reduced water clarity could result in a restructuring of the ecosystem from one dominated by visual predators and suspension feeders to one dominated by species that deposit feed or rely on chemosensory mechanisms (Watling & Norse, 1998). Re-settled silt can affect the pumping and feeding rate of scallops, inhibiting growth and decreasing survival rate (Stevens, 1987). Riemann (1991) found that trawling and dredging increased oxygen consumption by re-suspending buried organic material that result in reduced dissolved oxygen in the water column; ammonia and silicate levels also increased. Increases in the amount of ammonium in the water column during the summer months in the Gulf of Maine has been attributed to the release of nitrogen from the sediments by trawling (Pilskaln, 1998). A change in the chemical/nutrient flux between the seabed and water column could stimulate phytoplankton production, which could benefit some species. Alternately, in heavily trawled shallow seas, decreased water clarity from suspended sediments could reduce light penetration and therefore, primary production. However, the long term effect on the ecosystem as a whole is not clearly understood.

3.4 Natural Disturbances of the Seabed

In many ways the seabed may be in a constant state of flux as its topography is constantly being altered by natural and biological processes, as well as by fishing activity. Storms, currents, tides, icebergs and underwater seismic activity can displace bottom material and re-suspend sediments (Hall, 1999; Kaiser, 1998). Storms create high-energy environments in shallow water, an effect which diminishes as wave energy attenuates with depth. Amos and Judge (1991) determined that winter storms on the Eastern Canadian continental shelf were responsible for sediment transport to depths of 120 m although Schwinghamer et al. (1998) found this might occur as deep as 146 m. Episodic semidiurnal tidal currents have been found to create near bottom flow velocities sufficient to re-suspend bottom sediments in water depths of 200 m on the Nantucket Shoals (Csanady et al., 1988). Side-scan sonar images taken on the Grand Banks have shown that icebergs can create scours approximately 60 m wide and up to 3 m deep (Anon., 1994).

The foraging activity of crustaceans, fishes and marine mammals can re-distribute seabed sediments and create sedimentary re-suspension. Some animals such as the California Gray Whale have the ability to remove large volumes of material in one bite (Oliver & Slattery, 1985, cited in Watling & Norse, 1998). Sediments can be disturbed by bioturbation (i.e. movement of sediment particles as a result of the feeding and burrowing activities of animals). The burrowing of larger benthic organisms such as bivalve mollusks and polychaetes can cause sediment mixing and disrupt other smaller life forms that live in the sediment. However, the overall impact of bioturbation is generally considered to be low as smaller sediment dwellers are able to repair the damage to burrows and tubes (Watling & Norse, 1998). While foraging activity can have severe localized consequences, when considered in the context of the entire continental shelf, overall impact is likely to be low.

In relatively shallow, high energy environments (i.e. water depths less than 150 m), the physical effects of fishing may no longer be visible after approximately 1 to 2 years (Brylinsky et al., 1994; Dolah et al., 1987; Kaiser et al., 1998; Schwinghamer et al., 1998). This is strong evidence to support that natural and biological processes are constantly influencing the structure of benthic communities in these environments. It has been suggested (Sheperd, 1983; Kaiser & Spencer, 1996; Kaiser et al., 1998; Posey et al.; 1996 cited in Kaiser, 1998) that such communities, having adapted to regular disturbances as a result of natural and biological processes, are more resistant to the adverse effects of fishing than communities not regularly disturbed. Thus, fishing activity represents a much lower disturbance when measured against the background of a high level of natural variability in the environment. Much less is known about the effects of fishing in deep water, given that most quantitative studies have taken place on the relatively accessible continental shelf where most commercial fishing takes place (Kaiser, 1998). However, this absence of information on the effects of commercial fishing on deepwater habitats and the presence of relatively quiescent shallow water habitats makes generalization difficult.

Although organisms living in high-energy environments may be more adapted to fishing disturbances, they are not immune to them. Prena et al. (1999) found a decrease in species homogeneity and a reduction in total biomass of benthic communities exposed to periodic trawling over a 3-year period on the Grand Banks of Newfoundland, an area frequented by storms and icebergs. Hall (1999) argues that while it is important to place fishing disturbances in context with those imposed by natural processes, this is not reason enough to suggest that the effect of fishing is irrelevant or inconsequential.

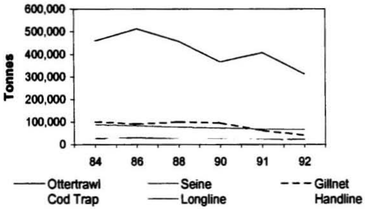
Bottom fishing has a direct impact on benthic habitats by physically altering the topographical features of the seabed and redistributing the structure within its sediments. The magnitude of this impact depends on the type of fishing gear, its weight and the nature of the substrate. Habitats occurring in high-energy environments, such as shallow waters exposed to tides and currents, tend to recover from the effects of fishing more rapidly than those in more benign regions. High-energy environments are inhabited by opportunistic species adapted to the constant change that is associated with the less physically stable seabeds found in these areas. Fauna occurring in more stable seabeds tends to be the most resistant to change and therefore the most susceptible to the long term effects of fishing. This may be the case in deep-water habitats which, may prove to be particularly vulnerable to external disturbances. Nonetheless, habitats exposed to continuous fishing pressure are likely to remain in a permanently altered state.

Chapter IV: Factors Influencing the Selection of Harvesting Technology

4.1 Introduction

In many fisheries there is more than one type of fishing method that can be used to catch any particular species. It is widely acknowledged that some fishing gears and fishing methods are more wasteful and damaging to the environment than others. Therefore, given alternatives, it would seem reasonable that fishers switch to a more environmentally friendly technology and that fisheries managers ban or severely restrict the use of inappropriate gear types. Bottom trawls are used by a large portion of the world's fishing fleet and is the predominate gear type in use in Atlantic Canada (figure 4.1). Approximately 40% of the landed value of the entire harvest in 1998 was caught with bottom trawls. The global widespread use of this gear type suggests there are operational and socioeconomic reasons why it is preferred over other gear types for fishing on or near the seabed.

Why is a particular gear used in a fishery? Rivard (1999) suggests that an important factor in the selection of fishing gear in the Southwestern Nova Scotia groundfish fishery is cultural and historical attachment. Communities come to develop an expertise in a particular gear type and this is passed on to younger generations of fishers.



Source: Fisheries Resource Conservation Council, 1994.

Figure 4.1 Landings by Gear Type in Atlantic Canada from 1984 to 1992.

