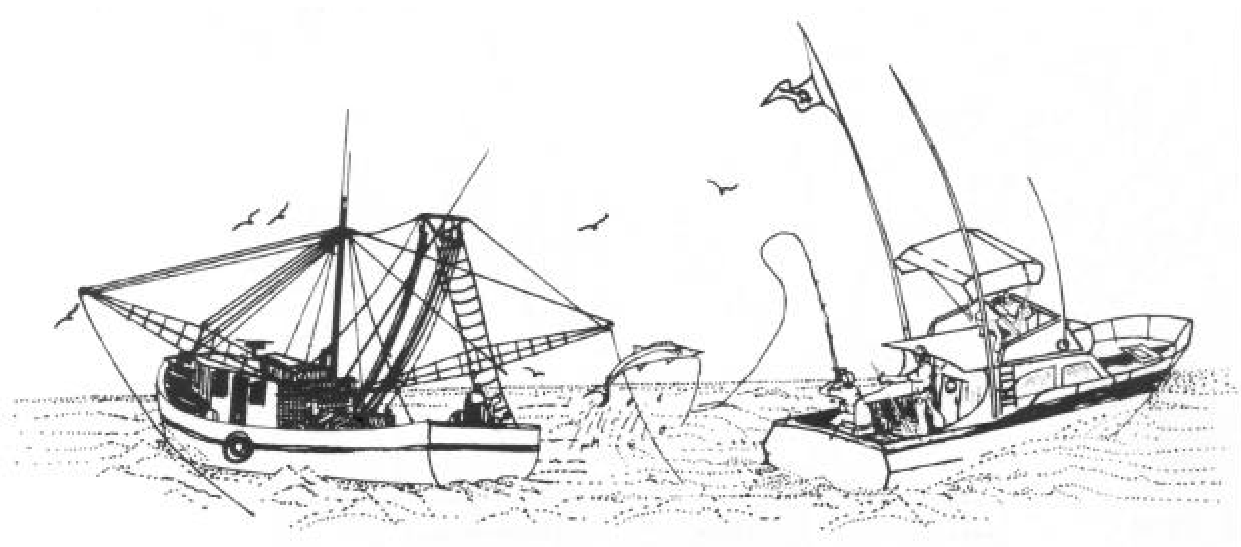
ANNOTATED BIBLIOGRAPHY OF FISHING IMPACTS ON HABITAT - SEPTEMBER 2003 UPDATE



Gulf States Marine Fisheries Commission

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Annotated Bibliography of Fishing Impacts on Habitat - September 2003 Update

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Introduction

This is the third in a series of updates to the Gulf States Marine Fisheries Commission's *Annotated Bibliography of Fishing Impacts on Habitat* originally produced in February 2000. The Commission's Habitat Subcommittee felt that the gathering of pertinent literature should continue. The third update contains 52 new articles since the publication of the last update. The update uses the same criteria that the original bibliography and first and second updates used to compile articles. It attempts to compile a listing of papers and reports that address the many effects and impacts that fishing can have on habitat and the marine environment. The bibliography is not limited to scientific literature only. It includes technical reports, state and federal agency reports, college theses, conference and meeting proceedings, popular articles, and other forms of nonscientific literature. This was done in an attempt to gather as much information on fishing impacts as possible. Researchers will be able to decide for themselves whether they feel the included information is valuable.

Fishing, both recreational and commercial, can have many varying impacts on habitat and the marine environment. Whether a fisher prop scars seagrass, drops an anchor on a coral reef, or drags a trawl across the bottom, each act can alter habitat and affect fish populations. While fishing can have many varying impacts on habitat, this bibliography tries to narrow its focus to the physical impacts of fishing on habitat. It does not try to include the ecosystem effects of fishing. Removal of predators, prey, and competitors can have very serious and extensive effects on the ecosystem, but it is not addressed here. Also, the bibliography tries not to include bycatch issues and the act of discarding bycatch back into the marine environment. While the bibliography includes research on physical fishing impacts on animals, if the animal was caught or retained and then later discarded, the bibliography does not deal with this issue. Some included papers may not directly apply to the above guidelines. However, it is thought that inferences can be made on how this action could affect other habitat, animals, or environments, i.e., lost gear that affects a marine mammal could also affect fish in the same way.

The bibliography is global in scope. The bibliography's global nature was an attempt to include similar fisheries and gear types throughout the world. While it might not be possible to compare gear types and fishing methods from one area to another directly, some conclusions can be drawn and inferences made on the associated habitat impacts. Although global in scope, only reports and articles in English were included.

Most of the articles in this update were published since the last update, but older articles were included if they were not already in the bibliography. The annotated bibliography is now available on the Commission's web site at http://www.gsmfc.org/fishingimpacts.html. It is also available as a ProCite® searchable database. Users of this document should feel free to contact the editor with comments, suggestions, and updated information.

Bell, S.S., M.O. Hall, S. Soffian, and K. Madley. 2002. Assessing the impact of boat propeller scars on fish and shrimp utilizing seagrass beds. Ecological Applications. Vol. 12(1):206-217.

Abstract: We investigated the relationship between damage from boat propeller scarring in seagrass (*Thalassia testudinum*) beds and the abundance of three faunal taxa commonly associated with seagrass vegetation in Charlotte Harbor and Tampa Bay, Florida. We chose sites with no damage (reference sites) to compare to those with propeller scarring within each of the two geographic locations. Thirty 141-m^2 sites in both Charlotte Harbor and Tampa Bay, representing a gradient of scarring from 6% to 31% of the total area, were sampled in spring and winter 1996 along with reference sites to evaluate effects of propeller damage on abundance of the pinfish, *Lagodon rhomboides*, and the pipefish, *Syngnathus scovelli*. Additionally, 60 sites in both Charlotte Harbor and Tampa Bay representing areas with up to 50% scarring and comparison reference sites were sampled in spring 1997 to investigate whether propeller scar damage impacted epibenthic shrimp abundance and community structure in seagrass. Our results indicated no significant difference in pinfish density in scarred vs. reference areas; fish abundances were remarkably similar between sites regardless of the differing amount of vegetation removal. Patterns of pinfish abundance between damaged and reference sites were consistent over seasons (spring vs. winter) and between geographic locations (Charlotte Harbor vs. Tampa Bay). Pipefish abundance was significantly higher in scarred vs. reference seagrass beds in Charlotte Harbor in spring. Moreover, total shrimp densities were not significantly different between propeller-damaged and reference sites at either geographic location. *Hippolyte zostericola* was the most abundant of the eight most dominant shrimp species in both scarred and reference sites at both locations but comprised a higher relative proportion of the shrimp community in scarred sites in Tampa Bay. While our study targeted some of the highest reported levels of scarring within Tampa Bay and Charlotte Harbor, negative impacts on fish and shrimp abundance were not detected. Higher levels of scarring that lead to degeneration of seagrass bed stability may need to be present before nekton are affected.

Boese, B.L. 2002. Effects of recreational clam harvesting on eelgrass (*Zostera marina*) and associated infaunal invertebrates: in situ manipulative experiments. Aquatic Botany. Vol. 73(1):63-74.

Abstract: The effect of recreational clam harvesting on eelgrass (*Zostera marina* L.) was experimentally tested by raking or digging for clams in experimental 1 m^2 plots located in a Yaquina Bay (Newport, OR) eelgrass meadow. After three monthly treatments, eelgrass measures of biomass, primary production (leaf elongation), and percent cover were compared between experimental and control (undisturbed) plots. Benthic macro (retained on 0.5 mm mesh sieve) and mega (retained on 3 mm sieve) infaunal samples were also taken to compare species number and abundances. Results indicated that clam raking did not appreciably impact any measured parameter. In contrast, clam digging reduced eelgrass cover, above-ground biomass and below-ground biomass in measurements made 1 month after the last of three monthly treatments. Although differences between control and treatment plots

persisted 10 months after the last clam digging treatment, these differences were not statistically significant. Approximately 10% of the eelgrass of Yaquina Bay is subjected to recreational clamming and as this activity is generally less intense than that employed in this study, it is unlikely that recreational clamming has a major impact on eelgrass beds in the Yaquina estuary. This conclusion should be viewed with caution as multi-year disturbances were not investigated and there are differences in sediment characteristics and clam abundances between experimental sites and those sites that are intensively harvested by the public.

Bordehore, C., A.A. Ramos-Esplá, and R. Riosmena-Rodríguez. 2003. Comparative study of two maerl beds with different otter trawling history, southeast Iberian Peninsula. Aquatic Conservation - Marine and Freshwater Ecosystems. Vol. 13(Supplement S):S43-S54.

Abstract: 1) A comparative study of the characteristics of sediment structure and associated assemblages was conducted in two areas with different trawling histories, one with low trawling pressure and protected since 1989 (Marine Reserve of Tabarca), and another with a high frequency of trawling (Benidorm). 2) The study was based on seasonal quantitative and qualitative sampling of macrofauna, megafauna and algae, over a period of 1 year, using scuba diving and dredging. 3) Sediment composition differed between sites. Overall, Tabarca had a coarser sediment than Benidorm where there was a higher mud content and no vertical stratification. At Tabarca there was a differential vertical profile, with a higher percentage of coarse sediment in the surficial horizon, which corresponded mostly to rhodoliths. Benidorm had more mineral gravel, and Tabarca a higher percentage of biogenic gravel. 4) There were no differences between sites in the percentages of live and dead rhodoliths in the sediment. Cover of rhodoliths, however, was four times greater at Tabarca. Maximum size of rhodoliths was greater at Tabarca (mean 16.18 mm S.D. 5.73) than at Benidorm (mean 7.64 mm S.D. 2.16). 5) The number of species of algae did not differ significantly between sites: 155 species were found at Tabarca, and 153 at Benidorm, with 13 and 10 exclusive species respectively. Although both algal assemblages were qualitatively similar, there were significant differences in the cover of the main species. At Tabarca, the cover of Corallinales was around 50% of total algal cover, while at Benidorm approximately 90% of the cover was due to non-Corallinales algae, mainly species from the genus Peysonnelia. 6) The number of macrofaunal species at Tabarca was greater than at Benidorm, with 293 (144 exclusive spp.) and 204 (53 exclusive spp.) species, respectively. Density and biomass of macrofauna was also greater at Tabarca. 7) Based on our observations, well preserved Mediterranean maerl grounds are sites with a high diversity and also support a high macrobenthic secondary production which may be important for species of commercial interest. High trawling pressure on maerl areas may affect assemblages negatively by breaking up rhodoliths, diminishing their cover and hence affecting the associated biota.

Bradshaw, C., L.O. Veale, and A.R. Brand. 2002. The role of scallop dredge disturbance in long-term changes in Irish Sea benthic communities: a re-analysis of an historical dataset. Journal of Sea Research. Vol. 47(2):161-184.

Abstract: Benthic community data collected between 1938 and 1950 by N.S. Jones were compared with modern samples from seven sites in the Irish Sea. Multivariate and univariate methods were used to compare community change over time and examine the possible impact of scallop dredging over the 60 year time period. A conservative approach to data analysis ensured that observed differences in faunal composition between time periods were not due to differences in sampling methodologies or taxonomic identification. The community composition changed at all sites, though to different degrees. The amount of change was related to how long a site had been fished, rather than fishing intensity. Mobile, robust and scavenging taxa have increased in abundance, while slow-moving or sessile, fragile taxa have decreased. Differences between historical and modern samples were greater than could be accounted for by the natural variability of the system (as indicated by spatial and temporal replication at three sites) and indicate real long-term change. This study emphasizes that, in the absence of good-quality data series and experiments, the use of fuzzy historical data is often the only possible way to judge long-term change and can yield valuable results.

