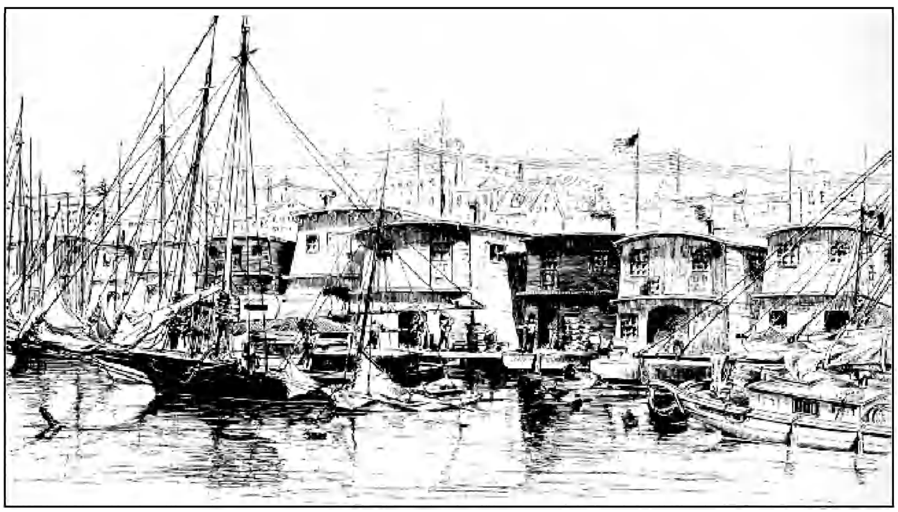
# A Review of National and International Literature on the Effects of fishing on Benthic Habitats

**Korie A. Johnson**



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http://www.nmfs.noaa.gov/habitat/habitatprotection/essentialfishhabitat10.htm

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## PREFACE

This document summarizes existing information on the effects of fishing activities on benthic marine habitats. It was prepared by the National Marine Fisheries Service (NMFS) Office of Habitat Conservation with the intent of providing the Fishery Management Councils (Councils) with a reference document to assist in assessing adverse effects of fishing to essential fish habitat (EFH). The scope of this document is limited to habitat effects; thus, ecosystem effects resulting from physical disturbance or removal of target species and bycatch are not addressed. The first part of this document reviews the statutory requirements and information needed to understand impacts of fishing. The second part of the document provides an overview of the major types of effects, as provided in scientific reviews, that could occur as a result of fishing. The third part of this document reviews published and unpublished scientific literature, and summarizes scientific reviews and studies on fishing gear effects on habitat on a case by case basis. The section is organized by gear type, and then by habitat within specific gear types. Papers are presented within specific habitat type sections based on the information provided in the papers, without the use of any standardized habitat classification system. The summaries present methods, results, and conclusions as reported by the authors. There is no attempt to evaluate the validity of the scientific approach or the conclusions reached in each study, although most of the studies and reviews discussed herein have been peer reviewed. The final portion of the document reviews the current state of information and the range of management philosophies discussed in the literature regarding minimization of fishing effects.

# I. INTRODUCTION

## A. STATUTORY REQUIREMENTS

The 1996 Amendments to the Magnuson-Stevens Fishery Conservation and Management Act (MSA) require that fishery management plans (FMPs) minimize to the extent practicable adverse effects on EFH caused by fishing (Magnuson-Stevens Act section 303(a)(7)). Pursuant to the EFH regulations (50 CFR 600.815(a)(2)), FMPs must include an evaluation of the potential adverse effects of fishing on EFH. The evaluation must consider the potential adverse effects of all fishing gear types used in waters designated as EFH, not just those gears used in the fishery in question. It must also consider potential impacts of fishing on different types of habitat found within EFH for all federally-managed species. In completing this assessment, FMPs must be based on the best scientific information available, and can include other appropriate information sources as well (e.g., economic data, anecdotal information). Included in this assessment should be consideration of the establishment of research closure areas and other measures to evaluate impacts of fishing activities that may adversely affect EFH.

To assist Councils in meeting the above mandates, this report summarizes available information concerning effects of fishing on marine habitats. Information sources include peer reviewed scientific journals, as well as non peer-reviewed reports. Major bibliographic sources include Rester (2000), NMFS Alaska Fisheries Science Center bibliography (Wion and McConnaughey 2000), and numerous ICES reports. In addition, a thorough literature search was completed to ensure inclusion of articles up to May 2002. This document is limited to major fishing gear types: trawls, dredges, traps/pots, seines, set gillnets, and set longline. Available information on mud, sand, gravel (including pebble, cobble and boulder), coral/outcrop/seamount, and seagrass habitats from all geographic areas is summarized.

### B. INFORMATION NEEDED TO ASSESS EFFECTS ON HABITAT

The effects of fishing gears on habitat depend on a number of factors, including the nature, magnitude and frequency of the impact, and the recovery time of the habitat and biological community affected by the gear. These factors in turn depend on characteristics of the gear (e.g., type, weight, towing speed, depth of penetration), the intensity and areal extent of the disturbance, and the biological, physical, chemical and oceanographic characteristics of the area impacted (Hall et al. 1993, Brylinsky et al. 1994, Hall 1994, Auster and Langton 1999, DeAlteris et al. 1999, Kaiser 2000). The influence of so many factors complicates understanding the effects of fishing gear on habitat and ultimately on the populations of fishes and invertebrates that utilize that habitat.

To fully evaluate the impacts of fishing gear on habitat, and how habitat impacts affect sustainability of fish populations, improved information is needed on:

1) the spatial extent of fishing-induced disturbance (fishing effort) by gear type;
2) the distribution of habitat types;
3) the effects of specific gear types (and configurations within gear types), along a gradient of effort, on specific habitat types;
4) the relative importance of fishing gear effects and natural disturbance;
5) the role that seafloor habitats and impacts on those habitats have in the population dynamics of fishes; and
6) natural changes/trends in communities and ecosystems.

## II. SCOPE OF GEAR EFFECTS

Types of potential effects on habitat from fishing fall into specific categories, including alteration of physical structure, sediment suspension, chemical modifications, benthic community changes, and ecosystem changes. These general effects are discussed below.

### A. ALTERATION OF PHYSICAL STRUCTURE

Physical effects of fishing gear can include scraping, ploughing, burial of mounds, smoothing of sand ripples, removal of stones or dragging and turning of boulders, removal of taxa that produce structure, and removal or shredding of submerged aquatic vegetation (Fonseca et al.1984, Messieh et al. 1991, Black and Parry 1994, Gordon et al. 1998, Kaiser et al. 1998, Lindeboom and de Groot 1998, Schwinghamer et al. 1998, Auster and Langton 1999, Kaiser et al. 1999, Ardizzone et al. 2000). These physical alterations reduce the heterogeneity of the sediment surface, alter the texture of the sediments, and reduce the structure available to biota as habitat. As mobile gear is dragged across the seafloor, parts of some gears can penetrate up to 5-30 cm into the substrate under usual fishing conditions, and likely to greater depths under unusual conditions (Drew and Larsen 1994). This action can leave tracks or even trenches in the seafloor, depending on the sediment type. It is unknown whether or to what extent these man-made features might compensate for the sediment smoothing actions of the gear.

## B. SEDIMENT SUSPENSION

Resuspension of sediments occurs as fishing gear is dragged along the seafloor. Effects of sediment suspension can include reduction of light available for photosynthetic organisms, burial of benthic biota, smothering of spawning areas, and negative effects on feeding and metabolic rates of organisms. If resuspension occurs over a large enough area it can actually cause large scale redistribution of sediments (Messieh et al. 1991, Black and Parry 1994). Resuspension may also have important implications for nutrient budgets due to burial of fresh organic matter and exposure of deep anaerobic sediment, upward flux of dissolved nutrients in porewater, and change in metabolism of benthic infauna (Mayer et al. 1991, Pilskaln et al. 1998).

Effects of sediment resuspension are site-specific and depend on sediment grain size and type, water depth, hydrological conditions, faunal influences, and water mass size and configuration (Hayes et al. 1984, LaSalle 1990, Barnes et al. 1991, Coen 1995). Effects are likely more significant in waters that are normally clear compared with areas that are already highly perturbed by physical forces (Kaiser 2000). Schoellhamer (1996) concluded that resuspension by natural mechanisms in a shallow estuary in west-central Florida was less frequent and of smaller magnitude than anthropogenic mechanisms (e.g., fishing) and that sediments disturbed by fishing were more susceptible to resuspension by tidal currents. Modeling by Churchill (1989) concluded that resuspension by trawling is the primary source of suspended sediment over the outer continental shelf, where storm-related stresses are weak. In the Kattegat Sea, Sweden, sandy sediments above the halocline were more affected by wind-induced impacts than by fishing effort, but mud sediments below the halocline experienced an increase in the frequency of disturbance by 90% in the spring and summer and by 75-85% in the autumn and winter due to fishing (Floderus and Pihl 1990). Thus, even when recovery times are fast, persistent disturbance by fishing could lead to cumulative impacts. In contrast, Dyekjaer et al. (1995) found that in Denmark, although local effects of short duration might occur, annual release of suspended particles by mobile fishing gear is relatively unimportant compared with that resulting from wind and land runoff.

Chronic suspension of sediments and resulting turbidity can also affect aquatic organisms through behavioral, sublethal and lethal effects, depending on exposure. Species reaction to turbidity depends on life history characteristics of the species. Mobile organisms can move out of the affected area and quickly return once the disturbance dissipates (Simenstad 1990, Coen 1995). Even if species experience high mortality within the affected area, species with short life history stages and high levels of recruitment or high mobility can repopulate the affected area quickly. However, if effects are protracted and occur over a large area relative to undisturbed area, recovery through recruitment or immigration will be hampered. Furthermore, chronic resuspension of sediments may lead to shifts in species composition by favoring those species that are better suited to recover or those that can take advantage of the pulsed nutrient supply as nutrients are released from the seafloor to the euphotic zone (Churchill 1989).

## C. CHANGES IN CHEMISTRY

Fishing gear can result in changes to the chemical makeup of both the sediments and overlying water mass through mixing of subsurface sediments and porewater. In shallow water this mixing might be insignificant in relation to that from tidal and storm surge and wave action, but in deeper, more stable waters, this mixing can have significant effects (Rumohr 1998). In a shallow, eutrophic sound in the North Sea, fishing caused an increase in average ammonia content (although horizontal variations prevented interpretations of these increases) and a decrease in oxygen due to the mixing of reduced particles from within the sediments (Reimann and Hoffman 1991). Also in the North Sea, fishing enhances phosphate released from sediment by 70-380 tonnes per year for otter trawls and by10,000-70,000 tonnes per year for beam trawlers (ICES 1992). These pulses were compensated by lower fluxes after the trawl passes. It is important to remember that these releases are recycling existing nutrients, rather than adding new nutrients, such as inputs from rivers and land runoff (ICES 1992).

It is unclear how changes in chemistry might affect fish populations. During seasons when nutrients are low, the effective mixing of the sediments could cause increased phytoplankton primary production and/or eutrophication. ICES (1992) concluded, however, that these pulses are compensated by lower fluxes after the trawl has passed, and that the releases from fishing gear that recycle existing nutrients are probably less influential than new inputs from rivers and land runoff (ICES 1992).

## D. CHANGES TO BENTHIC COMMUNITY

Benthic communities are affected by fishing gear through damage to the benthos in the path of the gear and disturbance of the seafloor to a depth of up to 30 cm. Many kinds of epibenthic animals are crushed or buried, while infauna is excavated and exposed on the seabed. This is in addition to smothering addressed above.

Specific impacts from fishing depend on the life history, ecology and physical characteristics of the biota present (Bergman and Van Santbrink 2000). Mobile species that exhibit high fecundities and rapid generation times will recover more quickly than non-mobile, slow-growing organisms. In Mission Bay, California, polychaetes with reduced larval phases and postlarval movements had small-scale dispersal abilities that permitted rapid recolonization of disturbed patches and resulted in maintenance of high infaunal densities (Levin 1984). Those with long-lived larvae were only available for successful recolonization if the timing of disturbance coincided with periods of peak larval abundance, however, these species were able to colonize over much larger distances. Rijnsdorp and Van Leeuwen (1996) found increased growth (based on back calculated growth from otolith growth zones) in the smallest size classes of plaice in the North Sea correlated to eutrophication and seabed disturbance from beam trawls. The authors hypothesized that trawling caused a shift in the benthic community from low-productive, long-lived species to high-productive, short-lived species that benefitted from increased nutrient availability due to anthropogenic activities. This potentially could have lead to increased prey availability, and thus, higher growth rates for the juvenile plaice.

The physical structure of biota also affects their ability to sustain and recover from physical impacts with fishing gear. Thin shelled bivalves and starfish show higher damage than solidshelled bivalves in fished areas (Rumohr and Krost 1991). Animals that are able to retract below the surface of the seafloor or live below the penetration depth of the fishing gear will sustain much less damage than epibenthic organisms. Animals that are more elastic and can bend upon contact with fishing gear will suffer much less damage than those that are hard and inflexible (Eno et al. 2001). Kaiser et al. (2000a) found that chronic fishing around the Isle of Mann, UK had removed large-bodied fauna such that benthic communities are now dominated by smaller-bodied organisms that are less susceptible to physical disturbance. Off the northwest shelf of Australia, a switch of dominant species from lethrinids and lutjanids (which are almost exclusively associated with habitats supporting large epibenthos) to saurids and nemipterids (which were found on open sand) occurred after removal of epibenthic fauna by trawling (Sainsbury et al. 1993, 1994).

Increased fishing pressure can also lead to changes in distribution of species, either through movement of animals away from or towards the fished area (Kaiser and Spencer 1993, 1996a, Ramsay et al. 1996, Kaiser and Ramsay 1997, Ramsay et al. 1998, Bradshaw et al. 2000, Demestre et al. 2000). Frid and Hall (1999) found higher prevalence of fish remains and scavengers and a lower abundance of sedentary polychaetes in stomach contents of dabs in the North Sea in areas of higher fishing effort. Kaiser and Spencer (1994) document that gurnards and whiting aggregate over beam trawl tracks and have higher numbers of prey items in their stomachs shortly after trawling. Based on these studies, researchers have speculated that mobile fishing may lead to increased populations of species that exhibit opportunistic feeding behavior. Fonds and Groenewold (2000) modeled results for the southern North Sea indicating that the annual amount of food supplied by beam trawling is approximately 7% of the food demand of common benthic predators. This level could help maintain populations but is insufficient to support further population growth.

### E. Changes to Ecosystem

As discussed above, the use of some types of fishing gear can affect benthic community composition. It is possible that these changes at the community level are in turn resulting in effects on harvested populations and ecosystems. Ecosystem changes are not specifically addressed in this report due to the lack of research concerning ecosystem effects due to fishing activities.

## III. SUMMARY OF LITERATURE ON GEAR EFFECTS

### A. Research Approaches

A number of research approaches have been used to assess gear impacts to habitat. One method compares closed (or lightly fished) areas to open (or heavily fished) areas to identify changes to habitat that may be attributable to fishing activities. Determining the specific cause of any observed differences is difficult, however, if the unfished areas are unfished precisely because they are ecologically different from the fished areas. Furthermore, it is important to remember that those areas currently closed to fishing may have been significantly altered from previous fishing, such that differences are masked (Margetts and Bridger 1971, Caddy 1973, McAllister and Spiller 1994, Dayton et al. 1995, Auster et al. 1996, Kaiser et al. 1996a, Bradshaw et al. 2000, Frid and Clark 2000).

To avoid the difficulties with control areas many researchers have undertaken small scale experiments looking at varying levels of fishing intensity on habitats. These types of studies provide information on a specific gear type on a specific habitat type, but the scale at which they are conducted may make it difficult to detect effects (Thrush et al. 1995, Hewitt et al. 1998, Cappo et al. 1998, Bradshaw et al. 2000) or allow us to extrapolate to the scale of the fishing grounds (Daan 1991) or to the range of habitats utilized by a given fish species (Langton et al. 1995).

Another approach taken to elucidate effects of fishing on habitat is the comparison of historical (or pre-fishing) biological community data with present day data. With this approach, the same area is sampled over time and the historical data is used as the control. Long-term data sets that allow this comparison, however, are not always available. When such data are available, it may be difficult or impossible to separate out effects resulting from fishing activities from effects of natural and other human induced effects (Hall et al. 1993, Thompson 1993, Hall 1994, Kroncke 1995, Glemarec et al. 1996, Botsford et al. 1997, Kaiser 2000). However, Lindeboom and de Groot (1998) state that "combined with the results ...on the immediate effects of bottom fisheries on the benthos and the comparison between fished and unfished areas, it has to be concluded that the observed trends in benthic invertebrates were to a great extent caused by the direct and indirect effects of fisheries and not solely by eutrophication and/or pollution as interpreted in previous studies (e.g., Rachor 1990, Kronche 1995)."

Despite limitations of study approaches, there does exist an extensive amount of scientific research from various geographic regions of the world's oceans that provides us with information on the effects of fishing to habitat. This information must be used when addressing the Magnuson-Stevens mandate to minimize adverse effects of fishing to EFH to the extent practicable. The National Research Council (2002) report on effects of trawling and dredging concludes that "although there are still habitats, gears, and geographic regions that have not been adequately studied and characterized, there is an extensive literature on the effects of fishing on the seafloor. It is both possible and necessary to use this existing information to more effectively manage the effects of fishing on habitat."

## B. REVIEWS

A number of authors have reviewed, to verying extents, existing scientific literature on the effects of fishing on habitat (e.g., Auster et al. 1996, Cappo et al. 1998, Collie 1998, Jennings and Kaiser 1998, Rogers et al. 1998, Auster and Langton 1999, Hall 1999, Collie et al. 2000a, Lindeboom and de Groot 2000, Barnette 2001, National Research Council 2002).

A number of review papers have focused specifically on the physical effects of bottom trawls. According to an ICES working report (1973), otter trawls, beam trawls and dredges are all similar in their types of impacts on the seabed, but the magnitude of impact increases from shrimp to sole beam trawls with tickler and stone guards, to Rapido trawl, to mollusc dredge. Kaiser et al. (1996a) and Collie et al. (2000a) state that, because beam trawls are used almost exclusively in areas that are adapted to frequent wave/tidal action, they are less likely to result in adverse effects on habitat. Moran and Stephenson (2000) conclude that semi-pelagic trawls towed above the seafloor inflict less damage/mortality on benthos, but result in lower catches of target fishes and that the light trawl gear currently in use in northwest Australia results in less mortality (15.5% vs. 89% documented by Sainsbury et al. in 1994) than heavy gear used in the past. These statements should be evaluated for trawl gear used in U.S. fisheries.

In 1971, de Groot and Appledorn published a review of trawl damage to biota, and stated that nemertea, annelids, bivalves, and sea potatoes are all damaged extensively by trawl tickler chains. A review of the effects of trawling by species group in the North Sea concluded that nearly all coelenterates in the trawl path are destroyed, damage to bryozoans is insignificant, annelids suffer considerable damage, damage to molluscs depends on the thickness of the shell, ophiuroids and sea potatoes are badly damaged, and sea stars are readily caught in trawl nets (de Groot 1984). Auster et al. (1996) reviewed 3 studies of mobile fishing gear in the Gulf of Maine and concluded that mobile fishing gear alters the seafloor, and reduces complexity, sedimentary structures, and emergent epifauna. Lindeboom and de Groot (1998) conclude that while trawling intensity remains high, biological communities affected by trawling may never recover to their original condition. Collie (1998) reviewed studies from New England and concluded that results indicate that hard bottom benthic habitats (e.g., boulders and gravel pavement) experience significant impacts of bottom fishing gear, while mobile sand habitats are less vulnerable. Fonds and Groenewold (2000) conclude that although mobile fishing might attract scavengers to fished areas, the annual amount of food made accessible by beam trawling is insufficient to support further population growth. In contrast, de Groot (1984) had earlier thought that although individual animals might be affected, food sources are readily available such that disturbance is not affecting fish at the population level.