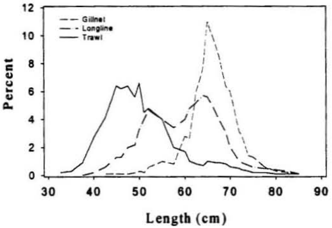
Over time the community becomes heavily capitalized both intellectually and monetarily in a specific technology, and as consequence will resist change. In addition, the DFO has tended to enshrine these initial gear choices in its licensing restrictions and, therefore, many fishers would be prevented from changing gear types even if otherwise motivated to do so.

In presenting a balanced argument for or against bottom harvesting technologies with respect to their potential impact on the marine environment, it is useful to examine the factors that influence the selection of gear type by fishers. This might best be done by comparing the selectivity, technical performance, environmental impacts and socio-economic considerations of three different and competing gear types; the otter trawl, longline and gillnet. It is generally accepted that there are no other alternatives to most bottom excavation types of gear (e.g. wet and dry hydraulic dredges) used to remove buried benthic species and therefore they will not be considered here.

4.2 Selectivity

Fishing gears are generally most effective over a specific range of sizes and species of fish and this is referred to as size and species selectivity. Figure 4.2 illustrates the relative size selectivity and catching power of longlines, trawls and gillnets fished simultaneously on the same grounds. Longlines have a tendency to catch larger fish as a result of fish behavior and gear dependent fishing strategies employed by the fisher (Asmund & Lokkeborg, 1996). The large spatial coverage of longline hooks favors larger fish that have a wider distribution tending to range further in search of food and therefore have the greatest chance of encountering a hook. Larger fish also out compete small fish for the same baited hook. Conversely, when fish densities are low and there is a larger proportion of smaller fish in the population, longlines will tend to catch more small fish (Engas et al., 1993).

Bait and hook size can influence size selection, however, the relative inefficiency of longlines, in terms of catch per unit time, will dictate that the fisher use a larger hook and therefore select for the larger fish. This inefficiency will also dictate that the fisher leaves the grounds when the catch of small fish becomes too great. Small fish reduce profitability, not only because they are less marketable, but because they also occupy hooks intended for the larger fish. Species selectivity is similarly affected, as fishers will leave an area where non-target species reduce profitability. This is in contrast to trawl gear where the catches of small fish do not affect the catches of large fish.



Source: Nedreaas et al., 1993.

Figure 4.2 Size Distributions of Greenland Halibut Taken with Longlines, Trawls and Gillnets.

Species and size selection in trawling is a function of the horizontal and vertical distribution of fish over the seabed, fish behavior to the oncoming gear and the selection properties of the gear (Parrish et al., 1964). Selectivity begins at the trawl doors and occurs at the sweeplines, net mouth, footgear and in the trawl body. Trawls tend to catch larger numbers of smaller fish when compared to longlines and gillnets (Aldebert et al., 1993; O' Rielly, 1988; Nedreaas et al, 1993). In theory, the appropriate choice of mesh size should provide good size selection properties, however, in the codend, where fish are retained, meshes can become clogged with fish, masked by flatfish and other species and become elongated under load thereby decreasing the mesh opening. Recent advances in trawl gear technology have improved species selection in some fisheries. For example, the use of a Nordmore grate in some shrimp fisheries mechanically separates finfish from shrimp, allowing finfish to escape unharmed.

Of the three gear types considered, gillnets are the most size selective. The mesh opening restricts the range of body girth sizes that can become entangled and held in the net. Smaller fish swim through the meshes while the larger fish are physically too big to escape and are therefore retained. Larger/older fish tend to have better visual acuity and therefore may have an advantage in avoiding gillnet meshes. To a certain degree mesh selection in gillnets can be influenced by mesh color and gear construction.

4.3 Operational Considerations

Each type of gear has specific operational characteristics, which should be evaluated with respect to two important criteria; the quality of catch landed and catching efficiency expressed as fuel consumed per kilogram of fish caught. The quality of trawl caught fish is mostly dependent on how long the net is towed and how much fish is allowed to accumulate in the codend before hauling. During long tows fish tend to become crushed and bruised as the codend fills, and long tows will generate higher quantities of fish, that take longer to process (Botta & Bonnell, 1988). Quality in any fishery is very much a function of how little the fish is handled and how quickly it can be processed and put on ice.

The quality of fish caught on longlines tends to be higher than those caught in trawls. The nature of longlining is such that fish are brought aboard individually and processed immediately, the supply of fish being continuous over the period of hauling. This is in contrast to trawling where the entire catch presents itself at one time. Fish captured by gillnets may be of poor quality if left in the sea too long. Gillnet caught fish die almost immediately and therefore quality becomes inversely related to soak time. To some extent this can be controlled with good fishing practices i.e. increasing the hauling frequency by decreasing the total number of fleets fished.

It has been argued that by modifying fishing practices, trawls and gillnets are equally capable of landing high quality products as those caught by longliners (Rivard, 1999). Theoretically this may be true, however, it may also be argued that these operational deficiencies (from a quality control perspective) are inherent in the economic success of these gears and attempts to remove them will result in unacceptable reductions in overall efficiency. For example, reducing the duration of a tow in the trawl fishery to the point where quality is best may result in catch rates per unit effort so low that fishing becomes unprofitable.

Trawlers consume more than 3 times as much energy per kilogram of fish caught than either gillnet or longline vessels (Taivo & Laevastu, 1988). For most of the fishing cycle, trawlers are operating at close to maximum power as they drag gear through the water and over the seabed. By contrast, longline and gillnet vessels operate at or below their optimal cruising speed during both shooting and hauling.

Each gear type has specific technical limitations depending on water depth, bottom type, current, tide and bottom contours. For example trawls are limited to areas of relatively flat bottom free of large rocks and boulders. Gillnets are prone to fouling and breaking free of their moorings in areas of high current and waves. Longlines and gillnets are particularly difficult to set and retrieve in ice infested waters.

4.4 Environmental Considerations

Each type of fishing gear has a distinctly unique impact on the environment. For example bottom trawling has a marked effect on the seabed and benthic communities whereas gillnets and longlines are known to incidentally catch marine mammals and seabirds. While the effects of fishing gear on the environment can be varied, subtle and in many instances relatively unknown, there is consensus that post-catch mortality, ghost fishing and seabed impacts are the significant issues surrounding longlines, gillnets and otter trawls.

The survival of fish after escapement is an import issue on which there is little information. This is in part due to the difficulty in conducting experiments to measure how long a fish survives after escaping from fishing gear. There is a certain amount of trauma, stress and physical contact resulting in loss of scales and protective mucous with all three gears. Intuitively one would think that these factors are most significant in trawl gear and for small pelagic fishes such as herring this may be the case, however, with cod and haddock, studies have shown survival rates after escapement of 80-95% (Bjordal & Lokkeborg, 1996). Again, the data is poor but Bjordal & Lokkeborg (1996) suggest that it may be possible to infer that the survival rate of escapees from longlines and gillnets should be no worse than that of trawls.

