Examination of

"Fisheries Harvest Using Bottom Disturbing Gear and Techniques on Submerged Lands – Justification for a Finding of Appropriateness of a Refuge Use, Monomoy National Wildlife Refuge"

A Report Prepared for the
Town of Chatham, Massachusetts
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By

Coonamessett Farm Foundation Inc

277 Hatchville Road
East Falmouth, Massachusetts, USA 02536
508-356-3601 FAX 508-356-3603
contact@cfarm.org
www.coonamessettfarmfoundation.org

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Background

The US Fish and Wildlife Service's (FWS) Draft Comprehensive Conservation Plan (CCP) and Environmental Impact Statement (EIS) for the Monomoy National Wildlife Refuge (Monomoy) outlines management strategies for the next 15 years in Monomoy. Three management alternatives are listed. Alternative A, Current Management, would implement little change in the current management structure. Alternative B, Enhanced Management of Habitat and Public Uses, is the preferred alternative for FWS. Alternative C, Natural Processes, is also being considered. Under all alternatives FWS is prohibiting fishing using any bottom disturbing gear or techniques including otter trawls, scallop dredges, hydraulic clam dredges, and fish weirs. This prohibition is an effort to protect the benthic communities and the submerged aquatic vegetation (SAV), primarily eelgrass, that provide a food source for birds, habitat for fish and other aquatic organisms, substrate for recruiting shellfish, and sediment and shore stabilization. FWS notes that there has been a decline of SAV in state waters including in areas near Monomoy, though the SAV data is limited for this region. Conservation measures to protect SAV have been very successful. FWS is hoping to protect the SAV beds and the benthic communities at Monomoy with the restriction on bottom disturbing fishing gear and techniques.

In addition to restricting bottom disturbing fishing methods, Alternatives B and C would also prohibit the harvest of epibenthic shellfish (e.g., scallops, oysters, mussels) with the exception of recreationally hand harvesting for scallops. Manual harvesting of molluscan infauna (e.g., quahogs, razor clams, and soft shell clams) would still be permitted, while chemical extraction methods such as salt and chlorine would not be allowed. However, there was concern as to the strength of scientific support justifying these recommendations, which would ultimately limit or prevent traditional fishery (finfish and shellfish) practices. In response, the Town of Chatham requested a literature review to examine risks and benefits associated with traditional fishing practices in the Refuge area, including recommendations for possible modifications of these practices.

Introduction

This report provides a science-based review and assessment of statements contained in the Draft Comprehensive Conservation Plan/Environmental Impact Assessment (CCP/EIS), and the literature cited by the U.S. Fish and Wildlife Service (FWS), justifying the ban on traditional fishing practices using bottom disturbing gear as well as mussel harvesting. However, after reviewing the scientific information provided by the FWS to justify its conclusions, the Town asserts that the supporting documentation used by the FWS is outdated, insufficient, and, in some instances, uses inappropriate comparisons between fishing gear types and areas fished. The potential for bottom fishing gear to damage or remove emergent epiflora and epifauna (e.g. seagrasses and hydroids), alter physical structures (e.g. bottom topography), and disturb benthic biogeochemical processes, particularly in offshore waters, is well established (see NEFMC 2011). However, many studies, including recent work in the Northwest Atlantic, make clear that these potential adverse effects are not universal (e.g. Stokesbury and Harris 2006); are strongly dependent on local processes (Harris et al. 2014) and; despite recent popular attention, should not be assumed when evaluating the risks and benefits of fishing (NEFMC 2011). Furthermore, the nature of fishing effects studies present substantial experimental design challenges and therefore only support very limited inference beyond the sites actually sampled. In other words, it would be scientifically inappropriate to extrapolate the results of certain studies and apply those results to systems not relevant to the studied sites. Overall, this review reveals there is insufficient scientific evidence to conclude that a complete ban on mussel harvesting and bottom disturbing fishing gear and practices within the CCP/EIS will create the benthic habitat protections the FWS desires.

Section 1. Review and Analysis of Statements Made in the CCP/EIS

This section includes a review and analysis of statements both in the CCP/EIS and in the accompanying Findings of Appropriateness that justify the proposed ban on bottom disturbing fishing gear and techniques. The majority of these statements are found in Appendix D.

1.1 Statements made in the CCP/EIS justifying the proposed ban on bottom disturbing fishing gear and techniques within the DOT.

Statement 1, Volume 1, Chapter 2, page 2-33: "Even deeper water SAV beds are vulnerable to damage from channel maintenance, beach renourishment, or fishing trawls or dredges."

This statement emphasizes the many threats anthropomorphic influences pose to deep water submerged aquatic vegetation beds; however, it has no accompanying citation or scientific justification.

Statement 2, Volume 1, Chapter 3, page 3-114: "Shellfishing can also alter benthic communities or impose direct competition for shorebirds that feed on target organisms. For example, mechanical harvesting of cockles in South Wales resulted in their decline, and although shorebird foraging rates increased immediately following harvesting as birds took advantage of newly exposed prey, subsequent declines of bird activity lasted 50 days for Eurasian oystercatchers and 80 days for Eurasian curlews and various gull species (Ferns et al. 2000)."

Statement 2 indicates that mechanical harvesting of cockles in South Wales altered benthic communities and competition for shorebirds, as seen by the decline in bird activity in harvested areas. This statement should be revisited based on the authors' interpretation of the data. First, the bird counts were made using bird tracks, which by the author's estimate have a R^2 value of 0.79 and are not 100% accurate at predicting actual bird counts. Second, while there were significant differences in bird counts at sites between sampling days, there were also differences at reference sites. This would indicate an influence outside of the treatment that the author does not consider. Additionally, all bird species did not follow the same pattern of decrease on the harvested sites. The prevalence of some species increased as a result, and not all the differences occurred during the same period. All of these points bring into question the authors' conclusion that harvesting directly altered bird forging habits. Statement 2 should therefore be disregarded due to the lack of appropriate supporting data.

Statement 3, Volume 1, Page 4-43: "Effects of sediment re-suspension can include reduced light available for photosynthesis, burial or smothering of benthic biota and spawning areas when anoxic conditions result, and negative effects on feeding and metabolic rates of intertidal organisms (Johnson 2002)".

This statement lists the multiple effects that sediment re-suspension can have on marine species, but it should be disregarded due to a lack of proper support. Johnson (2002) is simply a literature review of literature on the effects of bottom disturbing gear and does not constitute primary literature. The statement needs to be supported with the scientific literature that investigated the themes in Statement 3. Since it is not, Statement 3 does not present sufficient justification for banning bottom gear.

Statement 4, Volume 1, Page 4-59 "Direct and indirect mortality induced by shellfish harvest, recruitment, reproductive failures that delay population recovery, and shifts in species diversity toward smaller, short-lived and more mobile species can reduce the abundance of preferred prey items for higher trophic level predators such as amphipods, copepods, echinoderms, gastropods, crabs, fish, or birds (Peterson and Estes in press, Piersma et al. 2001, Verhulst et al. 2004)."

Statement 4 proposes shellfish harvesting as one of the many causes of reduction in preferred prey items for higher trophic levels. This statement should be omitted due to lack of appropriate supporting literature. Studies by Piersma et al. (2001) and Verhulst et al. (2004) both suffer from poor experimental design. Peirsma et al. (2001) used control sites that were selected by lack of fishing effort, instead of at random, and were significantly different from the start of the experiment. Additionally, this study did not account for anthropogenic changes that may have occurred in the area during the time of the experiment. Without a proper control and with other possible sources of disturbance, any conclusion about the effects of harvesting would be questionable. Verhulst et al. (2004) indicated significant differences in sex and location, but there was no explanation of the inferior condition of males or the reason birds do not simply fly to better locations. These inconsistencies show that declining avian condition cannot be attributed to harvesting, and signify the need for further research to investigate the factors influencing oystercatchers' condition. In summary, Peirsma et al. (2001) and Verhulst et al. (2004) come to questionable conclusions and do not address the broad issues that Statement 4 emphasizes. Lastly, Peterson and Estes is another literature review that therefore cannot be cited as primary literature. The information Statement 4 is trying to use in Peterson and Estes as support is attributed to other authors. Without proper supporting literature Statement 4 should be disregarded as justification for the banning of bottom disturbing gear.

1.2 A Review of Statements made in the Finding of Appropriateness for Fisheries Harvest Using Bottom Disturbing Gear and Techniques, CCP, Volume 2, D 18-19.

Ten references cited in Appendix D, pages 18 and 19, which were presented as a scientific argument justifying the banning of bottom disturbing fishing gears in the sub-tidal area, were closely examined. Three statements with supporting citations constitute the majority of the justification. The structure and scope of these statements fall short of the quality needed to address the important issues at hand. The reliability of the supporting citations could also be called into question due to their design, analysis, and site locations. Without clarification and additional supporting information, the proposed comprehensive ban is unwarranted.

Statement 1: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)"**.**

It is assumed this statement is describing the comparison of hand harvesting to other "mechanical" techniques in a specific inter-tidal habitat. Statement 1 is both structurally problematic and poorly supported by its citations. The inclusion "such as rakes, plungers, or shovels" does not apply to hydraulic or mechanical techniques, and causes some confusion about what techniques are at issue. The fact that the authors have categorized hand harvesting techniques as hydraulic or mechanical dredges indicates a general lack of familiarity with shellfish harvesting. Additionally, MacKenzie and Pikanowski (2004) and Murari et al. (2006) are studies that focus on sub-tidal habitats and thus cannot support conclusions involving inter-tidal habitats.

The papers referenced above are also the only citations that use hand rakes in their experimental design, invalidating the comparison made in the statement. In the experiments of the remaining references, Ferns et al. (2000), Kraan et al. (2007), Peirsma et al. (2001), Verhulst et al. (2004), use mechanical harvesting techniques such as tractor towed dredges and suction dredges, which are not used in the Monomoy fishery. Tractor dredging is described as similar to potato harvesting, a large dredge pulled behind a large tractor which skims off a preset depth of substrate and feeds it into a rotating drum. The smaller items fall between the mesh of the drum while larger marketable cockles are rolled toward a hatch for bagging (Cotter et al. 1996). Ferns et al. (2000) indicated the grinding in the separation drum during harvest was the major source of mortality for benthic organisms; this process is not present in hydraulic or bottom dredging used around Monomoy.

Lastly, Peterson and Estes is a broad synthesis of wide ranging topics that can affect marine environments. Peterson and Estes do not include data or conclusions about bottom dredging of their own in the report. The information Statement 1 is trying to use in Peterson and Estes as support is attributed to other authors. The confusing structure and the lack of support from its citations invalidate the justification of Statement 1.

Further review of the citations themselves also revealed issues with some of the experiments. One such problem found throughout the cited literature is site selection bias; without a proper reference, the possible sources of influence cannot be identified and any conclusions about the effects of harvesting would be speculation, at best. Piersma el al. (2001), Verhulst et al. (2004), and Kraan et al. (2007) suffered from site selection bias and used reference sites that were statistically different from their experimental sites. The experiment's reference sites were limited to areas un-harvested by fishermen or with the large assume that: "on average, the only difference between protected and unprotected areas is the possibility to legally harvest shellfish" (Verhulst et al. 2004).

These experiments failed to provide evidence that differences were not already present before harvest and accounted for by other sources of variance. For example, Piersma et al. (2001) mentions extensive changes taking place during the harvest, but never acknowledges the effects they may have on the benthic community. Piersma et al. (2001):

> From 1941, the western edge of the island of Griend has repeatedly been reshaped by various types of breakers and dikes. The last reconstructions were carried out during the summers of 1985 and 1988. A 2·5-km long sand dike was built west and north of the old circular island (Janssen et al. 1994).

The authors attempt to use harvesting as the sole source of change in the benthic communities when other sources of disturbance are present. The paper tries to account for the lack of pre-harvest data by comparing to a nearby site, which only highlights the variability in benthic community in the area.

Some of the experiments cited by Statement 1 suffered from other issues. In Peirsma et al. (2001), some of the analysis uses repeated t-test for comparisons and does not account for the increased chance of making a Type I error, incorrectly rejecting the null hypothesis. MacKenzie and Pikanowki (2004) is a poorly designed experiment with no pre-sampling, low sample size, small adjacent plots, unequal time between sampling, and assumptions about mobile organisms' movement. The conclusion of no treatment effect should be attributed to the poor design, not the actual testing of the treatment effects.