Auster and Langton (1999) review 22 studies from a wide geographic range and concluded that mobile fishing gear reduces habitat complexity by: (1) directly removing epifauna or damaging epifauna leading to mortality, (2) smoothing sedimentary bedforms and reducing bottom roughness, and (3) removing taxa which produce structure (i.e., taxa which produce burrows and pits). They also concluded that for fixed gear, the area impacted per unit effort is smaller than for mobile gear, but the types of damage to emergent benthos appear to be similar (but not necessarily equivalent per unit effort).

Jennings and Kaiser (1998) completed an extensive review and concluded that fishing activities lead to changes in the structure of marine habitats and influence the diversity, composition, biomass, and productivity of the associated biota. They further conclude that these effects vary according to gears used, habitats fished, and magnitude of natural disturbance, but will tend to increase with depth and the stability of the substrate.

Collie et al. (2000a) analyzed 39 published studies to compile and evaluate current findings regarding fishing gear effects on habitat. Regarding the type and use of research, the authors found: (1) 89% of the studies were undertaken at depths less than 60 m; (2) otter trawl gear is the most frequently studied; (3) most studies have been done in Northern Europe and Eastern North America. The authors also had several conclusions pertaining to effects of fishing gear: (1) intertidal dredging and scallop dredging have the greatest initial effects on benthic biota, followed by otter trawling and then beam trawling (although beam trawling studies were conducted in dynamic sandy areas, where effects might be less apparent); (2) fauna in stable gravel, mud and biogenic habitats are more adversely affected than those in less consolidated coarse sediments; (3) recovery appears most rapid in less physically stable habitats (inhabited generally by more opportunistic species); (4) we may accurately predict recovery rates for small-bodied taxa, but communities often contain one or two long-lived, vulnerable species; (5) large-bodied organisms are more prevalent before trawling (Greenstreet and Hall 1996, Frid and Clark 1999, Veale et al. 2000); and (6) the mean initial response to fishing impacts is negative (55% reduction of individual taxa). Based on these findings, the authors suggest that the scientific community abandon short-term small-scale experiments and argue for support to undertake larger scale experiments that mirror the timing and frequency of disturbance by commercial fishing.

The most recent review was completed by the National Research Council (2002), which was asked by NMFS to study the effects of bottom trawling and dredging on seafloor habitats. In their report, they concluded that: (1) trawling and dredging reduce habitat complexity; (2) repeated trawling and dredging result in discernable changes in benthic communities; (3) bottom trawling reduces the productivity of benthic habitats; (4) the effects of mobile fishing gear are cumulative and are a function of the frequency with which an area is fished; (5) fauna living in low natural disturbance regimes are generally more vulnerable to fishing gear disturbance; (6) fishing gears can be ranked according to their impacts on benthic organisms; and (7) benthic fauna can be ranked according to their vulnerability.

## C. SUMMARY OF AVAILABLE SCIENCE

### 1. Bottom Trawls

#### a. Otter Trawls (Fish)

##### 1. Mud

Effects and Recovery

Pilskaln et al. (1998) deployed sediment traps in two 250 m, mud-clay basins, Wilkinson Basin and Jordan Basin, in the Gulf of Maine. Abundances of benthic, infaunal worms with no documented swimming activity coincided with seasons of higher trawling activity in those areas, based on NMFS effort data. Sediment trap data and effort data were not collected in the same year, but authors speculate that occurrence of worms in the traps are a result of those animals being dislodged and suspended by trawling.

Mayer et al. (1991) investigated the immediate effects of a single tow with a commercial otter trawl, with 90 kg doors and 18 m footrope with tickler chains, on mud substrate in a 20 m deep basin on the coast of Maine. Core samples were collected inside and outside of the trawl track before and one day after trawling. Core profiles were similar between the trawled and untrawled cores, indicating that a single pass with this otter trawl – unlike scallop dredging (see New Bedford scallop dredge - mud) – did not plow the bottom and bury surficial sediments. The trawl doors did produce furrows several centimeters deep.

DeAlteris et al. (1999) analyzed data from a 1995 side-scan sonar survey to assess effects of otter trawls over sand and mud sediments in lower Narragansett Bay, Rhode Island. Scars from otter trawl doors were evident in the side-scan sonar images, but were confined to the deeper mud-bottom channels. Tracks were 5-10 cm deep with berms that were 10-20 cm high. The longevity of scars was studied using SCUBA to monitor hand-dug trenches (approximately 15 cm deep and 1.2 m long). Scars at a 14 m mud site persisted more than 60 days, and were occupied by rock crabs. A quantitative model was developed to compare the magnitude and frequency of trawling and dredging impacts to those of natural physical and biological disturbances. In shallow sandy areas, where sediments are eroded daily, physical effects of fishing gear may be inconsequential. At the deeper mud-bottom site studied, erosion was predicted to occur less than 5% of the time, thus physical effects from fishing would last longer.

Brylinsky et al. (1994) examined physical and biological effects of experimental trawling, with a 18 m trawl with 200 kg doors and footrope with 29 cm rubber rollers, in a macrotidal (6-8 m at high tide) estuary in the Bay of Fundy, Nova Scotia. Sediments were characterized as silty and uniform to a depth of 10 cm. Four trawling experiments were conducted with chorophyll *a* (as indicator of benthic diatoms), meiofauna, and macrofauna samples taken inside the door furrow, under the area covered by the rollers, and outside the area trawled at 1-3 stations along each trawl. Trawl doors made furrows that were 30 cm wide and 5 cm deep, with berms of sediment on the outside, that were visible for at least 2-7 months, and rollers compressed sediments. Meiofauna were dominated by nematodes and macrofauna was limited to polychaetes and low densities of mud snails. Chlorophyll *a* and abundance of nematodes were reduced for approximately 1 month after trawling. Nematodes recovered fully after 4-6 weeks and chlorophyll *a* concentrations increased by fourfold after 80 days. The authors state that the quick recovery was expected since sediments in the area are commonly exposed to natural stresses by storms and winter ice. There were no consistent differences in abundance or species composition of polychaetes inside and outside trawl tracks.

Sanchez et al. (2000) conducted experimental trawling with a commercial otter trawl on muddy substrate off the Catalan coast in Spain. Study sites were fished at two intensities, single sweep (3.5 hrs) or double sweep (7 hrs). Infaunal samples, collected with van Veen grabs, were compared over time (0, 24, 102, and 150 hrs after fishing) between swept areas and control areas. Percent abundance of most major taxa (e.g., polychaetes, crustaceans, and molluscs) was similar between fished and unfished areas throughout the experiment. The total number of individuals and taxa were significantly higher in the single swept area after 150 hrs, but there were no effects on the number of taxa or individuals in the double swept area within 72 hours after trawling. For some taxa, there were significant differences in abundance between the trawled and un-trawled sites, but this was partially because of an increase in abundance in the fished area and a large decrease in abundance in the unfished area. Authors speculate that the increase of some species is indicative of natural variability at the experimental site exceeding any effects of fishing. They also note that some scavengers and predators could have been attracted to the swept area after fishing. Side scan sonar images of the swept area showed furrows left in the sediments by the trawl doors which remained visible throughout the experiment.

Ball et al. (2000) reviewed two studies of trawling in 30-40 m water depth over mud areas of the Scottish Sea and Western Irish Sea (Tuck et al. 1998, Ball et al. 1999), which used closed areas and shipwrecks as controls for experimental trawling. Tuck et al. (1998) conducted experimental trawling with rockhopper ground gear in an area closed to fishing for almost 30 years. The trawl used in the study had no net attached, thus effects of gear were caused by doors and groundrope only. Trawling was conducted one day per month for 16 months. Biological surveys were completed after 5, 10, and 16 months of disturbance and then after 6, 12, and 18 months of recovery in trawled and untrawled reference area. Trawl doors left furrows in the sediment, which were evident by side scan sonar for up to 18 months. There were no significant differences in infaunal species richness in the experimental and control sites prior to the beginning of the experiment or during the first 10 months of trawling, but species richness was significantly higher in the trawled site after 16 months of trawling and throughout the recovery period. Total infauna abundance was significantly higher in the trawled site prior to fishing, after 16 months of fishing, and after 12 months of recovery, but not after 18 months of recovery. Some species (primarily polychaetes) increased in abundance in the fished site, while others (e.g., bivalves) declined in abundance in the fished site. Species diversity of infauna was lower in the fished site prior to fishing, during 16 months of fishing, and after 12 months of recovery. There were no effects to total biomass. Overall, infaunal community structure in the two sites became significantly different after only 5 months of fishing, and remained so throughout the experiment. Results from Ball et al. (1999) are provided below in "Otter Trawl (Inverts)" section. Based on these two studies, Ball et al. (2000) concluded that prolonged trawling reduced the abundance of large-bodied fragile organisms and increased the abundance of opportunists, and ultimately resulted in an altered, but stable, community with fewer species and an increase in the number of small polychaetes. This altered state was maintained due to long recovery times (up to 18 months) of the habitats even when fishing was restricted during parts of the year.

Table 1. Summary of literature on effects of otter trawls (used to catch fish) on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Brylinsky et al. 1994** | Bay of Fundy | Inter-tidal | silt | tracks in sediment, decrease in nematodes and benthic diatoms, no effect on polychaetes | furrows visible 2-7 months; 4-6 weeks for nematodes; 1 month for benthic diatoms | experimental trawling |
| **DeAlteris et al. 1999** | Narragansett Bay, Rhode Island | 14 m | mud | tracks (5-10 cm) and adjacent berm (10-20 cm) in sediments; | scars maintained > 60 days | observations with side-scan sonar, monitored hand dug scars |
| **Mayer et al. 1991** | Maine | 20 m | mud | trawl tracks, no difference in core profiles | | core samples before and after single trawl tow |
| Pilskaln et al. 1998 | Gulf of Maine | 250 m | mud and clay | infauna appearantly dislodged and suspended | | deployed sediment traps in fishing grounds |

Table 1. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Sanchez et al. 2000** | Catalan coast, Spain | 30-40 m | mud | tracks in sediment, no difference in species composition, increase in total abundance and abundance of some species of infauna | | experimental trawling in commercial fishing ground |
| **Tuck et al. 1998** | Scotland | 30-35 m | 95% silt and clay | tracks in sediment, increased bottom roughness, in crease in infauna species richness, decrease in diversity, no change in total abundance or biomass, some species increased and others decreased in abundance | physical effects still evident after 18 months of recovery, partial recovery of infauna species after 12 months and epifauna species after 6 months | experimental trawling in area closed to fishing for 25 years |

Conclusions

Three of the four papers summarized here involved experimental manipulations. Those that address physical effects report that trawl doors leave tracks in the sediment that remain visible for up to 18 months. A short-term study conducted in fishing grounds reports no change in species composition, but an increase in infauna abundance in response to trawling. A longterm study in an area closed to fishing reports that prolonged fishing results in increased species richness, decreased diversity, and no change in total abundance or biomass.

### 2. Sand

Effects and Recovery

Diver observations in Long Island Sound 1983-1984 (Smith et al. 1985) showed minor surface sediment disturbance (less than 1" deep) within the sweep path of an otter trawl with 6 ft doors, 30-60 ft scissors, 60-110 ft extended wing nets, and 3/8" chain on the footrope. Sediments in the study area were described as sand with mud and clay. Much of the disturbance was by wake turbulence suspending small epifaunal organisms, silt and flocculent material as the net passed, rather than by the direct physical contact of the net with the bottom. A Achumming effect@ attracted mobile predators due to exposure of prey organisms. Trawl door tracks (in sand, less than 2" deep; in mud, 4-10" wide, 2-6" deep) were the most notable evidence of trawl passage. These tracks were obscured by tidal currents, but attracted mobile predators. Alteration of existing lobster burrows was minor and appeared easily repairable by resident lobsters. Roller gear of unspecified size on mud bottom left shallow scoured depressions; spacers between discs reduced scouring.

In the DeAlteris et al. (1999) study in Narragansett Bay, Rhode Island (described above), hand-dug trenches at a 7m deep sandy site lasted 1-4 days.

Gilkinson et al. (1998) studied the effects of otter doors on infaunal bivalves by observing an otter door model deployed in a test tank with sand bottom, designed to simulate the sediment of the northeastern Grand Banks. The trawl door created a berm in the sediments (average height 5.5 cm) with an adjacent scour (2 cm) furrow. All 42 bivalves were displaced and left exposed, but only two were damaged.

Schwinghamer et al. (1998) examined physical effects of experimental otter trawling (31-34 hours within a 2 month period for 3 years) over sandy habitat (120-146 m) in the Grand Banks, Newfoundland that had been fished extensively since the early 1980's and then closed to fishing in 1992. Effects were examined 1 and 2 years after trawling stopped. The trawl used was an Engel 145 otter trawl with 1250 kg oval otter boards and 46 cm rock hopper gear. Trawled areas were smoother and cleaner while untrawled areas were hummocky, mottled, and had more flocculated organic matter. Tracks left by trawl doors increased the topographic relief of the area and were visible for at least 10 weeks, but were not visible or faintly visible after a year. Prena et al. (1999) compared trawl bycatch and samples taken by an epibenthic sled from trawled and untrawled corridors in this area and found that in trawled areas, total macrofaunal invertebrate biomass was 24% lower with decreases in sand dollars, brittle stars, soft corals, snow crabs and sea urchins. No significant effects were evident in dominant mollusc species. Kenchington et al. (2001) also found immediate reduction (significant in 1 of 3 years of sampling) in the total abundance of benthic epifauna and infauna from grab and video samples, and in the abundance of 13 taxa (mostly polychaetes) but concluded that there was little indication of long-term effects on infauna and that when disturbance was evident, it mimicked natural disturbance.

Moran and Stephenson (2000) conducted experimental otter trawling in fished and unfished areas on the continental shelf of northwest Australia (50-55 m). No information on bottom type was provided, but it was presumed to be sand (see Sainsbury et al. 1994). Macrobenthos (>20 cm) which were dense at the study site, were surveyed in trawled and untrawled areas before and after four trawling events (four trawl tows per event) with 2 day intervals between each event, using a video camera mounted on a sled. Mean density of benthos declined exponentially with increasing tow numbers with four tows reducing the density by about 50% and a single tow reducing density by about 15%. This estimate is lower than the estimate in Sainsbury et al. (1994; 89%) for removal of sponges in the same general area. The disparity may be explained by the fact that Moran and Stephenson (2000) used a lighter trawl, with 20 cm disks separated by 30-60 cm spacers, than Sainsbury et al. (1994).

McConnaughey et al. (2000) sampled megafauna from 42 paired unfished (inside closed area) and heavily fished areas (between 44-52 m depth) using an otter trawl that was modified to catch and retain macrofauna in the eastern Bering Sea. Two study sites were sampled, one with sand substrate with ripples in 44-52 m depth and one with coarse sand substrate with occasional 4 m mounds at 61-82 m depth. The authors concluded that: 1) sedentary megafauna (e.g., anemones, soft corals, sponges, whelk eggs, ascidians), neptunid whelks and empty shells were more abundant in unfished areas; 2) motile groups (e.g., crabs, sea stars, whelks) and infaunal bivalves exhibited mixed responses, suggesting the importance of life history considerations, such as habitat requirements and feeding modes; and 3) overall diversity and niche breadth of sedentary taxa was greater in unfished areas. Furthermore, long-lived, slow-growing taxa were significantly more patchy in highly fished areas, suggesting a slow impact recovery process.

In addition to experimental trawling in silty sediment, Brylinsky et al. (1994) also conducted experimental trawling in an area of the Bay of Fundy with coarse sand overlain by a silty layer up to 10 cm deep. Two types of trawls (18 m and 24 m) and three types of doors (180 kg, 200 kg, and 270 kg) were used. The footrope of all trawl configurations had 29 cm rubber rollers and no tickler chains. With heavier gear, trawl doors scoured furrows 80-85 cm wide and 2-4 cm deep and rollers compressed sediments. Lighter gear compressed sediment, but did not result in any scouring. Furrows were visible for at least 2- 7 months. Similar to the silty sites, benthic diatoms and nematodes were significantly lower inside trawl furrows, decreases were not as severe as the silty site, however, because of lower initial abundances. Nematodes recovered fully after 4-6 weeks and chlorophyll *a* concentrations increased by fourfold after 80 days. There were no consistent differences in abundance or species composition of polychaetes inside and outside trawl tracks.

On the continental shelf (>200m) in NW Australia, research surveys documented a shift in finfish species dominance from those that occur predominantly within habitats that contain large epibenthic organisms (*Lethrinus*, *Lutjanus*, and *Epinephalus*), to those that favor open sandy habitats *(Nemipterus* and *Saurida),* in conjunction with the development of a commercial stern and pair trawling fishery (Sainsbury 1987 and Sainsbury et al. 1993, 1994). Trawl closure areas implemented in response to these changes (closed for 5 years at time of data collection) resulted in increased density of *Lutjanus* and *Lethrinus* and increased abundance of small benthos, but no changes in the abundance of large benthos. Density of these fishes and abundance of both large and small benthos continued to decrease in the areas open to trawling. These results, along with video surveys of habitat used by target fishes, indicate that changes in species abundance and composition were at least in part a result of the damage inflicted on the epibenthic habitat by the demersal trawling gear. Video observations from a camera mounted on a trawl showed that sponges >15 cm were removed from the substrate during 89% of observable encounters with the trawl groundline.

Bergman and Van Santbrink (2000) sampled benthic fauna before and 24-48 hours after a single sweep with a commercial otter trawl over shallow (30-40 m) sandy areas and deeper (40-50 m) silty sand areas in the southern North Sea. In silty sand, direct mortality of benthic megafauna was 0-52% for bivalves, 7% for gastropods, 0-26% for echinoderms, and 3-23% for crustaceans. In sand areas, mortality of sedentary megafauna was 0-21% for bivalves, 12-16% for echinoderms, and 19-30% for crustaceans. Some deaths were not caused directly by the passage of the trawl, but instead were caused by disturbance, exposure, and subsequent predation.