Many fishing gears can continue to fish for some period of time after being abandoned or lost at sea, this is commonly referred to as ghost fishing. Ghost fishing is generally not considered to be a problem in both longlining and trawling. Longlines stop fishing after the bait is lost from the hook, this occurs early in the fishing processes as a result of fish feeding or bottom scavengers. Mortality is limited to approximately one fish per hook. Trawls are lost less frequently than longlines or gillnets, probably because they remain attached to the vessel at all times. When they are lost they remain fixed to the bottom and are unable to catch fish.

Gillnets, however, pose a significant problem with respect to ghost fishing. Gillnets are frequently lost at sea as a result of weather, tides, poor positioning, loss of surface floats, snagging on the bottom, abandonment and interaction with other fishing gear. It has been found that gillnets can continue to catch and kill fish for up to 10 years after they are lost (Asmund & Lokkeborg, 1996). Fish become entangled in the meshes and subsequently act as bait attracting scavengers and other predators. Scavenging in turn, clears the meshes and the process repeats itself. Seabirds are attracted to, and can become ensnared in, baited longline hooks while they are being deployed or retrieved from the sea. In Newfoundland, during the period from 1981 to 1984, it was estimated that over 100,000 marine birds and mammals have died as a result of becoming caught in drifting gillnets (Moore & Jennings, 2000).

4.5 Economic Considerations

The efficiency of longlining depends on the number of fully baited hooks, the density of fish in the area and their average size. Loss of bait to seabirds, scavengers, non-target species and shipboard practices reduces the number of hooks available to fish. At low fish densities, longliners can compete effectively with trawlers as they fish over a much larger spatial area. However at higher fish densities, longlines can only catch as many fish as there are effective hooks in the water. By contrast, the catch rate of gillnets and trawlers increase roughly in proportion to abundance. Gillnets were found to catch 3 times the amount of fish per day as longlines during an experimental middle distance fishery on the Grand Banks of Newfoundland during 1987 (O' Rielly, 1988). Trawlers in particular can achieve very high catch rates when fish densities are high, the limiting factor being the time required to process the catch.

Table 4.1 shows a comparison of the economic performance of longliners and trawlers in Southwestern Nova Scotia during 1985. In both vessel classes, longliners generated higher net revenue than trawlers. Longliners are less expensive to operate than trawlers and their products demand better prices in the marketplace. This may be due to the respective selection properties of the gear and the quality of fish landed. Trawlers generally land, on average, higher catches of smaller fish, whereas longlines tend to land smaller catches of larger fish.

Table 4.1 A comparison of the Economic Performance of Longliners and Trawlers in Southwestern Nova Scotia in 1984.

	Vessel Length and Gear Type			
	35-44 (ft)		45-64 (ft)	
	Longline	Trawler	Longline	Trawler
Survey Sample Size	24	20	18	21
Capital Investment ($)	134,775	226,352	177,464	298,022
Crew	4	3	5	3
Days Fished	76	85	70	75
Average Landings (kg)	185,268	209,728	149,780	435,308
Operating Costs ($)	34,776	21,632	50,252	50,217
Maintenance Costs ($)	13,850	15,493	20,119	35,630
Fixed Costs ($)	8,211	20,526	12,049	27,757
Labour Costs ($)	52,470	39,407	68,834	73,774
Catch/Day at Sea (kg)	2,438	2,467	2,140	5,804
Avg. Price ($/kg)	0.68	0.52	1.2	0.48
Avg. Crew Wage ($/day)	173	155	197	328
Revenue ($)	125,303	108,183	178,050	207,413
Costs ($)	109,307	97,058	151,254	187,378
Revenue Less Costs ($)	15,996	11,125	26,796	20,035

Source: Adapted from Anonymous, 1985

Interestingly, for the larger vessel category, trawlers caught approximately three times as much fish as the longliners yet generated revenues marginally lower than the longline fleet. While average crew wages are higher in the trawler fleet, more fishers are employed in the longline fleet. The initial higher capital outlay for equipment and higher daily operating costs mean the trawler must catch considerably more fish to remain profitable. By this measure, trawling is less efficient and arguably more wasteful.

Another consideration in comparing longlining and trawling is their respective effects on the age structure of the stock. In the process of catching more small fish, trawlers have a much higher potential for growth overfishing. In a bioeconomic analysis of the mixed gear groundfish fleet operating on the Scotian shelf, O' Boyle et al. (1991) found that over time, trawlers will displace longliners as the dominant harvesting technology because they catch fish at smaller sizes before they can recruit to a size large enough to be utilized by the longline fishery.

Trawling is by far the most popular method of fishing for groundfish in Atlantic Canada and in many industrialized nations. Although there are technical limitations to each gear type in terms of when, how, where and what species each may be applied to, these limitations are not sufficient to explain the overwhelming popularity of bottom trawling. It is often argued that trawling is the more efficient method of fishing, however, this is not necessarily the case. Trawlers do catch significantly more fish at a lower catch per unit effort, but this fish tends to be smaller and of lower value. The initial capital costs and operating costs of trawlers are much higher than those of longliners and gillnetters, and therefore the breakeven point is much higher. Trawlers appear to compete well against other gear types because they are able to sustain high catch rates at times of low and high abundance, year round. Low prices resulting from small sizes and reduced quality are offset by high volumes. Equally important, these high volumes provide a continuous supply of raw material and year round employment to the processing sector.

During the latter half of the 20th century when marine resources were perceived to be virtually inexhaustible and little was known about the effects of fishing gear on the environment, most efforts were directed at maximizing the catch per unit effort. Declining fisheries resources and an increased awareness of the potential for long-term environmental damage and significant economic and ethical consequences requires re-examination of harvest technologies. Otter trawling clearly has the greatest potential to impact benthic communities, and also harvests the fisheries resource early in its life history stage with the attendant risk of growth over-fishing. However, there are technical measures that can be taken to lessen the impact of otter trawling on the seabed and these will be discussed further in Chapter 5. Taking into consideration the intrinsic value of marine habitat and net revenue returned per kilogram of fish caught, both longlining and gillnetting appear to be the more economically efficient fishing practices that are more compatible with conservation-oriented fisheries management.

Chapter V: Fisheries Management: Approaches and Solutions

5.1 Introduction

Traditionally fisheries have largely been managed on the basis of single fish populations. By assessing the abundance of a particular stock and determining an annual catch quota, fishing effort can be theoretically regulated to maximize production at a level sustainable over the long term. This has proven not to be the case. Fisheries, the world over, have often collapsed or approached collapse under single-species based management strategies. While over-fishing as a result of excess capacity is a common theme in these tragedies, so is the uncertainty in attempting to predict the behavior of a dynamic marine ecosystem. More recent approaches to fisheries management promote the understanding of the interactions between commercial verses non-commercial species and predator /prey relationships as well as the intrinsic conservation value of maintaining critical habitat and biodiversity.