The two papers that involve bird presence, Ferns et al. (2000) and Verhulst et al. (2004), suffer from conflicting assumptions. In Ferns et al. (2000), birds are assumed to be able to detect low prey levels on a scale of < $50m^2$ and avoid such areas. In Verhulst et al. (2004), it is assumed birds ignore lower prey levels and remain in areas on a scale of km^2. These assumptions are in conflict and are vital to the conclusions of the papers.

Overall Statement 1 provides insufficient justification for a comprehensive ban on bottom disturbing fishing gear and techniques. The statement itself is confusing, the citations provide little support, and the citations themselves are faulty. Statement 1 should be disregarded.

Statement 2: "Depending on the spatial scale involved, changes in bottom topography can have profound effects on benthic infauna (Ray 2005). Dernie et al. (2003) showed that a difference of only 10 centimeters in the amount of material removed during mechanized shellfish harvest from a sand flat in Wales, UK resulted in a substantial decrease in benthic fauna recovery rate. Plots where 20 cm of sediment were removed required 208 days for infaunal community reestablishment, whereas plots with only 10 cm removed recovered in 64 days."

This statement emphasizes the different recovery rates of infaunal community for different depths of removal the bottom sediment on inter-tidal flats. This statement should be questioned as justification for closure because it has been copied verbatim from Ray (2005). Ray (2005) does not support the statement, and the Dernie el al. (2003) experiment suffers from design flaws. First, Ray (2005) is a broad summary of sources of disturbance on benthic infauna in shallow areas with the purpose of advising channel dredging. The conclusion of the Ray (2005) pertains to the idea that little information is available about shallow water estuaries and it may be due to vague language when describing specific water depths. Furthermore, Ray (2005) contains no original information about changes in topography effecting benthic infauna and should not be used as supporting citation for this statement. Lastly, Dernie et al. (2003) does investigate the effects of bottom topography on benthic infauna, but the justification it lends to the broad banning of bottom harvesting is questionable due to the design and conclusions of their experiment. Dernie et al. (2003) dug out pits in a manner very unlike actual harvesting, then found strong correlations that suggest the water remaining in the pits following sediment removal for the two disturbed treatments may have influenced the time to recovery. The sediment in the plots was completely removed down to 10 to 20 cm allowing water to pool; this is much deeper than the disturbance caused by small 36 inch light weight toothless bay scallop dredges used around Cape Cod. For example, the New Bedford style 15 ft. offshore toothless dredge disturbs sediment 5-9 cm deep and only temporarily re-suspends the sediment, not completely removing it from the site (Mayer et al. 1991). Due to its technical issues, and inappropriate, unsupportive citations Statement 2 should be disregarded as justification for the broad banning of bottom disturbing gear.

Statement 3: "Fisheries harvest using bottom disturbing gear and techniques can degrade eelgrass beds through substrate disturbance (Neckles 2005). "

This statement emphasizes the negative effects bottom disturbing gear and techniques can have on eelgrass beds when the fishing disturbs the substrate. The citation supporting this statement should be questioned for appropriateness due to its broad assumptions. The study was investigating the impact of bottom dredges on eelgrass meadows and their subsequent recovery and found significant differences at treatment sites compared to control sites. The study's first problem was the lack of detail in the description of the dredges; specifically, the author assumes a type of steel frame with a chain-link bag was used. The details of the dredge might have consequence in understanding its impact on eelgrass. Additionally, there are some assumptions within the study that lead to site selection bias. The treatment sites selected were chosen because of their noticeable disturbance patterns. It was first assumed disturbance was caused by dredging, and then analysis found differences between treatment sites and controls. Little information was known about what dredging was occurring, the condition of the sites prior to harvesting, or if there was dredging how the fisherman chose the site. The single citation supporting Statement 3 made such broad assumptions that its conclusions must be called into question; therefore Statement 3 should be disregarded as justification for broad banning of bottom disturbing gear.

In conclusion, there is little valid justification contained in the CCP/EIS for the broad banning of bottom disturbing gear. There are only three clear statements in the report attempting to justify the closure. The statements are confusing, narrow in scope, and supported by inappropriate or questionable citations. With only the information contained in the report, the justification of the broad banning is unsupported.

1.3 A Review of Statements Made in the CCP/EIS Finding of Appropriateness for Mussel Harvesting, Volume 2, D 32-33.

This review examines 4 references cited in Appendix D, pages 31 – 33. These references were presented in the CCP/EIS as supporting literature in the justification of the banning of mussel harvesting in Monomoy NWR. The statements fail as credible justification due to the lack of scientific evidence. In fact, some of the statements have no supporting evidence backing their conclusions; the citations that are provided do not support the statements or have questionable conclusions. Therefore, we conclude the information supplied in the CCP/EIS fails to justify the banning of mussel harvest.

Statement 1: "Mussels are an important food source for many migratory birds. We would be providing additional protection for priority wildlife species by not allowing harvest of this species. For example, blue mussels are the most important food item during the winter for common eiders, a Service focal species, congregating in Nantucket Sound (MA DFG 2006)".

This statement emphasizes the importance of mussels as a food source for migratory birds, and states that harvest closure would provide an additional buffer of protection for vulnerable species. This statement has inappropriate literature support. The reference (MA DFG 2006) does not provide data or conclusions of its own in the report. Any justification that Statement 1 could draw from MA DFG 2006 should be disregarded without proper information about the original source. The portion of the statement concerning the protection provided by closure has no appropriate supporting citations and therefore Statement 1 should be disregarded.

Statement 2: "Mussel spat is one of the most important food items of southward migrating red knots (proposed for listing as a threatened species under the Endangered Species Act) using Cape Cod from July through October (Harrington et al. 2010)".

This statement identifies mussel spat as one of the most important food sources for southward migrating red knots; however, this point is not supported by literature cited. Harrington et al. (2010) is mostly an observational paper with no statistical analysis on food item choice of red knots. The observational information that is provided in Harrington et al. (2010) concludes knots in the North Bay forged in habitat where mussel spat was abundant, while knots in the South Bay fed on Gem Clams. The authors do not actually mention knots feeding on mussel spat, simply that they foraged in mussel shoals or in areas where mussel spat was abundant. In conclusion, Statement 2 lacks supporting citations and should be disregarded as justification for the banning of mussel harvesting.

Statement 3: "Mussels are also a common food of American oystercatchers, which typically visually sight their prey in slightly submerged shellfish beds (http://amoywg.org/american-oystercatcher/food-habits/; accessed March 2013)".

Statement 3 concludes mussels are a common food source for American oystercatchers, and oystercatchers feed by sight on submerged beds; however, this statement is not supported by the cited material. The American Oystercatcher Working Group's webpage on the food habits of oystercatchers is a light review of available information on oystercatcher forging but includes no data or conclusions of its own. The site does reference other papers that list more than 9 possible prey species for oystercatchers, including Hand et al. (2010) which states mussels comprise just 4% of total oystercatcher diet in South Carolina. As there is no information supporting the specific importance of mussels to oystercatcher's diet, Statement 3 should be disregarded as justification for the banning of mussel harvest due to the lack of provided supporting literature.

Statement 4: "The most common harvest techniques for non-subterranean shellfish (such as dragging and mechanical and hydraulic dredging) are so efficient that mussel beds can be depleted very quickly. Dragging can have severe impacts on subtidal habitat structure by removing large areas of vegetation, such as eelgrass (Neckles 2005)."

This statement concludes that harvesting techniques for mussels can quickly deplete beds, and dragging can remove large areas of eelgrass and negatively impact sub-tidal habitat; however, this statement is not supported by the given citation. The portion of the statement about the efficient removal of mussels has no provided supporting citation, nor does Neckles (2005) address this topic. Neckles (2005) investigated the impact of bottom dredges on eelgrass meadows and their subsequent recovery and found significant differences at treatment sites compared to control sites. The primary issue with this study is a lack of detail in the description of the dredges; for instance, the author merely assumes a type of steel frame with a chain-link bag was used. The details of the dredge might lend understanding to its specific impact on eelgrass. Additionally, there are some assumptions made which lead to site selection bias; the treatment sites selected where chosen because of their noticeable disturbance patterns. It was first assumed the disturbance was caused by dredging and analysis then found differences between treatment sites and controls. Little information was known about if there actually was dredging, and if so, what type of dredging was occurring, the condition of the sites prior to harvesting, or how the fisherman chose the site. In light of these multiple issues, Statement 4 lacks sufficient justification for the banning of mussel harvest.

In conclusion, the four statements analyzed above fail as justification due to the lack of scientific evidence and inappropriate or questionable citations. Therefore, the CCP/EIS does not provide sufficient support for a ban on mussel harvesting in Monomoy NWR.

1.4 Insufficient Scientific Justification for Proposed Ban on Bottom Disturbing Fishing Gear and Techniques

Bottom dredging can disturb benthic communities, but the permanence and magnitude of the impact is subject to the characteristics of the system and fisheries practices (Dayton et al. 1995; Jennings and Kaiser 1998; Collie et al. 2000). Community structure and habitat complexity are the two major features that can be altered through dredging fishing practices (Auster et al. 1996; Collie et al. 1997; Kaiser et al. 2002). For example, in gravel substrate of the northern Georges Bank, Collie et al. (1997) found higher species richness in apparently undisturbed areas compared to harvested areas. Additionally, in a study off the coast of Maine, Auster et al. (1996) found altered substrate and biogenic structure when monitoring a site before and after 6 years of dredging. Other studies have found similar results, but the extent of the disturbance is variable and can be influenced by multiple factors (Collie et al. 2000; Kaiser et al. 2006). Most of the studies that observed extensive impacts from dredging were conducted at deep sites with more sensitive substrate such as silt or pebbles (Collie et al. 2000). In sandy, high energy environments supporting more resilient fauna, there is a significantly quicker recovery rate back to "normal" than at silt or gravel sites (Collie et al. 2000; Kaiser et al. 2006). Gear type also influences the level of benthic disturbance; scallop dredges were found to impact the benthic community less than intertidal dredging (bait digging, clam kicking, bait dredging, and clam suction harvesting) (Collie et al. 2000). Thus, truly effective fisheries management should consider the ecological community as well as the fishing gear and methods.

Since there is no literature on the effects of bottom disturbing fishing gear and techniques in the Monomoy area, an assessment of fisheries impacts should use studies conducted in systems with similar characteristics. Monomoy is a shallow, dynamic system, with high energy waves, tides, and currents. The submerged lands around Monomoy Island are recognized to be high-energy sand environments subject to extensive natural disturbance. In this regard, there are likely many similarities to nearby Georges Bank (Harris et al 2012) where significant work has been done on the impacts of fishing gear in the ocean habitat. The bottom substrate around Monomoy Island and large portions of Georges Bank is mostly sand (Poppe et al., 2006; Harris and Stokesbury, 2010), which is more resilient to disturbance than fine silt and organic matter (Schratzberger and Warwick, 1999; Ferns et al. 2000; Collie et al. 2000).

The region's groundfish fishermen primarily use bottom tending otter trawls to harvest finfish (cod, flounder, haddock etc.) on Georges Bank and Nantucket Shoals. Otter trawling has been found to have some of the lowest impact of bottom-disturbing gear (Collie el al. 2000, Kaiser et al. 2006). Some studies of otter trawling on sandy substrate have shown little to no impact (Drabsch et al. 2001; Gibbs et al. 1980; Hall et al. 1993). Other reports have found significant effects from otter trawls, but the experimental trawls were conducted in areas much deeper than Monomoy (Schwinghamer et al. 1998; Moran and Stephenson, 2000).

New England's scallop fishermen employ large toothless dredges to harvest sea scallops in the offshore waters. A toothless dredge is generally referred to as a New Bedford style dredge. New Bedford dredges can come in a variety of sizes ranging from large offshore ocean dredges (typically 15 feet wide and can weigh up to 1870 kg (Stokesbury, 2006) to small, lightweight inshore dredges (approximately 24" to 36" across and weighing only 30-50 pounds). The small lightweight bay scallop toothless dredge is the style commonly used in Nantucket Sound and around Monomoy Island for shallow water inshore bay scallop harvesting.

Studies have shown the New Bedford style offshore toothless scallop dredge can impact shallow, sandy habitat, altering both bottom features and species abundance (Auster et al. 1996; Watling et al. 2001). However, differences in species abundance between dredged and non-dredged sites may last less than 6 months, while bottom features normalized after storm events less than one year later (Auster et al. 1996; Watling et al. 2001). Overall, most bottom-disturbing gear deployed in shallow, sandy systems, had minimal impact, primarily due to the inhabiting organisms' adaptation to frequent natural disturbance (tides, waves, storms).