Cahoon, L.B., M.H. Posey, W.H. Daniels, and T.D. Alpin. 2001. Shrimp and crab trawling impacts on estuarine soft-bottom organisms. Unpublished Report. UNC Wilmington. Wilmington, North Carolina. 8 p.

Abstract: This project addressed questions about the possible impacts of trawling for crabs and shrimp in North Carolina estuaries on populations of organisms associated with soft-bottom habitats. The organisms of interest included benthic microalgae, demersal zooplankton, and macrobenthic animals, encompassing the lower trophic levels in the benthic food chain and the essential trophic coupling that supports estuarine fishery production. The approaches used in this project included sampling before and after experimental trawling at several estuarine locations, sampling in areas actively trawled and closed to trawling, and sampling during several seasons over two years to address seasonal and interannual effects. Sampling began in February 1999 and ended in November 2000 at six locations in the Pamlico River Estuary. Commercial fisherman Henry Daniels provided the use of his trawler for experimental work. Experimental trawling had no significant effect on the biomass of benthic microalgae, no consistent effect on the abundance of demersal zooplankton, and only a slight but non-significant effect on the abundances of benthic macrofaunal animals. Benthic microalgae were significantly more abundant in untrawled locations than in trawled locations, with strong seasonal variation as well. Abundances of demersal zooplankton were not significantly or consistently different between untrawled and trawled locations. There were higher abundances of benthic macrofauna in trawled locations than at untrawled locations, but only at certain times of the year. There also were few differences in the benthic macrofauna dominating at trawled and untrawled locations.

Seasonality was very important and interannual variation was observed, but less important than seasonal differences. We conclude that there is little evidence of direct, negative impacts of trawling activity on these soft-bottom organisms. Seasonality differences were more impressive than all other differences. Although trawling per se does not seem to have a consistent effect on estuarine soft-bottom benthos, there are interesting differences between trawled and untrawled habitats that merit further investigation.

Chiappone, M., A. White, D.W. Swanson, and S.L. Miller. 2002. Occurrence and biological impacts of fishing gear and other marine debris in the Florida Keys. Marine Pollution Bulletin. Vol. 44(7):597-604.

Summary: This study examined forty-five sites in the Florida Keys to determine the spatial extent and frequency of remnant fishing gear, determine the factors affecting the spatial variability of marine debris occurrence, and determine the biological impacts of marine debris on reef biota such as hard corals and sponges. Four debris items accounted for 90% of all debris. They were monofilament line (38%), wood from lobster traps (20%), fishing weights, leaders and hooks (16%), and rope from lobster traps (13%). The researchers found that 49% of all debris occurrences caused some type of damage to reef biota. Debris types causing the greatest damage were hook and line gear (68%), especially monofilament line (58%), followed by debris from lobster traps (26%), especially rope (21%). The researchers determined that biological impact from debris may be considerable, and the impacts are among a suite of factors that affect the structure and condition of reefs in the Florida Keys.

Chicaro, L., A. Chicharo, M. Gaspar, F. Alves, and J. Regala. 2002. Ecological characterization of dredged and non-dredged bivalve fishing areas off south Portugal. Journal of the Marine Biological Association of the United Kingdom. Vol. 82(1):41-50.

Abstract: Macro and meiobenthic communities of two fishing areas (Vilamoura and Lagos) in the western part of south Portugal (Algarve coast) were analyzed. Both locations had been under severe dredge-fishing impact until four years previously. Vilamoura has since continued to be dredged, while fishing activity in Lagos was stopped in 1995 as a response to overfishing. For each location, three replicate areas were analyzed at depths of 7-9 m. In each of these areas, 18 quadrats for macrofauna and 12 cores for meiofauna were randomly sampled by SCUBA divers during September 1999. The Shannon-Weiner diversity index was higher for meiofauna in the fished area, whereas macrofauna diversity was higher in the recently non-fished area. Bray-Curtis dissimilarity between the two areas was 87.82%. Major differences were found between Ampeliscidea, *Amphiura mediterranea*, *Spisula solida*, Haustoriidae, Nemertinea and *Diogenes pugilator* populations at the two sites. There was higher abundance but lower biomass of potential macrofaunal scavengers in the fished area, and carnivore biomass was also higher in this area. Deposit-feeders dominated meiofauna abundance in both study areas. The community structure of the continuously fished area was dominated by small, opportunistic, short-lived species while the community

structure of the recently non-fished area was dominated by more fragile and long-living sessile organisms.

Chicharo, L., M. Chicharo, M. Gaspar, J. Regala, and F. Alves. 2002. Reburial time and indirect mortality of *Spisula solida* clams caused by dredging. Fisheries Research. Vol. 59(1-2):247-257.

Abstract: Clam-dredging results in the exposure of *Spisula solida* individuals not caught by the dredge. Subsequent survival depends on clam damage, reburial time, and the time needed by predators to reach the impacted area. We analyse these variables and discuss the importance of predation on exposed *S. solida* caused by dredge fishing. Sampling was performed in July 2000 off the southern coast of Portugal, at Vilamoura, a traditional *S. solida* sandy fishing ground. We compared the time needed for *S. solida* individuals to rebury themselves, relative to the abundance of potential predators. Bivalves collected by divers were placed on the seabed, and the times required for reburial were measured. These were compared with the times needed for reburial of the clams exposed by dredge impact. At each of three dredge tracks, we analysed the number of predators that entered three equal quadrats (0.0250 m^2) per minute. These results were compared with a non-affected control area. Impact caused by the fishing dredge significantly increases the number of exposed *S. solida* clams ($p<0.05$) and the abundance of potential predatory species ($p<0.05$). The brittle star *Ophiura texturata* was the most abundant and first species to reach the dredge track (less than 3 min after dredge impact). Other species reaching the dredge track were *Pomatochistus* spp. (6 min after impact), *Diogenes pugilator*, and *Nassarius reticulatus* (both 9 min after impact). Although predators reached the impacted area while *S. solida* bivalves were still exposed, our results suggest that predation on the non-buried clams in the dredge track is not a major factor for subsequent indirect mortality of *S. solida*.

Chicharo, L., J. Regala, M. Gaspar, F. Alves, and A. Chicaro. 2002. Macrofauna spatial differences within clam dredge-tracks and their implications for short-term fishing effects studies. Fisheries Research. Vol. 54(3):349-353.

Abstract: *In situ* observations of clam dredging showed that the effects of the dredge on the benthic macrofauna may not be constant during a tow. A sand buffer forms in front of the gear approximately 10m after the beginning of a tow, and this pushes the sediment partially aside. In this study, we analyze differences in abundance, the number of taxa present, diversity, and evenness within sections of dredge-tracks in a disturbed, fished area and a non-fished area along the southern coast of Portugal. These areas were sampled by divers before and after dredge-fishing activity. At each site, three dredge-tracks were produced. These tracks were divided in three longitudinal sections (start, middle and end) and two transverse sections (track and edge). Six quadrants were used to sample macrofauna in each section of every track and edge. Our results show differences exist in macrofaunal distribution and abundance across sections of a dredge-track. These differences should be

considered in any assessment of the short-term ecological impact of dredges on benthic macrofauna.

Cryer, M., B. Hartill, and S. O'Sheab. 2002. Modification of marine benthos by trawling: toward a generalization for the deep ocean? Ecological Applications. Vol. 12(6):1824-1839.

Abstract: Anthropogenic disturbance of deep-sea benthic systems, especially by fishing, has increased markedly in the last 40 years. Deep-sea mining and extraction of fossil fuels can occur at extraordinary intensity at individual sites, but the large number of fishing vessels and their mobility probably makes commercial trawling the most pervasive of our marine activities to depths of up to about 1200 m. Knowledge of the effects of trawling on soft-sediment, benthic communities is, however, limited to shallow, coastal systems, mostly at small spatial scales. We extend that knowledge to deeper systems at the scale of commercial fishing by assessing the effects of bottom trawling in northeastern New Zealand. We characterized the invertebrate catch of 66 research trawls spread along 220 km of continental slope in depths of 200–600 m (encompassing about 2400 km^2). At each site, we indexed the intensity of previous trawling using trawl-by-trawl fishing returns. A suite of multivariate analyses revealed that fishing activity was negatively associated (after excluding the effects of depth and location) with invertebrate species richness and diversity and with the density of several taxa. Our models explained up to two thirds of the variation in the invertebrate catch of research trawls. After excluding the effects of depth and location, we attributed 11–40% of total variation to fishing. Concordance among the results of several multivariate methods based on different analytical approaches and assumptions reveals a strong and coherent pattern in the data that is consistent with the predicted and observed effects of trawl fisheries and other sources of physical disturbance. We infer that trawling probably changes benthic community structure and reduces biodiversity over broad spatial scales on the continental slope as well as in coastal systems. Such effects would have important implications for local and regional biodiversity and for the development and management of sustainable fisheries.

Dayton, P.K., S. Thrush, and F.C. Coleman. 2002. Ecological effects of fishing in marine ecosystems of the United States. Pew Oceans Commission, Arlington, Virginia. 45 p.

Abstract: Are the oceans in crisis because of fishing? Perhaps they are not. Data from the last decade of United Nations' reports suggests that global fishing yields have kept pace with increasing fishing effort. However, this simple correlation tells little of the story. Indeed, the reality of declining yields has been obscured by chronic misreporting of catches, by technological advances in gear that increase the capacity to locate and capture fish, and by shifts among industrial fishing fleets toward lowertrophic-level species as the top-level predators disappear from marine ecosystems. Do these global realities transfer to the United States? Yes. They may not transfer at the same scale, but with the addition of recreational impacts of fishing, the elements are consistent. In the 2001 report to Congress on the status of U.S. stocks, the National Marine Fisheries Service (NMFS) found that approximately one-third of the stocks for which the status was known were either overfished or experiencing

overfishing. Though increasing application of conservative single-species management techniques has begun to improve conservation in recent years, it remains that current levels of fishing result in significant ecological and economic consequences. The combined effects of overfishing, bycatch, habitat degradation, and fishing-induced food web changes alter the composition of ecological communities and the structure, function, productivity, and resilience of marine ecosystems. A discussion of these ecological consequences serves as the basis for this report. Understanding the ecological consequences of exploitation is a necessary component of ecosystem-based management, an approach called for by the NMFS Ecosystem Principles Advisory Panel in a report to Congress in 1999. It requires (1) knowledge of the total fishing mortality on targeted and incidentally caught species, including mortality resulting from regulatory discards and bycatch; (2) investigations of the links between species (e.g., predators and prey, competitors) and the habitat within which they reside; and (3) recognition of the trade-offs to biodiversity and population structure within ecosystems that result from high levels of extraction. Current fisheries practice effectively ignores these essential requirements. Based on our review of the ecological effects of fishing, we recommend that ecosystem-based management incorporate broad monitoring programs that directly involve fishers; ecosystem models that describe the trophic interactions and evaluate the ecosystem effects of fishing; and fieldscale adaptive management experiments that evaluate the benefits and pitfalls of particular policy measures. In adopting this approach, it is incumbent upon the citizens of the United States to recognize their position as the resource owners, and to properly hold the U.S. government responsible for management that ensures that benefits are sustained through time. It is also imperative that the regulatory milieu be restructured to include marine zoning designed to reduce management error and cost, and provide sites for evaluating the effects of fishing. The regulatory milieu should also provide substantive support for law enforcement by developing enforceable regulations, require the use of vessel monitoring systems, and require permitting and licensing for all fisheries. If we are serious about saving our fisheries and protecting the sea's biodiversity, then we need to make swift, and perhaps painful, decisions without the luxury of perfect knowledge, while still grappling for a more thorough understanding of the ecological mechanisms driving population dynamics, structuring communities, and affecting biodiversity. We must also hold the managers responsible when there is inaction. Otherwise, sustained fisheries production is unlikely.