Prior to the 20th century, most of the world's fisheries that were managed were done so in the absence of any meaningful science. Management decisions were based on judgements and inferences about the stock. In the 20th century, many industrial countries moved to impose controls to maximize production and reduce wasteful fishing practices. Concepts such as Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY) and $F_{0.1}$ were used to describe harvest levels and fishing mortality in terms of sustainability and conservation. Mathematical models such as Virtual Population Analysis (VPA) and Multi-Species Virtual Population Analysis (MSVPA) were developed to describe and forecast the population structure of exploited stocks. Unfortunately, concepts such as MSY, MOY and $F_{0.1}$ rely on the fundamental assumption that ocean productivity is a steady state system not subject to major change. Furthermore, models such as VPA do not effectively take into consideration the effect of removing both target and non-target species from the ecosystem and how these would affect predator/prey relationships and species interactions.

Fisheries science has a limited ability to comprehend and understand the complex and largely unobservable marine environment (Lauck et al., 1998). The uncertainty associated with environmental change, recruitment, growth and the difficulty in quantifying the impact of fishing activity are significant issues in this respect. $F_{0.1}$, a management criteria used to regulate many of Canada's marine fisheries, is a level of fishing mortality at which the slope of the yield per recruit curve is 0.1 times greater than the slope of the yield per recruit curve when fishing mortality =0. Although this represents a much more conservative approach than MSY, fishing effort level can be set too high if there is unaccounted for mortality in a fishery as a result of unreported catches, by-catch, discards and unaccounted for incidental mortality. Clearly, such uncertainties should be considered and incorporated into the decision making process when determining exploitation strategies.

The full impact of fishing gear on benthic habitats and implications for species dependent on such habitat is not clearly understood but it is widely accepted that the ecosystem undergoes change when subjected to fishing activity (Anonymous, 1992). Much of the current research suggests that bottom trawling reduces habitat complexity, resulting in a shift in species towards those more tolerant of disturbance. In addition to the intrinsic value of preserving species, loss of habitat structure could result in reduced productivity and growth rates of harvested populations and a net loss in ecosystem productivity. It therefore makes sense from both a conservation and economic point of view to examine fisheries management options that take into consideration the uncertainty associated with the ecosystem and the potential impacts fishing gear may be having on productivity.

5.2 Ecosystem Management

As a starting point, the management of fisheries resources from an ecosystem perspective requires that we acknowledge the highly interdependent relationships that exist between species, their habitat and the environment. Both the population and ecosystem management philosophies strive to optimize the social and economic benefits from having a commercial fishery. However, where the population-based management focuses on how much can be taken while attempting to ensure some measure of sustainability, the ecosystem approach considers the same question in the context of how fishing activity affects the entire ecosystem and its future biological productivity. Integral to this concept is the maintenance of species and genetic diversity.

Fundamental to the ecosystem approach is the recognition that human harvesting activities impact the ocean environment and that this is acceptable within limitations set by society. Laevastu et al. (1996) describes the basic principles of ecosystem management as: 1) commercial fishing must be carefully regulated with consideration to future recruitment and productivity, taking into account natural variability in reproduction and predator/prey relationships, 2) limiting the removal of non-target species to a level consistent with the maintenance of a sustainable biomass and an orderly, functioning ecosystem, 3) maintenance of biodiversity and 4) determining minimum biomass levels that balance economic demand against unacceptable biological and aesthetic impacts to the ecosystem. Manipulation of the ecosystem, for example the removal of top predators to increase the numbers of their prey, is also an option under ecosystem management.

Table 5.1 illustrates clearly the breadth of information provided by the ecosystem approach to assess the effect of harvesting activities on the ecosystem. Not surprisingly, the data requirements of ecosystem management are enormous. The present state of the ecosystem must be determined using surveys, population models and evaluations, simulations and other biological sampling. It is necessary to quantify the variability in the environment, the magnitude of the processes involved, and their effect on the ecosystem. Economic analysis must be available to support and substantiate the socioeconomic demands on the resource and the biological impact of various harvesting strategies must be assessed.

Table 5.1 A Comparison of Information Provided by the Population and Ecosystem Management Approaches.

	Availability	
Type of information needed	Single-species approach	Ecosystem approach
Size of resource (stock)	Estimation with cohort analysis if data available	Equilbrium biomass computed: Less stringent data requirements
Natural fluctuations	Not available	Computed, including the effects of environmental anomalies
Response to fishery	Computed for target species, no interspecies interactions included	Computed for all species, fishing and natural mortality interactions and effects on non-target species included.
Interactions between species	Not included	Included in the computations via predation, competition, by-catch
Possible optimum yield	Computed without interspecies interactions	Computed with consideration of the whole ecosystem
Rate of change of biomass and recovery rates	Only rate of change to fishery computed	Computed as caused by all factors within the ecosystem
Recruitment to fishery	Can only be estimated	Computed, function of predation, environment, anomalies and other factors
Spatial distribution and vulnerability to gear	Not possible to compute	Computed in models with spatial resolution.

Source: Laevastu et. al., 1996.

While very costly, and in some instances, beyond the capabilities of scientific investigation, ecosystem management could clarify the impact of human activities and thereby force society to consider these in the context of how we use the environment. Population management, for the most part, acknowledges ecosystem impacts but has failed to move beyond single species models. This shortcoming could be due to the inadequacies of the presently available multi-species models and/or the inability of fisheries managers to incorporate this often radically new information into their decision making processes (Gulland, 1991; Brugge & Holden, 1991).

Under ecosystem management the impacts of fishing gear, and in particular bottom interacting gear, would have to be quantified and taken into consideration. The loss of species diversity, habitat structure and biomass could lead to an overall loss in the productivity of the ecosystem, impacting all species as well as those of commercial importance. Where impacts are considered to be unacceptable in the context of management goals, alternative harvesting strategies may be employed to mitigate these effects. These strategies could include prohibiting gear types, technical modifications to the fishing gear to lessen impacts, or the adoption of Marine Protected Areas.

5.3 Marine Protected Area's

Marine Protected Area (MPA) is a term given to an area of ocean that is subjected to varying restrictions on its use, either for commercial or recreational purposes. Sometimes referred to as marine parks, marine reserves, marine sanctuaries and conservation zones, MPAs may vary in the area they encompass and the number of restrictions applied to harvesting activities within it. The overall aim of an MPA is to preserve biodiversity and enhance fisheries by reducing or eliminating activities that impact fish populations and critical habitat. A closed or restricted zone within a productive fishing area also provides a buffer against the uncertainties associated with attempting to predict sustainable harvest levels in a dynamic ecosystem.