The impact of dredging on avian communities in Monomoy National Wildlife Refuge is a major concern of FWS, but there is evidence that some forms of dredging produce additional prey items and may alter the system to favor avian communities. Connell (1978) proposed the intermediate disturbance hypothesis, which postulates that if a system remains stable for too long, species diversity is lost due to competition. Additionally, if a system is disturbed too often, species diversity is lost due to mortality of slow growing/colonizing organisms. Some studies have reported an initial decrease in benthic biomass after dredging, followed by an increase in select species (Jennings et al. 2001; Duplisea et al. 2002). The species that increase tend to be polychaete worms, opportunistic colonizers well-adapted to disturbance (Jennings et al. 2001; Barry, 1989). Dredging may result in the increase of polychaete abundance providing a major food source for many shore birds (Wilson 1990; Tsipoura and Burger, 1999; Sutherland et al. 2000; Atkinson et al. 2003; Cohen et al. 2008; Cornell Lab of Ornithology www.allaboutbirds.org). Allowing continued dredging in this area may influence the availability of prey items of some shorebirds.

Little is known about the interaction between fisheries and molluscivore birds. There is evidence correlating shellfish harvest with increased mortality of molluscivore bird species, but many fisheries have found management strategies that ameliorate this relationship (Schmechel, 2002). In areas where there is competition between fisheries and bird species over shellfish, additional stress in the form of inclement winter weather can increase mortality (Camphuysen et al. 1996; Atkinson et al. 2000). Yet, in some areas there are recovering or stable populations of molluscivore birds alongside commercial shellfish harvest (Norris et al. 1998). Stillman et al (2001) found no significant effect of fishing effort on oystercatcher populations in two areas of the United Kingdom as a result of modeling bird-fishery interactions. In some studies, an abundance of prey did not result in decreased bird mortality (Goss-Custard et al. 2004). This suggests that there may be other factors influencing bird mortality and supports the potential for sustainable management of shellfish harvest that prioritizes molluscivore bird survival.

This review revealed relevant scientific information that the FWS may have neglected in their decision to ban bottom disturbing fishing gear and techniques The literature used by FWS to justify a comprehensive ban failed to include system details that are so critical to understanding the impacts of dredging. Based on this review the impacts of bottom dredging appear to be slight given the characteristics of the Monomoy system (sandy substrate, shallow depths, etc.) and certainly less impactful then alleged by the FWS. There is evidence of impacts on molluscivore birds, but the relationship is still not fully understood (Camphuysen et al. 1996; Atkinson et al. 2000). Management practices in some fisheries seem to have addressed most shorebird issues without banning of bottom dredging fisheries (Schmechel, 2002). In conclusion, this literature review and analysis indicates that the disturbance caused by bottom disturbing fishing gear and techniques in the Monomoy area appear to be significantly less than that alleged by the FWS in the CCP/EIS due to the reliance on outdated, inappropriate and sometimes incorrect studies. Indeed some of the literature reviewed suggested the impacts were minimal and may in fact have positive benefits to certain bird species. However, this finding is only suggestive and far from conclusive. By now it should be obvious that more scientific information on the effects of bottom disturbing gear of the size and type used on Cape Cod in high energy systems like the Monomoy area is needed before a comprehensive ban can be scientifically justified and supported.

Section 2. Analysis of Literature Cited in the CCP/EIS

American Oystercatcher Working Group. 2011-12. http://amoywg.org/american-oystercatcher/food-habits/; accessed March 2013)

Context of Reference:
As cited: "Mussels are a common food of American oystercatchers as well; they typically visually site these prey in slightly submerged shellfish beds (http://amoywg.org/american-oystercatcher/food-habits/; accessed March 2013)."

As cited: "Mussels are also a common food of American oystercatchers, which typically visually sight these prey in slightly submerged shellfish beds (http://amoywg.org/american-oystercatcher/food-habits/; accessed March 2013)."

Objective and Overview: The objective of the website is to provide information on the forging habitats of oystercatchers.

Species: American Oystercatcher (*Haematopus palliates*)

Possible Faults

- This website is a review of some of the available literature on forging habits of oystercatchers, it contains no original data or conclusions.
- The citation is not in the Bibliography for this section.

Dernie, K. M., Kaiser, M. J., Richardson, E. A., and Warwick, R. M. 2003. Recovery of soft sediment communities and habitats following physical disturbance, Journal of Experimental Marine Biology and Ecology (285-286), 415-434.

Context of Reference:
As cited: "Dernie et al. (2003) showed that a difference of only 10 centimeters in the amount of material removed during mechanized shellfish harvest from a sand flat in Wales, UK resulted in a substantial decrease in benthic fauna recovery rate. Plots where 20 cm of sediment were removed required 208 days for infaunal community reestablishment, whereas plots with only 10 cm removed recovered in 64 days."

Objective and Overview: The study investigated the possibility that physical parameters could be used as surrogates for biological recovery when quantifying the response of benthic assemblages to physical disturbances. The site of the experiment was in Menai Strait, southeast of Anglesey, United Kingdom, on intertidal sand flats. The experiment compared 3 treatments: 10 cm of sediment removed from a plot, 20 cm of sediment removed from a plot, and no disturbance. The two disturbance treatments where designed to recreate disruption from hydraulic suction dredging and tractor dredging. The three treatments each had five replicates and where sampled on days 1,4,8,16,32, 64, and then every two months until there was no significant difference in community between undisturbed and disturbed sites.

System Energy: Menai Strait ranges from 500 meters to 7.5 km in width and experiences low wave energy and strong tidal currents.

Bottom Type: Sediment at the sites consist of 90% 125-250 µm sand and 1% silt and clay, with occasional 5% cockle shell debris.

Analysis: In most species a 99% probability of detecting a 10% change in population.

Species: *Bathyporeia sarsi* (mobile crustea), Carcinus maenas (mobile crustea), *Cerastoderma edule, Corophium arenarium* (mobile crustea), Hydrobia ulvae (mobile aquatic snail)*, Pygospio elegans,* Scoloplos *armiger, Tubificoides benedii*,

Results / Conclusion: In plots were 10 cm of sediment was removed the faunal community recovered within 64 days. In plots were 20 cm of sediment was removed recovery occurred within 208 days. Though there were no significant differences in community between the shallow and deep disturbed plots throughout the experiment. There were no significant differences between undisturbed and disturbed plots for any of the sediment fractions or organic content at any time during the experiment. The depth of the water remaining in the disturbed plots decreased with time and correlated (R =.70) with temporal changes in community.

The project was not successful in establishing a physical parameter for the indexing of biological habitat recovery.

Possible Faults

- This study was conducted on inter-tidal flats and does not address sub-tidal habitat.

- The reports data suggest that the water remaining in the pits from removing sediment for the two disturbed treatments may have influenced the time to recovery. The sediment in the plots was completely removed down to 10 or 20 cm, this is deeper than a New Bedford toothless dredge usually digs. The New Bedford toothless dredge digs 2-3 cm and only re-suspends the sediment, not completely remove it from the site.

Ferns, P.N., D.M. Rostron, and H.Y. Siman. 2000. Effects of mechanical cockle harvesting on intertidal communities. Journal of Applied Ecology 37: 464-474.

Context of Reference:
As cited: "Shellfishing can also alter benthic communities or impose direct competition for shorebirds that feed on target organisms. For example, mechanical harvesting of cockles in South Wales resulted in their decline, and although shorebird foraging rates increased immediately following harvesting as birds took advantage of newly exposed prey, subsequent declines of bird activity lasted 50 days for Eurasian oystercatchers and 80 days for Eurasian curlews and various sea gull species (Ferns et al. 2000)."

As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

Objective and Overview: The study investigated the effects of tractor-towed cockle harvest on intertidal communities and shorebird activity in Burry Inlet, South Wales. The experiment compared 4 treatments: tractor-towed harvest and undisturbed on muddy substrate, and tractor-towed harvest and undisturbed on sandy substrate. Each treatment was replicated in 6 plots in each substrate. Each site was sampled before and after harvesting on day 0, then sampled again on day 15 and 86. The muddy site received an additional sampling on day 174.

System Energy: The estuary covers an area 42 km^2, has a mean spring tidal range of 8 m, and has a variable fetch (Nio et al. 2009).

Bottom type
Muddy sites' substrate consisted mainly of particles of two sizes, 125 µm and approximately 3 µm. The sandy sites' substrate consisted mainly of particles of 125 µm.

Analysis: Data was indexed for species dominance by Simpson's index and equitability by Shannon evenness. Indices were compared using a Student's t-test. The effects of harvesting, time, and plot on community was determined by ANOVA.

Species: Aquatic: *Scoloplos armiger, Pygospio elegans* (tube dwelling), *Hydrobia ulvae, Nephtys hombergi, Bathyporeia pilosa, Cerastoderma edule, Lanice conchilega*
Shorebirds: *Numenius arquata* (curlew), *Haematopus ostralegus* (oystercatcher), *Calidris alpine* (dunlin), Black-headed gull, common gull

Results / Conclusion: The muddy site community had more sedentary species, while the sand site had more mobile species. There was significant change in species richness, dominance, and equitability when comparing pre and post-harvest for both sand and muddy sites. Some invertebrate densities remained low for the duration of the experiment in the muddy sites (174 days), while most recovered after 59 days. High population density recovered in the sand sites in 39 days. After an initial increase in bird activity post-harvest, there was a significant reduction in oystercatchers, curlews, and dunlins on both the sand and muddy sites on days 21 and 45. No significant differences between treatments were detectable 115 days after harvest.

The study did show there was some impact on habitat from bottom Tractor-pulled cockle dredging.

Possible Faults

- Study investigated the impacts on intertidal and does not address sub-tidal habitat.
- Sand sites, similar to what is found in Monomoy, were quick to recover.
- The tractor pulled dredges are not used in harvesting near Monomoy. The dredge described in this study is similar to a potato harvester, a large dredge pulled behind a large tractor skims off a preset depth of substrate and feeds it into a rotating drum. The smaller items fall between the mesh of the drum while larger marketable cockles are rolled toward a hatch for bagging (Cotter et al. 1996).
- Paper indicated grinding in the separation drum during harvest is the major source of mortality, which is not present in hydraulic dredging.
- Bird predation is high immediately post-harvest on the exposed flats and could be cause of density decline. Submerged harvesting could decrease impact.

- Shorebird species are hard to identify from prints and non-feeding birds' tracks are indistinguishable from feeding birds.

- Results were mixed for species, date, and sites for bird count differences

Harrington, B.A., S. Koch, L.K. Niles, and K. Kalasz. 2010b. Red knots with different winter destinations: differential use of an autumn stopover area. Waterbirds 33(3): 357- 363.

Context of Reference:
As cited: "Mussel spat is also one of the most important food items for southward migrating red knots (a candidate species) using Cape Cod from July through October (Harrington et al. 2010b)."
As cited: "Mussel spat is one of the most important food items of southward migrating red knots (proposed for listing as a threatened species under the Endangered Species Act) using Cape Cod from July through October (Harrington et al. 2010)."

Objective and Overview: The goal of the study was to investigate habitat utilization between red knots with different winter migration stopover sites. The sites of the research were along the southeastern edge of Cape Cod, Massachusetts (North Pleasant Bay, South Pleasant Bay, North Beach, South Beach, North Monomoy, and South Monomoy). Data collected to identify habitat use included counts, band id, plumage age, stopover time, and forging behavior.

Species: Red Knots (*Calidris canutus*)

Results/Conclusion: This study was merely observational. Much of the results are the author's observations with no analysis. By Sept. 1 there were significantly more tagged red knots from Florida and the mid-Atlantic shore than the Delaware Bay shore. Before Sept 12 knots in the South Bay had more basic plumage than knots in the North Bay.

Possible Faults

- The paper is mostly observational and most of its conclusions are not supported by statistical analysis.

- The number of knots observed is very low.

Johnson, K.A. 2002. A review of national and international literature on the effects of fishing on benthic habitats. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, NOAA Technical memorandum NMFS-F/SPO-57. 77 pp.

Context of Reference:
As cited: "Effects of sediment re-suspension can include reduced light available for photosynthesis, burial or smothering of benthic biota and spawning areas when anoxic conditions result, and negative effects on feeding and metabolic rates of intertidal organisms (Johnson 2002)."