Dolmer, P. 2002. Mussel dredging: Impact on epifauna in Limfjorden, Denmark. Journal of Shellfish Research. Vol. 21(2):529-537.

Abstract: Species composition and population density of epibenthos are described in two areas in Limfjorden, Denmark. Both areas covered both a mussel fishing ground and an area that has been permanently closed for mussel dredging since 1988. Furthermore, mussels were dredged in a part of the mussel fishing grounds in both areas four months before the investigations. The rest of the fishing grounds had not been exploited for at least four years. This study describes the short-term impact (4 mo) and long-term impact (> 4 y) of mussel dredging using the permanently closed areas as controls. The data were analyzed by multivariate statistics. In both short-term study areas significant effects of dredging were observed. A number of taxa (sponges, echinoderms, anthozoans, molluscs, crustaceans, and ascidians) had a reduced density or were not observed in fished areas four months after the fishing was ended. In one of the two long-term areas, significant differences in species composition and density were observed between fished and closed areas, indicating that the fishery may have a long-term impact on the epibenthic community, whereas in the other long-term area no difference was observed between fished and control areas. Significant reductions in the amount of shell debris and gravel were observed in the dredged areas. The impact of the loss these benthic structural components on ecosystem processes and functions is discussed.

Donohue, M.J., R.C. Boland, C.M. Sramek, and G.A. Antonelis. 2001. Derelict fishing gear in the northwestern Hawaiian Islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. Marine Pollution Bulletin. Vol. 42(12):1301-1312.

Abstract: Marine debris threatens Northwestern Hawaiian Islands' (NWHI) coral reef ecosystems. Debris, a contaminant, entangles and kills endangered Hawaiian monk seals (Monachus schauinslandi), coral, and other wildlife. We describe a novel multi-agency effort using divers to systematically survey and remove derelict fishing gear from two NWHI in 1999. 14 t of derelict fishing gear were removed and debris distribution, density, type and fouling level documented at Lisianski Island and Pearl and Hermes Atoll. Reef debris density ranged from 3.4 to 62.2 items/km^2. Trawl netting was the most frequent debris type encountered (88%) and represented the greatest debris component recovered by weight (35%), followed by monofilament gillnet (34%), and maritime line (23%). Most debris recovered, 72%, had light or no fouling, suggesting debris may have short oceanic circulation histories. Our study demonstrates that derelict fishing gear poses a persistent threat to the coral reef ecosystems of the Hawaiian Archipelago.

Drabsch, S.L., J.E. Tanner, and S.D. Connell. 2001. Limited infaunal response to experimental trawling in previously untrawled areas. ICES Journal of Marine Science. Vol. 58(6):1261-1271.

Abstract: There is considerable argument about the effects of bottom trawling on the benthos. Many studies have been done on recently trawled grounds, where community composition has already been modified, and further effects are likely to be minimal. This study tests the effect of trawling on macroinfaunal assemblages in an area where little or no trawling had occurred in the previous 15 years. A spatially replicated Before-After, Control-Impact (BACI) design was used, with adjacent trawl and control corridors. Sampling was done in the same two small sites within each corridor before and after trawling to minimize confounding due to spatial variation. Despite this rigorous design, changes consistent with an effect of trawling were not detected. At only one of the three locations was a potential effect detected. These inconsistent results could be due to different disturbance regimes at each location, influencing the vulnerability of fauna to further

disturbance. Given the high levels of variability in infaunal assemblages, however, the changes could also be due to asynchronous natural variation. The combination of high spatial and temporal variability, in association with light trawling gear, means that prawn trawling in South Australia does not have consistent effects on infauna.

Duplisea, D.E., S. Jennings, S.J. Malcolm, R. Parker, and D.B. Sivyer. 2001. Modelling potential impacts of bottom trawl fisheries on soft sediment biogeochemistry in the North Sea. Geochemical Transactions. Vol. 2:112-117.

Abstract: Bottom trawling causes physical disturbance to sediments particularly in shelf areas. The disturbance due to trawling is most significant in deeper areas with softer sediments where levels of natural disturbance due to wave and tidal action are low. In heavily fished areas, trawls may impact the same area of seabed more than four gamma per year. A single pass of a beam trawl, the heaviest gear routinely used in shelf sea fisheries, can kill 5-65% of the resident fauna and mix the top few cm of sediment. We expect that sediment community function, carbon mineralisation and biogeochemical fluxes will be strongly affected by trawling activity because the physical effects of trawling are equivalent to those of an extreme bioturbator, and yet, unlike bioturbating macrofauna, trawling does not directly contribute to community metabolism. We used an existing box-model of a generalized soft sediment system to examine the effects of trawling disturbance on carbon mineralisation and chemical concentrations. We contrasted the effects of a natural scenario, where bioturbation is a function of macrobenthos biomass, with an anthropogenic impact scenario where physical disturbance results from trawling rather than the action of bioturbating macrofauna. Simulation results suggest that the effects of low levels of trawling disturbance will be similar to those of natural bioturbators but that high levels of trawling disturbance prevent the modelled system from reaching equilibrium due to large carbon fluxes between oxic and anoxic carbon compartments. The presence of macrobenthos in the natural disturbance scenario allowed sediment chemical storage and fluxes to reach equilibrium. This is because the macrobenthos are important carbon consumers in the system whose presence reduces the magnitude of available carbon fluxes. In soft sediment systems, where the level physical disturbance due to waves and tides is low, model results suggest that intensive trawling disturbance could cause large fluctuations in benthic chemical fluxes and storage.

Duplisea, D.E., S. Jennings, K.J. Warr, and T.A. Dinmore. 2002. A size-based model of the impacts of bottom trawling on benthic community structure. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 59(11):1785-1795.

Abstract: Bottom trawling causes widespread disturbance to the sediments in shallow-shelf seas. The resultant mortality of benthic fauna is strongly size dependent. It is empirically demonstrated that beam trawling frequency in the central North Sea had a greater effect on fauna size distribution in a soft sediment benthic community than variables such as sediment particle size and water depth. Accordingly, the impacts of trawling disturbance on benthos are simulated using a model consisting of 37 organism size classes between 1 μg and 140 g wet weight. The model produced a production-biomass versus size relationship consistent with published studies and allowed us to predict the impacts of trawling frequency on benthos size distributions. Outputs were consistent with empirical data; however, at high yet realistic trawling frequencies, the model predicted an extirpation of most macrofauna. Empirical data show that macrofauna persist in many heavily trawled regions; therefore, it is suggested that trawling by real fisheries is sufficiently heterogenous to provide spatial refuges less impacted by trawling. If correct, this analyses suggests that fishery management measures that do not reduce total effort but do lead to effort displacement and spatial homogenization (e.g., temporarily closed areas) may have adverse effects on the systemic persistence of intermediate- and large-sized macrofauna.

Enticknap, B. 2002. Understanding the effects of bottom trawl fisheries on Alaska's living seafloor. Unpublished Report. Alaska Marine Conservation Council. 22 p.

Summary: This report examines the effects of bottom trawling in the North Pacific by reviewing the literature of fishing effects in the Alaska region and worldwide. The report also characterizes the commercial bottom trawling fleet in the North Pacific. The characterization includes reviewing historical fishing effort, fleet composition and gear types, and the habitats where fishing occurs.

Environmental Justice Foundation. 2003. Squandering the seas: How shrimp trawling is threatening ecological integrity and food security around the world. Environmental Justice Foundation, London, UK. 45 p.

Executive Summary: Shrimp trawlers, particularly those in the tropics, can catch over 400 marine species in their nets. These non-target species or 'bycatch' are often discarded by shrimp fishermen - either they are inedible or are simply not worth retaining when shrimp is worth up to 30 times more per kilogram. Shrimp fisheries typically produce bycatch-to-shrimp ratios of 5:1 in temperate areas and 10:1 in the tropics. However, higher ratios have been found, such as 21:1 in the case of the Australian Northern Prawn Fishery. This essentially means 21 kg of marine organisms are caught in order to obtain 1 kg of shrimp. Currently, tens of millions of tonnes of bycatch are taken by shrimp trawl fisheries worldwide each year. Most shrimp trawlers discard this non-target catch. Shrimp fisheries alone are responsible for one third of the world's discarded catch, despite producing less than 2% of global seafood. Shrimp often ends up on the tables of wealthy consumers in the developed world. It is a luxury item. For poor fishing communities, fish is a necessity. Globally, 450 million people rely on fisheries as a source of food and income. In Bangladesh, the fisheries sector provides 78% of animal protein intake for the average person. Equally high dependencies are found in other developing nations, yet it is countries such as these that face food security issues linked to overfishing. People in the developing world witness shrimp trawlers – sometimes foreign-owned – destroy their traditional fishing grounds and incidentally catch and squander local fish stocks. In some cases this fishing is

illegal, in other cases it is the result of fisheries agreements, such as those between the EU and African nations. Yet those who suffer the environmental costs of shrimp trawling are unlikely to see the financial rewards of these agreements. Shrimp trawling frequently takes place in shallow coastal waters, which act as nursery grounds for many commercial fish species. Trawling removes vast numbers of juvenile fish that are needed to sustain fish stocks. In addition, by dragging large, heavy nets along the seabed, habitats that support marine life are damaged. One study found that the pass of a single trawl could remove up to 25% of seabed life. In heavily-trawled areas, habitats have little chance to recover and in some cases may be permanently altered. Shrimp trawling is thought to disrupt entire marine communities, altering biomass, size structure and diversity. Populations of vulnerable species are rapidly reduced. These species tend to be slow-growing and long-lived with low reproductive output and/or those dependent on structurally diverse seabed habitats. Some of these, such as turtles, are already endangered as a result of other human activities. Shrimp trawling presents one of the greatest threats to their continued survival. Indeed, it is estimated that 150,000 sea turtles are killed annually by shrimp trawlers. A creature that has lived on Earth for millions of years could be wiped out by consumer demand for a high value seafood. Damage caused by shrimp trawling is so significant that leading scientists have compared it to clear-cutting forests. However, unlike deforestation, the impacts of shrimp fisheries are only just beginning to receive international attention. Reports written by leading intergovernmental organizations, including the United Nations Environment Programme, the Global Environment Facility and the Food and Agriculture Organization, state that many shrimp fisheries are presently unsustainable and advocate changes to current patterns of exploitation. Shrimp trawling is one of the most wasteful, destructive and inequitable ways to exploit the oceans. The Environmental Justice Foundation is campaigning to promote a precautionary approach to shrimp fisheries that prioritizes social and ecological sustainability. Within this report, EJF proposes a series of recommendations outlining how shrimp fisheries can be managed in a more just and responsible way.

Fossa, J.H., P.B. Mortensen, and D.M. Furevik. 2002. The deep-water coral *Lophelia pertusa* in Norwegian waters: distribution and fishery impacts. Hydrobiologia. Vol. 471(1-3):1-12.