MPAs are intended to offer a refuge for spawning fish and ensure that the age structure of a stock remains intact by protecting the older more fecund individuals who would otherwise be more susceptible to fishing gear. Older individuals are typically larger and have the reproductive capacity to contribute more to the growth of the stock than the younger and smaller fish, which are not captured by the gear. Allowing the age structure of a stock to become a function of natural mortality rather than fishing mortality would greatly increase the average size and number of individuals within the MPA. Poulin and Roberts (1993) reported an increase in the abundance and size in 45% (Saba Marine Park) and 59% (Hol Marine Reserve) of recorded commercial species in two Caribbean marine parks 4 years after cessation of fishing. Further benefits of the MPA include the protection of non-target species that would otherwise be discarded as by-catch and the preservation of critical benthic habitats and species. Removal of target and non-target species can alter community structure and lead to a loss of genetic diversity both within a species and within a stock. Fishing removes both predators and prey from the food web, resulting in multiple ecological changes to the ecosystem (Dayton et al., 1995).

Restriction or elimination of fishing activities may benefit bottom dwelling species and benthic habitats. Bottom trawling is known to affect benthic species by direct contact or indirectly by altering the sediment structure, causing sediment re-suspension and changing the chemical cycling between the sediment water interface. Protecting benthic species is not only important in preserving biodiversity but conserves an important food source for bottom dwelling species (Methven, 1999). Many infaunal and epifaunal species play a critical role in nutrient cycling necessary for primary production.

MPAs can be used as a fisheries management tool to "set aside" a portion of the population and habitat in the event of overfishing. This may have naturally occurred in the early days of many of the East Coast fisheries when much of the offshore was inaccessible to poorly equipped inshore vessels (Shackell & Lien, 1995). Lauck et al (1998) suggest an MPA could serve as a source of breeders who could repopulate the over-fished area, however, the protected area would need to be large enough to contain up to 50% of the original population and include important spawning grounds.

Clearly, MPAs offer many net benefits in managing sustainable fisheries and protecting biodiversity. The simplest way to avoid the potential impacts of bottom fishing activity on benthic communities is to establish a no-take MPA, but at what cost? To successfully serve as a re-population source and to provide a buffer against episodic climate change reserves need to be spatially large, encompassing productive fishing grounds and habitats. This means a loss of productive fishing grounds to the fishing industry and potentially increased effort on unrestricted areas. While this loss may translate into economic loss for some sectors of the fishing industry there can be long-term net economic benefits associated with MPAs (Dixon, 1993; Farrow, 1996).

5.4 Gear Modifications

The impact of some fishing gears on the seabed may be reduced through design modifications and altering the manner in which the gear is used. In most fisheries, gear regulations are limited to defining the classification of gear is to be used i.e. bottom trawl, mid-water trawl, cod trap, etc. and minimum allowable mesh sizes. The specifics of gear construction and rigging are left to the individual user and these are often determined by catching efficiency and vessel size. Consequently, most fishing gears used on, or near, the seabed have been designed and are rigged to have maximum contact with the seabed (Jennings & Kaiser, 1998). Traditionally, economics and practicality have driven fishing gear design towards generic nets which could be used for a number of different species over a range of bottom types inevitably resulting in unnecessary by-catch and damage to the more sensitive benthic habitats. Recently, efforts in fishing gear research have focused on designing "subtle" fishing gear that exploits the unique behavioral characteristics of the target species while minimizing the impact on non-target species and the seabed.

As discussed in an earlier section, trawls and dredges impact the seabed in a number of different ways; by physically impacting species that live on and under the surface, by redistributing surface sediments, by altering the topography of the seabed and by re-suspending sediments. The extent of the disturbance is dependent on towing speed, the size and weight of the gear and the type of bottom over which it is towed.

Empirical studies and underwater observations of commercial fishing grounds suggest that, of the components of a bottom trawl that touch the bottom i.e. sweeplines, bridles and footgear, the trawl doors are likely to have the most impact (Jenner et al., 1991; Krost et al., 1990). Goudey & Loverich (1987) suggest that a reduction in crab by-catch and damage in the Bering Sea Yellowfin Sole fishery may be attributed to a new high aspect ratio trawl door. Being hydrodynamically efficient, the tall and narrow design operates at shallower angles of attack than conventional doors and subsequently creates a smaller "foot print" across the seabed. Further benefits of the design include reduced bottom contact force and keeping a larger portion of the sweep wire off the seabed. Some bottom trawling techniques, such as pair trawling do not require trawl doors and it may be possible to develop a trawl gear rigged such that the doors need not touch the bottom (Anonymous, 1999).

Footgears have been successfully modified to reduce weight and the area of sea floor swept without adversely affecting catch rates. Research with some species has shown that the sand cloud generated by a minimum number of bottom contacting components is sufficient herding stimulus and that many of bobbins and disks used in traditional footgears may be redundant (Anonymous, 1999; West, 1987). Other technical modifications to the gear may lessen its impact on the bottom; for example increasing the length of the upper bridle relative to the lower bridle reduces the weight of the gear on the bottom. In some fisheries it may be possible to dispense with the footrope altogether and use wing end weights to keep the fishing line close to the seafloor. In some instances, a mid-water trawl could be used in place of a bottom trawl.

There are new techniques and technical options available to fishers to reduce the impact of their gear on benthic habitats. Some of these show much promise but most have yet to be implemented and tested under commercial conditions. We must temper our optimism with the reality that towed fishing gear relies heavily on the herding stimulus generated by the sand and mud re-suspended as a consequence of towing over the bottom (Main & Sangster, 1981). The mere presence of this re-suspended sediment represents a major disturbance to the seabed and the resident infauna and epifauna. It therefore seems unlikely that any meaningful reduction in benthic impacts can come from measures that could ultimately reduce capture efficiency.

Chapter VI: Legislative Obligations

6.1 Introduction

Up until the 20^{th} century customary international law and practice was such that the world's oceans could largely be used by anyone in any manner and freedom of the seas was a right guaranteed to all. Overexploitation of many of the world's fisheries resources in the latter half of the 20^{th} century has resulted in the creation of Exclusive Economic Zones (EEZ) within which countries exercise their sovereign rights to manage fisheries resources and limitations have been placed on high seas fishing. Declining global catch rates have been the catalyst for a shift in international policy from maximizing production towards sustainability, ecosystem protection, the consideration of biodiversity and precautionary management. The use and exploitation of the world's ocean resources is now governed by a number of important international agreements and organizations which strive to understand and preserve the oceans for future generations. With respect to the laws, agreements and policies governing the protection of benthic habitats, it is necessary to consider, internationally, the United Nations Convention for the Law of the Sea (UNCLOS), codes developed under the auspices of the Food and Agriculture Organization of the United Nations (FAO) and, in the Canadian context, the Fisheries Act and the Oceans Act.