Objective and Overview: The report is a summary of the existing information on the effects of bottom disturbing fishing gear on benthic habitat. The purpose of the document is to provide reference for

Fisheries Management Councils in assessing the impacts of fisheries. The document summarizes scientific studies by bottom type and also includes some management practices.

Results / Conclusion: There is currently enough information available to allow Councils to assess the effects of fishing on essential fisheries habitat. The report and additional documents should provide a guide for Councils when reviewing management practices.

Possible Faults

- The report provides no data or conclusions of its own.

- In the summary of paper recommendations, the concern voiced by authors is on the use of dredges on seagrass, there is no mention of the re-suspension of sediment specifically.

Kraan, C., T. Piersma, A. Dekinga, A. Koolhaas, and J. Van der Meer. 2007. Dredging for edible cockles *Cerastoderma edule* on intertidal flats: short-term consequences of fishermen's patch-choice decisions for target and non-target benthic fauna. ICES J. Mar. Sci. 64:1735–1742.

Context of Reference:
As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

Objective and Overview: The study made two comparisons in the intertidal areas of the western Dutch Wadden Sea, one of communities at sites to-be-dredged and sites un-dredged and one of communities at pre and post-dredged sites. The dredges used at the sites were Dutch suction dredges.

System Energy: Dutch Wadden Sea covers 890 km^2 with spring tides of 2 m.

Bottom Type: Sediment in the sea has a median grain size of 140 – 200 µm

Analysis: Data was analyzed with Student t-test.

Species: *M. edulis*, Heteromastis filiformis, Crangon crangon, E. americanus, Carcinus maenas, M. viridus, T. tenuis

Results / Conclusion: No p-values are provided for undredged and to-be-dredged comparisons, but ratios for C. edule, M. edulis, N. diversicolor, E. americanus, and M. balthica were higher in to-be-dredged sites. When undredged and dredged site were compared M. edulis, H. filiformis, C. crangon, and E. amercanus showed significant negative short-term decreases in abundance

Possible Faults

- Reference selection for comparisons was biased and failed to find similar habitat for analysis. Without a proper reference the possible sources of influence cannot be identified and any conclusions about the effects of fishing effects would be speculation.

- During the to-be-dredged and un-dredged analysis, cores taken 250 m apart are assumed to constitute independent samples. There is no evidence supporting this assumption. The lack of independent samples invalidates use of a t-test.

- During the dredged vs. un-dredged analysis, samples were used from 'near-by' undredged sites, not from the actual dredging sites. Abundance was much higher in areas that were later dredged than in un-dredged area further highlighting the possibility of bias. The non-random, non-independent nature of sampling suggests there may be sampling bias. The final results were inconclusive results, some organisms exhibited decreases while others experienced increases.

Massachusetts Department of Fish and Game (MA DFG). Revised 2006. Massachusetts Comprehensive Wildlife Conservation Strategy. 750 pp. http://www.mass.gov/dfwele/dfw/habitat/cwcs/pdf/mass_cwcs_ final.pdf; accessed July 2011.

Context of Reference:
As cited: "Mussels are an important food source for many migratory birds and we would provide additional protection for priority wildlife species by not allowing harvest of these species. For example, blue mussels are the most important food item during the winter for common eiders (a Service focal species) congregating in Nantucket Sound (MA DFG 2006)."

Objective and Overview: The report is a 791 page strategy for the conservation of the biodiversity of Massachusetts. It relates processes for identifying habitat and species in need of conservation and conservation strategies. The report covers 22 habitat types and 257 species in need of conservation.

Possible Faults
- The report does not contain any original data or analysis of the food choice of the Common Eider. The report has a small section that mentions mussels as an important food item for Common Eider. The section is does not have any supporting literature.

MacKenzie C.L., and R. Pikanowski. 2004. Gear effects on marine habitats: harvesting northern quahogs in a shallow sandy bed at two levels of intensity with a short rake. North American Journal of Fisheries Management, 24(4):1221-1227

Context of Reference:
As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

Objective and Overview: This study investigated the effects of hand harvesting with common Rhode Island style quahog short rakes on invertebrate abundances and sediment composition in Raritan Bay, Sandy Hook, New Jersey. The experiment applied three treatments: a single harvesting event with a short rake during a season, three harvesting events with a short rake during a season, and undisturbed. Each treatment was replicated three times.

System Energy: The site of the experiment is in protected cove. Plots were installed at the base of a wave break covered with 0.5m of water at low tide. The total tidal range is 2 m.

Bottom Type: Sediment in the sea has a median grain size of 0.5mm.

Analysis: Data was analyzed with Student t-test.

Species: *Callinectes sapidus*, Northern quahogs*, Nematodes, Nemerteans, Polychaetes, Harpactacoid copepods, Ilyanassa obseleta, Amphipoda, Cirripedia, Bivalves, Crepidula fornicata. Noted absent species: Cerebratulus lacteus, Asterias forbesi,* large polychaetes

Results / Conclusion: No significant differences between treatments were found.

Possible Faults

- This was a poorly designed experiment with no pre sampling, low sample size, small adjacent plots, unequal time between sampling, and assumptions about mobile organisms' movement. The conclusion that there was no treatment effect should be attributed to the poor design, not the actual testing of the treatment effects.

Munari, C., E. Balasso, R. Rossi, and M. Mistri. 2006. A comparison of the effect of different types of clam rakes on non-target, sub-tidal benthic fauna. Italian Journal of Zoology, 73(1):75-82.

Context of Reference:
As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

Objective and Overview: The objectives of this study are to determine the impact of the use of the manual rake, the hydraulic rake, and the conveyor rake to harvest clams on sub-tidal mudflats in the Northern Adriatic on the benthic community, and to assess short-term community recovery time following raking. Plots where sampled on day 0, 3, 9, and 27.

System Energy: The experiment was conducted in the Po River Delta in the northwestern Adriatic Sea. The spring low tide mark was 0.3 m in the muddy bottom manual raked and hydraulic site, 0.2 m in the sandy bottom hand raked and hydraulic site, and 1.8 at the sandy bottom conveyor rake site.

Bottom Type: Sandy and muddy bottom plots were chosen.

Analysis: Data was analyzed using a two way ANOVA for the manual raked and hydraulic experiments and a simple ANOVA test was used for the conveyor data.

Species: *Polydora ciliata, Corophium orientale, Strblospio shrubsolii, Melita palmata, Corophium insidiosum, Neanthes succinea, Oligochaeta sp., Grammarus aequicauda, Grammarus insensibilis, Ruditapes philippinarum*

Results / Conclusion: For the muddy substrate experiment, total number of species was significantly reduced in comparisons of control to manual raked, and control to hydraulic raked. The benthic community at the hydraulic raked site was significantly more even than at the control sites. Diversity was also significantly higher at the hydraulic raked site than the manual raked site. Similarity among all three treatments was very high (SIMPER analysis > 63.8%). Time was not a significant factor.

For the sandy substrate experiment, the two treatments, time, and their interactions were significant factors for evenness and diversity. Number of species and abundance were significant for only treatment. Manual and control showed the highest dissimilarity (43%). The conveyor to control comparison showed the significant factors to be the treatment, time, and the interaction term. Community parameters were significantly altered in the conveyor plots for longer than the control as well.

The study was successful in showing there was a difference in the impact of harvesting techniques.

<u>Possible Faults</u>

- Author's conclusion: From our results, at least manual (MR) and hydraulic (HR) raking is unlikely to have persistent effects on infaunal communities of the Sacca. Recolonization by small infaunal species was relatively rapid, while the effects of MR and HR were comparable. Conversely, we found that the conveyor rake (CR) had a greater deleterious effect on the macrofaunal community than MR and HR. In conclusion, the mild disturbance due to MR and HR caused a little (and comparable) response to the biota, and this result can be useful for decision-makers facing the problem of combining the protection of the environment with fishermen's considerations.

- During the longitudinal study analysis, samples taken from the same transect at each time interval may be non-independent. The 2 way ANOVA does not account for this correlation structure, thus the p-value assumptions have been violated. Additionally, choosing samples along marked transects 'haphazardly' is inherently biased.

Neckles, H.A., Short, F.T., Barker, S., and Kopp, B.S. 2005. Disturbance of eelgrass Zostera marina by commercial mussel Mytilus edulis harvesting in Maine: dragging impacts and habitat recovery. Marine Ecology Progress Series. 285. 57-73.

<u>Context of Reference:</u>
As cited: "Fisheries harvest using bottom disturbing gear and techniques can degrade eelgrass beds through substrate disturbance (Neckles 2005)."

As cited: "The most common harvest techniques for non-subterranean shellfish (such as dragging and mechanical and hydraulic dredging) are so efficient that mussel beds can be depleted very quickly. Dragging can have severe impacts on sub-tidal habitat structure by removing large areas of vegetation, such as eelgrass (Neckles 2005)."

<u>Objective and Overview:</u> The objectives of this study quantify the extent of disturbance to eelgrass from commercial mussel harvesting and determine the time required for recovery in Maquoit Bay, Maine. The experiment examined plots representing three treatments: recently dredged for mussels (< 1 year), dredged for mussels in the past (> 2 years), and undisturbed. Sites were assumed to have been harvested with dredges hauled along the bottom. The dredge consist of a steel frame with a chain-link bag for the catch.

System Energy: Maquoit Bay in Maine is a shallow estuary that covers approximately 1013 ha with tides of 4 m.

Bottom Type: The bottom sediments consist of mud with extensive eelgrass meadows.

Analysis

Species: *Zostera marina,* eelgrass

Results / Conclusion: At the < 1 year since harvest sites, there was significantly less shoot density than the undisturbed, approximately 2-3 % of reference densities. Shoot height and eelgrass biomass were also significantly shorter in the harvested sites. In the areas that were harvested more than two years prior there was no difference in shoot morphometric, percent canopy cover, or shoot density when compared to eelgrass beds in undisturbed. Total eelgrass biomass was significantly lower at harvested sites then reference bed. There were no significant differences in any measured sediment characteristics between disturbed and reference sites.

The study did show there was some disturbance on eelgrass caused by bottom dredging.

Possible Faults

- The description of the dredges is lacking detail and assumes what type was used.

- There is some site selection bias. The treatment sites selected where chosen because of their noticeable disturbance patterns as experimental sites. Little information was known about the actual dredging that was occurring or the condition of the sites prior to harvesting.

Peterson, C.H., and J.A. Estes. Conservation and management of marine communities. In (M.D. Bertness, S.D. Gaines, M.E. Hay, eds) Marine community ecology, Sinauer Associates, Inc, Sunderland, MA, pp.469-507.

Context of Reference:

As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

As cited: "Direct and indirect mortality induced by shellfish harvest, recruitment, reproductive failures that delay population recovery, and shifts in species diversity toward smaller, short-lived and more mobile species can reduce the abundance of preferred prey items for higher trophic level predators such as amphipods, copepods, echinoderms, gastropods, crabs, fish, or birds (Peterson and Estes in press, Piersma et al. 2001, Verhulst et al. 2004)."

Objective and Overview: This chapter is an overview of the important anthropogenic factors effecting marine ecosystems. The goal of the text is to present the complexity and of marine systems and the many indirect ways humans affects them. By emphasizing the complexity of the systems, fisheries managers may be encouraged to make more holistic choices when making policy.

Results / Conclusion: Our present management processes are flawed and do not take into account the global influences in our marine systems.

Possible Flaws

- The report includes no data of its own, and the conclusions it meets are only distantly related to bottom disturbing fishing.

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. J. Appl. Ecol. 38:976–990

Context of Reference:
As cited: 'Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)'.

As cited: "Direct and indirect mortality induced by shellfish harvest, recruitment, reproductive failures that delay population recovery, and shifts in species diversity toward smaller, short-lived and more mobile species can reduce the abundance of preferred prey items for higher trophic level predators such as amphipods, copepods, echinoderms, gastropods, crabs, fish, or birds (Peterson and Estes in press, Piersma et al. 2001, Verhulst et al. 2004)."

Objective and Overview: The objective of the study was to identify any impact of shellfish harvest by documenting long term recovery patterns. By comparing sediment characteristics and bivalve stock in the areas that has been harvested for shellfish and undisturbed areas the study investigated the impact on intertidal communities intact and shellfish settlement. The site of the experiment was near Griend Island in the Dutch Wadden Sea. Cockle suction-dredges were used on harvest sites.

System Energy

Bottom Type: The sediment at the sites had an initial median grain size of 166.2 µm.

Analysis: Data was analyzed with a before after control impact (BACI) design and tested with Student's t-test for significance.