Abstract: The paper presents documentation on the distribution of, and damages to, deep-water reefs of the coral *Lophelia pertusa* in Norwegian waters. The reef areas have traditionally been rich fishing grounds for long-line and gillnet fisheries, and the coral habitat is known to support a high diversity of benthic species. Anecdotal reports claim that trawlers often use the gear, wires, chains and trawl doors to crush the corals and clear the area before fishing starts. To get an overview of the situation, information about the distribution and damage were collected from the literature, fishermen, and our own investigations. The results show that the corals are abundant, particularly on the mid Norwegian continental shelf between 200 and 400 m depth. In general, it seems that the largest densities are distributed along the continental break and at ridges of morainic origin. The reports from fishermen suggested severe damage to the corals and *in situ* observations using ROV confirmed the presence of mechanically damaged corals located on trawling grounds. A first estimate of

the fishery impact indicates that between 30 and 50% of the reef areas are damaged or impacted. Fishermen claim that catches are significantly lowered in areas where the reefs are damaged. Potential ecological consequences of the destruction are discussed.

Gordon, D.C., Jr., K.D. Gilkinson, E.L.R. Kenchington, J. Prena, C. Bourbannais, K. MacIsaac, D.L. McKeown, and W.P. Vass. 2002. Summary of the Grand Banks otter trawling experiment (1993-1995): Effects on benthic habitat and communities. Canadian Technical Reports in Fisheries and Aquatic Science. No. 2416, 72 p.

Abstract: A three-year experiment was conducted to examine the effects of repetitive otter trawling on a sandy bottom ecosystem at a depth of 120-146 m on the Grand Banks of Newfoundland. The most pronounced impacts were the immediate effects on habitat physical structure. However, these effects were relatively short-lived since the available evidence shows that the habitat recovered in about a year or less. Except for snow crabs and basket stars, direct removal of epibenthic fauna by the otter trawl appeared to be insignificant because of its very low efficiency in catching benthic organisms. Immediately after trawling, the mean biomass of epibenthic organisms (as sampled with an epibenthic sled) was reduced on average by 24%. The most affected species were snow crabs, basket stars, sand dollars, brittle stars, sea urchins and soft corals. Both the immediate and long-term impacts of otter trawling, as applied in this experiment, on the resident benthic infauna (as sampled by a large videograb) appeared to be minor. Significant effects could not be detected on the majority of species found at the study site, including all the molluscs. All available evidence suggests that the biological community recovered from the annual trawling disturbance in less than a year, and no significant effects could be seen on benthic community after three years of otter trawling. The habitat and biological community at the experimental site are naturally dynamic and exhibited marked changes irrespective of trawling activity, and this natural variability appeared to over-shadow the effects of trawling.

Grant, J. 2000. Modelling approaches to dredging impacts and their role in scallop population dynamics. Pages 27-36 in Alaska Department of Fish and Game and University of Alaska Fairbanks, A workshop examining potential fishing effects on population dynamics and benthic community structure of scallops with emphasis on the weathervane scallop *Patinopecten caurinus* in Alaskan waters. Alaska Department of Fish and Game, Division of Commercial Fisheries, Special Publication 14, Juneau.

Summary: This paper seeks to quantify some of the impacts of scallop dredging on scallop populations. Dredging consequences are divided into two categories: habitat alteration and gear-induced damage and mortality. Regarding habitat alteration, the paper examines disruption of scallop sediment substrate for juvenile scallops and resuspension of sediments.

Guidetti, P., G. Fanelli, S. Fraschetti, A. Terlizzi, and F. Boero. 2002. Coastal fish indicate human-induced changes in the Mediterranean littoral. Marine Environmental Research. Vol. 53(1):77-94.

Abstract: Coastal fish assemblages were studied to assess two sorts of human impacts in south-western Apulia (SE Italy, Mediterranean Sea). Fish assemblages were evaluated by visual census along two rocky locations impacted by a sewage outfall discharging nearshore (S) and by date-mussel (*Lithophaga lithophaga*) fisheries (F), respectively, and at two control locations (Cs). Multivariate analyses showed that fish assemblage structures at S and F differed from those at Cs. Asymmetric ANOVAs indicated that species richness were significantly lower both at S (~27%) and at F (~35%) compared with Cs. Total fish abundance was 5- to 7-fold higher at S than at Cs, while the values recorded at F were comparable to those of Cs. At S, average abundances of planktivorous fish and POM feeders were higher, and those of labrids and sparids of the genus *Diplodus* were lower, respectively, than at Cs. Labrids of the genus *Symphodus* and small serranids were significantly less abundant at F than Cs. Data suggested that coastal fish respond to the impact caused by the sewage discharge and provided a framework to assess potential benefits of its future displacement to deeper waters. For the first time, moreover, this study provided suggestive evidence that the habitat destruction caused by the illegal date-mussel fisheries may affect fish assemblages.

Hall-Spencer, J., V. Allain, and J.H. Fossa. 2001. Trawling damage to Northeast Atlantic ancient coral reefs. Proceedings: Biological Sciences. Vol. 269(1490):507-511.

Abstract: This contribution documents widespread trawling damage to cold-water coral reefs at 840-1300 m depth along the West Ireland continental shelf break and at 200 m off West Norway. These reefs are spectacular but poorly known. By-catches from commercial trawls for deep-water fish off West Ireland included large pieces (up to 1 meter square) of coral that had been broken from reefs and a diverse array of coral-associated benthos. Five azooxanthellate scleractinarian corals were identified in these by-catches, *viz. Desmophyllum cristagalli, Enallopsammia rostrata, Lophelia pertusa, Madrepora oculata* and *Solenosmilia variabilis*. Dating of carbonate skeletons using 14C accelerator mass spectrometry showed that the trawled coral matrix was at least 4,550 years old. Surveys by remotely operated vehicles in Norway showed extensive fishing damage to *L. pertusa* reefs. The urgent need for deep-water coral conservation measures is discussed in a Northeast Atlantic context.

Hall-Spencer, J.M., J. Grall, P.G. Moore, and R.J.A. Atkinson. 2003. Bivalve fishing and maerl-bed conservation in France and the UK - retrospect and prospect. Aquatic Conservation - Marine and Freshwater Ecosystems. Vol. 13(Supplement S):S33-S41.

Abstract: 1) Maerl beds are carbonate sediments, built by a surface layer of slow-growing coralline algae, forming structurally fragile habitats. 2) They are of international conservation significance, often supporting a high biodiversity and abundant bivalve molluscs. 3) Experimental fishing for scallops (*Pecten maximus*) on French and UK grounds has shown that although large epifauna are often killed, many organisms escape harm as they burrow deeply or are small enough to pass through the dredges. 4) Bivalve dredging is currently one of the main threats to European maerl grounds as it reduces their biodiversity

and structural complexity and can lead to long-term degradation of the habitat. 5) Protecting maerl grounds is of importance for fisheries since they provide structurally complex feeding areas for juvenile fish (e.g. Atlantic cod - *Gadus morhua*) and reserves of commercial brood stock (e.g. *Ensis* spp., *P. maximus* and *Venus verrucosa*). 6) We outline improved mechanisms to conserve these ancient and unique biogenic habitats.

Jennings, S., M.D. Nicholson, T.A. Dinmore, and J.E. Lancaster. 2002. Effects of chronic trawling disturbance on the production of infaunal communities. Marine Ecology Progress Series. Vol. 243:251-260.

Abstract: Trawling causes widespread physical disturbance in shallow shelf seas. While the impacts of trawling on the biomass and community structure of benthic fauna are well known, no existing studies have quantified the effects of trawling disturbance on the absolute production of small benthic infauna. We investigated the effects of beam trawling disturbance on the production of small benthic infauna (AFDM > 0.78 to 62.5 mg) at 9 sites that were subject to a 17.5-fold range in annual trawling disturbance, using a size-based approach that could be applied to other soft-bottom systems. We developed a generalized additive model to test for relationships between trawling disturbance and infaunal production and size structure, after accounting for differences in sediment characteristics and depth. The statistical power of our analyses to detect linear and non-linear relationships between production and disturbance, including increased production at intermediate levels of disturbance, was high (>90% probability of detecting a 50% change in production across the range of disturbance). The analyses showed that trawling frequencies of 0.35 to 6.14 times per year did not have a significant effect on the production of small infauna or polychaetes. This result contrasts with order of magnitude decreases in the production of large infauna, and shows that small polychaetes with fast life histories are less vulnerable to trawling disturbance. Since small infaunal polychaetes are a key source of food for flatfishes, we conclude that beam trawling disturbance does not have a positive or negative effect on their food supply.

Jiang, W., and G. Carbines. 2002. Diet of blue cod *Parapercis colias* living on undisturbed biogenic reefs and on seabed modified by oyster dredging in Foveaux Strait, New Zealand. Aquatic Conservation: Marine and Freshwater Ecosystems. Vol. 12(3):257-272.

Abstract: 1) Little has been done to assess the potential impact of habitat modification by bottom fishing gear on the feeding habits of demersal fishes. An analysis is presented of the diet of blue cod in Foveaux Strait, southern New Zealand, based on the gut content of fish taken in winter 1999 from two sites where each site consisted of both undisturbed biogenic reefs and reefs modified by oyster dredging. 2) Of the 420 guts collected, 13% were empty. The overall mean wet weight of gut content was <4 g. No significant habitat or site effects were detected for the proportion of empty guts or the amount of food consumed. 3) A pattern was detected that blue cod on dredged habitats generally fed on more crustaceans than those on undistributed habitats. Blue cod from undisturbed habitat also displayed a more diverse

diet than those taken from dredged habitat. These results suggest that long-term disturbance of seabed habitat by the oyster fishery in Foveaux Strait has caused changes to the diet of blue cod. The findings also suggest that actions should be taken to protect the biogenic reefs from further damage if the blue cod fishery and related resources are to be effectively managed. 4) Changes in prey diversity with increasing fish size were also found, with prey diversity (Shannon-Wiener index) increasing from 0.83 to 1.35 over a range of fish size from <25 cm to larger than 34 cm. A total of 52 prey taxa were identified in the diet of blue cod. Crustaceans were the main component, followed by mollusca and polychaeta. Fish, echinodermata and other were less important in the diet.

Kaiser, M.J., J.S. Collie, S.J. Hall, S. Jennings, and I.R. Poiner. 2002. Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries. Vol. 3(2):114-136.

Abstract: Fishing affects the seabed habitat worldwide on the continental shelf. These impacts are patchily distributed according to the spatial and temporal variation in fishing effort that results from fishers' behaviour. As a consequence, the frequency and intensity of fishing disturbance varies among different habitat types. Different fishing methodologies vary in the degree to which they affect the seabed. Structurally complex habitats (e.g., sea-grass meadows, biogenic reefs) and those that are relatively undisturbed by natural perturbations (e.g., deep-water mud substrata) are more adversely affected by fishing than unconsolidated sediment habitats that occur in shallow coastal waters. These habitats also have the longest recovery trajectories in terms of the recolonization of the habitat by the associated fauna. Comparative studies of areas of the seabed that have experienced different levels of fishing activity demonstrate that chronic fishing disturbance leads to the removal of high-biomass species that are composed mostly of emergent seabed organisms. Contrary to the belief of fishers that fishing enhances seabed production and generates food for target fish species, productivity is actually lowered as fishing intensity increases and high-biomass species are removed from the benthic habitat. These organisms also increase the topographic complexity of the seabed which has been shown to provide shelter for juvenile fishes, reducing their vulnerability to predation. Conversely, scavengers and small-bodied organisms, such as polychaete worms, dominate heavily fished areas. Major changes in habitat can lead to changes in the composition of the resident fish fauna. Fishing has indirect effects on habitat through the removal of predators that control bio-engineering organisms such as algal-grazing urchins. Fishing gear resuspend the upper layers of sedimentary seabed habitats and hence remobilize contaminants and fine particulate matter into the water column. The ecological significance of these fishing effects has not yet been determined but could have implications for eutrophication and biogeochemical cycling. Simulation results suggest that the effects of low levels of trawling disturbance will be similar to those of natural bioturbators. In contrast, high levels of trawling disturbance cause sediment systems to become unstable due to large carbon fluxes between oxic and anoxic carbon compartments. In low energy habitats, intensive trawling disturbance may destabilize benthic system chemical fluxes, which has the potential to propagate more widely through

the marine ecosystem. Management regimes that aim to incorporate both fisheries and habitat conservation objectives can be achieved through the appropriate use of a number of approaches, including total and partial exclusion of towed bottom fishing gears, and seasonal and rotational closure techniques.