Table 2. Summary of literature on effects of otter trawls (used to catch fish) on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Bergman and Van Santbrink 2000 | North Sea | shallow, deep | sand (1-5% silt, 0.2-0.37mm), silty sand (3-10% silt, 0.15-0.17mm) | decrease in abundance of sedentary megafauna | | experimental trawling (6 sites) |
| **Brylinsky et al. 1994** | Bay of Fundy | inter-tidal | coarse sand overlain with silty layer | tracks in sediment, decrease in nematodes and benthic diatoms | furrows visible 2-7 months; 4-6 weeks for nematodes; 1 month for benthic diatoms | experimental trawling |

Table 2. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **DeAlteris et al. 1999** | Rhode Island | 7 m | sand with sand waves | no tracks/berms evident | hand dug scars recovered in 1-4 days | observations with side-scan sonar, divers monitored hand dug scars |
| **Gilkinson et al. 1998** | test tank to simulate Grand Banks of Newfoundland | | sand | 5.5 cm berm adjacent to 2 cm furrow; bivalves displaced | | observed effects of commercial otter door model in test tank |
| **Kenchington et al. 2001** | Grand Banks, Newfoundland | 120 m - 146 m | fine to medium grain sand (~0.17 mm) | short-term reduction in total abundance and abundance of some infauna and epifauna in 1 of 3 years | | experimental trawling in area lightly fished for > 19 years |
| **McConnaughey et al. 2000** | Eastern Bering Sea, Alaska | 44-82 m | 44-52 m: sand w/ ripples; 61-82 m: coarse sand w/ mounds | decrease in sedentary megafauna abundance, decrease in diversity, decrease in habitat complexity (e.g., biogenic substrate) | patchiness of longlived, slow growing taxa suggests slow recovery | compared unfished and fished sites (2 sites) |
| **Moran and Stephenson 2000** | Northwest Australia | 50 m – 55 m | presumed to be sand | significant decrease in macrobenthos | | experimental trawling in unfished area |
| **Prena et al. 1999** | Grand Banks, Newfoundland | 120 m - 146 m | fine to medium grain sand (~0.17 mm) | decrease in epibenthic macrofauna biomass | | experimental trawling in area unfished for >10 years |
| **Schwinghamer et al. 1998** | Grand Banks, Newfoundland | 120 m - 146 m | fine and medium grain sand (0.125-0.250 mm) | tracks in sediment, smoothed sediments and removed biogenic mounds and flocculated organic material, organisms and shells organized into linear features | tracks last up to 1 year | experimental trawling in area unfished for >10 years |
| **Sainsbury 1987, Sainsbury et al. 1993, 1994** | NW Australia | < 200 m | calcareous sands | epibenthic macrofauna removed, change in fish species composition , increased abundance of small (<25 cm) benthos | some reversal of trends within 5 years, longer for recovery of large epifauna | compared historical data (before and during fishery) to data collected after inside and outside area closed for 5 years |
| Smith et al. 1985 | Long Island Sound, New York | | sand, mud/clay | tracks in sediment (1" in sand, 4" in mud/clay), attraction of predators, suspension of epibenthic organisms | tracks "naturalized" by tidal currents | video and diver observations |

## Conclusions

Based on the results of 11 studies, 6 of which involved experimental trawling, physical effects of trawling on sand habitat include trawl door tracks left on the seafloor, smoothed sediments, and removal of biogenic mounds. At greater depths (>120 m) tracks were evident up to 1 year after trawling. At shallow sites (< 7 m) tracks were no longer visible after a few days. The four studies that examined effects of chronic trawling documented decreased abundance and biomass of sedentary macrofauna, decreased diversity. Studies that examined effects of short-term or pulse trawling documented changes in the abundance of some infaunal and epifaunal taxa, such as polychaetes, nematodes, and benthic diatoms, which mimicked natural disturbance. Recovery ranged from weeks in intertidal areas to possibly years at depths of 80-200 m.

### 3. Gravel

Effects and Recovery

Between 1987 and 1993, modifications to fishing gear allowed fishermen to trawl previously inaccessible rocky, boulder habitat in the Gulf of Maine. Bottom conditions were observed in a July 1987 submersible dive to 94 m depth near the top of Jeffreys Ledge (Auster et al. 1996). At that time the presence of large (>2m diameter) boulders in the area precluded fishing. A thin layer of mud covered the gravel and boulders. The rock surfaces supported large numbers of erect sponges, as well as sea spiders, bryozoans, hydroids, anemones, crinoid sea stars, and ascidians. Smaller mobile fauna, including several species of crustaceans, snails, and scallops, were also abundant. When the area was resurveyed in August 1993, much of the mud veneer was gone and there was evidence that boulders had been moved, apparently by otter trawling. Abundance of erect sponges was greatly reduced, and most of the associated epifaunal species were not present. In laboratory predation experiments (Lindholm et al. 1999) decreased habitat complexity lead to increased predator success, and therefore, decreased survival of 0-year cod. Thus, authors speculate that reduction in benthic epifauna by mobile fishing could affect fish populations.

Freese et al. (1999) document the effects of a single passage of a bottom trawl (Nor'easter otter trawl with 0.6 m tire gear on the footrope and 0.45 m rockhopper discs and steel bobbins on the wings) over cobble-boulder habitat (93% pebble) in the eastern Gulf of Alaska (water depth 206-274 m). The trawl moved and overturned boulders and caused significant decreases in emergent epifauna (e.g., anemones, sea whips and some sponges). The tire gear produced 1-8 cm deep imprints in less compact substrate. Of the sponges affected, 14% of finger sponges were knocked over, 67% of vase sponges were damaged, and morel sponges were crushed and torn apart. Fifty five percent of seawhips counted were broken or pulled out of the substrate. Brittle stars were damaged, but reticulate anenomes and motile invertebrates were not. The authors did not record recovery rates, but concluded that chronic trawling would probably show greater reduction in density of these taxa.

Table 3. Summary of literature on effects of otter trawls (used to catch fish) on habitat with gravel substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Auster et al. 1996** | Gulf of Maine (Jeffrey's Ledge) | 94 m | gravel/boulder with thin mud veneer | gravel base exposed, decrease in epifauna abundance, boulders moved | | submersible and video observations before and after trawling |
| **Freese et al. 1999** | Gulf of Alaska | 200 m - 270 m | 93% pebble, 5% cobble, 2% boulder | boulders moved, furrows 1-8 cm in sediment, layer of silt removed, decreased abundance and damage to sponges, anemones, and sea whips | | video observations 2-5 hrs after experimental trawling |

Conclusions
Only 2 papers on the effects of otter trawls to gravel habitat were available, both of which were observational. These studies showed that trawling on gravel habitats removes fine sediments, moves stones and boulders, and decreases abundance of epibenthic macrofauna and reduces the cover they provide.

## 4. Coral Reefs and Seamounts

Effects and Recovery
A number of studies have recorded damage to coral reef habitats due to trawling. A single trawl tow over a newly discovered coral reef at 230-280 fathoms in the Gulf of Mexico brought over 300 lbs of coral to the surface (Moore and Bullis 1960). Reports from fishermen and ROV observations confirm the presence of mechanically damaged corals located on trawling grounds on the mid-Norwegian continental shelf at 200-400 m depth (Fossa et al. 2001). A single pass with a trawl (otter trawl with 40/54 fly net,12.2-m headrope, and 16.5-m footrope with 30 cm rubber rollers and 15-cm rubber discs, 1.8 x 1.2 m China V-doors) in a hard bottom sponge and coral community at 20 m in Grays Reef, Georgia, damaged finger sponge, vase sponge, barrel sponges, whip coral, fan coral, stick coral, and stony tree coral, and caused a significant decrease in density of barrel sponges (Van Dolah et al. 1987). In this case, the community recovered within a year. The authors speculate that because these species harbor numerous invertebrate prey species, damage could affect important nearshore fish populations. Extensive destruction to bryozoan coral mounds in Tasman Bay, New Zealand during the 1970s and 1980s, which has in turn reduced juvenile tarakihi and snapper abundance, is thought to have been caused by chains, bobbins, sweep wires and otter boards of mobile fishing gear (Bradstock and Gordon 1983).

Hall-Spencer et al. (2002) conducted ROV video observations and analysis of commercial otter trawl catches from the West Ireland continental shelf break and West Norway to document effects of fishing on deep water (200 m – 1300 m) corals. Otter trawls in the commercial fishery were fitted with rockhopper gear and 900 kg otterboards. The skippers actively avoided fishing over uneven ground, thus only 5 out of 229 trawls observed included large amounts of coral as bycatch. In these 5, however, pieces of coral up to ~1 $m^2$ were landed on deck. ROV videos documented trawled areas with sparse living coral, coral rubble littering the seafloor, and track marks on the seafloor. Unfished areas had no trawl marks and large expanses of coral with sessile macrofauna. Radiocarbon dating of the coral fragments indicate mean growth rates of 1.1 mm/yr with ages over 4500 years.

Seamounts have also suffered extensive damage from trawl fishing. Corals from seamount slope areas comprised the largest bycatch in trawl tows (using otter trawls with large bobbins along the ground rope) taken in depths of 662-1524 m in tropical New Zealand (Probert et al. 1997). These coral patches may require over 100 years to recover, and many were probably crushed or overturned without coming to the surface in the net. Koslow and Gowlett-Holmes (1998) and Koslow et al. (2001) sampled benthic fish and invertebrate macrofauna over seamounts in Tasmania subject to varying levels of fishing effort by orange roughy otter trawls. Results demonstrated that in heavily fished areas, substrates were predominantly bare rock or coral rubble and sand, colonial corals and associated fauna were lacking, and species abundance and richness were lower than in lightly fished areas. Although the absence of survey information prior to fishing precludes definitive conclusions, authors attribute these differences to fishing effort and recommend permanent closed areas to protect the seamount ecosystem.

Table 4. Summary of literature on effects of otter trawls (used to catch fish) on coral reef habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Bradstock and Gordon 1983** | New Zealand | 10-35 m | bryozoan coral mounds | destruction of mounds, decreased size and density of coral, decrease in abundance of juvenile fishes | | observations |
| **Hall-Spencer et al. 2002** | West Ireland, West Norway | 200 m, 840 m - 1300 m | deepwater coral reef | track marks, destruction of reefs, decrease in sessile macrofauna | > 4000 yrs | ROV video observations and analysis of commercial trawl catches |
| Koslow and Gowlett-Holmes 1998; **Koslow et al. 2001** | Tasmania | 600-1500 m | seamounts with various substrates ( e.g., mud, sand, rock, coral rubble, barnacles) | removed colonial coral, decrease in macrofauna abundance and species richness | | compared 14 seamounts with various fishing effort |
| **Probert et al. 1997** | New Zealand | 660-1500 m | seamounts | coral damaged and collected in trawls | | observations of commercial by-catch |
| **Van Dolah et al. 1987** | Georgia | 20 m | low-relief hard bottom | damage to sponge and coral species, decreased density of barrel sponge | within 1 year | experimental trawling (1 trawl tow) |

Conclusions

The five studies summarized here all show that otter trawls damage sponge and coral species, in both nearshore and seamount habitats, resulting in a decrease in fish and invertebrate macrofauna abundance and density.

## 5. Variable habitats

Effects and Recovery

Side scan sonar and video observations were used to document the cumulative effects of various mobile fishing gears used in Bras D'Or Lakes and St. Peters Canal, Nova Scotia (Canadian Department of Fisheries and Oceans 1993). Water depths ranged from 10 - 500 m, and bottom sediments included rich organic mud, clay, pebbly mud, well-sorted sand, gravel and boulders. Otter doors left parallel marks in the sediments, with fainter marks from the footgear and bobbins. These marks were seen predominantly in muddy sediments.

Engel and Kvitek (1998) compared lightly and heavily fished areas off central California with similar sediments (gravel, sand, silt/clay) and depth (180 m) using still and video photography, Smith-McIntyre grab samples and fish stomach contents (English sole, Dover sole and Pacific sanddab). Results indicated that the heavily fished sites had more trawl tracks, exposed sediment/shell fragments, fewer rocks and mounds, and less flocculent material. All invertebrate macroepifauna were more abundant in the lightly trawled areas, with significantly higher densities for seapens, seastars, sea anemones, and sea slugs. The number of polychaete species was higher in lightly trawled areas, but densities of nematodes, oligochaetes, and ophiuroids were higher in heavily trawled areas in all three years (although in most cases differences were insignificant). No differences were detected for crustaceans. One polychaete species that was the most important prey item for English sole, Dover sole and Pacific sanddab was more abundant in the heavily trawled area in all three years, with sifnificant differences in 2 of the 3 years. The authors concluded that trawling reduces habitat complexity and biodiversity while increasing opportunistic infauna and prey important in the diet of some commercially important fish species.

Riemann and Hoffmann (1991) assessed the water column effects of otter trawling in a shallow, eutrophic sound (Limfjord) in Denmark. Suspended particulate matter, oxygen, and nutrient (phosphorus and nitrogen) levels were measured at a number of stations throughout the water column at a dredged and a control site in two different locations before trawling, immediately afterwards, and 30 and 60 minutes later. Maximum water depth was 7.5 – 11 m. No information on sediment type was given. Trawling was performed for 15 minutes with a small (6-m wide) commercial eel trawl. Average suspended particulate matter increased significantly at both sites immediately after trawling, but returned to pre-trawl levels 60 minutes later. There was no significant effect on oxygen and either minor (non-significant) increases, or no clear trends, in most nutrients. Ammonia increased significantly immediately after trawling at one site, but marked differences before trawling between the control and the experimental site complicated the interpretation of this result.

Table 5. Summary of literature on effects of otter trawls (used to catch fish) on habitat with mixed substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Bridger 1972 | English Channel | 10-20 m | sand and shell with small stones, muddy sand with patches of flint | stones dislodged and overturned, sand ripples smoothed, ridges and grooves created | | diver observations over various habitat types |
| **Engel and Kvitek 1998** | central California | 180 m | gravel, sand, silt, clay | tracks in sediment, fewer rocks and mounds, decrease in flocculent material and abundance of epibenthic macrofauna, increase in density of nematodes, polychaetes, oligochaetes and ophioroids | | compared epifauna and infauna between a lightly fished site and heavily fished site |
| **Riemann and Hoffmann 1991** | Denmark | 7.5 m - 11 m | | significant increase in suspended particulate matter | turbidity returned to normal within 1 hour | water column sampling before and after experimental dredging at two locations |
| High 1998 | Northwest USA | | various | tracks in sediment, increased turbidity, benthic fauna and rocks dislodged | | diver observations over various habitat types |

Conclusions

Four papers observe effects of otter trawls on habitats with a mixture of sediment types. Physical effects mirror those reported for sections above, including the overturning of stones, tracks in sediment, sediment re-suspension, and smoothing of seafloor. The one paper that addresses biological effects reports that trawling results in a decrease in epibenthic macrofauna, and an increase in opportunistic infauna. One paper that addresses chemical effects of trawling found no significant effects. No information is provided on recovery.

### b. Otter Trawls (Invertebrates)

#### 1. Mud

Effects and Recovery

Ball et al. (2000) sampled benthic macrofauna in offshore areas (75 m depth), a heavily fished site and a "pseudo control" shipwreck site that had not been fished for about 50 years, within *Nephrops* prawn trawl fishing grounds in the Irish Sea. Grab samples were taken before and 24 hours after trawling. Due to the paucity of organisms and low biomass, there were no significant differences in macrofauna sampled before and after trawling the heavily fished site. There were, however, fewer species and individuals, and lower species diversity in the commercially trawled area than near the shipwreck. At the shipwreck site, the number of species, number of individuals, and biomass decreased with increasing distance from the ship. Sixty-nine species found at the offshore wreck site were not found at the experimental fishing site. Large specimens of some molluscs and echinoderms were most common near the wreck, whereas only juveniles of these species were sampled in the trawled area.

Drabsch et al. (2001) sampled benthic macroinfauna prior to and 2-3 weeks after experimental trawling with a commercial prawn otter trawl in an area of South Australia where little to no fishing had occurred for 15 years. Three study sites were used, with a trawled and control corridor at each site. At one study site located at 20 m depth with fine silt sediments, otter boards left tracks in the sediments and the footline and net smoothed topographic features and removed 28% of epifauna. Trawling resulted in a significant decrease in total abundance and in the abundance of 1 taxonomic group of polychaetes. Similar changes were not evident for any other taxa.

Harris and Poiner (1991) compared 1964 surveys taken in water depths of 17 - 21 m in the Gulf of Carpentaria, Australia prior to commercial prawn fishing, with 1985-86 surveys taken in the same areas after 20 years of commercial fishing (otter trawls for banana and tiger prawn). Sediments were characterized as mud transitions zones. Between the sampling periods, total demersal fish abundance decreased from 897 fish/ha to 283 fish/ha, 18 of 82 species (found mostly at the deeper sampling depth) decreased, and 12 of 82 species (bentho-pelagic species found mostly at nearshore sites) increased. There were no significant correlations between fishing effort and changes in species abundance, but the data suggest the decreased abundance in 18 taxa was a result of fishing effort and bycatch. The authors speculate that the increase in the 12 bentho-pelagic taxa might be related to disposal of fish bycatch.

Hansson et al. (2000) examined effects of experimental shrimp trawling on pure clay habitats at 75-90 m in a Swedish fjord. Benthic macrofauna were collected using a Smith-McIntyre grab four times (1-5 months) before and four times (5-9 months) after experimental trawling at 3 trawled sites and 3 untrawled sites. The study sites were located in an area closed to fishing for 6 years. The otter trawl used had a 10 m head rope, 14 m ground rope with 20 kg of lead, and 125 kg otterboards. For 61% of the species sampled, abundances were negatively affected by trawling. Total biomass (at all 3 sites) and total abundance (at 2 sites) decreased significantly, but significant reductions were also observed at control sites. Individual phyla responded differently to trawling; echinoderm (mostly brittlestars) abundance decreased significantly, total abundance of polychaetes was not affected (although some families increased and some families decreased), and amphipods and molluscs were not affected.

Table 6. Summary of literature on effects of otter trawls (used to catch invertebrates) on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Ball et al. 2000** | Irish Sea | 75 m | sandy silt | decrease in infauna and epifauna richness, diversity and abundance | | compared heavily fished area and un - fished area near a shipwreck |
| **Drabsch et al. 2001** | South Australia | 21 m | fine silt | significant decrease in total macroinfauna abundance | | experimental trawling (1 station) in area with no trawling for 15 years |
| **Harris and Poiner 1991** | Australia (SE Gulf of Carpentaria) | 17 m - 21 m | mud transition | decrease in demersal fish abundance | | comparison of survey data from 1964 and 1985/86 |
| **Hansson et al. 2000** | Sweden | 75-90 m | clay | decrease in abundance of 70 % of macrofauna, signifanct decrease in brittlestar abundance | | experimental trawling (for 1 year) in area closed to fishing for 6 years |

Conclusions

The three studies summarized here do not report on physical effects. Biological effects of shrimp otter trawls include a decrease in species richness, abundance, diversity and biomass of invertebrate benthic macrofauna, and a decrease in demersal fish abundance. In two studies of the biological effects of shrimp trawling in areas that had not been fished for a number of years, many species were less abundant after a year of sustained trawling, but significant reductions in total macrofauna abundance and the abundance of some taxa were only noted for individual trawled sites. No information is provided on recovery.

## 2. Sand

Effects and Recovery

In addition to sampling at mud bottom in South Australia, Drabsch et al. (2001) described above sampled at two 20 m sites with medium-coarse sand sediments and shell fragments. As with the silt site, trawl boards left tracks in the sediment, smoothed topographic features and removed macroepifauna. In contrast to results from the mud site, trawling did not result in any changes in abundance of macroinfauna. The only change which was attributed to trawling was a decrease in the density of one family of polychaetes at one location 2-3 weeks after trawling.

Gibbs et al. (1980) sampled benthic macrofauna (epifauna and infauna), using Smith MacIntyre grabs, prior to and following the seasonal commercial prawn fishery, and prior to and after experimental trawling repeatedly for a period of 1 week (using 10-m otter trawl with 1075 by 537 mm flat otter boards and chain spiders) in New South Wales, Australia. Samples were taken in muddy sand (0-30 % mud/clay) at three sites within the fishing grounds and one unfished control site. Trawl footropes only lightly skimmed the bottom and disturbed very little sand. Trawling did create a plume of sand, but after repeated trawls, the seafloor was only slightly modified. Dissimilarity coefficient and community statistics showed no significant differences in macrobenthos between the 3 fished sites and the control site before or after experimental trawling or after the commercial trawling season.