Species: *Cerastoderma, Macoma, Mya*

Results / Conclusion: For the sediment grain size analysis, there were significant temporal effects and differences between sites. There was no interaction between the time and site factors indicating no difference in the changes between sites. Similar analysis of silt content showed significant differences between sites and for select years some time and interaction term effect. The analysis of total density and biomass was significantly different between harvested sites and the control, but no difference between harvested sites. When analyzing specific species, the treatment sites exhibited significant decline in density for Cerastoderma and Mya when compared to the reference. Generally, Macoma was significantly higher in density for both site post-harvest and Cerastoderma spatfall was higher at the cockle harvested site.

Possible Faults

- There is some site selection bias. The site chosen for the reference was significantly different from the treatment sites in community and substrate. Analysis uses repeated t-test for comparisons and does not account for the increased chance of making a type I error, incorrectly rejecting the null hypothesis. Paper tries to account for the lack of pre-harvest data by comparing to a nearby site, which only highlights the variability in community. The author mentions extensive changes taking place during the harvest, but never acknowledges the effects they may have:

- From 1941, the western edge of the island of Griend has repeatedly been reshaped by various types of breakers and dikes. The last reconstructions were carried out during the summers of 1985 and 1988. A 2·5-km long sand dike was built west and north of the old circular island (Janssen et al. 1994). The central saltmarsh and creek were undisturbed.

Ray, G. L. 2005. Ecological functions of shallow, unvegetated estuarine habitats and potential dredging impacts (with emphasis on Chesapeake Bay), WRAP Technical Notes Collection (ERDC TN-WRAP-05-3), U. S. Army Engineer Research and Development Center, Vicksburg, MS. http://el.erdc.usace.army.mil/wrap (accessed December 2013).

Context of Reference:
As cited: "Depending on the spatial scale involved, changes in bottom topography can have profound effects on benthic infauna (Ray 2005)."

Objective: This report is a summary of what is known about the ecological functions of tidal waters ranging in depth from mean low water to 1.2 m below mean low water.

Conclusion: Little quantitative information is available about shallow water estuarine habitat, due in part to the vague definition of shallow waters.

Possible Faults

- The report has a strong emphasis on the potential impact of boating, particularly on birds. Also the dredging the report is researching is not commercial fishing, but navigational.

Stevenson, D., Chiarella L., Stephan, D., Reid, R., Wilhelm, K., McCarthy, J., Pentony, M. 2004. Characterization of the fishing practices and marine benthic ecosystems of the northeast US shelf, and an evaluation of the potential effects of fishing on essential habitat. NOAA Tech Memo NMFS NE 181; 179 p. http://www.nefsc.noaa.gov/nefsc/publications/ (last accessed January 2013).

Context of Reference: Stevenson et al (2004) provided a useful summary of available scientific information on physical and biological impacts for different gear and bottom types on the Essential Fish Habitat (EFH) around Monomoy refuge.

Objective: This report provides data and literature assistance for fulfilling the Essential Fish Habitat (EFH) mandates of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) for the NOAA Fisheries Service's Northeast Region. FMPs must include an evaluation of the potential adverse effects of fishing on EFH, including the effects of fishing activities regulated under other federal FMPs.

Possible faults

- FMPs must describe each fishing activity, and must review and discuss all available and relevant information such as information regarding the intensity, extent, and frequency of any adverse effect on EFH, the type of habitat within EFH that may be adversely affected, and the habitat functions that may be disturbed. In completing this evaluation, councils are expected to use the best scientific information available, as well as other appropriate information sources.

- The report was published in 2004, in the last decade relevant information and data may have become available. See Section 4.

- The report comes to no conclusions of its own, only summarizes other sources.

Verhulst, S., K. Oosterbeek, A. L. Rutten, and B. J. Ens. 2004. Shellfish fishery severely reduces condition and survival of oystercatchers despite creation of large marine protected areas. Ecology and Society 9(1): 17.

Context of Reference:
As cited: "Direct and indirect mortality induced by shellfish harvest, recruitment, reproductive failures that delay population recovery, and shifts in species diversity toward smaller, short-lived and more mobile species can reduce the abundance of preferred prey items for higher trophic level predators such as amphipods, copepods, echinoderms, gastropods, crabs, fish, or birds (Peterson and Estes in press, Piersma et al. 2001, Verhulst et al. 2004)."

As cited: "Impacts of hydraulic or mechanical shellfish dredges (such as rakes, plungers, or shovels) on intertidal bottom structure and benthic invertebrates are typically greater and longer lasting than those from hand harvest (Ferns et al. 2000, Piersma et al. 2001, MacKenzie and Pikanowski 2004, Verhulst et al. 2004, Munari et al. 2006, Kraan et al. 2007, and Peterson and Estes in press)."

Objective and Overview: The study used Marine Protected Areas (MPA) to investigate the effect of shellfish harvest on oystercatchers in the Dutch Wadden Sea. Oystercatchers where sampled for condition at shellfish harvested areas and undisturbed areas.

Species: *Cerastoderma edule* (cockle), *Haematopus ostralegus* (oystercatcher)

Results / Conclusion: The Dutch Wadden Sea exhibited significant decrease in oystercatcher population from 1987 to 1997. There was no significant difference in oystercatcher populations between harvested and the control MPAs. Oystercatcher bills in MPAs showed significantly more shellfish diet wear. Indexes of condition for birds were generally statistically lower in harvested areas.

Possible Faults

- Sample sizes are very low for some of the test.

- More information on the behaviors of the oystercatchers is needed to explain some of the assumptions about the selection of feeding grounds, condition sex biases, and sex bias prey choice.

2.1 Additional relevant literature

Bishop, M.J., C.H. Peterson, H.C. Summerson, D. Gaskill 2005. Effects of harvesting methods on sustainability of a bay scallop fishery: dredging uproots seagrass and displaces recruits. Fishery Bulletin, 103(4), pp. 712-719.

Objective and Overview:
The study ascertained the impact of dredge and hand scallop harvesting in seagrass through a comparison of controlled and impacted sites in Boque Sound, North Carolina.

Results / Conclusion:
Hand harvest had statistically higher efficiency. Dredging increased dislodgement of seagrass 127 times above natural drift, but it did not significantly reduce biomass in sampling one month after dredging. Hand harvest was more efficient and less damaging to seagrass beds. Dredging removed more biomass, but it also seemed to stimulate growth. Juvenile scallop abundance was depressed in dredged plots.

Sciberras, M., Hinz, H., Bennell, J.D. (2013) "Benthic community response to a scallop dredging closure within a dynamic seabed habitat." Marine Ecology Progress Series 480: 83-98.

Objective and Overview:
The study examined the impact of the intensity of scallop dredging on benthic communities in Cardigan Bay, Wales.

Site Characteristics:
Cardigan Bay has moderate energy levels with a substrate consisting of ribbons of sand and gravel.

Results / Conclusion:
Environmental characteristics did not significantly differ between control and treatment. No significant differences were found in communities between dredged and protected areas for any time period. Scallop density and benthic communities were not significantly different for comparisons of areas where dredging was allowed for 6 months, a year, and permanently closed.

LeBlanc, Stéphan N., Hugues P. Benoît, Heather L. Hunt. 2014 Broad-scale abundance changes are more prevalent than acute fishing impacts in an experimental study of scallop dredging intensity. Fisheries Research 161: 8-20.

Objective and Overview:
The study evaluated the impact of different intensities of scallop dredging in the southern Gulf of St. Lawrence, Canada.

Site Characteristics:
Northumberland Strait: The depth at this site was 20-26m and the substrate consisted of sand-gravel and bedrock.
Baie des Chaleurs: The depth at this site was 7-10 m and the substrate consisted of gravel-cobble.

Results / Conclusion:
Fishing intensity was not significant at the individual taxa level in the short-term or long-term. At the community level, there was a significant short-term negative effect of fishing intensity, but not a long-term effect. Hydraulic dredging had the highest impact on substrate, followed by scallop dredges and otter trawls, then fixed gear. Hard substrates were more vulnerable to impact than soft substrates.

Lindholm, J., Auster, P., & Valentine, P. 2004. Role of a large marine protected area for conserving landscape attributes of sand habitats on Georges Bank (NW Atlantic). Marine Ecology Progress Series, 269, 61-68.

Objective and Overview:
The study compared sand microhabitats in fished and unfished areas on the Georges Bank. The microhabitats investigated were featureless sand, rippled sand, sand with emergent fauna, bare gravelly sand, gravelly sand with attached fauna, whole shell, shell fragments, sponges, and biogenic depressions.

Site Characteristics:
Closed Area II: Nine of the sites were in <60 m of water (mobile sand), the rest were deeper than 60 m (immobile sand).

Results / Conclusion:
Water depth was a highly significant factor in the abundance of emergent fauna, featureless sand, and rippled sand microhabitats. Shell fragment microhabitat abundance was significantly different between fished and unfished areas. There were few measureable differences in a site closed to fishing for 4.5 years on Georges Bank compared to fished areas. Depth also was an important factor in the abundance of microhabitat.

Stokesbury, K. D., & Harris, B. P. 2006. Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. Marine Ecology Progress Series, 307, 85-100.

Objective and Overview:
The study examined similarity indices, taxonomic category diversity, and individual abundance within each category in an area impacted by a short-term sea scallop fishery on Georges Bank.

Site Characteristics:
Closed Area II (CAII): Mean water depth was 61 m for control and treatment. Each area had mid-water currents of approximately 45 cm s^{-1} (Brown and Moody 1987). The substrate consisted of more than 86% sand and granule/pebble.
Nantucket Lightship Closed Area (NLCA): Mean water depth was 52 m for the control and 66 m for the treatment. The area had mid-water currents of approximately 60 cm s^{-1} (Brown and Moody 1987). The substrate consisted of more than 74% sand and granule/pebbles.

Results / Conclusion:
CAII: Sea scallop, bryozoans/hydrozoans, starfish, hermit crabs, and sponges were significantly different in September 1999 compared to July 2001 for the control and July 1999 and July 2001 for treated areas. Sea scallop, bryozoans/hydrozoans, other fish, sponges, skates, crabs, and haddock were significantly different in July 1999 compared to August 2000 for the treated area. Sea scallop, bryozoans/hydrozoans, other fish, skates, hake, haddock, eelpout, crabs, and hermit crabs were

significantly different in August 2000 compared to October 2000 for the treated area. Sea scallop, starfish, other fish, hake were significantly different in Oct 2000 compared to July 2001 for the treated area.
NLCA: Sea scallop and bryozoans/hydrozoans were significantly different in August 2000 compared to June 2001 for treated areas. Starfish, bryozoans/hydrozoans, and hake were significantly different in July 1999 compared to August 2000 for the control area and other fish and hake were significantly different for the treated area for the same time period.
Differences found at treatments sites during the experiment were similar to differences found at control site. Additionally, there were significant changes in fauna and substrate composition between all surveys in control and treated areas supporting the theory that limited fishing effort alters benthic habitat less than natural disturbance on Georges Bank.

Sullivan, M. C., Cowen, R. K., Able, K. W., & Fahay, M. P. (2003). Effects of anthropogenic and natural disturbance on a recently settled continental shelf flatfish. Marine Ecology Progress Series, 260, 237-253.

Objective and Overview:
The study explored the effect of mobile commercial scallop dredge harvesting on yellowtail flounder and its nursery habitat on New York Bight.

Site Characteristics:
New York Bight: The sites chosen for the study were in 45, 67, and 88 m of water.

Results / Conclusions:
There was a significant short-term increase in yellowtail abundance post-treatment at the dredge sites. Seasonal differences obscured any long-term dredging effect trends. Differences in plots indicated strong spatial variability in abundance. Size structure in yellowtail shifted towards smaller individuals at two of the three study sites. There was no significant effect of dredging on benthic prey abundance, but there was significant seasonal variability.
Dredging was followed by an increase in yellowtail abundance, seasonal trends strongly affected abundance of both yellowtail and benthic prey, and natural disturbance of the bottom was strong in the study area and beyond the mid-continental shelf.

Table 1. A summary of shorebirds present in the Monomoy area and a description of their diets.