Kaiser, M.J., J.S. Collie, S.J. Hall, S. Jennings, and I.R. Poiner. 2002. Impacts of fishing on marine benthic habitats. Abstracts of papers presented at the Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem. Reykjavik, Iceland, 1-4 October 2001. FAO Fisheries Report No. 658.

Abstract: Fishing affects seabed habitats worldwide. However, these impacts are not uniform and are affected by the spatial and temporal distribution of fishing effort, and vary with the habitat type and environment in which they occur. Different fishing methodologies vary in the degree to which they affect the seabed. Structurally complex habitats (e.g., seagrass meadows, biogenic reefs) and those that are relatively undisturbed by natural perturbations (e.g., deep-water mud substrata) are more adversely affected by fishing than unconsolidated sediment habitats that occur in shallow coastal waters. Structurally complex and stable habitats also have the longest recovery trajectories in terms of the re-colonization of the habitat by the associated fauna. Comparative studies of areas of the seabed that have experienced different levels of fishing activity demonstrate that chronic fishing disturbance leads to the removal of high-biomass species that are composed mostly of emergent seabed organisms. Fishing also has indirect effects on habitat through the removal of predators that control bio-engineering organisms such as algal-grazing urchins on coral reefs. However, such effects are only manifested in those systems in which the linkages between the main trophic levels are confined to less than 10 species. Management regimes that aim to incorporate both fisheries and habitat conservation objectives can be achieved through the appropriate use of a number of approaches, including total and partial exclusion of towed bottom fishing gears, and seasonal and rotational closure techniques. Different management regimes can only be formulated and tested once objectives and criteria for seabed habitats have been defined.

Kaiser, M.J., and F.E. Spence. 2002. Inconsistent temporal changes in the megabenthos of the English Channel. Marine Biology. Vol. 141(2):321-331.

Abstract: A survey was undertaken of the benthic communities found at ten stations that were sampled by Norman Holme in the 1950s. These stations were selected because Holme recorded the presence of large bivalve species (*Glycymeris glycymeris* and *Paphia rhomboides*). Fauna with large body-size are known to be most susceptible to disturbance by human activity, so the presence or absence of these organisms might indicate whether such disturbance has increased at these sites since the 1950s. As expected, differences were detected in the community composition between sites that were located in deeper or shallower water. These differences were consistent for the communities sampled in the present study and for those sampled by Holme. The brittlestar *Ophiothrix fragilis* was highly abundant at only one site. Nevertheless, long-lived bivalve species still occurred at most of the sites sampled in 1998. *G. glycymeris* was absent from two sites sampled in 1998 and *P. rhomboides* was absent from only one site in 1998. Holme suggested that his reported decline in the abundance of *O. fragilis* might be attributed to the increase in bottom fishing in the English Channel. However, the continued presence of long-lived bivalves at most sites would suggest that other factors could be responsible. A comparison of bivalve and echinoderm species that occurred in the 1950s and in 1998 indicated the occurrence of relatively large temporal changes, as might be expected over a period of more than 40 years. However, this occurred at eight of the ten sites. At two sites, the spatial variation was quantitatively similar to the temporal variation. This suggests that areas of the sea bed exist that have a similar community composition to those found prior to the general increase in bottom-fishing disturbance.

Koenig, C.C. 2001. Oculina banks: habitat, fish populations, restoration, and enforcement. Unpublished Report to the South Atlantic Fishery Management Council. Charleston, South Carolina.

Abstract: The shelf-edge *Oculina* coral reef ecosystem, known only from off the central east coast of Florida, is unique among coral reefs and exists nowhere else on earth. The azooxanthellate (i.e., lack symbiotic algae) branching coral typically produces 1 – 2 meter diameter coral heads which often coalesce into thicket-like habitats with exceedingly high biodiversity, similar to that of tropical coral reefs. Historical accounts indicate very high densities of economically important reef fish as well as grouper spawning aggregations associated with the coral habitat. The uniqueness, productivity, and vulnerability of the Oculina habitat moved the South Atlantic Fishery Management Council (SAFMC) in 1984 to declare a significant portion (92 nmi^2) of the habitat an HAPC. This legislative action purportedly protected the coral from trawling, dredging, and most other mechanically disruptive activities. Evidence of demographic impacts of fishing on grouper spawning aggregations further stimulated the SAFMC in 1994 to close the original HAPC for a period of 10 years to bottom fishing as a test of the effectiveness of a fishery reserve in protecting the reproductive capacity of groupers. Further expansion of the original HAPC to cover 300 nmi^2 was instated in 2000. A 1995 submersible survey suggested that much of the habitat, the economically important fish populations, and the grouper spawning aggregations described in the 1970s were decimated by 1995. A broad-scale submersible and ROV survey conducted in September 2001 found that most (90%) of the *Oculina* habitat within the EORR is reduced to an unconsolidated rubble and the damage north of the EORR may be greater. To our knowledge, only about 8 hectares (20 acres) of fully intact *Oculina* thicket habitat remain in the OHAPC and probably in the world. Restoration experiments were run from 1996 to 1999 to evaluate the transplantation potential of *Oculina*. High rates of transplant survival induced NMFS to support a significant restoration effort in 2000 and 2001. Results of the restoration efforts of 2000 indicate that restoration structures designed to simulate *Oculina* habitat are attracting groupers, snappers, and amberjack, and may be sites of grouper spawning aggregations. *Oculina* habitat and fish populations within the EORR were

described quantitatively (expressed in terms of density, nos./hectare) using a system of two cameras with attached lasers. Although fish populations observed in 2001 were not directly comparable to those observed in 1995, there was a noted increase in grouper numbers and size and especially an increase in the abundance of males of gag and scamp, suggesting the reoccurrence of spawning aggregations of both species. Juvenile speckled hind were observed in *Oculina* thickets, suggesting a nursery function for this species. Evidence is very strong that shrimpers are still illegally trawling within the OHAPC, and suggestions are made to eliminate such threats to this vulnerable, but productive habitat. We have initiated work on a habitat map of the OHAPC and produced a protocol to continue habitat mapping.

Koenig, C.C., F.C. Coleman, C.B. Grimes, G.R. Fitzhugh, K.M. Scanlon, C.T. Gledhill, and M. Grace. 2000. Protection of fish spawning habitat for the conservation of warm-temperate reef-fish fisheries of shelf-edge reefs of Florida. Bulletin of Marine Science. Vol. 66(3):593-616.

Abstract: We mapped and briefly describe the surficial geology of selected examples of shelf-edge reefs (50-120 m deep) of the southeastern United States, which are apparently derived from ancient Pleistocene shorelines and are intermittently distributed throughout the region. These reefs are ecologically significant because they support a diverse array of fish and invertebrate species, and they are the only aggregation spawning sites of gag (*Mycteroperca microlepis*), scamp (*M. phenax*), and other economically important reef fish. Our studies on the east Florida shelf in the Experimental Oculina Research Reserve show that extensive damage to the habitat-structuring coral *Oculina varicosa* has occurred in the past, apparently from trawling and dredging activities of the 1970s and later. On damaged or destroyed *Oculina* habitat, reef-fish abundance and diversity are low, whereas on intact habitat, reef-fish diversity is relatively high compared to historical diversity on the same site. The abundance and biomass of the economically important reef fish was much higher in the past than it is now, and spawning aggregations of gag and scamp have been lost or greatly reduced in size. On the west Florida shelf, fishers have concentrated on shelf-edge habitats for over 100 yrs, but fishing intensity increased dramatically in the 1980s. Those reefs are characterized by low abundance of economically important species. The degree and extent of habitat damage there is unknown. We recommend marine fishery reserves to protect habitat and for use in experimentally examining the potential production of unfished communities.

Kutti, T. 2002. Analyses of the immediate effects of experimental otter trawling on the benthic assemblage of Bear Island (Fishery Protection Zone), Barents Sea. Masters Thesis. University of Bergen.

Abstract: An experiment with the aim of investigating the effects of otter trawling on marine benthic fauna and assemblages was conducted in a gravely benthic ecosystem at 100 meters depth. The experimental site is situated within the Fishery Protection Zone around Bear Island, Barents Sea and has been protected from fishing activity since 1978. To quantify the

effects of the trawl-disturbance a BACI design (Before and After/Control and Impact) was adopted. Replicate samples were collected using a Snaeli epibenthic sledge, before and after trawling and in additional control areas. Fauna > 5mm was sorted and identified. The sampling procedure was video supervised and the area sampled was determined using this information together with positioning data. This thesis gives a description of the Bear Island benthic assemblage and presents an analysis of the immediate effects of intensive short term experimental otter trawling on the benthic organisms and assemblages in the area. In total, 16 higher taxa and 163 species were identified. Of these, 126 species had not earlier been reported from the Bear Island area. The benthic assemblage was characterized by a small-scale patchy distribution of fauna and the samples were dominated by ophiuroids constituting 24% of all specimens. Other common taxa were the polychaetes (15%), bivalves (13%), cirripeds (12%) and echinoids (11%). The most common species were *Ophiura sarsii*, *Balanus balanus*, *Nothria conchylega*, *Nuculana minuta* and *Strongylocentrotus droebachiensis*. Cirripeds and echinoids dominated the biomass of the assemblage. The small-scale patchy distribution of habitat and fauna within the experimental area aggravated the sampling and due to an unexpected large intersample variance of species, effects of trawling were difficult to assess on individual species. Multivariate analyses, however, indicate that the intensive experimental trawling had a homogenizing effect on the Bear Island benthic assemblage. Cluster analyses and ordinations show that most stations sampled after trawling are clearly distinct from the stations sampled before trawling. Physical damage inflicted on the fauna by the trawl gear, however, could not be detected. Intensive otter trawling affected the benthic assemblage mainly through a resuspension of the surface sediment and through a relocation of shallow burrowing infaunal species to the surface of the seafloor. We found a significant increase in the abundance of a majority of the infaunal bivalves, some common burrowing gastropod species and anthozoans in the experimental area immediately after trawling. There was, however, a reduction in the total biomass in trawled areas and calculations show that diversity, based on biomass data, was significantly higher after trawling. This was probably dependent on the reduced abundance and biomass of the dominant species *Balanus balanus* after trawling. The reduced abundance was most likely due to trawl by-catch. We found a significant increase in the biomass of the brittle star *Ophiura sarsii* after trawling. We also expected to find an increased abundance of other scavenging species after trawling, but except for a small increase in the abundance of *Hyas aranues* and *Pagurus* sp., no such increase could be detected.

McCallum, B.R. 2002. The impact of mobile fishing gear on benthic habitat and the implications for fisheries management. Masters Thesis. Memorial University of Newfoundland. 82 p.