Frid et al. (1999) developed *a priori* predictions concerning the effects of fishing by *Nephrops* prawn otter trawls on benthic macrofauna species abundances, and tested those predictions using time series (27 years) of Van Veen grab data from sand habitats in 55 m of water and silt/clay habitats in 80 m of water in the North Sea. The time series was broken into 3 periods of fishing effort: low, moderate, and high. Taxa predicted to increase with fishing effort included errant or mobile polychaetes and ophiuroid and asteroid echinoderms. Taxa predicted to decrease with fishing effort included sedentary or fragile taxa such as echinoid echinoderms, large bivalves, and sedentary polychaetes. Outside fishing grounds those taxa predicted to increase and/or decrease with fishing remained constant. Inside heavily fished areas those taxa predicted to increase with fishing were significantly more abundant during the period of high fishing effort, but those predicted to decline remained the same. Results indicate that species abundances in both areas were affected by natural changes in organic input, but that inside heavily fished areas macrofauna abundance was influenced more by fishing.

In addition to sampling at mud bottom in the Irish Sea, Ball et al. (2000) described above sampled benthic macrofauna in lightly-fished, inshore prawn trawl fishing grounds and at an unfished (for about 50 years) “pseudo” control site near a shipwreck. Both areas were at 35 m depth with muddy sand sediments. Differences between the fished site and the wreck site were similar in kind but less pronounced than at the mud, heavily fished, offshore site. There were reductions in species richness, total abundance, biomass, and diversity. Larger reductions in these parameters at the offshore site could have resulted from differences in historical fishing intensity, depth or substrate. Fifty-eight species found at the inshore wreck site were not found at the experimental fishing site. Other polychaetes were more common at the fished site.

Table 7. Summary of literature on effects of otter trawls (used to catch invertebrates) on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Ball et al. 2000** | Irish Sea | 35 m | mudy sand | decrease in total abundance, richness and diversity | | compared heavily fished area and un- fished area near a shipwreck |
| **Drabsch et al. 2001** | South Australia | 20 m | coarse sand with shells | furrows in sediment, smoothing of topographic features, removal of 28% of macroepifauna, no effects on macroinfauna | | experimental trawling (2 stations) in area with no trawling for 15 years |

Table 7. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Frid et al. 1999** | North Sea | 55 m, 80 m | 55 m station sand with 20% silt/clay; 80 m station > 50% silt/clay | changes to macroinfaunal abundances | | 27 year monitoring at lightly and heavily fished sites |
| **Gibbs et al. 1980** | New South Wales, Australia | shallow estuary | sand with 0-30% silt/clay | no significant effects on macrobenthic infauna or epifauna | | sampled before and after commercial fishing season |

Conclusions

Three studies, all using different study approaches, are summarized here. Physical effects of shrimp trawls on sand habitats include tracks in the sediments and smoothing of the seafloor. One study, conducted at 20 m water depth, reports negative effects of trawling on the abundance of macroepifauna, but no effects on macroinfauna. Another study, conducted in a shallow estuary, concludes that there are no effects of trawling to either macroinfauna or macroepifauna. No information is provided on recovery of biological communities.

### c. Roller Frame Trawls

#### 1. Submerged Aquatic Vegetation

Effects and Recovery

Studies in Florida (using “Tarpon Springs" and "St. Petersburg" shrimp roller trawls with 4.5 - 8 inch rollers, and 75kg shrimp roller trawl with steel rollers) have shown that trawling with side frame trawls in seagrass beds gathers unattached algae and deciduous leaves, but does not decrease mean shoot density, number of blades, blade length or below ground biomass (Tabb 1958, Futch and Beaumariage 1965, Meyer et al. 1991) as long as rake teeth do not extend below the roller. Authors agree, however, that shrimp trawls should include gear specifications to minimize damage to seagrasses. Long-term, chronic effects have not been studied.

Table 8. Summary of literature on effects of roller frame trawls on seagrass habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Futch and Beaumariage 1965** | Florida | shallow | *Thalassia* beds | no significant effects on seagrass | | experimental trawling (3 sites) |
| **Meyer et al. 1991** | Florida | shallow | *Thalassia* beds | no significant effects on seagrass | | experimental trawling |
| Tabb 1958 | Florida (Biscayne Bay) | shallow | *Thalassia* beds | no significant effects on seagrass | | experimental trawling |

Conclusions

Three separate experimental studies agree that roller frame trawls have no significant effects on seagrass habitats (all three studies were conducted in *Thalassia* beds in Florida).

## d. Beam Trawls

### 1. Mud

Effects and Recovery

Schratzberger et al. (2002) examined effects of beam trawling on meiofauna in mud habitats at 59 m depth in the North Sea. Meiofauna were sampled with a circular corer at trawled and untrawled sites both before and after experimental trawling with a 4-m beam trawl with 80 mm mesh and chain matrix. Sample areas were described as relatively lightly fished by the commercial trawl fishery. At trawled sites species richness and nematode biomass decreased with increased fishing effort with decreases being most pronounced immediately after trawling. However, changes in species richness and nematode abundance were similar at both control and trawled sites. Thus, the authors concluded that there were no short-term or medium-term impacts on meiofaunal diversity or biomass, and that any impacts due to trawling were minor in relation to seasonal changes in the community.

Table 9. Summary of literature on effects of beam trawls on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Schratzberger et al. 2002** | North Sea | 59 m | mud | no significant differences in meiofauna at trawled and control sites | | experimental trawling |

Conclusions

Results of one study conclude that beam trawling has no significant impact on meiofauna in mud habitat.

### 2. Sand

Effects and Recovery

Schratzberger et al. (2002; see above) also conducted experimental trawling at a muddy sand site in the North Sea. At trawled sites species richness and nematode biomass decreased with increased fishing effort with decreases being most pronounced 1 month after trawling. Similar changes occurred at control and trawled sites, leading the authors to conclude that impacts due to trawling were minor in relation to seasonal changes in the community.

Margetts and Bridger (1971) used SCUBA and video cameras to observe physical effects of a 9.1 m Dutch beam trawl with 0.2 x 0.7 m runners, and 3 part bridle at a water depth of 22 m in the English Channel. Beam trawls left furrows in and smoothed both hard sand and mud-sand sediments. Furrows and sediment suspension were much more discernible on muddy sediment. Fonteyne (2000) used measurements of pressure change, sediment type, and side scan sonar images to examine the physical effects of a 4-m beam trawl with tickler chain matrix over Goote Bank off Belgium and the Netherlands. The author concluded that the effects on the seabed are related to weight of gear, towing speed, and sediment type. On densely packed fine sand overlaid with a silt layer, the trawls resuspended the upper 1 cm of the sediments, so that the resulting surface sediments were harder and less rough. In most disturbed areas, sediments recovered to pre-trawl conditions within 15 hours. Tracks remained visible, however, for 52 hours in coarse sand and for 37 hours in fine sediments.

Bergman et al. (1990) and Bergman and Hup (1992) studied the effects of beam trawls in the North Sea. Their study site was in a lightly fished area with water depth of 30 m and medium-hard sandy sediments. Experimental trawling was repeated with a 7000 kg, 12-m beam trawl with ticklers until full coverage of the study site was achieved 3 times. Macrofauna were sampled with a bottom grab and 2.8 m beam trawl before, 8 hours after, and 16 hours after trawling. Experimental trawling resulted in physical penetration of the gear to at least 6 cm, and a 40-65% decrease in density of starfishes, small heart urchins, tube-dwelling polychaete worms, and small crustaceans. Many other species did not change and a few increased, possibly due to a change in vertical distribution with trawling disturbance. The authors discuss the possibility that because the area has been fished, alterations to the biota may have already occurred during past decades.

Bergman and Van Santbrink (2000) sampled benthic macrofauna before and 24-48 hours after experimental trawling (with 12-m beam trawl with ticklers, 4-m beam trawl with ticklers and 4-m beam trawl with chain matrix) over shallow sandy areas and deep silty sand areas in the North Sea. Results showed a 5-40% mortality of gastropods, starfish, crustaceans, and annelid worms and a 20-65% mortality of bivalves. Some deaths were not caused directly by the passage of the trawl, but were instead caused by disturbance, exposure, and subsequent predation. Authors speculate that mortalities would increase in the summer months when animals migrate to the sediment surface.

Philippart (1998) analyzed bycatch records of demersal fishes and macro-epifaunal invertebrates from commercial fishermen when the bottom fishery in the southeast North Sea changed from otter to beam trawling. Beam trawlers caught proportionally more invertebrate species (e.g., whelks, urchins, squids, and crabs) than otter trawls and had a catch efficiency (for both targeted and non-targeted species) of 10 times higher than that of the otter trawl.

The effects of beam trawls have been studied extensively in two specific areas in the eastern Irish Sea. One site consists of stable, coarse sand and gravel and the other consists of mobile sand ribbons and megaribbons (Kaiser and Spencer 1996b, Kaiser et al. 1996b, 1998, 1999). Following experimental trawls (10-12 passes) with a 3.5 tonnes, 4-m beam trawl with chain matrix, sand ripples were flattened, sediments were less consolidated (due to the chain matrix), and fine materials were suspended and moved away by tidal currents. Short-term changes to biota in the more stable environment included a 54% reduction in the number of infaunal species and 40% reduction in individuals (due to removal of less common species), a decrease in slow-moving epifauna and an increase in mobile species. Furthermore, serpulid worm tubeheads were significantly lower in fished sites, but densities were unaffected at the scale and intensity of fishing in the study because the worms were often attached to rocks that passed through the net, and thus could recolonize between sampling. These changes in biota were detectable for up to 6 months. No differences in biota were detected at the sites with more mobile sediments. The authors comment that although effects were short-term, the length that effects endure depends on the timing of the impact. For example, effects might be less evident if they coincide with peak settlement of benthic fauna or during a time of frequent natural disturbances.

Rijnsdorp and Vingerhoed (2001) examined stomach contents of plaice and sole in the North Sea. No clear differences in stomach contents were found between areas inside and outside of the "plaice box" which has reduced trawling effort by 12-m beam trawls. However, a comparison between recent (1996) and past (~1900) data revealed a shift in major prey types from dominance of bivalves to dominance of polychaetes. The authors comment that the observed changes agree with those predicted from trawl damage studies (i.e., increase in short-lived taxa and decrease in long-lived taxa), but note that similar changes could also be a result of eutrophication and pollution.

Table 10. Summary of literature on effects of beam trawls on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Bergman and Van Santbrink 2000 | North Sea | shallow, deep | shallow sand (1-5% silt, 200-370 mm), deep silty sand (3-10% silt, 150-170 mm) | decrease in benthic macrofauna abundance (epifauna and infauna) | | experimental trawling (6 sites) |
| **Bergman and Hup 1992** | North Sea | 30 m | fine to medium-hard sand | trawl penetrates to 6 cm, decrease in benthic macrofauna abundance | | experimental trawling (1 site) |
| Fonteyne 2000 | Belgium, The Netherlands | 20-30 m | coarse sand, fine sand with layer of silt | tracks in sediment; alteration in sediment composition, suspension of sediments | sediments recover in 15 hrs, tracks visible for 52 hrs on coarse sand, 37 hrs on fine sand with silt | observations (2 sites) |
| **Kaiser and Spencer 1996b, Kaiser et al. 1996b, 1998, 1999** | Irish Sea | 12-20 m, 26-35 m | medium sand with ripples, coarse sand with gravel and shell debris | sediments smoothed, suspended, and less consolidated; decrease in benthic macrofauna abundance in stable sediments, no effects on macrofauna in mobile sediments | 6 months in stable sediments | experimental trawling (1 site) |
| Margetts and Bridger 1971 | English Channel | 22 m | hard sand with gravel and stones | 15 mm tracks in sediment; smoothing of surface, stones rolled | | SCUBA and video observations |
| Margetts and Bridger 1971 | English Channel | 22 m | muddy sand | 80-100 mm tracks in sediment, smoothing of surface, resuspension of sediments | >10 min | SCUBA and video observations |
| **Philippart 1998** | North Sea | | | increase bycatch of macroepifauna | | analyzed catch data over 20 years during switch from otter trawl to beam trawl commercial fisheries |

Table 10. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Rijnsdorp and Vingerhoed 2001** | North Sea | | | change in composition of prey species | | compared 1990 stomach contents and 1996 stomach contents inside and outside of area closed to fishing |
| **Schratzberger et al. 2002** | North Sea | 39 m, 59 m | muddy sand | no significant effects on total abundance or species richness of meiofauna | | experimental trawling at lightly fished sites |

Conclusions

Ten studies, including 6 experimental, 2 observational, 1 using time series data, and 1 examining fish gut contents inside and outside a closed area, were available for inclusion in this report. Physical effects of beam trawls on sand habitats include suspension of sediments, alteration of sediment composition, smoothing of the seafloor, and trawl tracks in the sediment that remain visible for hours to months. Results from one study conclude that beam trawling decreases macrofauna abundance in stable sediments, but has no effect on macrofauna in mobile sediments. Six additional studies report that beam trawling decreases the abundance of macrofauna. A change in species composition of prey species associated with prolonged beam trawling is also reported. No information is provided on recovery from biological effects.

### e. Rapido Trawls

Rapido trawls resemble toothed beam trawls and are used in the Adriatic Sea – in sandy offshore areas to harvest scallops and in muddy inshore areas to harvest flatfish. Hall-Spencer et al. (1999) used underwater video 1 hour and 15 hours after trawling to examine the physical and biological effects of a 3-m Rapido trawl towed 5 times at a depth of 25 m in the Gulf of Venice, Italy. Trawling erased infaunal burrow openings, decreased the abundance of slow moving/sessile benthos, such as scallops, sea cucumbers and large fragile bivalves, and increased the abundance of mobile scavengers.

Pranovi et al. (2000) used sandy sediment areas around shipwrecks (as unfished area) in the Adriatic Sea for experimental fishing with Rapido trawls. Trawls produced flat tracks that were still clearly visible after a week, disturbed the upper 6 cm of the sediment, but did not affect sediment grain size. Divers observed that fishing removed debris and resulted in a 50% reduction of epifaunal organisms. Total abundance and total biomass of infauna collected in core samples decreased immediately after trawling, but increased again after only 1 week. However, a comparison of the shipwreck control areas to fishing areas demonstrated that several taxa were significantly less abundant in the fished areas, which the authors suggest indicates a long-term cumulative effect not evident from the short-term experimental study design. The authors also recognized that the presence of the wreck in the control area could modify the local benthic community, thus confounding results.

Table 11. Summary of literature on effects rapido trawls on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Hall Spencer et al. 1999** | Gulf of Venice, Italy | shallow | sand | erased burrow openings, decrease in slow moving and sessile epifaua, increase in scavengers | | experimental trawling |
| **Pranovi et al. 2000** | Adriatic Sea | 24 m | sandy | removed debris from seafloor, decrease epifauna, reduction in infaunal abundance and biomass | fauna recovered in1 week | experimental trawling in unfished area near shipwreck |

Conclusions

Results of 2 studies indicate that rapido trawls disturb the upper 6 cm of sandy seafloor, reduce abundance of epifauna, and temporarily reduce the abundance and biomass of inaunal organisms. Infauna recovered quickly (1 week) in one study.

## 2. Dredges

### a. Hydraulic Clam Dredges

#### 1. Sand

Effects and Recovery

Meyer et al. (1981) used SCUBA to observe effects of a small (4' wide) hydraulic clam dredge in a surfclam bed located near Rockaway Beach on the south shore of Long Island, New York. The depth was 11 m and the sediment was silty sand. The dredge formed trenches that were the same width as the dredge and over 20 cm deep. Mounds of sand were formed on either side of the trenches. The dredge raised a cloud of silt 0.5- 1.35 m in height, which settled within 4 minutes. Two hours after dredging trench walls began slumping. After 24 hours the dredge track was less distinct, appearing as a series of shallow depressions. The dredging attracted predators, with lady and rock crab preying on damaged clams, and starfish, horseshoe crabs and moon snails attacking exposed but undamaged clams. By 24 hours after dredging, the abundance of predators appeared to have returned to normal.

MacKenzie (1982) sampled benthic invertebrate assemblages in three ocean quahog beds with contrasting fishing histories: one had never been fished, one had been actively fished for two years, and one had been fished for about a year and then abandoned. All three beds were in very fine to medium sand sediments in 37 m off southern New Jersey. No significant differences were found in numbers of invertebrate individuals, numbers of species or species composition between previously dredged and undredged areas. Hydraulic dredging thus did not appear to have any lasting effect on the invertebrate populations in these beds. Polychaetes and bivalves exposed by dredging presumably were able to reburrow and survive.

Medcof and Caddy (1971) conducted SCUBA and submersible observations to compare effects of hydraulic dredges (without teeth) to non-hydraulic dredges with teeth, in shallow water (7-12 m) sand inlets in south Nova Scotia. On sand and sand-mud habitats, hydraulic dredges left smooth tracks with steeply cut walls that were an average of 20 cm deep and slowly filled in by slumping, whereas non-hydraulic dredges left tracks that were 3-10 cm deep and had a raked appearance. The hydraulic dredge raised sediment clouds, which seldom exceeded 0.5 m in height and usually settled within 1 minute. Dredge tracks were still easily recognizable after 2-3 days.

Murawski and Serchuk (1989) used manned submersibles in 1986-1987 to observe effects of experimental dredging on sand and mud bottom habitats. Studies were conducted in offshore areas ranging from east of Delaware Bay to south of eastern Long Island (water depths not reported). The authors reported that hydraulic dredges in the Mid-Atlantic penetrate deeper into the sediments than do scallop dredges and, on a per-tow basis, result in greater short-term disruption of the benthic community and underlying sediments. In coarse gravel, the sides of the dredge-created trench soon collapsed, leaving little evidence of dredge passage. There was also a transient increase in bottom water turbidity. In finer-grained, hard-packed sediments, tracks persisted several days after dredging. Non-harvested organisms (e.g., sand dollars, crustaceans, worms) were substantially disrupted by the dredge. Sand dollar assemblages appeared to recover quickly. Starfish and benthic feeding fish were abundant in dredge tracks, probably feeding on exposed infauna.

Pranovi and Giovanardi (1994) studied the effects of a 2.7 m wide hydraulic dredge in 1.5-2 m depths in Venice Lagoon (Adriatic Sea). In 1992, divers took sediment and infaunal samples from experimentally-dredged and control areas both in and outside commercial fishing grounds immediately after dredging and every 3 weeks for 2 months. The dredge created 8-10 cm deep furrows, one of which was clearly visible 2 months later. In this study, sediment grain size was not significantly affected by dredging, although portions of the fishing grounds which had been predominantly silt and clay sediments 15 years earlier now had a considerably higher sand content. Within the fishing grounds, faunal numbers and biomass were significantly reduced in the experimental plot immediately following dredging. Densities, especially of small species, recovered two months later, but biomass did not. Outside the fishing grounds, immediately after passage of the dredge, there were no significant faunal differences between dredged and undredged areas.

Tuck et al. (2000) examined the effects of a hydraulic (water jet) dredge on the seabed and benthic community in a shallow (2-5 m), sandy site in the Outer Hebrides, on the west coast of Scotland. In the study area, sediments consisted of moderately well-sorted medium or fine sand and tidal currents reached speeds as high as 3 knots. Core samples and diver and video observations were taken before, during, immediately after, 5 days after, and 11 weeks after dredging, inside and outside 6 dredge tracks. Immediately after dredging, sediments had dredge tracks with a depth similar to the dredge blade and distinct vertical walls that collapsed once the dredge was hauled. The sediment within the tracks was fluidized to a depth of approximately 0.3 m, and there was significantly more silt in the sediments outside the tracks than inside. After 5 days, tracks and depth of fluidized sediments remained the same, but the change in silt composition was no longer evident. After 11 weeks the tracks were no longer visible, but 0.2 m of sand was still fluidized. Immediately after dredging, the number of species and total abundance was lower in fished tracks. At 5 days, number of species and total abundance recovered, but there was a significant decrease in the proportion of polychaetes and an increase in the proportion of amphipods. Bivalves were not affected by dredging. The biological community recovered completely within 11 weeks. Owing to the strong currents, epifauna in the area was very sparse: the only change observed after dredging was the attraction of crabs into the area to scavenge on material disturbed by the dredge.