Common Name	Diet
Piping Plover	Polychaetes (Nereis sp), Amphipod, isopod, diptera larvae
Semipalmated Plover	Polychaetes (Capitellidae, Spionidae) Oligochaete worms, Horseshoe crab eggs (Limulus polyphemus)
American Golden Plover	Insects, Small Invertebrates
Black-bellied Plover	Polychaetes (Nereis Succienea), Small Mys sp.
American Oystercatcher	Bivalves, Starfish, Crabs, Jellyfish, Horseshoe mussel (Modiolis demissus)cockles (Cerastoderma edule) and mussels (Mytilus edulis)
Ruddy Turnstone	Mostly Crabs, Clams, Littorinid snails, amphipods, Horseshoe crab eggs (Limulus polyphemus)
Red Knot	Horseshoe crab eggs (Limulus polyphemus), Gem clams?
Sanderling	Polychaetes (Capitellidae, Spionidae, Horseshoe crab eggs (Limulus polyphemus)
Dunlin	Nephtys sp, Phyllodocids, Spionids
White-rumped Sandpiper	Small Aquatic Invertebrates, Insects
Western Sandpiper	Small Aquatic Invertebrates, Insects, polychaetes
Pectoral Sandpiper	Insects, Small Invertebrates
Least Sandpiper	Polychaetes, Oligochaete worms, Horseshoe crab eggs (Limulus polyphemus)
Semipalmated Sandpiper	Small Aquatic Invertebrates, amphipod crustacean Corophium volutator
Willet	Small Aquatic Invertebrates, Insects, Surface-dwelling fastropod (cerithidea californica)pelecypods, amphipods
Short-billed Dowitcher	Small Aquatic Invertebrates, Insects
Long-billed Dowitcher	Small Aquatic Invertebrates, Insects
Marbled Godwit	Small Aquatic Invertebrates, Insects
Hudsonian Godwit	Small Aquatic Invertebrates, Insects
Whimbrel	Small Aquatic Invertebrates, Insects, Fish
Glossy Ibis	Crustaceans, Insects, Reptiles, Amphibians
Herring Gull	Fish, Squid, Invertebrates, Crustaceans, Birds, Mammals, Carrion
Laughing Gull	Insects, Fish, Squid, Invertebrates, Crustaceans, Birds, Mammals, Carrion
Great Black-backed Gull	Fish, Invertebrates, Birds, Carrion, Offal
Black Skimmer	Fish, Crustaceans shrimp
Least Tern	Fish, Invertebrates
Roseate Tern	Fish, Invertebrates
Common Tern	Fish, Crustaceans, Insects
Eider duck	Mollusca

Section 3. Fishing Effects: New England Federal Commercial Fisheries[1]

Stevenson et al. (2004) produced NOAA Technical Memorandum NMFS-NE-181 entitled *Characterization of the Fishing Practices and Marine Benthic Ecosystems of the Northeast U.S. Shelf, and an Evaluation of the Potential Effects of Fishing on Essential Fish Habitat*. This report was written by members of the Northeast Region Essential Fish Habitat Steering Committee between 2001 and 2004 "*to provide assistance in meeting the Essential Fish Habitat (EFH) mandates of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) for the NOAA Fisheries Service's Northeast Region*". This work was subsumed by a much more extensive report developed by the New England Fisheries Management Council's Habitat/ Ecosystems/ Marine Protected Areas Plan Development Team in 2011 (see NEFMC 2011). Subsequently, the main findings of NEFMC (2011) were published by Grabowski et al (2014). Importantly, a number of the core findings resulting from the NEFMC (2011) literature review were directly investigated by Harris et al. (2014).

New England Fishery Management Council (2011). The Swept Area Seabed Impact (SASI) approach: a tool for analyzing the effects of fishing on essential fish habitat. Newburyport, MA: New England Fishery Management Council Report.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires fishery management plans to minimize, to the extent practicable, the adverse effects of fishing on fish habitats. To meet this requirement, fishery managers would ideally be able to quantify such effects and visualize their distributions across space and time. Members of theNew England Fisheries Management Council's Habitat/ Ecosystems/ Marine Protected Areas Plan Development Team created the Swept Area Seabed Impact (SASI) model to provide such a framework, enabling managers to better understand: (1) the nature of fishing gear impacts on benthic habitats, (2) the spatial distribution of benthic habitat vulnerability to particular fishing gears, and (3) the spatial and temporal distribution of realized adverse effects from fishing activities on benthic habitats.

SASI translates literature based habitat feature susceptibility and recovery information into quantitative modifiers of swept area. The model combines area swept fishing effort data with substrate data and benthic boundary water flow estimates in a geo-referenced, GIS-compatible environment. Contact and vulnerability-adjusted area swept, a proxy for the degree of adverse effect, is calculated by conditioning a nominal area swept value, indexed across units of fishing effort and primary gear types, by the nature of the fishing gear impact, the susceptibility of benthic habitats likely to be impacted, and the time required for those habitats to return to their pre-impact functional value.

First, the authors conducted a formal vulnerability assessment that served two related purposes: (1) a review of the habitat impacts literature relevant to Northeast US fishing gears and seabed types, and (2) a framework for organizing and generating quantitative susceptibility and recovery parameters for use in the SASI model. The vulnerability assessment **only considers adverse (vs. positive) effects and effects on habitat associated with the seabed (vs. the seabed and the water column). This bounding does not preclude the possibility of positive impacts from fishing on seabed structures or fauna, nor is it intended to indicate that the water column is not influential habitat for fish. The former is possible, and the latter is likely. However, as per the EFH Final Rule, only adverse effects are considered and,**

[1] *Contributed by The Fisheries, Aquatic Science, & Technology (FAST) Laboratory at Alaska Pacific University, Director - Brad Harris, Ph.D.*

because fishing gears do not substantively alter the water column, effects from fishing on the pelagic water column are assumed to be negligible. This assessment was published by Grabowski et al. (2014).

Next, they describe and parameterize the nominal and contact adjusted area-swept of otter trawls, (including groundfish, scallop trawls, shrimp trawls, squid trawls, and raised footrope trawls), New Bedford-style scallop dredges, hydraulic clam dredges, demersal longlines, sinking gill nets, and traps. They then defined physical seabed habitats spatially using the available substrate and model-derived benthic boundary shear stress (natural disturbance) data; geological and biological features were than inferred to these habitats. Next adverse effects from fishing were estimated spatially by implementing the vulnerability matrices locally. This involved combining an unstructured grid (Voronoi tessellation) based on the locations of geological samples and a 10 x 10 km structured grid based on simulated fishing effort and on realized effort from 1996 to 2008 based on Vessel Trip Reports. The sensitivity of the simulated results to variations in recovery duration, susceptibility and recovery scoring, and geological and biological feature weighting was explored. Next the authors used sophisticated spatial statistical analyses to assess the spatial structure of the simulated results and to identify fishing effect "hotspots". A novel "equal-area permutation test" was developed to assess the relative efficacy of existing closures. Then the practicability (or opportunity costs) were assessed to (1) understand and quantify the trade-offs inherent in the use of durable fishing gear closed areas, (2) define measurable thresholds for achieving the requirements to minimize adverse effects on habitat from fishing to the extent practicable, and (3) assess the potential changes in aggregate adverse effects from opening currently closed areas.

This report concludes with an analysis to determine whether or not aggregate adverse fishing effects would increase or decrease after opening a previously closed area, given existing profit-to-adverse effect relationships in the vicinity of the potential opening and reasonable assumptions about how those relationships would translate onto newly opened fishing grounds. The authors report that due to the redistribution and dispersal of fishing effort and the relative similarity of habitats inside and outside of the closed areas that "... *for nearly all area and gear type combinations,* ***opening existing closed areas to fishing is predicted to decrease aggregate adverse effects. For mobile bottom tending gears, which comprise nearly 99% of all adverse effects in our region, allowing fishing in almost any portion of the area closures on Georges Bank is estimated to substantially decrease total adverse effects from fishing****. Closures in the Gulf of Maine appear to also decrease aggregate adverse effects, but the magnitude of these reductions is substantially smaller."*

Grabowski, J. H., Bachman, M., Demarest, C., Eayrs, S., Harris, B. P., Malkoski, V., Packer, D., Stevenson, D. (2014). Assessing the Vulnerability of Marine Benthos to Fishing Gear Impacts. Reviews in Fisheries Science & Aquaculture, 22(2), 142–155.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires US fishery management plans to minimize, to the extent practicable, the adverse effects of fishing on essential fish habitats (EFHs). Grabowski et al (2014) described development of a formal vulnerability assessment in which 97 publications were reviewed by NEFMC (2011). To meet this requirement the authors developed a framework to quantify and assess benthic impacts of the six most common bottom disturbing gears (>99% of bottom disturbing fishing effort) in New England: otter trawls, scallop dredges, hydraulic clam dredges, gillnets, longlines, and traps. After a comprehensive review of the habitat impacts literature relevant to Northeast USA fishing gears and seabed types the authors developed a framework for generating and organizing quantitative susceptibility (based on percent loss of structural habitat from a single interaction with the gear) and recovery (i.e., the time required for recovery of lost structure) parameters for each biological (e.g., sponges) and geological (e.g., sand ripples) feature common to the following five substrates: mud, sand, granule–pebble, cobble, and boulder in low- and high-energy environments.

In general, they found that both susceptibility and recovery scores were highest for hydraulic dredges and lowest for fixed gears (e.g., traps). For bottom trawls and scallop dredges, geological features in mud, sand, and cobble-dominated substrates were more susceptible to gear impacts than features found in granule–pebble and boulder substrates. Biological features were equally susceptible to impacts across the five substrate types. Susceptibility of biological and geological substrate features was not affected by energy level and geological features affected by bottom trawls and dredges took longer to recover in low-energy granule–pebble, and low- and high-energy cobble and boulder than in mud and sand substrates. Biological feature recovery times did not vary by substrate or energy level. The authors suggest that cobble and boulder substrates are the most vulnerable to impacts from mobile bottom disturbing gear. They highlight the importance of considering the resilience of specific components of habitat such as emergent epifauna or geological formations that serve as EFH by providing shelter and a source of food for fish.

Harris, B.P., Stokesbury, K. D. E. and Grabowski J. H. 2014. Effects of mobile fishing gear on geological and biological structure: A Georges Bank closed versus open area comparison. Final Report, 2011 Atlantic Sea Scallop Research Set-Aside Program Grant: NOAA/NMFS NA11NMF4540026.

Harris et al. (2014) were awarded Scallop Research Set-aside funding to examine the differences in taxa density, the presence- absence of biological and geological structures, the percent area covered by the structures and the vertical heights of structure-forming taxa at two study sites on Georges Bank with adjacent fished (*Impact*) and 17-year old closure (*Reserve*) areas.

Using a battery of tests on physical and biological characteristics, they established that *Impact* and *Reserve* areas within the study site were appropriately similar replicates that differed in the amount of trawl and dredge fishing effort they had endured over the past 17 years (i.e. study site “treatments”). Based on the high levels of ongoing and observed past trawl and dredge fishing in the *Impact* areas, they expected to find clear and profound evidence of damage compared to the *Reserve* areas with mobile fishing gear prohibitions.

The Northern Edge and the Little Georges study areas were surveyed in June 2011. Sixty random stations were selected in the *Reserve* and *Impact* areas of both study sites and at each station four replicate samples were collected using live feed video and still cameras. The authors employed sophisticated generalized linear mixed models (GLMM) implemented in a Bayesian framework to examine the differences in density, presence/ absence, and areal coverage of the biological and geological structures in *Impact* and *Reserve* areas. Separate regressions were run for taxa or taxonomic groups, and for the coverage of all biological structures combined. Presence/ absence data and percent cover were modeled using Binomial GLMMs; density data were modeled using a Normal GLMM. Previous video survey work on Georges Bank showed strong local autocorrelation in habitat features (Harris and Stokesbury 2010) and species distributions (Adams et al. 2010). Generalized linear mixed models were appropriate given the hierarchical structure of the two-stage sampling design, controlling for potential pseudoreplication associated with replicate quadrats within stations. In all cases (except vertical height; see below) the models were fit with Reserve (*Impact* or *Reserve*), Site (LG or NE), and a Reserve x Site interaction as fixed effects, and Station (nesting quadrats) as a normally distributed random intercept.

The authors found no clear pattern in density, presence-absence, areal coverage or vertical height of biological or geological features between *Impact* and *Reserve* areas within the two study sites. Overall 68 tests were expected to show positive reserve effects; 16 had insufficient data for modeling and of the remaining 52, 33% were positive, 31% were negative and 37% showed no reserve effects (Figure 1). Twenty-eight tests were expected to show negative reserve effects; 18% were positive, 32% were negative and 50% showed no reserve effect (Figure 2).