Abstract: Marine fisheries for demersal fishes, crustaceans and mollusks are commonly conducted using otter and beam trawls, dredges and rakes. The ecology and behavior of these commercially valuable species requires that such fishing gears, in order to be effective collectors, must come into contact, and often penetrate the seabed. Concern has long been expressed about the impact of bottom fishing activity on benthic environments and there is now a strong consensus within the scientific community that mobile fishing gear can alter the benthic communities and structures on the seabed. However, the short and long term consequences of this disturbance and the implications for management of future fisheries are not well understood. This paper attempts to examine the issue of fishing gear disturbances of the seabed from a holistic perspective. The mechanisms by which mobile gear impacts the seabed, are considered, as well as the spatial and temporal distribution of this impact in the context of natural disturbances. The selectivity, technical performance, environmental and socio-economic impact of otter trawls is contrasted with other non-bottom contacting fishing technologies. The seabed has long been protected by various national and international agreements and treaties, however, these have rarely, if ever, been effective. Various management alternatives to mitigate the adverse effects of bottom contacting fisheries are therefore discussed.

Morgan, L.E., and R. Chuenpagdee. 2003. Shifting gears: Addressing the collateral impacts of fishing methods in U.S. waters. Pew Science Series on Conservation and the Environment. 42 p.

Executive Summary: With global reports of declining fisheries catches, and with the disintegration of many local fishing communities here in the United States, there is much debate about how best to manage our fisheries. Traditionally, fisheries have been managed on a numbers basis, species by species. In what is referred to as single species management, the focus is on how many fish can be removed before we cause deleterious effects to future stocks. What is all too often lost in this assessment is the impact of how we fish what gear we use, how it is deployed, and its consequences for the health and sustainability of our marine species and ecosystems. While specific problems, such as the collapse of New England groundfish fisheries, are widely covered by the media, the ongoing harm to non-target species and damage to marine ecosystems caused by fishing is largely overlooked. Currently, almost one-quarter of global fisheries catches are discarded at sea, dead or dying, each year. Scientists estimate that 2.3 billion pounds of sea life were discarded in 2000 in the United States alone. In addition, many uncommon, threatened, or endangered species, such as sharks, sea turtles, seabirds, and marine mammals, are killed in fishing operations. There is growing concern that fishing gears that contact the seafloor damage the very habitats that marine life depend on for their survival. These collateral impacts of fishing gears, whether the incidental take of an endangered seabird or the destruction of a deep-sea coral reef, alter marine food webs and damage habitats, reducing the ability of marine ecosystems to sustain fisheries. Fishers, scientists, and managers acknowledge that these problems exist, but the complexity of assessing ecological impacts associated with different gears, how we fish, has long been a stumbling block to the serious consideration of gear impacts in fisheries management decisions. By synthesizing existing information and using expert knowledge, Shifting Gears documents and ranks the collateral impacts of various fishing gear classes. This ranking will help fishers, conservationists, scientists, managers, and policymakers in addressing the urgent need to reduce the impacts of fishing. Although previous studies document the impacts associated with specific fishing gears, Shifting Gears is the first to integrate information on bycatch and habitat damage for all major commercial fishing gears, gauge the severity of these collateral impacts, and compare and rank the overall ecological damage of these gears. While there has been clear documentation of collateral impacts in some fisheries, until now no scientific method has addressed what types of impacts are considered most harmful. It is difficult for any one sector of science or society to determine the answers to such questions as which is more ecologically damaging, a gear that kills endangered sea turtles or one that destroys a portion of a deep-sea coral forest. Social science methods can help us answer such questions by integrating the knowledgeable viewpoints and values of fisheries and marine professionals to fill gaps in current ecological assessments. These answers, in turn, provide enhanced understanding of collateral impacts, which is needed for ecosystem-based management. Ecosystem-based management focuses on maintaining the health and viability of the ecosystems on which fish depend for their survival, rather than simply calculating, species-by-species, the number of fish that can be removed. The innovative "damage schedule" approach used in this study combines existing information with the knowledgeable judgments of those involved in fisheries issues to produce a ranking of the impacts of commercial fishing gears. Using data compiled from over 170 sources, an expert panel of fishers, managers, and scientists reviewed impacts of ten commercial fishing gears widely used in the United States. The results of this workshop were summarized and incorporated into an anonymous survey that was distributed to fishery management council members (including fishers), scientists who served on the National Research Council's Ocean Studies Board or its study panels, and fishery specialists of conservation organizations. These professionals were asked to consider the suite of collateral impacts of various gear classes in paired comparisons, each time choosing which set of impacts they considered to be ecologically most severe. Contrary to general expectations, the results of this survey show remarkable consensus among the different groups: there was consistent agreement about which fishing gears are the most and least damaging to marine resources. The respondents rated the ecological impacts from bottom trawls, bottom gillnets, dredges, and midwater (drift) gillnets relatively "high," impacts from longlines, pots and traps relatively "moderate," and the impacts from hook and line, purse seines, and midwater trawls relatively "low." In addition, these marine professionals consistently judged habitat impacts to be of greater ecological importance than bycatch impacts. Taking gear impacts into account is an important first step in the move toward ecosystem-based management. Shifting effort from the gears deemed to have high impacts to those with low impacts is one way to improve fisheries management. Other methods for mitigating gear impacts include closing areas to certain types of fishing and developing new, less harmful fishing technologies or gear deployment practices. This report can serve as the basis for future policies to reduce the impact of fisheries on marine life and their habitats. The time has come for fishery managers and conservation organizations to add fishing selectively, avoiding habitat damage, and protecting marine biodiversity as important components in maintaining ocean ecosystems and healthy fisheries. The results of this report demonstrate that people with diverse interests and experiences agree on the relative severity of ecological damage caused by different fishing gears. This consensus ranking demonstrates that common ground exists for better management of the collateral impacts of fishing gears.

National Research Council. 2002. Effects of trawling and dredging on seafloor habitats. National Academy Press, Washington, D.C. 126 p.

Summary: This report summarizes and evaluates existing knowledge on the effects of bottom trawling on the structure of seafloor habitats and on the abundance, productivity, and diversity of bottom-dwelling species in relation to gear type and trawling method, frequency of trawling, bottom type, species and other important characteristics. The report also summarizes and evaluates knowledge about changes in seafloor habitats associated with trawling and indirect effects of bottom trawling on non-seafloor species. Finally, the report recommends how existing information could be used more effectively in managing trawl fisheries and future research to improve understanding of the effects of bottom trawling on seafloor habitats.

Nilsson, H.C., and R. Rosenberg. 2003. Effects on marine sedimentary habitats of experimental trawling analyzed by sediment profile imagery. Journal of Experimental Marine Biology and Ecology. Vol. 285-286:453-463.

Abstract: Demersal trawling causes significant impact on marine benthic habitats including sediment biogeochemistry and faunal composition. To examine the effect of shrimp trawling on benthic sedimentary habitats a replicated Before/After (B/A) experiment was performed in the Gullmarfjord, Western Sweden, after 6 years protection against trawling activities. The experimental area was randomly divided into three control transects and three trawling transects each ~1.5 km long. The experimental fishery activity was designed to mimic the extent and the trawling procedure used before the banning with 80 hauls per site and year. All transects were sampled three times in 1996 before the experimental trawling activity was started, and three times during the experimental trawling activity in the autumn of 1997. Along each transect, 10 replicated sediment profile images (SPIs) were taken randomly at each sampling. The status of the sedimentary habitat was assessed by the parameterisation of a benthic habitat quality (BHQ) index combining sediment surface and subsurface variables and the redox conditions observed in the SPIs. A significant interaction between B/A and treatment was observed in mean BHQ-index. Changes of the BHQ-indices were larger in trawled areas than the natural variation in the experimental area. Mean BHQ-indices in trawled transects were lower than in control transects after the experimental trawling activity was started. In about 43% of the SPIs a severe mechanical disturbance was observed, which introduced a significantly increased spatial variance of BHQ-indices in trawled areas compared to control areas.

Northeast Region Essential Fish Habitat Steering Committee. 2002. Workshop on the effects of fishing gear on marine habitats off the northeastern United States, October 23-25, 2001, Boston, Massachusetts. Northeast Fishery Science Center Reference Document 02-01. 86 p.

Summary: This document is a review of a workshop where experts in the fields of benthic ecology, fishery ecology, geology, fishing gear technology, and fisheries gear operations assisted the New England Fishery Management Council, the Mid-Atlantic Fishery Management Council, and NMFS in: 1) evaluating the existing scientific research on the effects of fishing gear on benthic habitats; 2) determining the degree of impact from various gear types on benthic habitats in the Northeast; 3) specifying the type of evidence that is available to support the conclusions made about the degree of impact; 4) ranking the relative importance of gear impacts on various habitat types; and 5) providing recommendations on measures to minimize those adverse impacts. The experts analyzed the effects of clam dredges, scallop dredges, otter trawls, pot and traps, sink gillnets, bottom longlines, beam trawls, and pelagic gear. The experts prioritized fishing gear impacts and made action recommendations.

Orth, R.J., J.R. Fishman, A. Tillman, S. Everett, and K.A. Moore. 2001. Boat scarring effects on submerged aquatic vegetation in Virginia (Year 1). Final Report to the Virginia Saltwater Recreational Fishing Development Fund. Virginia Marine Resources Commission. Newport News, Virginia. 24 p.

Abstract: Submerged aquatic vegetation (SAV) in Chesapeake Bay has received significant attention in recent decades due to increasing understanding of the importance of these habitats for ecological functions, including fisheries habitat. Yet, SAV in many regions of the bay are at some of the lowest levels of abundance in recorded history. This has led state management agencies to adopt numerous policies and regulations to protect and restore these valuable communities. The Chesapeake Bay 2000 Agreement highlights SAV by recommitting to the goal of protecting and restoring 114,000 acres, revising existing restoration goals and strategies by 2002, and implementing a strategy to protect and restore SAV by 2002. In addition to addressing water quality issues, which are considered the major cause of SAV changes in distribution and abundance, there is increasing concern regarding how direct human impacts such as dredging and boating are affecting SAV. Aerial photography taken annually for monitoring SAV populations baywide has shown evidence of one form of human-induced damage - boat scarring. We therefore more closely examined photographs taken between 1987 and 2000 to evaluate this disturbance. Scarred sites were identified and assessed for key characteristics including intensity, orientation to shoreline, and scar curvature at each site. In addition, Virginia Marine Resources Commission (VMRC) enforcement personnel were surveyed for qualitative information on the occurrence of recreational and commercial fishing activities in Virginia's waters in vicinity of SAV beds. Aerial photographic analysis revealed 47 sites that had been scarred for at least one year, with 21 and 26 sites noted for the eastern and western shores, respectively. Scars along the eastern shore were clustered in the Tangier Island area, while along the western shore they were located from Mobjack Bay to Poquoson Flats. No scars were visible in grass beds between New Point Comfort and Smith Point on the western shore, or from Nandua Creek to Old Plantation Creek on the eastern shore. While many sites had scars noted in 5 years or fewer (49%), 11 sites (23%) had scars in 10 or more years, with 9 of these sites (82%)

located on the western shore. Scar attributes differed between eastern and western sites, with eastern shore scars being curved and randomly oriented. These eastern regions were reported by the VMRC bottom use survey to be heavily scraped. Scars on the western shore were generally associated with points of land, oriented perpendicular to shore and in straight lines, and were in regions of frequent haul seining as well as recreational use and scraping. This data suggests that scars on the eastern shore are consistent with observed boat tracks of crab scraping. Scars on the western shore are more consistent with observed haul seining activity. While recreational boats can also create scars in these areas, the lack of scars in recreationally important areas (that are not seined or scraped) minimizes the probability that these boats are a primary cause of the scarring observed in this study.