Table 12. Summary of literature on effects of hydraulic dredges on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Meyer et. al., 1981** | Long Island, New York | 11 m | silty sand | >20 cm deep trench, sand mounds, silt cloud, attraction of predators | trench nearly indistinct, predator abundance normal after 24 hours; silt settled in 4 minutes | SCUBA observations |
| **MacKenzie, 1982** | Southern New Jersey | 37 m | very fine to medium sand | no significant differences in number of individuals or species (infauna) | | comparison of heavily fished, recently fished and never fished area |
| Medcof & Caddy 1971 | Southern Nova Scotia | 7-12 m | sand and sand-mud | smooth tracks with steep walls, 20 cm deep; sediment cloud | sediment plume lasted 1 minute; dredge tracks still clearly visible after 2-3 days | SCUBA & submersible observations |
| Murawski & Serchuk 1989 | Mid-Atlantic | | sand, mud and coarse gravel | trench cut, increased turbidity, disruption of benthic organisms in dredge path, attraction of predators | trench filled quickly in coarse gravel, but took several days in fine sediments | submersible observations |
| **Pranovi & Gionovardi 1994** | Adriatic Sea (Italy) | 1.5-2 m | sand | 8-10 cm deep furrow; immediate decrease in abundance and diversity of benthic infauna in fishing ground; no effects outside fishing ground | after 2 mos, furrows still visible, infaunal densities in fishing ground recovered, biomass did not | experimental dredging in previously dredged and undredged areas in coastal lagoon |
| **Tuck et al. 2000** | Outer Hebrides, Scotland | 2-5 m | medium to fine sand | steep-sided trench (30 cm deep), sediments fluidized up to 30 cm, significant decrease in number of infaunal species and total abundance, polychaetes most affected | trench no longer visible but sand still fluidized after 11 weeks, species diversity and abundance recovered within 5 days, abundance of all species recovered after 11 weeks | diver observations and experimental dredging |

Conclusions
Results of six studies indicate that hydraulic clam dredges create a steep-sided trench up to 30 cm deep that persists from 1 day to >2 months, and a sediment cloud in the dredge path that lasts for a few minutes. One study showed that dredging also fluidized sand within the dredge track for at least 11 weeks. Two studies showed that dredging resulted in temporary disruption of infaunal species, and decreased species abundance and diversity, with recovery in approximately 8-11 weeks. In one study, there was evidence that infaunal communities in previously dredged locations were more severely affected than those in previously un-dredged locations. In contrast, one study found no significant differences in the numbers of infaunal individuals or species in heavily dredged, recently dredged, and undredged areas.

### b. Escalator Dredges

#### 1. Mud

Effects and Recovery
Effects of escalator dredging on water quality and benthic infauna were examined in an intertidal, mud flat habitat (<94% silt/clay before harvest) in Maine (Kyte et al. 1975, summarized in Coen 1995). Variables studied were hydrography, grain size, salinity, pH, dissolved oxygen, hydrogen sulfide, suspended sediments, nutrients, benthic infauna, and direct physical effects of the gear (tracks and trenches). Samples were taken prior to, during, and 10 months after dredging. Turbidity plumes only lasted for a short time and often did not reach ambient seston levels. There were few consistent effects on water column chemistry. Infaunal community effects were limited due to rapid recruitment of affected invertebrates in the path of the dredge.

Table 13. Summary of literature on effects of escalator dredges on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Kyte et al. 1975 | Maine | inter-tidal | mud | turbidity plumes, few consistent effects on water chemistry, limited effects on benthic community | rapid recruitment of benthic organisms | experimental dredging |

Conclusions
Results of one study indicate that escalator dredges do not have lasting adverse effects on intertidal mud habitat.

#### 2. Sand

Effects and Recovery
Maier et al. (1995) assessed the effects of mechanical escalator dredges in muddy sand tidal creeks in South Carolina by comparing pre- and post-dredging turbidity levels and benthic infaunal assemblages. Turbidity was monitored 2 weeks before, during, and 2 weeks after dredging at one location and during and immediately after dredging at another. Infaunal samples were collected 3 weeks before and 2 weeks after dredging in a harvested creek and in an unharvested creek. No commercial clam dredging had taken place in either of these creeks for 5 years. Turbidity was elevated in the vicinity of the dredge and immediately downstream while it was operating, but the sediment plumes only persisted for a few hours. Sampling failed to detect

any significant changes in the abundance of dominant infaunal taxa, or in the total numbers of individuals, after dredging. Effects of escalator dredging had no detectable effects on water quality at several sites with coarse-grained sediments in Washington (Tarr 1977). This information was summarized by Coen (1995).

Table 14. Summary of literature on effects of escalator dredges on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Maier et al. 1995 | South Carolina | | muddy sand | turbidity plumes, no significant changes in abundance of dominant infaunal taxa or total number of individuals after dredging. | turbidity plumes persisted for a few hours | before and after dredging study in harvested and un-harvested tidal creeks |
| Tarr 1977 | Washington | | coarse-grained sand | no effects on water quality | | see Coen (1995) – primary source not available |

Conclusions

Two studies indicated that escalator dredges fluidize sand, create trenches up to 30 cm deep, and resuspend fine sediments, but effects on water quality and benthic infauna appear to be minimal and short-term.

### 3. Submerged Aquatic Vegetation

Effects and Recovery

Godcharles (1971) conducted experimental escalator dredging in seagrass beds, *Caulerpa* algae beds, and sand bottoms in Tampa Bay, FL. The dredge water jets were capable of penetrating the sediments to a depth of 7 inches and left trenches that were 5 inches deep. Virtually all attached vegetation in the path of the dredge was uprooted leaving bare, open bottom areas. Dredges also uncovered a deep stratum of broken shells. Trenches were visible from 1-86 days, and while most sediments had hardened within a month, some remained soft over 500 days. Differences in silt/clay content between tracks and undisturbed areas became negligible after a year, but seagrasses had still not recolonized. Based on these findings, the author recommends a complete prohibition of dredging in areas with seagrasses and algae.

Damage to submerged aquatic vegetation (SAV) caused by escalator dredges in Chincoteague Bay, Virginia, was investigated by Orth et al. (1998). They reported a large number of circular “scars” in the vegetation, with 70-100% seagrass cover outside the scarred areas, an abrupt reduction to 15% or less at the scar edge, and low percent cover (<15%) across the scar until a second abrupt increase in cover occurred at the center where seagrass had not been disturbed. There were no measurable differences in percent cover estimates in the scarred portions of areas that were dredged during 1998 and 1 and 2 years previously, indicating that revegetation was proceeding very slowly. The authors concluded that even the most lightly impacted areas would require a minimum of 5 years to fully recover. Increased turbidity caused by persistent hydraulic clam dredging in shallow water where sediments have a high percentage of silt and clay could also inhibit light required by SAV for photosynthesis and growth (Ruffin 1995).

Table 15. Summary of literature on effects of escalator dredges on seagrass habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Godcharles 1971 | Tampa Bay, FL | | sand with seagrass and algae | water jets penetrate to 7 cm, create trenches 5 cm deep; uprooted vegetation, increased silt/clay content in dredge tracks | trench present up to 3 months, softened sediments >500 days; after 1 year, sediment content returned to normal, but seagrass still unrecovered | experimental dredging |
| Orth et al. 1998 | Chincoteague Bay, Virginia | | seagrass beds | circular "scars" left by dredges, severe loss of grass in dredge track | revegetation slow, estimated to take at least 5 yrs in lightly disturbed areas | observations |

Conclusions

Two studies indicate that escalator dredges used in shallow, sandy SAV habitat uproot seagrass, leave large holes in the bottom, fluidize sediments, and create trenches 5 cm deep. Trenches persisted for as long as 3 months and the silt/clay content returned to normal after a year. The time required for the bottom to "harden" was extremely variable (1 to more than 16 months). Revegetation of areas affected by dredging was shown to take more than a year and may take more than 5 years.

### c. New Bedford Scallop Dredges

#### 1. Mud

Mayer et al. (1991) investigated the immediate effects of scallop dredging at a shallow (8 m), nearshore site on the Maine coast with a mixed mud, sand, and shell hash substrate. The site was dragged once with a New Bedford style chain sweep dredge and core samples were collected before and one day after dragging. Dragging lowered the substrate by 2 ±1 cm and tilled the sediment to a depth of 9 cm, causing finer material (sand and mud) to be injected into the lower 5-9 cm of the sediment profile and a coarsening of the sediment above 5 cm. Organic matter profiles were strongly affected by dragging. Total organic carbon and nitrogen at the new sediment-water interface were markedly reduced in concentration after dragging and carbon increased significantly at the 5-8 cm sediment depth intervals. A diatom mat on the surface of the sediment was disrupted by the dredge and partially buried. The microbial community of the surface sediments increased in biomass following dragging.

Table 16. Summary of literature on effects of New Bedford scallop dredges on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Mayer et al. 1991** | Gulf of Maine | 8 m | mud with sand and shell hash | tilled sediment to 9 cm and left trenches up to 2 cm; decrease in fine sediments and organic matter at surface but increase at 5-9 cm depth; disruption of surface diatom mat | surface biomass increased within 1 day | experimental dredging |

Conclusions

One study indicates that a New Bedford scallop dredge tilled muddy sediments, decreased fine sediments and organic matter at the sea surface, and left tracks in the sediments.

## 2. Sand

Effects and Recovery

Sidescan sonar over Stellwagen Bank (depths of 20-55 m) showed that scallop dredging disturbed sand ripples and dispersed shell deposits in the troughs of sand waves (Auster et al. 1996). These features are restored periodically when large storms pass through the area.

Visual and photographic observations were made from a submersible before (1986) and after (1987) heavy commercial dredging at an offshore, gravelly sand bank (56 to 84 m) in the Gulf of Maine (Fippennies Ledge; Langton and Robinson 1990). Sediments throughout the area averaged 84% sand, with some gravel and a very small amount (<1%) of mud. Sediments in dredged areas changed from more organic-silty sand to a sandy gravelly appearance, apparently due to the disruption of amphipod tube mats. Piles of rock and scallop shells were observed, apparently deposited there when dredges were emptied at the surface. In addition, the density of three dominant megafaunal species (scallops, burrowing anemones and a tube-dwelling polychaete) decreased significantly between pre- and post-dredging observations.

The geochemical and biological effects of scallop dredging were examined in a shallow (15 m), silty-sand estuarine environment on the Maine coast (Watling et al. 2001). Bottom samples for sediment chemistry, microbiology and benthic infauna and epifauna were collected by divers in a control and an experimental plot before and after intensive dredging using a 2 m wide New Bedford style dredge. The dredge was equipped with chain sweeps, but no cutterbar. Sampling was conducted 4 and 5 months before dredging, immediately before and after dredging, and 4 and 6 months after dredging. The immediate effects of dragging were the loss of the fine fraction of the top few centimeters of sediment and a reduction in the food value of the sediment (significant reductions in enzymatically hydrolysable amino acids and total microbial biomass). Fine sediments still had not been restored six months after dragging, whereas the food value of the sediments in the experimental plot showed relatively complete recovery within 4-6 months. There was no difference in the number of macrofauna taxa present after dragging, but total abundance was reduced for up to four months. Differences were no longer detectable after 6 months.

Table 17. Summary of literature on effects of New Bedford scallop dredges on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location/Date | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Auster et al. 1996** | Stellwagen Bank, Gulf of Maine | 20-55 m | sand | smoothing of ripples and waves, dispersal of shell deposits in wave troughs | bottom features re-formed by large storms (>1 yr) | side-scan sonar survey |
| **Langton & Robinson 1990** | Fippennies Ledge, Gulf of Maine | 56-84 m | gravelly sand with some shell hash and small rocks | coarser substrate, disruption of amphipod tube mats, piles of small rocks and scallop shells; reduced density of tube dwelling polychaete and burrowing anemone | | submersible and photo observations before and after dredging |
| **Watling et al. 2001** | Damariscotta River, Maine | 15 m | silty sand | loss of fine surficial sediments, lowered food quality of sediment, reduced abundance of some species, no changes in number of taxa | benthic fauna recover after 6 months, recovery of food value within 4-6 months | experimental dredging at 1 site |

Conclusions

Three studies of the effects of New Bedford scallop dredges on sand habitat types are summarized. Dredging smoothed sand ripples, dispersed shell deposits, rocks and cobble, resuspended fine sediments, and left flat dredge tracks in the sediment. Dredging also reduced biogenic structure by disrupting amphipod tubes and reduced the abundance of tube-dwelling polychaetes and anemones. One study documented recovery of benthic infauna within 6 months.

### 3. Variable Sediments

Effects and Recovery

Caddy (1968) described diver observations of dredge effects in shallow scallop (*Placopecten magellanicus*) beds in the Gulf of St. Lawrence. The depth was about 20 m and the sediments ranged in texture from mud to clean sand. Fishing operations were conducted with a 2.4 m wide, 0.36 mt weight, offshore chain sweep scallop dredge (no teeth) that was modified to reduce its weight by replacing the forward drag bars with chains. The lateral skids produced two parallel furrows approximately 3 cm deep; a series of smooth ridges between them were caused by the rings in the chain belly of the dredge. Dislodged pieces of dead shell were more evident within the drag tracks than on the surrounding bottom.

Caddy (1973) used a two-man submersible to observe the effects of a 2.4 m wide offshore chain sweep scallop dredge (no teeth, weight 0.6 mt or 1300 lb out of the water) and a gang of three 0.8 m wide inshore Alberton style toothed dredges in Chaleur Bay, Gulf of St. Lawrence. Depth varied from 40 to 50 m, and the substrate was sand overlaid by glacial gravel, 1-10 cm in diameter, with occasional boulders up to 60 cm across embedded in the gravel. Scallops were harvested with Alberton dredges in this location beginning in 1969. Visual, photographic and video observations were made inside and outside the dredge tracks within an hour of each tow. Dredging suspended fine sediments and reduced visibility from 4-8 m to less than 2 m within 20-30 m of the track. Turbidity dispersed within 10-15 min of the tow, coating the gravel in the vicinity of the track with a thin layer of fine silt. The offshore dredge left a flat track in the sediment surface. Gravel fragments were less frequent inside the track, and many were overturned. Rocks 20-40 cm in diameter were dislodged, some boulders were overturned and others were plowed along, leaving a groove several meters long.

Table 18. Summary of literature on effects of New Bedford scallop dredges on habitat with mixed substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location/Date | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Caddy 1968** | Northumberland Strait, Gulf of St. Lawrence, Canada | 20 m | mud and sand | tracks (2 cm deep) in sediments, ridges from rings, dislodged shells in dredge tracks | | diver observations |
| **Caddy 1973** | Chaleur Bay, Gulf of St. Lawrence, Canada | 40-50 m | sand over gravel, with occasional boulders | suspended sediment, tracks in sediment, gravel fragments less frequent, rocks overturned, dislodged or plowed along bottom | | submersible and photo observations |

Conclusions

According to two studies on habitat with variable sediment types, New Bedford scallop dredging leaves tracks in the sediment, dislodges shells and rocks, and resuspends sediments.

### d. Toothed scallop Dredges

#### 1. Sand

Effects and Recovery

A detailed study of the physical and biological effects of scallop dredging was conducted in a large, semi-enclosed, predominantly tidal embayment (Port Phillip Bay) in southeast Australia in 1991 (Currie and Parry 1996, 1999, Black and Parry 1994). The depths at the three study sites were similar (about 15 m), but the sites had different sediments and were exposed to different current strengths and wave characteristics. Sediments at the three sites, respectively, were predominantly fine and very fine sand, medium-fine sands, and silt and clay with shell fragments. Experimental plots were located in areas that were undredged by the commercial fishery for 3 years. Plots were experimentally dredged repeatedly over a 2-3 day period by commercial draggers using toothed "Peninsula" style dredges fitted with cutter bars that did not extend below the skids. The biological impacts of dredging were evaluated using a BACI (before, after, control, impact) experimental design. Recovery from the physical and biological impacts of dredging was monitored over a 14 month period.

Experimental dredging in the same location disturbed the top 10-20 mm of sediment, but sometimes penetrated up to 60 mm in softer sediments (Black and Parry 1994). Turbidity plumes extending 1-2 m into the water column were created within 2-16 seconds immediately behind the dredge, reaching sediment concentrations 2-3 orders of magnitude greater than the turbidity caused by storms. Sediment concentrations returned to natural storm levels after about 9 minutes at sites 60 and 80 m downcurrent of the experimental dredging plots. Smaller sediment plumes were also produced by the skids. Dredging smoothed sand ripples (Curry and Parry 1999) and biogenic mounds (Currie and Parry 1996) and produced parallel tracks up to 25 mm deep in the sediments. Tracks were still visible a month after dredging, but not after six months.

Sand ridges re-formed immediately following a storm that occurred five days after the area was dredged. Biogenic mounds re-formed after six months. Eleven months after dredging there were no visible differences in topography between the control plots and the dredged plots.

At one of the three sites in Port Phillip Bay, there was a significant decrease in the number of species in the dredged plot that persisted for 14 months (Currie and Parry 1996). In the 3.5 months following dredging, 6 of the 10 most common benthic species at this site showed significant decreases in abundance; most species decreased in abundance by 20-30%. Of the 6 species whose abundance was reduced, two were affected for 3.5 months, two for 8 months, and two for 14 months. Dredging impacts became undetectable for most species following their annual recruitment (6 months after dredging). Species that occurred on or near the sediment surface (e.g., tube-dwelling amphipods) were released into the water column by the first pass with the dredge, and species inhabiting deeper sediments (e.g., burrowing polychaetes) were dislodged as dredging continued. More mobile, opportunistic species inhabiting surface sediments increased in abundance during the 3.5 months after dredging. The maximum difference between the two plots occurred three weeks after dredging, suggesting that there are indirect effects such as increased predation of infaunal organisms that were uncovered by dredging. Only two and three of the ten most common species at the other two sites were significantly reduced in abundance, but authors note that reduced sampling intensity limited the statistical power of the tests (Currie and Parry 1999). The authors concluded that although scallop dredging results in biological impacts to benthic habitats, the reductions in density caused by dredging were small compared to effects from differences in sediment types or from natural changes in population densities, which occurred at the control sites during the year (Currie and Parry 1996, 1999).

Butcher et al. (1981) documented diver observations of scallop dredging in Jervis Bay, New South Wales, Australia, over large-grained firm white sand shaped in parallel ridges at depths below 13 m. The dredge design was not described, but had teeth which extended up to 5 cm below the leading edge of the dredge. Operation of the dredge flattened sand ridges and produced a sediment plume extending up to 5 m into the water column that settled out within 15 minutes. Dredge paths were clearly visible and “old” dredge paths could be seen.

Thrush et al. (1995) conducted an experimental study of scallop dredging at two high energy sites in the Mercury Bay area of the Coromandel Peninsula in New Zealand in 1991. One site was regularly exploited by commercial scallop fishermen and the other was not. The sediment at both sites was coarse sand, but was more poorly sorted and had a large fraction of shell hash at the exploited site. The depth was about 24 m at each site. Divers collected core samples and made visual observations in dredged and undredged areas at each site before dredging, within 2 hrs of dredging, and 3 months after dredging. At both sites, the dredge broke down the natural surface features (e.g., emergent tubes and sediment ripples) and the teeth created grooves approximately 2-3 cm deep. Changes in macrobenthic community structure in dredged areas differed from undredged areas for at least three months at each site. At both sites, significant differences in benthic community structure, and decreases in the density (mean number per core) and number of taxa of common macrofauna were apparent immediately after dredging. Three months later at the unexploited site, total density and the densities of 4 of the 13 most common taxa were still lower in the dredged plots. At the exploited site, total density in the dredged plot recovered after 3 months, but some species were still less abundant while others had increased in abundance. The authors concluded that the differences in recovery processes at the two sites were likely related to differences in the initial community composition and to differing environmental characteristics.