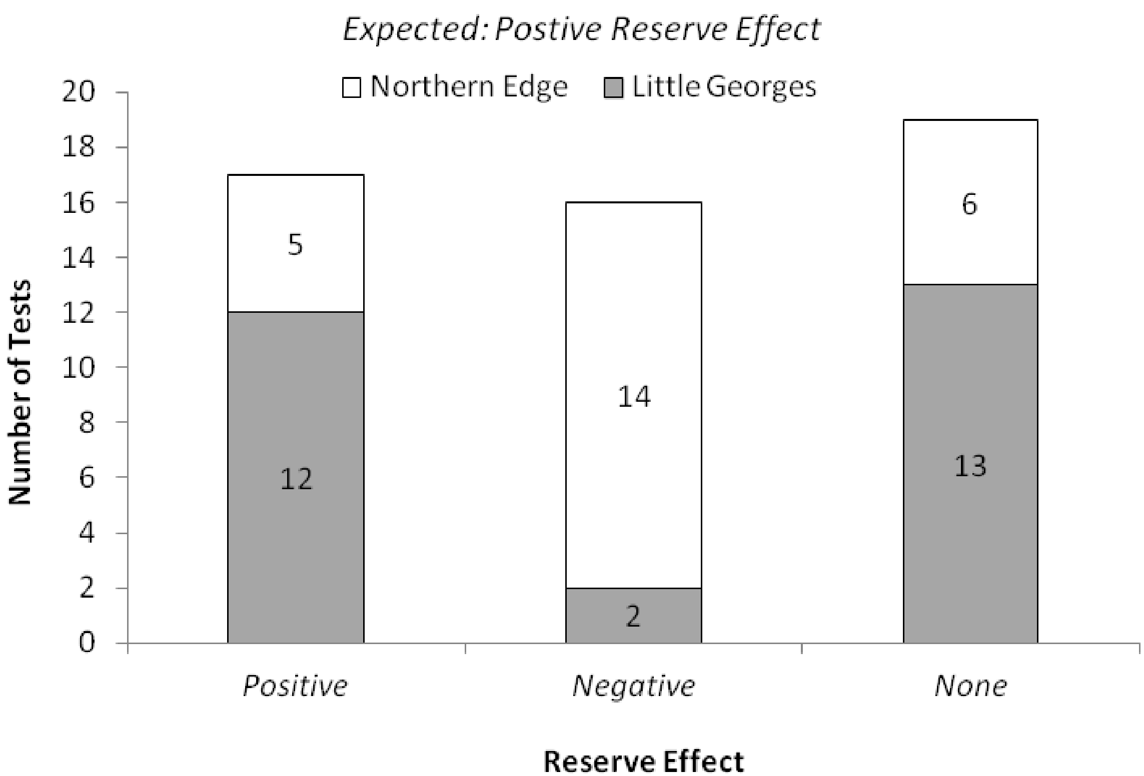

Figure 1. The number of tests indicating significant (positive or negative) and non-significant (none) reserve effects for the Little Georges and Northern Edge study sites. All were expected to show positive effects.

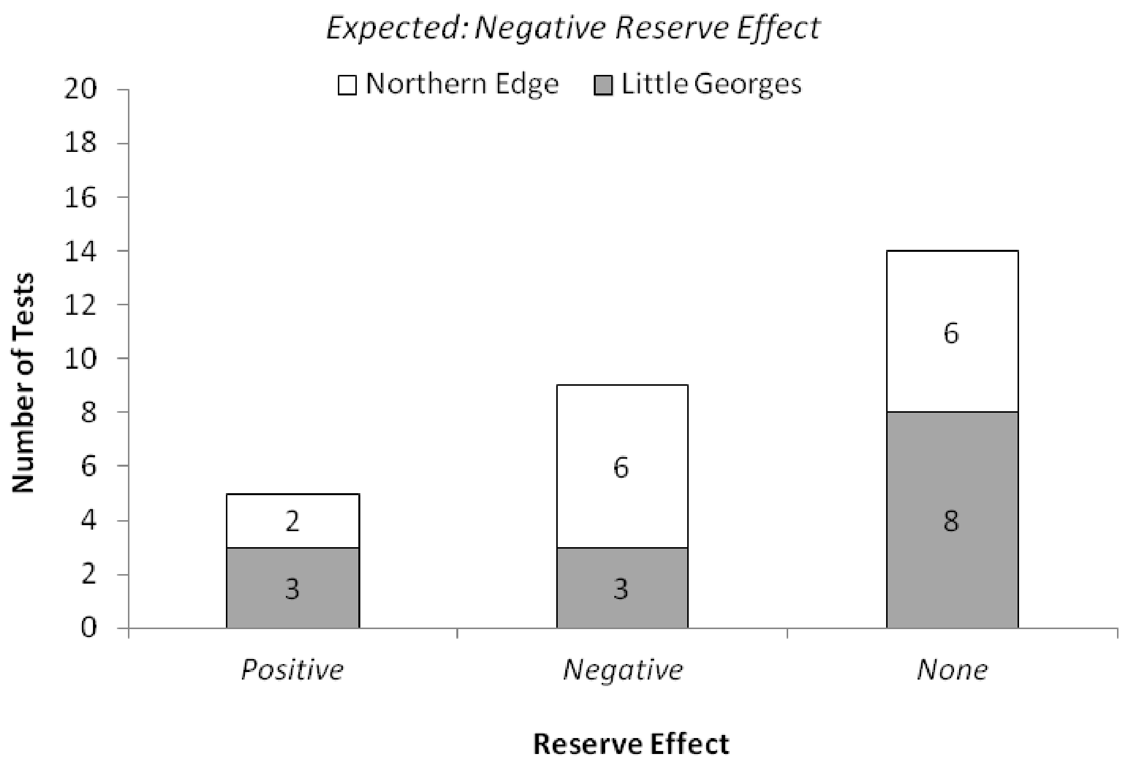

Figure 2. The number of tests indicating significant (positive or negative) and non-significant (none) reserve effects for the Little Georges and Northern Edge study sites. All were expected to show negative effects.

Results varied by study site, test type and feature. For example, the authors found that Bryozoans were more likely to occur and covered more area in the Little Georges *Reserve* area, but the opposite pattern occurred in Northern Edge; gravel pavements were more likely to occur in the Northern Edge *Reserve* areas but were less likely in the Little Georges *Reserve.* The reserve effects were inconsistent across study sites and were manifest in a broad range of biological and geological features. **The use of replicate study areas at two sites and an array of measures (density, presence-absence, cover, vertical height) provided substantial insight into the localized nature of fishing impacts. For example, data analysis would have led to different conclusions about the effect of fishing on benthic structures had the authors focused on only a single study site or feature type.** Evidence from Little Georges suggests that Closed Area I largely had no effect (51%) or a positive effect (37%) on features. In contrast, the Northern Edge tests indicate that Closed Area II typically had a negative effect on biological and geological structures (51%), with the remainder of structures exhibiting no effect (31%) or a positive effect (18%).

In prior work, Grabowski et al. (2014) identified 6 biological or geological features found in high-energy gravel habitats that were expected to experience more than 25% removal per trawl or dredge tow and require more than 2 years for recovery (Table 2). Of these, no piled gravel was detected in either study site, and only mussels showed a positive reserve effect (in the Northern Edge site). All other structures showed no effect or were either more likely to occur or covered more area in the *Impact* areas.

Table 2. Table indicating the susceptibility (% of structure removed) and recovery times (years) for six features expected to show strong positive reserve effects. Test results for the Little Georges (LG) and Northern Edge (NE) study sites are shown with symbols where "+" means significantly more in the reserve, "-" means significantly less in the reserve, " ≈" means no difference, and "na" means the feature was not detected.

	Susceptibility	**Recovery**	**Reserve Effect**	
Feature	*% of structure removed per tow*	*years*	*LG*	*NE*
Piled Gravel	> 50	> 5	na	na
Actinarian Anemones	25 - 50	2 – 5	≈	-
Brachiopods	25 - 50	2 – 5	≈	≈
Mussels	25 - 50	> 5	na	+
Filograna implexa	25 - 50	2 – 5	na	-
Sponges	25 - 50	2 – 5	≈	-

Prior to 1994, both the *Impact* and *Reserve* areas had experienced a long-term historical regime of intensive fishing. It is possible that the recovery period since the 1994 closures was too short to initiate substantial benthic community recovery. However, the review by Grabowski et al. (2014) indicates that 17 years is ample time for a wide range of benthic taxa to recruit and reach mature sizes, as well as time for some geological features to recover. The failure of geological features such as gravel piles to recover, which they found to be an important determinant of why coarse substrates are more vulnerable to mobile fishing gear, could explain the mixed results observed here on reserve effects. Collie et al. (2005) found fishing effects on gravel habitats near the Northern Edge study sites, and they speculated that 10 years may be required for community recovery. For both study sites, the reserve effect was significant for 49-69% of the metrics quantified, albeit with effects in both positive and negative directions, suggesting that the *Reserve* and *Impact* areas are substantially different. These differences could stem from inherent differences in the sites independent of reserve status. The authors found interaction between *Reserve* and sheer stress, with higher sheer stress observed at the Northern Edge where reserve effects were more commonly found to be negative. For many sessile erect species, increased sheer stress likely has a negative effect on their ability to recruit, survive, and grow tall in these environments.

Harris et al. (2014) suggest that the question regarding the relative importance of the drivers behind the observed distribution of biological and geological features which may provide essential habitat for managed fish species remains open. These drivers include natural physical disturbance regimes (e.g. currents and storms), recruitment delivery and settlement dynamics, trophic interactions, and mobile fishing gear contact. Generally, disturbances due to fishing are considered the primary driver of these distributions, but this work **suggests that in high energy regimes, natural disturbance and other ecological processes may be equally or more important. It is plausible that the distribution of biological and geological features in our study areas are more influenced by powerful tidal currents and frequent winter storm events (Harris et al. 2012), and frequent strong recruitment events (*sensu* Tian et al. 2009a and b) than by sustained and intensive fishing.**

Section 4. Assessment of the Collie, Escanero, and Valentine 1997 and 2000 papers on the impacts of benthic fishing.[2]

4.1 Introduction

We assessed the methodology, results, and interpretation of results for two highly cited papers regarding the impacts of fishing on benthic fauna in the NW Atlantic: Collie, Escanero, and Valentine 1997 (cited 355 times as of 9.9.14 according to scholar.google.com) and 2000 (cited 112 times), hereafter referred to as CEV1997 and CEV2000. Here we first briefly summarize CEV1997 and CEV2000, and then present our assessment of the strengths and weaknesses of the inference made from the papers.

4.2 Summary

CEV1997 uses benthic grab samples taken from a Naturalist dredge to compare benthic fauna assemblages at 6 study sites on Georges Bank (NW Atlantic) spanning a range of fishing-related disturbance levels that are believed to be of either no benthic fishing contact or high benthic fishing contact from trawl and dredge fishing. The study region and all study sites are focused on cobble pavement habitat, and sites were sampled over two April and November 1994 research cruises. The strength of fishing disturbance was assessed a priori by coarse scale effort information on commercial fishing in the region, and in situ by looking for evidence of trawl or dredge scars as well as using extant fauna to suggest whether fishing disturbance had been present in recent history. Data analysis operated on a suite of five ecological indices for the benthic communities: abundance, biomass, species richness (number of species), species diversity index (Shannon-Wiener), and species evenness. Benthic taxonomic information was screened for taxa not reliably sampled by the Naturalist dredge—chiefly excluding colonial animals and very small animals. Finally, size distributions of select taxa were also compared across sites. Statistical analysis included ANOVA, multivariate ordination (TWINSPAN) to identify taxa groupings by similarity, and finally Kolmogorov-Smirnov tests of size distributions. Results showed considerable variability across both undisturbed and disturbed sites, with deep sites as a group being different than shallow sites as a group. Results also showed significant effects of fishing disturbance “treatment” having a negative effect on abundance, biomass, and species diversity; no statistically significant or biologically significant results were found in terms of evenness, and no consistent pattern was found in terms of the size distributions of abundant species at disturbed or undisturbed sites. The authors’ key conclusions from the data are that across a gradient of depths and disturbance, benthic fishing has an impact on faunal communities on cobble pavement with structure forming sedentary invertebrates and brittle or fragile mobile invertebrates being most affected. Mobile scavengers were less affected by assumed treatments.