International law governing the world's oceans is defined by the United Nations Convention for the Law of the Sea (UNCLOS). Inter-governmental agencies such as the International Council for the Exploration of the Sea (ICES) in the North Atlantic and the

North Pacific Marine Science Organization (PICES) in the North Pacific support the UNCLOS by conducting and providing scientific information on behalf of their member States. Both agencies are mandated to promote the advancement of scientific knowledge about the oceans and to conduct research as directed by the member countries. The Inter-governmental Oceanographic Commission (IOC) is designated by the UNCLOS as the competent international organization for marine scientific research and has specific responsibilities under UNCLOS for the Convention for Biodiversity and the Framework Convention on Climate Change amongst others. The IOC cooperates through a memorandum of understanding with ICES and PICES and other international organizations such as the International Maritime Organization (IMO), International Atomic Energy Agency, World Meteorological Organization, and the UN Food and Argicultural Organization (FAO). The FAO is mandated by the UN to raise global nutritional levels and improve food production. Its Committee on Fisheries (COFI) was the catalyst for the International Code of Conduct for Responsible Fishing, an internationally agreed upon statement of principles and practices for responsible fishing.

Most developed nations had enacted fisheries policies and legislation prior to the Law of the Sea conferences, which were initially convened to settle jurisdictional issues. Canada's first fisheries legislation, the " Dominion Fisheries Act" dates back to 1868. The UNCLOS respects a Sovereign State's right to develop and manage fisheries and seabed resources within their EEZ's guided by the general principles outlined in the UNCLOS. While appearing somewhat convoluted, authority over the world's fisheries is straightforward, at least in theory if not in practice. UNCLOS governs the high seas, straddling stocks and some migrating stocks. Individual States develop their own policy within jurisdictions sanctioned by UNCLOS. With respect to legislation and international agreements that govern the impact of Canadian fishing operations on benthic habitats, further consideration must be given to the UNCLOS, the Oceans Act and the UN International Code of Conduct for Responsible Fisheries.

6.2 The United Nations Convention on the Law of the Sea

The International community had long recognized the need for a comprehensive agreement setting forth the rights and obligations of countries governing the use of the world's oceans and seabed resources. Negotiations between the 151 participating countries on the terms of the United Nations Convention on the Law of the Sea (UNCLOS) began in March of 1958 at UNCLOS I and lasted through UNCLOS II in 1960 and UNCLOS III in 1973. On December 10, 1982 at Montego Bay, Jamaica the finalized Convention, comprised of 320 articles and nine annexes was signed by 119 countries including Canada. The Convention did not come into force until November 16, 1994.

The UNCLOS is a unique document in that it seeks to govern virtually all aspects of ocean space. It delineates the territorial sea and exclusive economic zones of coastal States and defines the obligations of States with respect to environmental control, marine scientific research, economic and commercial activities and the transfer of technology.

The rights of navigation and over-flight in areas under Coastal State jurisdiction and on the open oceans are preserved. The agreement also confirms the right of all States to fish on the high seas with the obligation to cooperate with each other in managing and conserving ocean resources. Of particular importance is the Conventions provision of a compulsory and binding dispute resolution mechanism.

Although the Convention does not speak directly to the conservation of marine habitats or the protection of organisms living on or in the seabed, it does acknowledge the linkage between the health of the ecosystem and the viability of commercially important species. Article 61 addresses the conservation of living resources within the States EEZ:

> 61.2: " ....taking into account the best scientific evidence available to it, shall ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation."
>
> 61.4: " In taking such measures the coastal State shall take into consideration the effects on species associated with or dependent upon harvested species with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened."

The obligation of States with respect to the conservation of living resources of the high seas is out-lined in Article 119.1(b) of the Convention which, reads exactly as article 61.4.

The environmental provisions within the Convention focus primarily on the detrimental effects of marine and land-based pollution, mining on the seabed of the continental shelf and in the deep sea as well as ocean dumping. These provisions may be more of a statement of principles which serve to stimulate International cooperation than legal instruments by which to ensure meaningful cooperation and compliance (McManus. 1977). There appears to be no recognition of potential effects of fishing practices on the benthic environment or provisions for the protection and conservation of these resources. This could be a result of the somewhat outdated nature of UNCLOS. Given the slow evolution of international law and the time required to seek the consensus of 150 nations, it is not inconceivable that some provisions of UNCLOS do not reflect current scientific knowledge and public concern for environmental issues. UNCLOS appears to be primarily about the conservation and management of ocean resources as it relates to the sustainability of commercially important species. This is a rather narrow and focused view of the ocean and is not surprising, as many of the signatories to UNCLOS are maritime nations with developed or developing commercial fleets heavily dependent on these resources.

6.3 The Food and Agricultural Organization of the United Nations (FAO)

The FAO is an international organization mandated by its member nations to collect, analyse, interpret and desseminate information relating to fisheries, marine products, forestry and primary products to create higher standards of nutrition. Its role is solely advisory and its policies are non-binding to member nations. Recognizing the poor state of most fisheries on the globe, the FAO convened the International Conference on Responsible Fishing in Cancun, Mexico in May of 1992. During this meeting it was agreed that FAO would establish principles and standards governing conservation, management and fisheries development to ensure the sustainable exploitation of the Oceans resources. In 1995, the 28th Conference of FAO adopted the International Code of Conduct for Responsible Fisheries. Implicit within the code is the urgent need to protect aquatic habitats regardless of scientific uncertainty, section 6.5 of the General Principles states:

> 6.5: " States and sub-regional and regional fisheries management organizations should apply a precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment, taking account of the best scientific evidence available. The absence of adequate scientific information should not be used as a reason for postponing or failing to take measures to conserve target species, associated or dependent species and non-target species and their environment."

FAO defines the "precautionary approach" as:

> 6: ".... The application of prudent foresight. Taking account of the uncertainties in fisheries systems and the need to take action with incomplete knowledge, it requires, *inter alia* :
>
> a) consideration of the needs of future generations and avoidance of changes that are not potentially reversible;
>
> d) that where the likely impact of the resource is uncertain, priority should be given to conserving the productive capacity of the resource;
>
> h) appropriate placement of the burden of proof by adhering to the requirements above."

Fundamental to the precautionary approach is the burden of proof; the assumption that all fishing activities have environmental impacts and that these are not to be taken as inconsequential unless proven otherwise. The burden of proof is a potentially powerful instrument in curtailing destructive fishing practices. Unfortunately, the International Code of Conduct for Responsible Fisheries is a non-binding, voluntary statement of principles and guidelines. The Code on its own has no authority in law. While it reflects a heightened awareness of the need to access the impact of human activities on the ecosystem, its prime focus could be interpreted as ensuring the sustainability of important commercial species.