Eleftheriou and Robertson (1992) examined the effects of repeated scallop dredge tows in a shallow, sandy bay on the west coast of Scotland using photographic observations and grab samples of epifauna and large infauna before and after dredging. The authors note that there was no control in this study, and therefore no statistical tests of location or temporal effects on the benthic fauna. The depth at the study site was about 5 m and the sediment was well-sorted sand (mean grain size 0.194-0.205 mm). A 1.2-m wide scallop dredge with nine, 12-cm long teeth and chain bag removed was towed over the same track 25 times during a 9 day period. Dredge teeth penetrated the bottom to a depth of 3-4 cm. Dredging created furrows, eliminated natural bottom features, and dislodged large shell fragments and small stones. Dredging had no effect on the vertical distribution of grain size, organic carbon, or chlorophyll *a*. Grooves and furrows created by the dredge were eliminated shortly after dredging by wave action and tidal conditions. Infaunal invertebrates that were adapted to the stresses of a high-energy environment (e.g., amphipods and bivalves) were not affected, the number of small crustaceans increased significantly with successive tows, and crabs and starfish were attracted to feed on dead and damaged organisms left behind the dredge. There were no significant changes in biomass of the different taxonomic groups. The plowing effect of the dredge buried, damaged, or chased away organisms such as sea urchins, starfish, scallops, razor clams and sand eels (*Ammodytes* spp.), brittlestars, burrowing anemones, and swimming crabs.

Table 19. Summary of literature on effects of toothed scallop dredges on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Black & Parry 1994, 1999** | Port Phillip Bay, SE Australia | 15 m | muddy sand (0.09-0.22 mm mean grain size, 7.2-30.1% mud) | sediment plume, smoothing of seafloor, disturbance up to 6 cm into bottom | turbidity returned to normal storm levels within 9 minutes | experimental dredging (3 sites) |
| Butcher et al. 1981 | Jervis Bay, New South Wales, Australia | > 13 m | sand | sediment plume, flattening of sand ridges | plume settled within 15 minutes | diver observations |
| **Currie & Parry 1996, 1999** | Port Phillip Bay, SE Australia | 15 m | fine/very fine sand (15% mud, 0.09 mm mean grain size) | smoothing of mounds, depressions filled, tracks in sediment; reduced species diversity, reduced abundance of 6 of 10 most common species | mounds re-formed after 6 months, tracks visible 1-6 months; most species recovered within 6 mos, but some had not after 14 months | experimental dredging (1 site) |
| **Currie & Parry 1999** | Port Phillip Bay, SE Australia | 15 m | medium-fine sand (7.2% mud, 0.22 mm mean grain size) | removal of sand ripples, significant decrease in abundance of 3 of 10 infauna species | ripples re-formed by storm in 5 days | experimental dredging (1 site) |
| **Currie & Parry 1999** | Port Phillip Bay, SE Australia | 15 m | muddy sand with shell fragments (30.1% mud, 0.14 mm mean grain size) | significant decrease in abundance of 2 of 10 infauna species | | experimental dredging (1 site) |

Table 19. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Eleftheriou & Robertson 1992** | Loch Ewe, Scotland | 5 m | sand | no lasting physical effects; no significant effects on infauna adapted to high-energy environment; damage or mortality of larger epifauna, razor clams, and sand eels; aggregations of predatory species | | experimental dredging |
| **Thrush et al. 1995** | New Zealand | 24 m | coarse sand | surface sediment features removed, tracks 2-3 cm deep from teeth; change in community structure, reduced abundance of common taxa and number of taxa | after 3 months benthic community recovered at exploited sited, partially recovered at unexploited site | experimental dredging (2 sites) |

Conclusions

Evidence provided by seven studies in four different sandy bottom locations indicates that toothed dredges eliminate seafloor features, flatten sand ridges and remove sand ripples. Dredging also creates sediment plumes, but turbidity plumes dispersed within minutes. In low-energy environments, dredge tracks were still visible after 1 month, but after 6 months tracks were gone and biogenic mounds had reformed. Biological effects included damage or mortality of large epifauna and, in low or moderate-energy environments, reduced species diversity, numbers and abundance of many infaunal taxa. Most taxa recovered within 3-6 months, but some required more than 14 months. A study conducted in a shallow, high-energy environment that is regularly disturbed by storms indicated that none of the observed physical or biological effects of dredging – aside from the immediate mortality of large epifauna in the dredge track – lasted for more than a few days.

## 2. Gravel

Effects and Recovery

Samples of epibenthic bycatch were collected with a gang of four Newhaven type (spring-toothed) scallop dredges in June and October 1995 on 13 different commercial fishing grounds in the Irish Sea that had been exposed to different amounts of fishing effort during the preceding 60 years (Veale et al. 2000). Depths ranged from 20 to 67 m and sediment types were generally coarse sand and gravel, overlain with pebbles, cobbles, and dead shell. The dredges were equipped with short teeth (76 mm) and small belly rings (57 mm). Species diversity and richness, total number of individuals, biomass, and the production of most of the major individual taxa investigated all decreased significantly with increasing fishing effort, whereas species dominance increased with effort. Of all the environmental parameters examined (including depth, bottom hardness and texture), a combination of long- and short-term fishing effort best explained the observed differences in bycatch assemblages across sampling sites.

Kaiser et al. (1996a) compared the immediate effects of beam trawling and scallop dredging on benthic communities on a heavily fished scallop ground off the southwest coast of the Isle of Mann, adjacent to the closed area studied by Bradshaw et al. (2000). Three parallel waylines were established: one was fished 10 times with a 4 m commercial beam trawl fitted with a 80 mm diamond mesh codend towed at 4 knots, one was left undisturbed, and one was fished 10 times with two gangs of four Newhaven (spring-tooth) dredges. Both gears reduced the abundance of most species, and resulted in significant changes in the benthic community between fished and unfished waylines. There were no significant differences between the two fished waylines, even though they were fished by the different gear, which suggests that the disturbance caused by either gear had similar effects on the benthic community.

Bradshaw et al. (2001) conducting controlled scallop dredging experiments in a 2 $km^2$ closed area near the Isle of Man, in the Irish Sea, that was closed to commercial fishing by towed gear in 1989. The entire area adjacent to and inside the closed area had been heavily dredged for 50 years prior to the closure. Two experimental plots inside the closed area were dredged every two months or so for 5 years using two sets of four spring-loaded Newhaven-type scallop dredges towed 10 times along each line. In addition, three plots located outside the closed area are exposed to commercial scallop dredging. Grab samples were collected twice a year in all seven plots. Depth in the study area ranged from about 25 to 40 m and the seabed was a mixture of gravel, sand, and mud. Samples collected over a three-year period showed the same trend of experimentally dredged plots being more similar to commercially dredged plots than undredged plots in the closed area. However, none of these differences were significant, nor were there any clear trends for particular species or groups of species. There were also no significant differences in total species number or richness between treatments. There was evidence that dredging reduces benthic community heterogeneity. Sessile organisms were considered to be especially sensitive to dredging disturbance and were analyzed separately. Three years after experimental dredging began and 9 years after the area was closed, encrusting bryozoans, encrusting sponges, and small ascidians were more common in dredged plots, while upright forms such as bryozoans and hydroids were more common in the undredged plots.

In an earlier paper, Bradshaw et al. (2000) analyzed density estimates of epibenthic animals made during diver surveys in the undisturbed portion of the closed area. Many epifaunal species increased significantly in abundance between 1989 and 1998, including brittlestars, a spider crab, scallops, hermit crabs, and one species of starfish. The most significant changes occurred in the 5$^{th}$, 7$^{th}$, and 9$^{th}$ years after the area was closed.

Bradshaw et al. (2002) compared recent benthic sample data from 7 sites, located south and west of the Isle of Man subject to varying levels of fishing, to historical (from1938-1952; some of these data were analyzed by Hill et al. 1999) data collected when scallop dredging in the area was still very limited. Fishing disturbance for each site was evaluated in terms of total fishing effort of a sample fleet (1981-1993) and its coefficient of variation (greater values indicate a more even distribution of fishing disturbance from year to year), the number of years since fishing began, and a fishermen's index of total fishing effort since the start of the fishery. Time was a significant factor across all sites and, at two sites where spatial and temporal replicate samples were available, the historical samples were distinct from all the recent (1994-1999) samples collected at the same sites at different times. Taxa that decreased in abundance between the two time periods included species of brittlestars, hydroids, upright and encrusting bryozoans, encrusting worms, and barnacles. Taxa that were more abundant in recent samples included large-bodied tunicates, mobile crustaceans (shrimp, spider crabs and squat lobsters) and robust scavengers (whelks, hermit crabs, and starfish). Taxa that became more abundant had, on average, more "robust" life-history characteristics than those that decreased in abundance. Faunal similarity decreased significantly as the fishermen's index of effort and the number of years since fishing began increased. Similarly, the proportion of species "lost" between the two sampling periods increased significantly as the number of years since fishing began increased. The increase in total fishing effort, as estimated from fishermen's logbooks, had no effect. These results suggested to the authors that it is the length of time over which fishing occurs, rather than absolute levels of effort, which are important in structuring benthic communities. There was no clear evidence of a relationship between change in taxonomic diversity and fishing effort, although taxonomic distinctness – probably the best indicator of changes in biodiversity – decreased over time at two of the most heavily fished sites.

Caddy (1973) used a two-man submersible to collect visual, photographic and video observations of the effects of 0.8 m wide inshore Alberton toothed dredges in Chaleur Bay, Gulf of St. Lawrence. Depth varied from 40 to 50 m and the substrate was sand overlaid by glacial gravel, 1-10 cm in diameter, with occasional boulders up to 60 cm across embedded in the gravel. A gang of three dredges were attached to a common steel towing bar. The upper and lower edges of each dredge mouth were armed with blunt teeth 4 cm long. Tracks left by these dredges were shallow with a flat floor. Gravel was sparser inside than outside the track and dislodged boulders were commonly observed. Tooth marks were seen over sandy bottom. Spoil ridges were left between adjacent dredges and piles of small rocks were seen at intervals along the track.

Table 20. Summary of literature on effects of toothed scallop dredges on habitat with gravel substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Bradshaw et al. 2000, 2001** | Irish Sea | 25-40 m | gravel, sand, and mud | dredged plots had benthic communities more similar to commercially dredged plots 6-8 years after closure, more heterogeneous communities in undredged plots, encrusting species more abundant in dredged plots, upright species less abundant | increased abundance of several epifaunal species 5-9 years after closure | experimental dredging in portion of closed area |
| **Bradshaw et al. 2002** | Irish Sea | | sand and gravel | some taxa less abundant in recent samples, "robust" taxa more abundant; faunal differences and proportion of "lost" species between time periods increased significantly as number of years since fishing began increased, no effect of increases in total effort | | compared recent data from 7 sites exposed to varying amounts of fishing effort to data collected 50-60 years ago, when scallop fishing was very limited |

Table 20. (continued)

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Caddy 1973** | Chaleur Bay, Gulf of St. Lawrence, Canada | 40-50 m | gravel over sand, with cobble and boulders | tracks with berms in sand, boulders dislodged, rocks plowed by dredge | | submersible and photographic observations |
| **Kaiser et al. 1996(a)** | Irish Sea, west of Isle of Mann | | not given, assume gravel (see Bradshaw et al. 2000) | reduced abundance of most species | | observations |
| **Veale et al. 2000** | Irish Sea | 20-67 m | coarse sand or gravel, often overlain with pebbles, cobbles and dead shell. | decreases in species diversity and richness, and total number of individuals with increasing fishing effort | | compared bycatch from fishing grounds exposed to varying amounts of fishing |

Conclusions

Based on results of six studies of toothed scallop dredges on gravel sediments, dredging produced tracks in sediments, and disrupted and overturned gravel and boulders. Dredging also reduced the abundance of some infauna and epifauna, although some species were less abundant in a closed area, while others were more abundant. Many epifauna taxa recovered 5-9 years after the area was closed, but not before. Longterm changes in benthic communitites exposed to varying degrees of fishing effort could not be related solely to increased fishing activity; some sessile epifauna were more abundant in low effort fishing grounds, while others were more abundant in high effort grounds.

### 3. Live Bottom

Effects and Recovery

Hall-Spencer and Moore (2000) examined the effects of scallop dredging in the Clyde Sea, Scotland, on living calcareous rhodophytes by conducting single tows at depths of 10-15 m in an area that had been commercially dredged for 40 years and at a previously undredged area. A gang of three Newhaven dredges with spring-loaded teeth 10 cm long mounted 8 cm apart on a horizontal metal bar that was held off the seabed by a rubber roller at each end was used for experimental dredging. Immediate effects of dredging were noted and one transect at each site was monitored by divers 2-4 times a year over the following 4 years. Video recordings showed that the rollers and chain rings were in contact with the bottom while the dredge teeth projected fully into the maerl substratum (10 cm) and disrupted the seabed, creating a cloud of suspended sediment. Cobble, rocks and boulders <1 $m^3$ in size were overturned and dragged through the sediment. Dredges created 2.5-m wide tracks and erased natural bottom features (e.g., crab pits and burrow mounds). Sand and silt was brought to the sediment surface and living maerl was buried. Dredge tracks remained visible for 0.5-2.5 years depending on depth and exposure to wave action. Most megafauna on or within the top 10 cm of maerl were either caught in the dredges or left damaged on the dredge track. Large, fragile organisms (e.g., sea urchins and starfish) were usually broken on impact, whereas strong-shelled organisms (e.g., scallops, gastropods) usually passed into the dredge intact. Deep-burrowing species escaped dredge damage. Predatory species (e.g., whelks, crabs, and brittlestars) rapidly aggregated in the dredge track to feed. Species with regular recruitment and rapid growth recovered quickly, as did mobile epibenthic species which migrated into test plots soon after dredging. Slow-growing species and/or infrequently recruiting sessile organisms remained depleted on test plots at the undredged site 4 years after dredging occurred. The macrobenthic community at the previously dredged site returned to pre-experimental status within 2 years.

Table 21. Summary of literature on effects of toothed scallop dredges on livebottom habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Hall-Spencer & Moore 2000** | Clyde Sea, Scotland | 10-15 m | live bottom (maerl) | plowing of seafloor to 10 cm, overturned boulders, suspended sediment, smoothing of bottom features and burial of living maerl; megafauna in top 10 cm caught or damaged, aggregation of predatory species | tracks visible for 0.5-2.5 years, after 2 years macrobenthos at previously dredged site recovered, after 4 years some species at previously undredged still depleted | experimental dredging; recovery monitored for 4 yrs |

Conclusions

A single study of the effects of dredging on maerl beds showed that a single tow plowed the seafloor, destroyed and buried living maerl, overturned boulders, erased bottom features, and suspended sediment. Dredge tracks were visible for 0.5-2.5 years depending on depth and exposure to wave action. Biological effects included removal or mortality to infauna and large epifauna, and attraction of invertebrate predators and scavengers. The benthic community recovered completely at a previously dredged site within 2 years, but some species at a previously undredged site still had not recovered after 4 years.

### e. Suction Dredges

#### 1. Mud

Effects and Recovery

Hall and Harding (1997) evaluated the effects of suction and tractor dredging on intertidal infaunal communities in Auchencairn Bay, on the north side of the Solway Firth, on the west coast of Scotland. Sediments there are 60-90% silt/clay in the interior of the bay and 25-60% silt/clay in the center and outer parts of the bay. Cockles (*Cerastoderma edule*) are harvested in the bay, but suction dredging was prohibited 4.5 months before experimental dredging began and no significant tractor dredging activity was reported. Core samples were collected in control plots prior to suction dredging, and in experimental plots immediately after and 1, 4, and 8 weeks after dredging. Dredge tracks could not be seen after the first day. Immediately after dredging, there was a decrease in total abundance (up to 30%), number of species (up to 50%), and in the abundance of 3 of the 5 dominant species. Abundance increased over time with recovery of most effects by 8 weeks.

Table 22. Summary of literature on effects of suction dredges on habitat with mud substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Hall & Harding 1997** | Scotland | inter-tidal | mud | number of infaunal species and individuals decreased | most species recovered within 4-8 weeks | experimental suction dredging |

Conclusions
Results of one study showed that suction dredges in intertidal mud habitat resulted in tracks in the sediment that disappeared within 1 day, and decreases in the number of species and individuals of infauna, which recover within 4-8 weeks.

### 2. Sand

Effects and Recovery
Hall et al. (1990) studied the physical and biological effects of suction dredging for razor clams (*Ensis* spp.) in a shallow (7 m) sea loch on the west coast of Scotland. The depth at the study site was 7 m and the sediment was fine sand. The study site was unexploited but located near a recently-dredged area. Each experimental plot was dredged intensively for approximately 5 hours in order to simulate commercial fishing activity. Replicate experimental and control plots were sampled by divers immediately after dredging and 40 days later. After dredging, the experimental plots were crisscrossed by shallow trenches (0.5 m wide and 0.25 m deep) interspersed with larger holes (up to 3.5 m wide and 0.6 m deep) that were presumably produced when the dredge remained stationary for a brief period. Sediments in the holes and trenches were almost fluidized. After 40 days, however, none of these features remained. The number of infaunal species and total abundance were reduced immediately after dredging (significantly, for individuals), but there were no detectable differences 40 days later. There were no significant differences in the abundance of individual species on either sampling occasion. The authors concluded that dredging caused a short-term, non-selective reduction in the numbers of all infaunal species and that recovery from physical effects was accelerated by a series of winter storms and considerable sediment disturbance in the study area.

Effects of suction dredge harvesting of cultivated manila clams (*Tapes philippinarum*) on a muddy sand intertidal flat in southeast England were investigated by Kaiser et al. (1996c). Samples of benthic infauna and sediment were collected prior to, 3 hours after, and 7 months after harvest in one cultivated plot and in one control location. Immediately after harvest, large amounts of fine sand were resuspended by the dredge, exposing the underlying clay, and the total number of infaunal species and individuals (e.g., crustaceans and bivalves) were significantly reduced. The sediments and benthic community recovered completely within 7 months.

Table 23. Summary of literature on effects of suction dredges on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Hall et al. (1990)** | Scotland | 7 m | fine sand | shallow trenches and large holes; significant reductions in numbers and species of infaunal organisms | complete recovery of physical features and benthic community after 40 days | experimental dredging |
| **Kaiser et al. (1996)** | SE England | inter-tidal | fine sand | resuspension and loss of fine sand from sediment surface, significant reductions in total number of infaunal species and individuals | complete recovery within 7 months | experimental suction dredging |

Conclusions
Two studies on use of suction dredges in sand habitat concluded that dredging forms trenches and large holes in sediment, fluidizes sediments, resuspends fine sediment, and reduces the number of infauna species and individuals. Physical and biological habitat features recovered within 40 days in a subtidal environment and 7 months in an intertidal environment.