Piersma, T., A. Koolhaas, A. Dekinga, J.J. Beukema, R. Dekker, and K. Essink. 2001. Long-term indirect effects of mechanical cockle-dredging on intertidal bivalve stocks in the Wadden Sea. Journal of Applied Ecology. Vol. 38(5):976-990.

Abstract: There is world-wide concern about the effects of bottom-dredging on benthic communities in soft sediments. In autumn 1988, almost a third of the 50-km^2 intertidal system around the island of Griend in the western Dutch Wadden Sea was suction-dredged for edible cockles *Cerastoderma edule* and this study assessed subsequent effects. An adjacent area not directly touched by this fishery and an area from which the mussel *Mytilus edulis* beds were removed, served as reference areas. Sediment characteristics, together with the total stock size and settlement densities of *Cerastoderma*, *Baltic tellin*, *Macoma balthica* and soft-shelled clam *Mya arenaria*, were documented during 11 successive autumns before (August-September 1988) and after (August-September 1989-98) the suction-dredging event in fished and unfished areas. Four other areas in the Dutch Wadden Sea, where changes in densities of juvenile bivalves from 1992 to 1998 were measured, served as additional reference locations. Between 1988 and 1994, median sediment grain size increased while silt was lost from sediments near Griend that were dredged for cockles. The initial sediment characteristics were re-attained by 1996. After the removal of all *Mytilus* and most *Cerastoderma*, the abundance of *Macoma* declined for 8 years. From 1989 to 1998, stocks of *Cerastoderma*, *Macoma* and *Mytilus* did not recover to the 1988 levels, with the loss of *Cerastoderma* and *Macoma* being most pronounced in the area dredged for cockles. Declines of bivalve stocks were caused by particularly low rates of settlement in fished areas until 1996, i.e., 8 years after the dredging. A comparison of settlement in the short (1992-94) and medium term (1996-98) after cockle-dredging in several fished and unfished areas spread over the entire Dutch Wadden Sea, showed a significant negative effect of dredging on subsequent settlement of *Cerastoderma*. *Macoma* also declined, but not significantly. We conclude that suction-dredging of *Cerastoderma* had long-lasting negative effects on recruitment of bivalves, particularly the target species, in sandy parts of the Wadden Sea basin. Initially, sediment reworking by suction-dredging (especially during autumn storms) probably caused losses of fine silts. Negative feedback processes appeared to follow that prevented the accumulation of fine-grained sediments conducive to bivalve settlement.

Powell, E.N., K.A. Ashton-Alcox, S.E. Banta, and A.J. Bonner. 2001. Impact of repeated dredging on a Delaware Bay oyster reef. Journal of Shellfish Research. Vol. 20(3):961-975.

Abstract: The impact of commercial dredging on an oyster reef was evaluated at four sites chosen on New Beds, one of the most important commercial oyster beds in Delaware Bay. Dredging occurred on two of these sites in late October 1999, early and late November 1999, April 2000, and July 2000. Dredging was conducted according to standard industry procedures. Each day, dredging was continuous during approximately and 8-h period. Both one-dredge and two-dredge boats were used. Market-size oysters were culled and sacked in the standard manner. Total dredge coverage for the study was about 240,000 square meters on each experimental site. The most heavily dredged areas were completely covered by the dredge 4 to 6 times during the study. Two 8-h dredging events within a 10-day period produced barely detectable changes in the oyster population. Minor chipping and abrasion of the shell increased in frequency, but no other discernible impacts were found. Over the 10 month study that included five dredging events, many of the taphonomic indicators of dredge damage showed time-dependent trends that differed between control and experimental sites. However, these effects were limited mostly to minor chipping and indications of abrasive wear, rather than the more serious aspects of shell damage defined as major chipping, breakage, cracking, and shell perforation. A variety of population health indicators were assayed during the study, including the ratio of live oysters to boxes, condition index, *Perkinsus marinus* infection intensity, and oyster size-frequency distribution. These indicators should have monitored growth, disease pressure, and mortality. Essentially no significant effects could be discerned for any of these measures. Over a long time, dredging may significantly influence oyster bed physiography and community structure. However, once the bed has become a fished bed, this study suggests that moderate dredging that results in a yearly swept area of no more than four times the area of the bed is unlikely to result in significant further impact on the oyster populations living there.

Reed, J.K. 2002. Deep-water *Oculina* coral reefs of Florida: biology, impacts, and management. Hydrobiologia. Vol. 471(1-3):43-55.

Abstract: Deep-water *Oculina* coral reefs, which are similar in structure and development to deep-water *Lophelia* reefs, stretch over 167 km (90 nmi) at depths of 70–100 m along the eastern Florida shelf of the United States. These consist of numerous pinnacles and ridges, 3–35 m in height. Coral growth rates average 16.1 mm per year and biodiversity is very rich. Extensive areas of *Oculina* rubble may be due to human impacts (e.g., fish trawling and dredging, anchoring, bottom longlines) and natural processes such as bioerosion and episodic die-off. Early in the 1970s, the reefs were teeming with fish. By the early 1990s, both commercial and recreational fisheries, including scallop, shrimp, grouper, snapper and amberjack, had taken a toll on the reefs and especially on populations of grouper and snapper. A 315 km^2 (92 nmi^2) area was designated the Oculina Habitat of Particular Concern (HAPC) in 1984, prohibiting trawling, dredging, bottom longlines and anchoring, and

legislation was enacted in 2000 for expansion of the Oculina HAPC to 1029 km^2 (300 nmi^2). The United States Coast Guard has been charged with surveillance and enforcement of the ban on bottom fishing and trawling. The primary difficulties in protecting these reefs and other deep-water Marine Protected Areas are their remoteness and time required to engage an enforcement vessel. Education regarding the nature and importance of these rich resources is important for better self regulation and surveillance by the fishing community. Only by bringing deep-water reefs to the public, the fishing community, and enforcement agencies, through video, photos, and education will there be better understanding and acceptance for the need of protection for these unseen resources. This paper reviews the current knowledge on the deep-water *Oculina* reefs, including the biology, geology, human impacts, and history of conservation and management.

Roberts, J.M., D. Long, J.B. Wilson, P.B. Mortensen, and J.D. Gage. 2003. The cold-water coral *Lophelia pertusa* (Scleractinia) and enigmatic seabed mounds along the North-east Atlantic margin: are they related? Marine Pollution Bulletin. Vol. 46(1):7-20.

Abstract: In this study, an updated distribution of *Lophelia pertusa* between the Porcupine Seabight and Norwegian shelf is presented. It seems unlikely that enigmatic mound structures observed at water depths of more than 570 m during acoustic seabed surveys, particularly to the west of the Shetland Islands, are related to the occurrence of *L. pertusa*. At these depths in the Faroe- Shetland Channel, the predominant influence of cold Arctic water precludes its growth. Iceberg dumpsites are also considered unlikely explanations for the origin of these mounds, and they are interpreted as most likely to be related to the release of fluids at the seabed. When mound structures were investigated, no scleractinian corals were recovered at water depths >500 m. This study shows the importance of seabed temperature as an environmental control on cold-water coral distribution. The significance of cold-water coral habitats in sustaining high levels of local-scale biodiversity is now becoming apparent in parallel with increased hydrocarbon extraction and fishing activity beyond the shelf edge. There is growing evidence that these areas have been marked by the passage of deep-water trawls. It seems likely that trawling activity has already reduced the extent of cold-water coral distribution in this region of the North East Atlantic.

Rosenberg, R., H.C. Nilsson, A. Gremare, and J.M. Amouroux. 2003. Effects of demersal trawling on marine sedimentary habitats analyzed by sediment profile imagery. Journal of Experimental Marine Biology and Ecology. Vol. 285-286:465-477.

Abstract: Demersal trawling causes one of the most widespread physical and biological changes in marine shallow and shelf sedimentary habitats: trawl otter boards may create furrows in the sediment surface, while trawl nets and attached weights scrape the sediment surface. As a consequence, benthic animals are disturbed or killed, and resuspension of particles increase. The impact of trawling on benthic animals has traditionally been analyzed by changes in species composition and abundance, whereas frequency and distribution of trawl tracks are frequently analyzed by side-scan sonar. We have used sediment profile

images (SPIs) (30x22 cm) and observed furrows and other physical disturbances on the sediment surface that we attribute to trawling. In a manipulative experimental trawl study in Sweden (BACI design), significant impacts were found in trawled benthic habitats (73-93 m deep) compared with pre-trawling conditions and with reference areas. In particular, furrows from trawl boards had a severe ecological impact. In the Gulf of Lions (northwest Mediterranean), similar patterns were observed in the vast majority of 76 images taken at random at depths between 35 and 88 m in four different areas. Epifauna and polychaete tubes were generally either rare or not observed at all on trawled sediment surfaces. Burrows and feeding voids were, however, frequently present in some trawled areas and seemed to be comparatively less affected. Such biogenic structures in the sediment were generally associated with rather deep (3-4 cm) mean apparent redox profile discontinuities (aRPDs), which were measured digitally as the visible division zone between oxidised (sub-oxic) and reduced sediments. Increased roughness caused by the trawl boards acting on the sediment surface, e.g., depressions and protrusions, could have effects on sediment solute fluxes.

Schratzberger, M., T.A. Dinmore, and S. Jennings. 2002. Impacts of trawling on the diversity, biomass and structure of meiofauna assemblages. Marine Biology. Vol. 140(1):83-93.

Abstract: Disturbance due to trawling reduces the biomass and production of macro-infaunal invertebrate communities, implying that their total food-consumption rate will fall, and that production (carbon) reaching the sea floor will be processed by other animals that can withstand the effects of trawling. Meiofauna may be resistant to disturbance by trawling because they are likely to be resuspended rather than killed by trawls and because their short generation times would allow them to withstand elevated mortality. We used a BACI experimental approach to investigate the short-term effects of beam trawling on the diversity, biomass and community structure of meiofauna on real fishing grounds in the southern North Sea. Experiments at two locations showed that there were no short- to medium-term (1-392 days after experimental trawling) trawling impacts on meiofaunal diversity or biomass, but that there were mild effects on community structure. Any impacts due to trawling were minor in relation to seasonal changes in the meiofaunal communities. We assessed the power of our experiments to detect the effects of trawling and recorded a 44-85% chance of detecting a 50% change in species richness and a 65% chance of detecting an order-of-magnitude change in biomass. The power to detect changes in total abundance, however, was low (between 11% and 12% power for detecting a change of 50%). We suggest that meiofauna are more resistant to disturbance by beam trawling than are macrofauna and that they have the potential to withstand the effects of chronic trawling on real fishing grounds and to retain a key role in energy cycling.

Schratzberger, M., and S. Jennings. 2002. Impacts of chronic trawling disturbance on meiofaunal communities. Marine Biology. Vol. 141(5):991-1000.

Abstract: Bottom trawling causes chronic and widespread disturbance to the seabed in shelf seas. Meiofauna may be impacted directly or indirectly by this disturbance, since the passage

of trawls causes immediate mortality or displacement, changes sediment structure and geochemistry and affects the abundance of predators or competitors. Since meiofauna make a significantly greater contribution to benthic production than the larger macrofauna, there are compelling reasons to assess their response to chronic trawling disturbance. In this study, we determined the effects of trawling disturbance, season, sediment type and depth on the structure and diversity of nematode communities. Our analyses were based on comparisons between nematode communities in three beam-trawl fishing areas in the central North Sea. These areas were trawled with mean frequencies of 1 (low disturbance), 4 (medium) and 6 (high) times /year respectively. Our analyses showed that trawling had a significant impact on the composition of nematode assemblages. In two sampling seasons, the number of species, diversity and species richness of the community were significantly lower in the area subject to high levels of trawling disturbance than in the areas subject to low or medium levels of disturbance. However, levels of disturbance at the 'low' and 'medium' sites may have been insufficient to cause marked long-term changes in community structure. Many of the observed changes were consistent with responses to other forms of physical disturbance. The extent to which the observed changes in community structure reflect changes in the production of the nematode community remains unknown, although overall abundance was not significantly affected by trawling disturbance.