6.4 Canadian Fisheries Legislation

The Constitution Act of 1867 and the subsequent Dominion Fisheries Act of 1868 gives the Federal Government the almost exclusive authority to manage and regulate the fisheries in Canada. Initially, this included all inland and marine waters up to 3 miles from the coast but in 1977 Canada unilaterally extended its fisheries jurisdiction to include all waters up to 200 nm from its coasts. Although jurisdictional challenges by the provinces over the past century have defined and somewhat reduced these sweeping powers, the federal government's influence over Canadian fisheries policy remains extensive. The Fisheries Act gives wide discretionary powers to the Minister of Fisheries and Oceans and his or her senior administrators at DFO, making Canadian fisheries legislation unique amongst industrialized nations.

With respect to habitat management and protection, the Fisheries Act has been progressively strengthened to reflect growing public concern for the environment. In 1985, the Fisheries Act was amended to support a new fish habitat management policy that would prohibit activities that result in a net loss of habitat with an overall goal to increase fish habitat. Sections 35 (1) and 43 of the act deal specifically with the protection of habitat:

> 35 (1): "No person shall carry on any work or undertaking that results in the harmful alteration, disruption or destruction of fish habitat."

43: "The Governor in Council may make regulations for carrying out the purposes and provisions of this Act and in particular, but without restricting the generality of the foregoing, may make regulations

(a) for the proper management and control of the sea-coast and inland fisheries;

(b) respecting the conservation and protection of fish;

(h) respecting the obstructing and pollution of any waters frequented by fish;

(i) respecting the conservation and protection of spawning grounds."

Clearly, the negative impact of fishing activities on benthic habitats falls within the jurisdiction of the Fisheries Act. However, it is interesting to note that habitat tends to be defined in terms of its importance to fish and not being comprised of living organisms worthy of protection in their own right. Implicit within the Act are the principles of conservation and a precautionary approach to resource management, placing the "burden of proof" on the exploiter to demonstrate that his or her actions will not damage fish habitats (Shackell, 1995). Despite some evidence suggesting damage is being done to critical fish habitats, DFO has not required the Canadian fishing industry to prove that its harvesting methodologies are benign as a condition of license.

The failure of the Federal Government to use the legislative authority provided to it by the Fisheries Act to protect fish habitats may be related to policy and management issues that include insufficient ecological information, unclear departmental jurisdiction, fragmented legislation, lack of integrated coastal zone planning, an ineffective environmental assessment framework, inadequate public involvement, limited monitoring and evaluation, and lack of enforcement (Cote, 1992).

Particularly problematic to the issue of fishing gear impacts on the benthos is the lack of a clear understanding of how ecosystems function. The productivity of marine ecosystems is highly variable in nature, making it difficult to distinguish between natural variability and the anthropogenic effects of fishing gears. This is further complicated by the lack of any baseline information on the condition of the seabed prior to trawling or dredging activities. Being unable to access the effects of fishing against this background of short and long-term variability leaves DFO in the indefensible position in attempting to enforce habitat protection policies.

Ecological considerations, regardless of how highly held by both the government and industry, often take a back-seat to socio-economic issues. Regulation of the fisheries to meet specific economic objectives was a clearly stated objective in the DFO's 1976 Policy for Canada's Commercial Fisheries:

> "…….the objective of regulation has, with rare exception, been protection of the renewable resource. In other words, fishing has been regulated in the interests of the fish. In the future it is to be regulated in the interests of people who depend on the fishing industry."

Our political institutions are such that DFO may be under considerable pressure to ensure that the fishing industry remains viable to the detriment of our ocean resources (Shackell & Lien, 1995).

Recognizing the need for a comprehensive oceans management policy to focus and re-define policy objectives and fragmented legislation, the Canadian Government passed the Oceans Act in 1997. The new Act embraces the principles of sustainable development, integrated management and the precautionary approach to resource exploitation. Part II of the Act, in particular, directs the Minister to include industry "stakeholders" in the development of an oceans management strategy and provides for the establishment of MPA's.

As with previous legislation the Oceans Act gives the Minister of Fisheries and Oceans the tools and legislative authority to protect critical fish habitats. Canadian legislation requires the Minister of Fisheries and Oceans to protect habitat, an obligation which is strengthen by the Oceans Act. The question remains: is there the political will to overcome the objections of those who fail to see the long term benefits of preserving fish habitats and biodiversity in favor of short term economic gain? This, as it has always been, is the real challenge before DFO.

Chapter VII: Conclusions

Mobile fishing gear has a negative impact on infauna, epifauna and sedimentary structures, which form essential components of benthic marine habitat. The magnitude of this effect is dependent on the type and weight of gear, how it is used and the nature of the substrate. A meta- analysis of the available scientific literature suggests that bottom fishing can remove half of the benthic fauna, however actual removal rates and incidental mortalities can vary significantly between habitats, species and fishing practices. In general, repeated exposure to fishing disturbance results in a shift towards benthic communities dominated by smaller, faster growing species that are more tolerant to disturbance. Benthic fishing disturbances can result in a net loss of biodiversity and habitat. In addition to the moral and ethical issues this poses to society, bottom harvesting technologies have serious implications for the health of the ecosystem and the productivity of commercial fish stocks.

Benthic plants and animals and their remains, e.g. empty shells, together with sedimentary topographical features and biogenic structures are the essential components of marine bottom habitats. Although some components of the benthos, such as demersal fishes and crustaceans represent a harvestable resource, many non-commercial benthic species play important roles in the efficient functioning of the ecosytem. Infaunal organisms convert the organic wastes from phytoplankton and decaying plant matter into nutrients that are released from the sediments by various chemical processes. These nutrients are an important food source for many species. The burrowing of some infaunal species such as worms, mollusks and crabs create tubes and provides oxygen to the sediment. Sessile organisms create structures on the seabed providing physical relief. For the juveniles of many demersal species, these structures provide surfaces on which to feed and shelter against predation.

Most scientific studies concerning fishing gear effects on the benthos have been conducted in shallow water (< 100 m), at a relatively small spatial and temporal scale and over a limited range of fishing intensities. These studies may not be representative of the large scale and intensity of the commercial fishing that takes place on productive grounds and may be biasing our understanding of recovery periods. Fishing tends to be a highly directed activity and some analyses suggest that intensely scoured bottoms tend to represent a small portion of the overall fishing grounds. There is also a specific need for better information on the effects of fishing on deep water benthos given that these habitats are most vulnerable to external disturbances. Interpretation of these studies is further complicated by the fact that few virgin fishing grounds exist in the world, and we therefore have little knowledge about how benthic ecosytems looked prior to fishing activity. If the largest change in benthic communities took place during the initial stages of a fishery, then it may not be possible to detect trends in relatively small-scale studies in which benthic communities have already been altered. The effects of fishing must also be considered in context of a background of natural disturbances. In some areas, such as shallow continental shelfs and intertidal zones, storms, tides, icebergs, seismic events and the foraging activity of fishes and marine mammals may disrupt benthic communities as much or more than fishing gear.