### f. Other Non-Hydraulic Dredges

#### 1. Submerged Aquatic Vegetation

Effects and Recovery
Fonseca et al. (1984) examined the effects of small, hand-pulled scallop dredges on eelgrass near Beaufort, North Carolina. Two connected 65-cm wide, light-weight dredges were used, each weighing 13 kg and with no teeth on the dredge foot. Two study sites were selected, an exposed site with compacted sandy sediments with 19.8% silt and clay in the upper 3 cm and 5.2% organic matter, and a protected site where sediments were less compact and had a higher silt-clay content (22.3%) and lower organic content (2.6%) to a depth of 20 cm. Plots at each site were dredged 15 times, 30 times, or not at all. At both sites, the number of eelgrass shoots and biomass decreased significantly with increasing dredging. Both shoot number and leaf biomass were reduced to zero at the soft-bottom site after 30 dredge pulls. The proportional reduction in shoot number was greater at the soft-bottom site, but the hard-bottom site lost more biomass than the soft-bottom site because the initial biomass there was higher. The authors concluded that intensive scallop dredging for bay scallops, with this gear or with the heavier dredges pulled by power boats, has the potential for immediate as well as long-term reduction of eelgrass habitat.

Table 24. Summary of literature on effects of other non-hydraulic dredges on seagrass habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Fonseca et al. 1984** | Beaufort, North Carolina | very shallow, subtidal | sand with eelgrass | significant reduction in number of eelgrass shoots and biomass with increasing dredging | | experimental dredging (hand pulled) at two sites |

Conclusions
Based on the results of 1 study, repeated use of light-weight bay scallop dredges reduced eelgrass biomass in shallow, sandy habitat.

#### 2. Oyster Reefs and Mussel Beds

Effects and Recovery
Langan (1998) examined the effects of dredge harvesting on an oyster population and its associated benthic community in the Piscataqua River, which divides the states of New Hampshire and Maine. An oyster bed approximately 18 acres in size is located in the river channel and is divided nearly equally by the border between the two states. Maine allows commercial harvesting of oysters, but New Hampshire had not for many years prior to the study. The dredge used on the Maine side of the river is 30 inches wide, weighs approximately 60 lbs, and has blunt, 2-inch teeth and chain mesh bag. No significant differences between the two areas were found in the number, species richness, or diversity of epifaunal or infaunal invertebrates. Oligochaetes were equally abundant on both sides of the line, polychaete density was slightly

higher in NH, and total crustaceans and total molluscs were more numerous in ME. The size distribution of the oysters on the unexploited side of the river was skewed towards older, larger individuals. The concentration of suspended sediment 10 m behind the dredge was slightly more than double the ambient level (10 mg/l) and dropped off to the ambient level 110 m behind the dredge.

Dredging oyster reefs in the Neuse River, North Carolina reduced the mean height of the reefs by 29 ± 6 cm (Lenihan and Peterson 1998). Unharvested reefs lost only 0-2 cm of height over the one week duration of the experiment. The loss of oysters in the estuary during the last 50 years or so was attributed to the reduction of reef height by dredging and the effects of bottom water hypoxia.

Riemann and Hoffmann (1991) assessed the water column effects of mussel dredging in a shallow, eutrophic sound (Limfjord) in Denmark. Suspended particulate matter, oxygen, and nutrient (phosphorus and nitrogen) levels were measured at a number of stations throughout the water column at a dredged and a control site before dredging, immediately after dredging, and 30 and 60 minutes later. Maximum water depth was 9 m. The substrate was not described, but presumably was a mussel bed. Average suspended particulate matter increased significantly immediately following a single, circular, 15-minute dredging event using a 2 m-wide mussel dredge. Oxygen decreased steadily, but only slightly, at the dredged site and increased similarly at the control site during the sampling period. A large apparent increase in ammonia was obscured by large horizontal variations, particularly near the bottom. Changes in other nutrients were small. Increases in particulate matter and nutrients (particularly phosphorus) were also observed on a day with high wind velocity (15 m/sec) compared to a day with low wind velocity (3 m/sec).

Table 25. Summary of literature on effects of other non-hydraulic dredges on oyster reefs and mussel beds. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Langan 1998** | Piscataqua River, New Hampshire and Maine | | oyster bed | no differences in number of benthic invertebrates, species richness or diversity | | compared dredged and undredged sides of river |
| **Riemann & Hoffmann 1991** | Denmark | 7.5 m - 11 m | mussel bed | significant increase in suspended particulate matter | turbidity returned to normal within 1 hour | experimental dredging at 2 locations |
| **Lenihan & Peterson 1998** | Neuse River, North Carolina | 3 m, 6 m | oyster reefs | dredging lowered mean height of 1-m reefs by about 30% | | loss of oysters in last 50 years attributed to dredging and hypoxia |

Conclusions

Oyster dredging reduced the height of oyster reefs. Mussel dredging increased turbidity, slightly reduced dissolved oxygen concentrations in the water column, and caused apparent large increases in ammonia.

## 3. <u>Multiple Mobile Gears</u>

In many geographic regions, the same areas within fishing grounds are fished by a number of different mobile gears including otter trawls, beam trawls, mechanical dredges and/or hydraulic dredges (ICES 1993, DeAlteris et al. 1999, Kaiser 2000). Within these areas, it is difficult to differentiate effects on habitat and biota from any single specific gear type, but an opportunity exists to examine cumulative effects of multiple gear types.

### a. Sand

<u>Effects and Recovery</u>
A remotely operated vehicle (ROV) was used to compare conditions in and outside the Swans Island Conservation Area (depths 30-40 m) in the northern Gulf of Maine, which had been closed to mobile fishing gear for 10 years (Auster et al. 1996). Video transects indicated that on sand/shell bottom, habitat complexity was provided mostly by sea cucumbers attached to shell and other biogenic debris and by depressions created by mobile fauna. Both of these habitat features were significantly less common outside the closed area; this was attributed to harvesting or bycatch of the structure-providing species.

Side-scan sonar images of Stellwagen Bank in the Gulf of Maine taken in 1993 showed that storm-created coarse sand ripples (30-60 cm between crests and 10-20 cm high) with shell-filled troughs were disturbed by scallop dredging (Auster et al. 1996). ROV observations on the bank's crest (32-43 m depths) indicated otter trawls and scallop dredges remove aggregations of emergent hydroids and disturb benthic microalgal cover. Several shrimp species, which were abundant in the hydroid aggregations, were not observed in a swath from which hydroids had been removed by fishing gear. Observations in July 1994 showed that an ascidian species (which slightly increased bottom complexity) was widely distributed (but not present in otter trawl paths) and hydroids were absent.

The southern half of Closed Area II on Georges Bank was sampled 4½ years after it had been closed to fishing (Almeida et al. 2000). Preliminary conclusions from sampling paired stations just inside and outside the closed area included: 1) species composition, species diversity and richness of trawl-caught organisms inside the closed area were similar to those immediately outside the area; 2) numbers and biomass of haddock and yellowtail flounder were greater inside; 3) most other groundfish species had similar abundances inside and outside; some were slightly more abundant outside; 4) size distributions of fish and megainvertebrates were similar inside and outside, except sea scallops were significantly larger inside; and 5) total organic carbon in sediments was generally higher inside, and was related to sediment grain size. From analysis of videotapes and still photographs, greater abundance of emergent sponges inside the closed area was the only significant difference in microhabitat resources attributable to gear effects. It was speculated that the lack of major differences inside and outside the closed area was probably due to the area's sandy habitat type.

Kaiser et al. (2000b) sampled sediment type (with grab samples), and infauna and epifauna (with 2-m beam trawl and anchor dredge) along the south Devon coast in England: 3 high fishing effort areas open to all fishing (otter trawl, beamtrawl, scallop dredge and pots), 2 medium fishing effort areas open to mobile gear for 6 months out of the year and pots year round, and 1 low fishing effort area only open to pots. Sediments followed a gradient from fine sand to medium sand and coarse-medium sand. Fine sand areas were located at 15-17 m depth. All others were located at 53-70 m depth. Within sediment types, there were significant differences in epifauna and infauna between areas with high, medium and low fishing effort. In fine sand areas, hydroids decreased and scavenging hermit crabs and starfish increased. In medium sand areas, large starfishes and tube-dwelling amphipods decreased, while scavenging crabs increased. In coarse-medium sand areas, several species of infauna decreased in biomass and abundance including hydroids, soft coral and small urchins, while crabs and seastars increased in abundance. Areas closed to draggers had higher total biomass, and higher abundances of emergent fauna (e.g., soft corals and hydroids) that increased habitat complexity. Areas open to draggers were dominated by smaller-bodied fauna and scavenging taxa. The authors concluded that removal of epibenthic fauna by fishing had decreased habitat complexity, possibly causing the biological community to shift to an alternative stable state.

In contrast, Hall et al. (1993) sampled benthic macroinfauna (with grabs) from demersal fishing grounds in the North Sea (Turbot Bank) using distance from shipwrecks as a proxy for fishing intensity. Sediments were characterized as coarse sand at 80 m depth. No significant differences were evident, instead species abundance was strongly related to sediment characteristics.

Table 26. Summary of literature on effects of multiple mobile gear on habitat with sand substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Almeida et al. 2000** | Georges Bank | | sand | size and abundance of fish and megainvertebrates similar inside and outside closed area, abundance of sponges higher inside | | comparison of samples inside and outside closed area. |
| **Auster et al. 1996** | Gulf of Maine (Swans Island) | 30-40 m | sand-shell | reduction in biogenic depressions and sea cucumbers | | ROV and video observations |
| **Auster et al. 1996** | Gulf of Maine (Stellwagen Bank) | 20-55 m | sand with gravel and shell | removal of epibenthic fauna and microalgal cover | | ROV and video observations inside and outside a closed area |
| **Hall et al. 1993** | North Sea | 80 m | coarse sand | no change in macro-infauna | | sampled infauna along distance from shipwreck (proxy for control) within demersal fishing grounds |
| **Kaiser et al. 2000b** | England (South Devon Coast) | 15-17 m | fine sand | decrease in biomass of infauna and emergent epifauna, increase in abundance of scavengers | | compared areas of high, medium and low fishing intensity |
| **Kaiser et al. 2000b** | England (South Devon Coast) | 53-70 m | medium sand | decrease in biomass of infauna and emergent epifauna, increase in abundance of scavengers | | compared areas of high, medium and low fishing intensity |
| **Kaiser et al. 2000b** | England (South Devon Coast) | 53-70 m | coarse-medium sand | decrease in biomass of infauna and emergent epifauna, increase in abundance of scavengers | | compared areas of high, medium and low fishing intensity |

Conclusions

Four studies on the effects of a combination of mobile gears on sand habitats are summarized in this report. ROV observations in areas inside and outside fishing grounds showed that fishing reduces biogenic depressions, reduction in microalgal cover, and removal of emergent epifauna. One study reports that fishing by a combination of otter trawls, beam trawls, and scallop dredges resulted in decreased biomass of infauna and epifauna, and increased abundance of scavengers. In contrast, one study using a shipwreck as a "pseudo control" and another that examined an area closed to fishing for 4 ½ years found no effects on macrofauna and no effects on species composition, diversity or richness of trawl caught organisms.

### b. Gravel

Effects and Recovery

In 1994 Collie et al. (2000b, 1997, 1996) sampled two shallow (42-49 m), gravel sites and three deep (80-90 m), gravel sites on Georges Bank that had varying histories of disturbance (as determined by side-scan sonar, bottom photographs and fishing records) by scallop dredging and otter trawling. Only one shallow and one deep site were classified as disturbed, but the other shallow site may have been previously fished (it had no boulders large enough to prevent fishing), and one of the two deep "undisturbed" sites had evidence of light dredging disturbance. Samples of megabenthic organisms taken with a 1 m wide Naturalists' dredge showed lower densities, biomass, species richness and species diversity at the disturbed sites than the undisturbed sites (Collie et al. 1997). Small polychaetes, shrimps and brittle stars were among the species that were less abundant or absent at the dredged sites. Analysis of videos and still photographs (Collie et al. 2000b) revealed the undisturbed sites had significantly higher percent cover of the colonial, rock-encrusting polychaete, *Filograna implexa*, and higher abundance of anemones, sponges, sculpins and plant-like animals. This emergent epifauna was considered to provide a complex habitat for mobile invertebrates and small fish at the undisturbed sites. Although other factors could have contributed to differences in emergent epifauna (e.g., sediments were coarser at undisturbed sites and epifauna was more abundant at deep sites), the authors concluded that fishing disturbance was the most likely explanation for the reduction in complexity and species diversity at the disturbed sites (Collie et al. 2000b).

An ROV was used to compare conditions in and outside the Swans Island Conservation Area (depths 30-40 m) in northern Gulf of Maine, which had been closed to mobile fishing gear for 10 years (Auster et al. 1996). Video transects indicated that on cobble/shell bottom, habitat complexity was provided mostly by emergent epifauna (e.g., hydroids, bryozoans, sponges, serpulid worms) and sea cucumbers. These species were less common outside the closed area; this was attributed to harvesting or bycatch of the structure-providing species.

Table 27. Summary of literature on effects of multiple mobile gear on habitat with gravel substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Collie et al. 1997** | Georges Bank | 42-49 m, 80-90 m | gravel pavement | decrease in megafauna abundance; aggregation of predators | | compared disturbed and undisturbed sites (6 sites); scallop dredge and otter trawl |
| **Collie et al. 2000b** | Georges Bank | 42-49 m, 80-90 m | gravel pavement | decrease in megafauna abundance, decrease in cover by emergent epifauna | | video and photo observations of disturbed and undisturbed sites (5 sites); scallop dredge and otter trawl |
| **Auster et al. 1996** | Gulf of Maine (Swans Island) | 30-40 m | cobble-shell | reduction in abundance and cover by emergent epifauna | | ROV and video observations inside and outside area closed to mobile gear for 10 years; dredge and trawl |

Conclusions

According to the studies summarized above, the use of multiple mobile gear on gravel habitat results in a reduction in epifauna abundance and cover, similar to effects of individual mobile gear on gravel habitats.

### c. Various Sediments

Effects and Recovery

Valentine and Lough (1991) used side scan sonar and a submersible to describe the effects of scallop dredges and trawls on sand and gravel bottom habitats on eastern Georges Bank. They noted that the most evident signs of disturbance occurred on gravel pavement, where long, low mounds of gravel had been formed by trawling and dredging. In some areas the sea bed was covered by trawl and dredge tracks. Gravel areas which were unfished (due to the presence of large boulders) had a biologically diverse community with abundant attached organisms. Conversely, the attached epifaunal community was sparse and the bottom was smoother in areas that had been disturbed by dredging and trawling.

Reise and Schubert (1987), Riesen and Reise (1982), and Reise (1982) compared invertebrate surveys in the Wadden Sea of northern Sylt taken between 1869 and 1986. Bottom sediments in these areas range from mud to coarse sand and some pebbles. The area is made up of tidal flats, shallow subtidal banks, and channels down to a depth of 23 m. Surveys were completed using oyster dredges and grabs. During the period of time encompassed by the various surveys, abundant oyster reefs were overexploited and seagrass beds were lost to a natural epidemic. Furthermore, fishermen have claimed to have deliberately eliminated *Sabellaria* reefs by towing heavy gear across them. The area is now dominated by soft sediments and mussel beds, which prior to 1920 were restricted to the shallows. Comparisons show that 28 species (8 associated with oyster beds, 8 with *Sabelleria*, and 7 with seagrasses) have declined in abundance. Twenty-three species (half are polychaetes) that were missing or rare in earlier surveys are now common. Epifauna were more abundant in the 1920s, and infauna were more abundant in the 1980s. In total 59% of all species have shown changes in abundance. These changes have balanced out, so that total abundance has remained relatively stable. Because of the multiple factors affecting this area, changes can not be attributed solely to fishing.

Side scan sonar and video observations were used to document the cumulative effects of various mobile fishing gears used in Bras D'Or Lakes and St. Peters Canal, Nova Scotia (Canadian Department of Fisheries and Oceans 1993). Water depths were greater than 10 m, and bottom sediments included rich organic mud, clay, pebbly mud, well-sorted sand, gravel and boulders. Scallop dredges left 3-4 m wide scars with teeth marks. These scars were seen mostly in gravel but also in silt.

Thrush et al. (1998) tested hypotheses regarding trends for benthic fauna in the Hauraki Gulf, New Zealand by sampling 18 locations exposed to varying fishing effort. Samples were taken by video, sediment cores, and grab or section dredge from areas fished predominantly by otter trawls with 480 kg doors and groundrope with 140-150 mm rubber bobbins and steel balls, but also by Danish seine and 2-m wide box dredge. Sediments were described as 1- 48% mud and depths ranged from 17-35 m. Side scan sonar revealed high incidence of trawl door tracks and scallop dredge marks in some areas, which concurred with estimates of fishing effort. After accounting for differences of location and sediment, 15-20% of the variability in macrofauna community composition was attributed to fishing. Analysis of video transect data showed that the density of large epifauna decreased significantly with increasing fishing effort. Analysis of core data showed that the density of echinoderms, the polychaete to mollusk ratio, total diversity, and species richness all decreased significantly with increasing fishing pressure, while the ratio of small to large *Echinocardium* (heart urchin) increased significantly with increasing fishing pressure. Analysis of grab/suction dredge data showed that density of deposit feeders and number and species richness of epifauna decreased with increasing fishing pressure, although these relationships were not significant. The authors conclude that their results indicate broad-scale changes in benthic communities directly related to fishing, and because they were taken over a large sampling area, suggest ramifications for the entire ecosystem.

Table 28. Summary of literature on effects of multiple mobile gear on habitat with mixed substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Canadian Department of Fish and Ocean 1993** | Nova Scotia (Bras D'or Lakes) | >10 m | variety (e.g., organic mud, clay, pebbly mud) | tracks with berms in sediment | | side scan sonar observations over various habitats |
| **Reise and Schubert, 1987; Riesen and Reise 1982; Reise 1982** | Wadden Sea | <23 m | sediments range from mud to coarse sand and some pebbles | oysters overexploited by dredges, *Sabelleria* reefs destroyed by heavy trawl gear, decrease in abundance of 28 species (molluscs and amphipods), 23 new species (mostly polychaetes) | no recovery, area now dominated by mussels | compared various surveys conducted between 1869 and 1986 ; seagrasses lost to natural epidemic during same period |
| **Thrush et al. 1998** | New Zealand | 17-35 m | variety of substrates with 1-48% mud | changes to macrofauna composition (# species, # individuals, diversity, and density of large epifauna increased with decreased fishing effort) | | sampled areas over gradient of fishing effort |
| Valentine and Lough 1991 | Georges Bank | | sand and gravel | tracks in sediments, removal of epifauna | | side scan sonar and submersible observations |

Conclusions
Because of the differences in gear types and habitat types in the studies summarized above, a synthesis of results is not appropriate.

## 4. Pots and Traps

### a. Various Sediments

Effects and Recovery
Eno et al. (2001) observed effects of pots (creels and 3 types of crustacean pots) set in water depths from approximately 14-23 m over a wide range of sediment types in Great Britain: mud communities with sea pens, limestone slabs covered by sediment, large boulders interspersed with coarse sediment, and rock. Observations demonstrated that sea pens were able to recover fully from pot impact (left in place for 24-48 hours) within 72-144 hours of the pots being removed. Pots remained static on the seafloor, except in cases where insufficient line and large swells caused pots to bounce off the bottom. When pots were hauled back along the bottom, a track was left in the sediments, but abundances of organisms within that track were not affected. The authors did record incidences of detachment of ascidians and sponges and damage to ross coral, but it was not clear if these resulted from this study or from previous damage. Authors conclude that no short-term effects result from the use of pots, even for sensitive species. The study did not examine chronic impacts.

Table 29. Summary of literature on effects of pots on habitat with various substrate. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| **Eno et al. 2001** | Great Britain | <23 m | mud | bending and uprooting of sea pens | sea pens re-root in 24-72 hours | experimental fishing (1 site) |
| **Eno et al. 2001** | Great Britain | <23 m | limestone slabs covered by sediment, coarse sediment with boulders | bending of sea fans | immediate after removal of pots | experimental fishing (1site) with 3 types of commercial pots |
| **Eno et al. 2001** | Great Britain | <23 m | rocky substrate | abundance of sponges increased | | experimental fishing (5 sites) with commercial crustacean pots |

Conclusions
A study on 3 different habitat types concluded that the use of pots and traps had no lasting effects on sea pens, sea fans, or sponges.