Sheridan, P., R. Hill, G. Matthews, and R. Appeldoorn. 2003. The effects of trap fishing in coralline habitats: What do we know? How do we learn more? Proceedings of the Gulf and Caribbean Fisheries Institute. No. 54:1-12.

Abstract: Trap fishing in United States waters occurs in coral habitats in the Florida Keys, Puerto Rico, and the Virgin Islands. Although the numbers of traps fished and the general placement areas of traps are known, there is little information on the exact placement of traps by habitat type, seasonal movement of traps among habitats, and potential for gear impacts to various habitats such as seagrasses, macroalgae, sponges, and hard and soft corals. We are beginning to examine the placement of traps in relation to habitat types and, in the future, will be conducting underwater surveys of traps and fishing techniques in all three locales to determine potential for habitat damage and for gear or method modifications, if necessary.

Smith, C.J., H. Rumohr, I. Karakassis, and K.N. Papadopoulou. 2003. Analyzing the impact of bottom trawls on sedimentary seabeds with sediment profile imagery. Journal of Experimental Marine Biology and Ecology. Vol. 285-286:479-496.

Abstract: Sediment profile imagery (SPI) was evaluated for the assessment of otter trawling impacts on the seabed. This technique allows the imaging of the topmost sediment layers in profile, including the sediment-water interface. Two areas in the Aegean Sea were investigated in time series, each with control and impact areas: a commercial fishing lane with soft sediments at approximately 200 m depth and an experimentally trawled lane with harder maerly sediments at approximately 80 m depth. In total, 158 images were taken at the deep ground and 124 at the shallow ground. A number of measurements were taken from

each image, leading to estimates of comparative penetration and small-scale seabed surface roughness. In addition, a large number of surface and subsurface attributes were noted in the images to form the basis of a multivariate analysis. Results indicated that penetration and roughness by themselves were not very good indicators, although roughness was a better indicator particularly in coarse sediments. The major reason for this is that the measurements alone (in particular roughness) do not distinguish between biological and anthropogenic disturbance. The multivariate analysis combining the measurements with the attributes was a good indicator in investigating trawling impacts in coarse sediments, where the lack of good penetration can be compensated by the view over the sediment surface, where more attribute-type data can be gathered. The SPI sampling window gives a relatively small imaged sample in comparison to other imaging techniques (side scan sonar, video, etc.) and in a heterogeneous environment, the more the replicates, the more reliable the method will be. A tiered imaging approach is recommended where more than one methodology is used.

Sparks-McConkey, P.J., and L. Watling. 2001. Effects on the ecological integrity of a soft-bottom habitat from a trawling disturbance. Hydrobiologia. Vol. 456(1-3):73-85.

Abstract: The effects of trawling disturbance on a soft-sediment system were investigated with a manipulative field experiment in an area that had been closed to shrimp trawling activities for 20 years. The area was also chosen for its weak natural physical agents, i.e., no scouring of sediments by storm events or tidal flow, allowing a quantitative assessment of the effects of trawling on the benthic fauna and geochemical properties of the soft substrate. The study examined the ambient spatial and temporal patterns of sedimentological variables and benthic species abundances over a time interval of 16 months for both the reference and the trawl stations before dragging the trawling gear over the predetermined trawl sites. Shifts in the patterns of the benthic infauna and geochemical variables were identified by the post-trawl samples that were collected at both the reference and trawl stations over the next 6 months. Post-trawl changes in the bottom topography did not translate into changes in the vertical profile of the sedimentological variables. Chlorophyll a content of the trawled surface sediments was significantly elevated immediately after the trawling event in comparison to the reference concentrations. Immediately after the trawling disturbance, numbers of species, species abundance and diversity decreased in the trawled area in comparison to the reference area. Sensitive species were found to be the bivalves; *Ennucula annulata*, Hampson, *Thyasira flexuosa* (Montagu), and *Yoldia sapotilla* (Gould), and polychaetes; *Chaetozone cf.setosa* Malmgren, *Anobothrus gracilis* (Malmgren), *Euchone incolor,* Hartman, and *Terebellides atlantis*, Williams. In contrast, the carnivorous nemertea, *Cerebratulus lacteus*, Verrill, was the resistant species to field manipulations on account of its predatory behavior; highly effective in seeking out freshly dead (dying) organisms and its active migration. Multivariate analysis confirmed the changes in the trawled community structure immediately following the trawling event and differences in the recovery patterns 6 months thereafter. Although the trawling disturbance was one of low frequency and intensity compared to commercial operations, the biological variables studied

indicated that successional processes in this soft-bottom community were altered, at least for a short period, in response to the trawling disturbance.

Steller, D.L., R. Riosmena-Rodríguez, M.S. Foster, and C.A. Roberts. 2003. Rhodolith bed diversity in the Gulf of California: the importance of rhodolith structure and consequences of disturbance. Aquatic Conservation - Marine and Freshwater Ecosystems. Vol. 13(Supplement S):S5-S20.

Abstract: 1) Rhodolith beds, unattached coralline reefs, support a high diversity and abundance of marine species from both hard and soft benthos. We used surveys in multiple shallow (3-20 m) beds in the Gulf of California to (1) examine seasonal patterns in associated floral and faunal diversity and abundance, (2) compare differences in faunal associations between rhodolith beds and adjacent sedimentary habitats, (3) examine the importance of complexity of rhodolith structure to community structure, and (4) estimate the impact of anthropogenic disturbance on rhodoliths and associated species. 2) Macroalgal richness was seasonal, and beds supported higher richness in winter (to 36 species) than summer (6-7 species), primarily due to foliose red algae. Strong seasonal variation in the abundance of dominant cover organisms was due to a shift from macroalgae and mat-forming colonial invertebrate species to microalgae. 3) The community in a rhodolith bed of high-density thalli (El Coyote average 11,000 thalli/m^2) had higher richness (52 versus 30 species) and abundance of epibenthic and crypto- and in-faunal species compared with an adjacent sand community. Species diversity and abundance was particularly high for unique cryptofaunal organisms associated with rhodolith interstices. Cryptofauna reached average densities of 14.4 organisms/cm^3 rhodolith, the majority of which were crustaceans, polychaetes and cnidarians along with rhodolith-specific chitons. 4) Results from sampling across a range of rhodolith morphs in the El Requeson bed (with lower average cryptofaunal densities of 2.3 organisms/cm^3) revealed that the total organisms supported by a rhodolith significantly increased with both complexity (branching density) and space available (thallus volume). These data suggest that reducing the population size structure, structural complexity and cover of living rhodoliths could decrease species richness and abundance. 5) While disturbance is a natural feature of these free-living beds, increased anthropogenic disturbance from trawling, anchoring and changes in water quality can directly impact the bed community through substrate alteration. Commercial fishing threatens rhodolith beds in the Gulf of California by decreasing rhodolith size and increasing sedimentation and burial rates. In addition to reducing direct destruction, conservation efforts should also focus on decreasing practices that break down thalli.

Tanner, J.E. 2003. The influence of prawn trawling on sessile benthic assemblages in Gulf St. Vincent, South Australia. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 60(5):517-526.

Abstract: Most experimental studies on the effects of trawling on the benthos use remote sampling techniques and are conducted in recently trawled areas. Thus it is difficult to

determine the effects of trawling on previously unfished areas, and the fates of individual animals cannot be followed. In this study, I follow the fates of individuals of several sessile taxa when exposed to experimental trawling in areas that have not been trawled for some 15–20 years. Although there was a significant trawling by location effect for all multivariate analyses and most individual taxa, I found that trawling had an overall negative effect on the benthos. Epifauna at trawled sites decreased in abundance by 28% within 2 weeks of trawling and by another 8% in the following 2–3 months (compared with control sites). Seasonal seagrasses were also less likely to colonize trawled sites than untrawled sites. The persistence of most taxa declined significantly in trawled areas compared with untrawled areas. In contrast to this, the recruitment rates of several taxa into visible size classes increased after trawling, presumably because of a reduction in competition.

Uhrin, A.V. 2001. Propeller scarring in a seagrass assemblage: effects on seagrass, physical processes, and response of associated fauna. Master's Thesis. University of Puerto Rico. 94 p.

Abstract: Damage to seagrasses by propeller scarring is common in coastal waters. Scarring has the potential to fragment seagrass beds resulting in habitat loss, decreased productivity, and the possibility for further erosion and degradation. A study was conducted in *Thalassia testudinum* beds in Puerto Rico to determine how seagrass plants, associated fauna, and physical processes are affected by this disturbance. Four treatments (propeller scar, seagrass/scar interface, and seagrass located 5 and 10 m from scars) were compared among 10 replicate seagrass beds. Scarring modified the faunal assemblage at the scale of the propeller-created gap; there was significantly lower total faunal abundance and fewer faunal species in scars. When individual taxa were considered, shrimp and mollusc abundances were significantly lower in scars. Resident fish abundance was not significantly different among treatments. Dominant shrimp species in scars differed from seagrass treatments. Crabs and molluscs responded negatively to scarring as indicated by significantly lower densities of these two taxa up to 5 m from scars. The extent to which these results "scale up" remains unknown and future studies should focus on larger, more intensely scarred areas.

Wassenberg, T.J., G. Dews, and S.D. Cook. 2002. The impact of fish trawls on megabenthos (sponges) on the north-west shelf of Australia. Fisheries Research. Vol. 58(2):141-151.

Abstract: We attempted to resolve widely different accounts of the impacts of fish trawls on large attached seabed fauna. We quantified the catch and damage by fish trawls on sponges and used a video camera in the trawl net to observe the effects of fishing gear on sponges. The depth of the 30 min trawl tows ranged from 25 to 358 m, with an average of 78.3 m. Sponges were caught in 85% of trawl tows (n=108). The mean catch of sponges was 87.2 kg for half-an-hour (S.D.=132.9 kg). The largest single catch of sponges was 797 kg. All catches with more than 100 kg of sponge were from waters shallower than 100 m. On the basis of our observations, we divided the sponges into two types (lump=broadbase, branched=narrowbase) and three height classes (<300, 301–500 and >500 mm). The size composition of sponges on the seabed, as observed on video, differed significantly from the composition of the catch: 80% of lump sponges and 100% of branched sponges less than 300 mm passed under the net; 68% of lump sponges and 80% of branched sponges between 301 and 500 mm in height passed under the net. Fewer than 3% of the intermediate-sized sponges were broken up as they passed under the net. Sponges larger than 500 mm high were impacted the most: only 30% of lump and 60% of branched sponges passed under the net. Of the 70% of lump sponges that passed into the net, at least 20% were broken into pieces. The branched sponges were either torn off by the footrope (20%) or were smashed and passed or rolled under the net (20%). Over 90% of another major megabenthic group, the gorgonians, passed under the net. Overall, the net removed about 14% of sponges and 3% of gorgonians. The impact of commercial trawling on megabenthos is estimated for an average year. Our results provide a mechanism for the two main effects of otter trawling: (1) reduction in megabenthos and especially understanding the effects of trawling on sponges; (2) changes in species composition in trawled areas.