Mobile fishing gear physically impacts the seabed by scraping, plowing and trenching sediments and displacing both large and small boulders. The scraping action of the ground cables and footrope of otter trawls and seines tends to flatten the topographical features of the seabed. Otter boards and dredges penetrate the bottom, displacing and redistributing sediments and impacting infaunal species up to 30 cm below the surface. Hydraulic dredges may move sediments and benthic life metres to hundreds of metres from their original habitat. The magnitude of these physical effects is variable, depending on gear type and the vulnerability of different bottom types to physical disturbance. Heavy gear that is towed slowly will physically disturb the bottom more than light gear towed quickly. Sediment mixing and re-suspension tend to be greater on loosely packed substrates such as sand and silt, and less on pebbles and rocks, that resist penetration by the fishing gear. Those infaunal and epifaunal species unable to detect and avoid the oncoming gear may be physically damaged, uprooted and displaced. Sub-surface structures can be destroyed and sediment redistribution may result in buried metabolized organic matter affecting respiration and the chemical/nutrient flux at the seabed/water interface.

Bottom fishing has the potential to remove a substantial proportion of the larger epibenthic megafauna. Communities dominated by high biomass species and sessile fauna are reduced in diversity and come to be populated with high abundances of small fast growing organisms. Epifaunal organisms are much less prevalent on heavily fished seabed. The extent of the initial damage and recovery period is related to the substrate type and environmental conditions. Habitat populated with species adapted to life in high-energy environments i.e. waves and currents have been found to recover from fishing disturbances quicker than those species inhabiting more benign environments. Chronic exposure to intense fishing pressure is likely to result in a permanently altered benthic ecosystem even in relatively dynamic environments. In summary, there is now a consensus within the scientific community that bottom trawling and dredging impacts the benthos, although there is still much debate about the consequences of such disturbances and how long it may take the benthos to recover.

Bottom contacting mobile fishing gears such as otter and beam trawls, seines, rakes and dredges are the dominant technologies used in the global harvest of marine resources. For some bivalve species such as scallops and clams, rakes and dredges are currently the only available harvesting technologies. Some flatfish species may only be taken with trawls, however, for many species there are a number of harvesting technologies that may be employed, with some gear having less of an environmental impact than other gear. Otter trawling impacts significantly more area of seabed than beam trawls, seines, rakes or dredges and is probably the least appropriate technology for conservation and sustainable fishing practices. This method is presently characterized by sustained high catches of small, low value fish and historically has been considered to be the most economically efficient method of catching many demersal species of fish.

However, if the intrinsic value of marine habitat and net revenue returned per kilogram of fish caught are considered, longlining and gillnetting may, in fact, be the more economically efficient fishing practices. These approaches are also more compatible with conservation-oriented fisheries management.

Global-wide resource collapses that have resulted from indiscriminate harvesting practices combined with heightened public environmental consciousness have begun to shift thinking from maximizing production to sustainability, ecosystem protection, maintenance of biodiversity and precautionary management. These new principles are reflected in international and national legislations such as the UNCLOS, FAO Code of Conduct and Canada's Ocean Act. Integral to these principles is the fundamental concept that the "burden of proof" will lie with the exploiter. This is in contrast to the traditional view (held by commercial fishing interests) that fisheries managers should demonstrate that fishing activity is deleterious to the environment. Unfortunately, much of this legislation represents no more than a statement of principles, and contains very little authority in law or enforceability. Although Canada's new Oceans Act reflects this new reality, it is interesting to note that even under the old Fisheries Act the Minister of Fisheries and Oceans was empowered to place the burden of proof on the exploiter, a power rarely if ever exercised. Regardless of how highly held by government and industry, ecological considerations have most often taken a back seat to socio-economic issues.

Traditional fisheries management concepts such as MSY, MEY, $F_{0.1}$ and fisheries models such as VPA are deficient in that they cannot predict the behavior of a dynamic marine ecosystem. This shortcoming may result from uncertainty associated with environmental change, recruitment, growth and the effects of fishing on the ecosystem. The ecosystem approach to fisheries management requires that we acknowledge this uncertainty and incorporate it into long-term exploitation strategies. Population and ecosystem management both strive to optimize the social and economic gains to be had from a commercial fishery, however the ecosystem approach considers the effects of fishing in the context of an ecosystem's future biological productivity. This is in contrast to population management, which by and large ignores the detrimental aspects of fishing.

MPAs provide a refuge from commercial fishing pressures and therefore provide a mechanism to preserve fish resources, biodiversity and critical habitats. Establishing no-take MPAs may allow entire ecosystems to revert to a pre-fished state by eliminating human activities within a specific geographical zone. These reserves can protect the age structure of stocks, critical habitats, spawning grounds and provide a source of breeders to re-populate over fished areas. However, to be effective, protected areas need to be large and encompass a variety of habitats that may often include prime fishing grounds. Similar to modifying fishing gear to reduce bottom impacts, MPAs have immediate and direct economic consequences to the commercial fishing industry, the rewards of which may not be evident, if ever, for some years.

There is a clear need for humankind to exploit the world's marine resources for socio-economic gain. But we need to recognize the impact this activity has on the ocean environment in terms of the loss of species, habitat and future ecological productivity. In the pursuit of economic gain from the oceans, we must achieve a balance between how much is taken and the associated costs. Fishing activity generally has a negative impact on the environment, and bottom fishing in particular has a significant impact on benthic communities. Society as a whole, and not just fishing industry stake-holders, must decide on an acceptable level of loss. The key to this debate may be assigning a more comprehensive monetary value to the benthos.

By approaching fisheries management from an ecosystem perspective, we may begin to understand better the linkages between ecosystems processes and harvesting activities, and from this may come some real attempts to mitigate the harmful effects of fishing. MPAs are a useful management tool to preserve portions of the ecosystem. Alternatively, with further scientific study we may be able to match specific gear types to geographic regions based on the susceptibility of habitat within that region. However, the success of ecosystem management may ultimately rest with the political will of governments that have traditionally catered to the fishing constituency. Unfortunately, failure to recognize the implicit link between the health of the ecosystem and the long-term productivity of fisheries resources may see these management alternatives ignored in favor of the short-term, high yield fishing activities typical of mobile gear fisheries.

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