### b. Coral

Effects and Recovery
Garrison (1997, 1998) observed commercial fish traps in the U.S. Virgin Islands, and found that 82-86% were set directly upon live substrate (e.g., stony corals, gorgonians, sponges, seagrasses or algae/sponge). In south Florida, Taylor and McMichael (1983) observed that preferred substrates for wire fish pots are coral reefs, live bottom (coral-sponge), limestone ledges, and outcroppings. Also in south Florida, Sutherland et al. (1983) completed a submersible survey of

derelict trap/pots following the closure of the trap fishery in the state. Traps were set either singly or in lines, and most were set within 20-45 m of a coral reef and rock ledge. Of 23 derelict/ghost traps, 15 were on sand or algal flats, 4 were on high profile reef, and 4 were in live bottom area.

A total of 2,000 out of 5,000 fish (arrowhead) pots observed by Quandt (1999) were set on coral reefs in St. Thomas, U.S. Virgin Islands. These pots resulted in scrapes and breakage to 5% of all corals observed and tissue damage to 47% of all gorgonians observed (tissue damage to 20% of each gorgonian). Based on the number of pots fished per year and the average area of coral reef damaged per pot, Quandt estimated that a total of 104 $m^2$ of coral reef is damaged by wire pot fishing per year in the U.S. Virgin Islands. The author discussed indirect effects to reproductive and recruitment capabilities if damaged corals suffer infections.

Appeldoorn et al. (2000) observed wire fish pots (arrowhead pots) set by commercial fishermen in La Parguera, Puerto Rico, and recorded sediment type and damage caused by deployment, soaking, and rehauling of traps. Of the traps observed, 45% were set on sand or mud and 44% were set on hard bottom or reef. Of the habitat types observed under traps, 23% of coral colonies, 34% of gorgonian colonies, and 30% of sponges were damaged by deployment. All traps deployed on hard bottoms or reef caused at least some damage to corals and gorgonians. Additional damage from hauling the traps to the surface occurred for 30% of the traps observed. The author estimated that approximately 64.7 $m^2$ of coral, 47.0 $m^2$ of gorgonians, and 4.7 $m^2$ of sponges are damaged within La Pargueara per year (total damage of 116.4 $m^2$ with 95% confidence limits of 35 to 202 $m^2$). The long-term fate of these individuals was not determined. Furthermore, the author found that trap-induced habitat damage was concentrated in certain areas, and concluded that there would be a higher potential for repeated damage within those areas. This concentration of effort is expected to have greater impacts than if the trap activity were spread over the whole shelf. Damage by fishing pots could add important cumulative effects on areas that are already experiencing damage from environmental conditions.

Van der Knapp (1993) also recorded injury to staghorn coral, other corals, sponges, and gorgonians from commercial traps in Bonaire, Netherlands Antilles. However, the author examined recovery times and found that gorgonians recover within a month, and staghorn corals begin to regenerate after 35 days. Recovery times are longer, however, if algae begin to grow in the damaged areas. The longterm fate of damaged individuals is unknown.

Table 30. Summary of literature on effects of pots and traps on coral reef habitat. Bold references indicate peer-reviewed journals. Blank cells indicate information was not provided by the reference.

| Reference | Location | Depth | Sediment | Type of Effects | Recovery | Comments |
|---|---|---|---|---|---|---|
| Quandt 1999 | U.S. Virgin Islands | | coral reefs | corals, gorgonians, sponges damaged | | observations of commercial fish pots |
| Appeldoorn et al. 2000 | Puerto Rico | | | corals, gorgonians, sponges damaged | | observations of commercial pots |
| Van der Knapp 1993 | Netherlands (Bonaire) | | coral reefs | corals, gorgonians, sponges damaged; algal growth in scars | staghorn corals begin regeneration after 35 days, gorgonians recover within a month | experimental pot fishing |

Conclusions
Three papers, 2 observational and 1 experimental, report that the use of pots and traps damages corals, gorgonians, and sponges. One of these studies reports recovery of gorgonians within a month and the initiation of regeneration to staghorn coral within 35 days. The study does not indicate the time needed for complete regeneration.

### 5. Set Gill Nets – Summary of Available Science

The majority of research concerning impacts of gillnets focuses on effects on populations resulting from ghost fishing by lost gear; few studies have examined adverse effects of gillnets on habitat. A few studies have noted that, upon retrieval, gillnets can become entangled in hard bottom areas, and snag and break coral (Breen 1990, Ohman 1993, Jennings and Polunin 1996, Kaiser et al. 1996c, Erzini et al. 1997, ICES 2000). Lost gillnets, in particular, often get caught on and damage or cover hard bottoms and reefs. However, these nets are quickly covered by encrusting epifauna, and eventually blend into the background habitat (Carr et al. 1985, Cooper et al. 1988, Erzini et al. 1997, ICES 2000). Erzini et al. (1997) observed that lost gillnets became incorporated into the reef and provided a complex habitat which was attractive to many organisms. Carr and Milliken (1998) noted that in the Gulf of Maine, cod reacted to lost gillnets as if they were part of the seafloor. Thus, other than damage to coral reefs, effects on habitat by gillnets are thought to be minimal (ICES 1991, 1995, Stephan et al. 2000).

### 6. Set Longline -Summary of Available Science

Very little information exists on the effects of longlining on benthic habitat. The principal components of the longline that can produce seabed effects are the anchors or weights, hooks and the mainline (ICES 2000). During submersible dives off southeast Alaska, NMFS scientists observed the following regarding halibut longline gear (NPFMC 1992): "Setline gear often lies slack on the seafloor and meanders considerably along the bottom. During the retrieval process, the line sweeps the bottom for considerable distances before lifting off the bottom. It snags on whatever objects are in its path, including rocks and corals. Smaller rocks are upended, hard corals are broken, and soft corals appear unaffected by the passing line. Invertebrates and other light weight objects are dislodged and pass over or under the line. Fish, notably halibut, frequently moved the groundline numerous feet along the bottom and up into the water column during escape runs disturbing objects in their path. This line motion was noted for distances of 50 feet or more on either side of the hooked fish."

## D. Recommendations from the Literature

### 1. Bottom Trawls

The majority of specific recommendations offered in the literature relate to gear design and deployment. Bergman and Van Santbrink (2000) recommend that the following management measures be considered for the southern North Sea, an area that is subject to considerable beam trawling: a significant reduction of trawling effort, development of gears less damaging for habitats and fauna, and designation of areas closed to fisheries for species and habitats that cannot be protected otherwise. Van Marlen (2000) recommends that more effort be put into developing electrified beam trawls that use electrical stimulation rather than mechanical disturbance to catch fish. While this method requires large investments up front, and could possibly require higher repair costs, the huge decrease in resistance of the gear should lower fuel costs considerably. A 1999 ICES working group report (ICES 1999) recommends that further research and development be completed for wheels used on beam trawls, ways to reduce friction or compression forces, and ways to reduce the number of weights on groundropes. Furthermore, they recommend a reduction of the sweep contact, possibly through use of semi-pelagic riggings and alternatives to mechanical stimulation.

Other recommendations focus on reducing gear interactions with certain habitat types. Lindeboom and de Groot (1998) recommend that the areas impacted by bottom trawls and the number of bottom trawlers be restricted from expanding and that the interactions with groups working on conservation of ecosystems be strengthened. For specific mitigation measures, they recommend: spatial closures, reduction of effort, gear substitution (e.g., static for mobile gear), and gear modifications (although this would only moderately reduce impacts). Many authors recommend the protection of specific, vulnerable habitats such as seamounts (Koslow and Gowlett-Holmes 1998, Probert et al. 1997), seagrasses (Godcharles 1971), and gravel beds with associated epifauna (Auster et al. 1996).

## 2. Dredges

Hydraulic dredges are towed more slowly and cover less ground per haul than most trawls (Stewart 1999), but have more area in contact with the bottom, and unlike trawls, are designed to penetrate the substrate to remove infaunal invertebrates (Rogers et al. 1998). Scallop dredges are towed at approximately 2 times the speed of most trawls, but they are designed to skim along the surface of the seafloor. Many authors have voiced concern over the use of hydraulic dredges in seagrass habitats because of the extensive damage and slow recovery of grasses within the dredge tracks (Manning and Dunnington 1955, Godcharles 1971, Jolley 1972, Chesapeake Bay Program 1995, Orth et al. 1998). No recommendations regarding use of dredges in other habitat types were offered in the literature.

## 3. Pots and Traps

Pots and traps are considered to be less damaging than mobile gear, because they are stationary in nature, and thus, come into direct contact with a much smaller area of the seafloor (Stewart 1999, Eno et al. 2001). Traps affect habitat when they settle to the bottom and when they are hauled back to the surface. While soaking, traps and pots with buoy lines of insufficient length may bounce or drag along the seafloor during rough seas. This movement will increase the amount and areal extent of damage. In many locations, traps are strung together by trotlines or longlines. These trotlines may cause further damage during deployment and retrieval by catching and shearing organisms if they are dragged along the bottom. Grappling hooks used to retrieve pots and traps can also cause damage by scraping the benthos.

Van der Knapp (1993) emphasizes the need for regulations that restrict trap fishing to sand areas or coral areas that regenerate completely (e.g., staghorn coral). Quandt (1999) recognized that regulations were needed to help control habitat impacts from trap fishing, but offered no specific recommendations for those regulations.

# IV. STATE OF INFORMATION

## A. Limits of Information and Need for Research

Ideally, in order to understand the ecosystem effects of fishing on habitat, research is needed that uses comparable, replicate fished and non-fished areas at the scale of fishing grounds for specific fisheries, and at a time-scale greater than the life span of the longest-lived species (Hall 1994). Unfortunately, the time and resources needed to complete this research can be prohibitive. Thus, most of the research to date has been limited in scope. Most studies concentrate on a single gear type and do not address cumulative effects of all gears used within a given fishing ground. Often research projects are simplified by examining effects on a specific habitat type. These small scale studies may not be applicable over larger areas (i.e., scale of fishing ground) that consist of a mosaic of habitat types. They also do not consider cumulative effects over long periods of time. Furthermore, estimates of recovery are often limited to measurements of recovery from a single (or limited) disturbance event rather than from ongoing impacts that commonly occur from fishing. Typically, the habitats against which recovery is measured have already been significantly altered by long-term effects of fishing, leaving an inaccurate picture of recovery times. Finally, where information is available on physical or biological effects, the role these habitat impacts have on harvested populations, in most cases, is unknown. Even when there is good time series information on fish abundance, there is a lack of empirical information on linkages between habitat and survival, which would allow modeling and experimentation to predict outcomes of various levels of disturbance (Auster and Langton 1999).

In addition to problems with research approach, questions have been reaised about details of data sampling and experimental design. Moran and Stephenson (2000) conclude that net sampling is not an accurate method of measuring effects on habitat because it does not indicate the number or types of organisms that are damaged or detached, but not caught, by the net. Rogers et al. (1999) question the level of sampling needed (e.g., community indices, species abundances) to best examine quantifiable effects of exploitation. For example, Sanchez-Jerez and Espla (1996) found that community changes due to trawling in *Posidonia* (neptunegrass) meadows were not evident at the phylum and class levels of benthic fauna, but that family and species levels of amphipods and isopods showed significant differences, and thus were the best indicators of trawling impacts for this geographic area. According to McConnaughey et al. (2000), lumping taxa for analytical purposes can mask species effects that are a result of functional processes rather than taxonomy. Jennings and Cotter (1999) state that vulnerable species are better indicators of fishing effects than community based measures that can be explained by factors other than fishing. These types of issues need to be evaluated when designing and interpreting studies on effects of fishing gear to habitat.

In order to better assess the effects of fishing gear we also need a better understanding of the distribution of fishing effort by gear type. Analyses of fishing effort have been completed in other countries (Rijnsdorp et al. 1998, Greenstreet et al. 1999, Jennings et al. 1999), but for most

United States fisheries we currently have no systematic way of tracking effort at the scale of habitat type within a given geographic area. Churchill (1989) attempted to summarize trawling effort in the Middle Atlantic Bight off the northeast U.S. using fishing effort data in 30' latitude x 30' longitude blocks. While areas impacted could be estimated over blocks, a lack of data on the extent of the area actually disturbed within each block, especially for static gears, made analysis of the impacts to habitat difficult. In an attempt to address this problem, other methods of estimating fishing effort have been explored. Authors have used incidence of damage to starfish (Kaiser 1996), scars in molluscan growth lines (Witbaard and Klein 1993) and side scan sonar of mobile gear tracks (Krost et al. 1990, Friedlander et al. 1999). These methods, however, also have limitations. Seastars and molluscs are affected differently by different gear types, and are not available over all geographic areas. And, detection of fishing effects by side scan sonar surveys depends on the timing of the survey relative to the timing of the fishing impact and the recovery time of the sediments.

Research also needs to evaluate natural impacts (e.g., storms) that occur over large geographic scales. In some areas these natural impacts may render local effects of fishing insignificant (Stevenson and Confer 1978, Daan 1991). Furthermore, the strength and occurrence of natural or non-fishing anthropogenic influences are strong determinants of recovery time (Flint and Younk 1983, Hall 1994, DeAlteris et al. 1999). In theory, communities in variable (or high energy) environments are capable of recovering more quickly than communities in more stable (or low energy) environments and, thus, are more resistant to disturbance (Flint and Younk 1983, Collie et al. 2000a).

Given the MSA mandate to minimize adverse effects of fishing on habitat in order to support sustainable fisheries, research is needed to address the limitations of existing information discussed above.

## B. MANAGEMENT PHILOSOPHIES

Given the current state of existing information, and the limitations on our ability to gather needed information, different philosophies have developed as to how we should manage fishing impacts to habitat. Many believe that we should look beyond scientific literature to anecdotal information and other "non-scientific" evidence. For example, Pederson and Hall-Arber (1999) discuss the extensive information on habitat condition and long-term habitat changes that can be gained from fishermen and incorporated into management decisions.

Under the precautionary approach to management, measures to minimize effects of fishing to habitat should be implemented based on the concept that the risk of allowing possibly irreversible damage to continue outweighs the short-term economic hardships that might be incurred. Many authors support a precautionary or risk averse approach to habitat conservation and protection (McAllister and Spiller 1994, Auster and Malatesta 1995, Dayton et al. 1995, Auster et al. 1997, Koslow and Gowlett-Holmes 1998, Carr and Milliken 1998, Collie 1998, Fogarty and Murawski 1998, Goñi 1998, Mirarchi 1998, Thrush et al. 1998, Auster and Langton 1999, Hall-Spencer et al. 1999, Langton and Auster 1999, Norse and Watling 1999, Turner et al. 1999, Auster and Shackell 2000, Frid and Clark 2000, ICES 2000, McConnaughey et al. 2000, Auster 2001, NRC 2002).

It has been argued that, although definitive evidence may not be available, studies have shown "beyond doubt" that some negative impacts from mobile fishing gear are occurring, and thus, that management decisions need to be made without waiting for more scientific evidence (Kenchington 1995, Lindeboom and de Groot 1998, Watling and Norse 1998, Gray 2000, NRC 2002). Kenchington (1995) argues that the burden of proof required in scientific research is not appropriate in fisheries management and that we need to take into account the risk that mobile fishing gear is significantly reducing fish production by modifying benthic habitats. Dayton et al. (1995) state that, while policy makers clearly understand the financial implications of reducing fishing effort when no adverse effects are occurring, there is no clear understanding of the financial implications of ecosystem effects and loss of resources by continuing to fish when impacts have occurred but not been detected.

A number of authors have recommended the use of closed areas for research and conservation (Bergman et al. 1990, Bergman and Hup 1992, Engel and Kvitek 1998, Rumohr 1998, Hall-Spencer et al. 1999, Auster and Shackell 2000, Ball et al. 2000). Hutchings (1990) recommends periodic closures of areas, strip trawling to leave regularly spaced islands of untrawled areas to supply recruits for replenishment, and modification of gear to minimize impacts. Carr and Milliken (1998) recommend that nations modify gear to target specific species, encourage the use of lighter sweeps rather than heavier gears, reduce the amount of sea bottom available to mobile gear, and opt for stationary gear over mobile gear. McAllister and Spiller (1994) recommend the establishment of nearshore continental shelf and slope protected areas, regular monitoring of impacts of different gear types, and a switch to gear types with low habitat impacts and low bycatch. Ball et al. (2000) recommend large areas closed to fishing to allow large scale experiments, with particular attention to deeper waters at the shelf edge and slope where natural disturbance is less common, sediments are highly bioturbated, and faunal assemblages are less capable of sustaining disturbance. Auster et al. (1997) recommend a more extensive use of closed areas, starting with a specific fishing gear within a geographical region and if existing knowledge suggests that negative effects on seafloor habitats are occurring from that gear (even if the available information is uncertain or inadequate), then management authorities define the habitats likely to be affected by that gear and designate marine protected areas for those habitats. Based on a fishermen survey by Fuller and Cameron (1998), fishermen generally approved of closing spawning areas during spawning and concurred that fisheries management should occur on an ecosystem level including habitat protection. A number of authors also support the use of adaptive management, in which fisheries research provides feedback to management decisions (Sainsbury et al. 1993, Thrush et al. 1998, Turner et al. 1999). For example, managers could implement closed areas and then adjust the size or location of those closed areas as scientific research bears new information, and we have a better understanding of effects of fishing to ecosystems.

Kaiser et al. (1999) argue that the magnitude of fishing effects varies greatly relative to the background of natural disturbances and that we need to consider subtle differences in habitat structure and assemblage composition before we can understand the consequences of fishing. Kaiser (1998) reviewed scientific studies on the effects of fishing in the North Sea and concluded that oceanic influences have greater ecological effects than localized effects of either eutrophication or fishing disturbance. Langton et al. (1996) suggest protection of "essential" habitats using a decision tree based on scientific information. Messieh et al. (1991) argue that we need to study effects on habitat that have the potential of causing widespread and long-term changes (e.g., gradual modification to surficial sediments and increased suspended sediment loads).

Despite this diversity of management philosophies, the MSA mandates that Councils minimize to the extent practicable adverse effects of fishing on EFH. Under National Standard 2 of MSA, Councils and the Secretary of Commerce must base conservation and management measures on the "best scientific information available." Under the Administrative Procedures Act, the decision to approve a measure must be supported by a record that suggests the measure will contribute to the conservation and management of the fishery resource based on analyses and conclusions that are neither arbitrary nor capricious.

## V. CONCLUSIONS

This document reviews available information on effects of bottom trawls, dredges, pots/traps, set gill nets and set longline to mud, sand, gravel, seagrass, coral reef and, in some cases, seamount habitats. Despite gaps in existing information (e.g., spatial extent of fishing effort, effects of specific gear configurations within specific habitat types, role of natural disturbance, link between habitat and fish population abundance) the numerous scientific studies summarized herein document physical and community effects of both mobile and static fishing gear to a range of habitat types. This document also reviews the various management philosophies regarding fishing impacts presented in the literature. These philosophies range from doing nothing until more information is available to establishing precautionary systems of closed areas to protect habitats and fish populations from uncertain consequences of human impacts.

For the most part, the information needed for Councils to assess effects of fishing on EFH is currently available. This document provides the basis for Councils to conduct fishery-specific evaluations of potential adverse effects of fishing on benthic habitats, which along with other appropriate information should guide decisions regarding management measures to conserve and protect fish habitat.

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