CEV2000 used data collected during the same research cruises as for CEV1997, however, only 5 of the 6 study sites were used. Data in this effort were taken from video and still photographic images. Non-overlapping images were viewed and assessed for substrate composition categories, the presence/absence of attached epifauna, and counts of megafaunal taxa when possible. Shannon diversity and evenness were then generated for count data. Data analysis involved frequency table analyses (tests of independence) for sediment category data, ANOVA for presence/absence frequency of

[2] *Contributed by The Fisheries, Aquatic Science, & Technology (FAST) Laboratory at Alaska Pacific University, Director - Brad Harris, Ph.D.*

select epifauna groups, ANOVA for percent cover of emergent epifauna (as one functional group), (implicit) t-tests for percent cover of emergent epifauna, (implicit) t-tests for counts of all epifauna as one functional group, (implicit) t-tests for the two diversity measures, frequency table analyses for biological count data, and multivariate ordination (TWINSPAN) to identify taxa groupings by similarity. Statistical tests comparing site-level data enjoyed high numbers of data points (video frames or still images) and thus identified high statistical significance in many cases, although biological significance was not always as evident. Still photographic images had higher resolution and identified more taxa than still frames from video data. Substrate data suggested statistically significant differences across all sites, however data indicated that all sites were dominated by pebble/cobble habitat. Video data showed substantial differences in the benthic communities at deep versus shallow sites, with deep sites containing a greater diversity of taxa. These data also showed both positive and negative effects associated with treatment sites, indicating substantial site-to-site variability in benthic communities. Similarly, the effect of assumed "treatment" manifested in opposite directions for shallow vs. deep sites for the percent cover of epifauna and the count-related indices (abundance, Shannon diversity, evenness), whereby "treatment" disturbance had a negative effect at deep sites and a positive effect at shallow sites. As with CEV1997, TWINSPAN found similarity amongst delicate taxa more strongly associated with undisturbed deep sites, and highly mobile taxa at disturbed sites. Conclusions from CEV2000 are analogous to CEV1997 insofar that delicate and biological structure forming taxa on cobble pavement may be sensitive to dredge and trawl fishing.

4.3 Strengths

Both CEV1997 and CEV2000 benefited from detailed data at a relatively high taxonomic resolution. Furthermore, the study included both spatial replication and temporal replication, albeit at a moderate level (6 or 5 sites, two occasions). Combined together, the two studies present a deep examination of benthic communities present in the sampled points, encompassing both video/still images as well as benthic grab samples. The statistical analyses were generally appropriate and included standard tests of means and frequencies, augmented with community-level metrics and multivariate analysis, thereby providing a picture of both specific taxa of interest and benthic communities as a whole. The analyses relied heavily on transforming data to fit the Normality assumptions of standard comparison of means tests (ANOVA, implicit t-tests), whereas explicitly modeling non-normal data using GLM(M) modeling would have better matched the data collected and allowed for more straightforward interpretation of data (e.g. as opposed to attaching meaning to an effect size in arcsine square root units). Nevertheless, statistical significance was typically < 0.05 and likely was robust to possible deviations from Normality for transformed data.

4.4 Weaknesses

Below, our critique of the CEV papers are categorized by statistical, study design, and interpretation based critique.

4.4.1 Statistical

- 1) The authors implement a nested design for both papers. In CEV1997 they use 6 study sites nesting 3 or more replicates within station within site. Similarly, in CEV2000 many video still frame and photographic still "replicates" were taken in close spatial proximity. Statistical analyses did not account for the nested structure of the data, for example through use of random effects at the station level or site level, in order to account for potential pseudoreplication by using data nested in space. The consequences of this are that p-values associated with tests for treatment, depth, or other effects may be too low (because the statistical models implicitly assume there is more independent information than may exist in reality). While ultimately, the discrepancy between inferences corrected for pseudoreplication versus the author's approach without control for nestedness in the data would require rerunning the authors' data with appropriate statistical models, it is noted that p-values in CEV1997 and CEV2000 were generally << 0.05 and thus probably did not result in incorrect inference (over-tendency to reject null hypotheses of no effect).

- 2) Sampling effort, as measured as the number of still video frames and photographic stills, was high in the CEV2000 paper, resulting in high statistical sensitivity and low p-values; however, in many cases it is not clear whether the results were biologically significant. Furthermore, it is difficult to attach interpretation to effect size differences for almost all of the data presented with the exception of untransformed numerical abundance data. For example, it is not clear what a 0.05 unit evenness discrepancy entails (e.g. CEV1997 Figure 6) or what a 25 unit "transformed biomass" (CEV1997 Figure 4) indicates. The implications of this are that, while CEV1997 in particular demonstrated a clear difference between disturbed and undisturbed sites, the biological magnitude or relevance of the observed differences is not clearly described.

4.4.2. Study design

- 3) Perhaps the most significant critique in our opinion of the CEV1997 and CEV2000 papers is that sampling locations were chosen a priori to maximize the observed difference in benthic communities between "undisturbed" and "disturbed" sites. While coarse scale fishing effort data were used to select spatial regions to search for study sites, ultimately the study sites, the stations within them, and the replicates at stations were chosen by finding physical evidence of fishing impacts and by using the extant assemblages of benthic fauna to suggest treatment level (i.e. fishing disturbed or not). Then the data are used to confirm that targeted sites-> stations -> replicates are indeed biologically different. For example, CEV1997 notes "The presence or absence of epifauna in the videos gave a second measure of degree of disturbance (pg 161)." Later in the same paper, it is noted that "Station locations were selected to be representative of the site and to provide contrast between disturbed and undisturbed sites." The implication of this is that the logic of the study is circular: a) the a priori hypothesis is that benthic fishing gear disturbs and changes benthic faunal communities, b) in searching for study locations, sites/stations/replicates that evince disturbed benthic communities must evince fishing disturbance and are thus asserted as "treatment" sites, and finally, c) the data show that sites have different benthic communities between sites asserted as undisturbed vs. those asserted as disturbed, thus the a prior hypothesis is confirmed. In such a chain of events, then it is not possible to separate out whether differences between benthic communities at study sites (which the authors have done a good job at describing and quantifying) are due to fishing disturbance of due to other reasons such as spatial variability in the distribution of benthic communities.

- 4) In a related comment to the use of the data to select treatment vs. control sites, the accuracy of the asserted treatment levels themselves is not clear. For example, the authors point out in CEV1997 (e.g. Table 1) and CEV2000 (pg. 1000) that the history of disturbance at sites is not clear, noting that some of the "undisturbed" sites—which were found to have richer benthic communities and were inferred as being less impacted than "treatment" sites—had evidence of prior fishing disturbance. Thus to some unknown degree, the authors may have been comparing a suite of sites that had previously experienced fishing gear. If the sites were not accurately categorized as fished/not fished but yet still yielded strong site-level differences, then this may be indication of strong site to site variability in benthic communities regardless of fishing history.

- 5) Importantly, the study design may suffer from endogeneity issues: dredge and trawl fishing occurs where scallops are highest, and scallop habitat may be associated with a different benthic community such that differences between fished vs. unfished sites would a priori have differences in benthic communities independent of any impacts from fishing. In fact, the data presented in CEV2000 show that "disturbed" sites do have higher incidence of scallop (CEV2000 Table 3A). It is not clear from the studies whether good scallop habitat looks "disturbed" relative to poor scallop habitat—for example, are scallop naturally negatively correlated with "fragile" polychaetes such as *F. implexa* for which the authors indicate are most susceptible to fishing impacts (CEV1997 pg. 162)? Or are bushy "plant like" benthic fauna naturally negatively associated with good scallop habitat (cf. CEV2000)? If so, then it is not clear whether fishing may "follow" scallop-like habitat, as opposed to producing scallop-like habitat (although conceivably a positive feedback loop is possible if dredge or bottom trawl disturbance produces habitat amenable to scallop rearing or recruitment).

- 6) Given the nested structure of the data, the study has little replication at the site level. For example, CEV2000 has two sites for deep-undisturbed, but then singular combinations of deep-disturbed, shallow-undisturbed, and shallow-disturbed. Thus, inference at the site-level is confounded between depth and disturbance regime (also see comment #4 above). For example, **one cannot refer in CEV2000 whether differences associated with disturbance are due to fishing impacts or site-to-site natural variability.** In CEV2000 in fact, the authors find that outcomes associated with "disturbance" work in opposite directions for deep vs. shallow sites—with only singular combinations of depth-disturbance level, and with potentially inaccurate disturbance "treatment" histories asserted at sites (comment #4 above), these results may be reflecting natural site-to-site variability.

- 7) Minor point: No indication is given as to why site # 11 (deep-undisturbed) was included in CEV1997 but not included in CEV2000. This site in question appeared to have behaved consistently with the other two deep-undisturbed sites in CEV1997, but with greater intra-site variability in metrics. It is not clear whether inclusion of site #11 in CEV2000 analyses would have affected inference from the study.

4.4.3 Interpretation

- 8) Results of CEV1997 and CEV2000 are specific to cobble pavement, as the authors do a good job at quantifying in CEV2000. Cobble pavement habitat is hypothesized to be most sensitive to bottom fishing (as opposed to sand and other sediment with high natural turnover) and dredge and bottom trawl are the most invasive bottom gear. Thus, any impacts identified here may be "worst case scenarios" for the most sensitive habitat and most invasive gear, and not a general study of all fishing impacts on all benthic habitat. **While the authors generally do a good job in noting that their results are relevant to cobble pavement on Georges Bank, other readers may**

inappropriately extrapolate these results to other systems and habitat types—something that is not possible given the study design (also see comments 1-7 above).

- The authors make strong efforts at interpreting the data in hand. While it is not straightforward whether the data in hand are in fact representative of potential impacts from fishing disturbance treatment (see comments 1-7 above), the authors' results stop at describing community-level differences in benthic communities. As the authors briefly mention, the link in changes to benthic community structure to the productivity of target species is not well understood. Thus results in CEV1997 and CEV2000, whether they are valid reflections on fishing impacts or not, do not provide inference about the relationship between fishing gear bottom contact and target (commercial fish and shellfish) stock productivity.

4.5 Conclusions

In summary, the CEV1997 and CEV2000 papers present high-resolution data on benthic communities and present detailed analysis on differences in benthic communities across sites. In our opinion, the inference made on the data in hand is valid and generally well executed; however, we have reservations regarding the design of the study, and therefore the conclusions drawn from the results. Of chief concern is that study sites were a priori chosen in a manner so as to result in substantial variation in benthic communities across sites (point 3); furthermore, the designation of "treatment" level itself was potentially inaccurate (point 4). Finally, the results may suffer from endogeneity insofar that commercial fishing targets scallop rich sites that may a priori harbor naturally different benthic communities than non-scallop and therefore non-fished sites (point 5). Together, these points call to question whether identified differences across study sites reflect natural variability across sites or fishing-related effects or some combination of both. We suspect the authors' results reflect a mix of the two possibilities—that is, differences may reflect fishing impacts (also see Hermsen et al. 2003), but also reflect substantial natural variability across sites. Undoubtedly, the benthos of Georges Bank experience high spatial variability in benthic community structure and distribution; to accommodate this variability and provide further insight into the effects of fishing on benthic communities (as well as insight as to whether the results in CEV1997 and CEV2000 are consistent across repeated studies), an experimental design need be undertaken, such as observing known-fished sites before and after cessation of fishing. A related study published in 2003 (Hermsen et al. 2003) presents time series of sampling at the CEV1997 and CEV2000 sites after a management experiment to close fishing in the study area; in this paper, some consistencies are found with CEV1997 and CEV2000, although many of the same study site selection criteria and endogeneity questions carry forward in the Hermsen et al. (2003) paper and many of the results are driven by a single study site and by scallop recovery.

Lastly, an important point to make is that the authors' results apply to cobble pavement habitat and bottom fishing gear such that these results may not be general to systems outside of dredge/trawl on cobble pavement on Georges Bank. The authors do make this point in their papers (e.g. Hermsen et al. 2003), albeit their chosen titles may be overly general. However, careless readers and special interest groups may take the authors' conclusions and extrapolate them inappropriately to systems not relevant to the studied sites.

Section 5. The European perspective on bottom contact fishing in near-shore coastal environments.[3]

5.1 Introduction

The waters of the continental shelf of northwest Europe have been demonstrated to be among the most heavily fished in the world (Jackson et al. 2001; Halpern et al. 2008; Roberts 2007). For the Greater North Sea specifically, various estimates suggest that heavily fished areas may be trawled as many as seven times a year (Goni 1998). How these impacts are ultimately manifest in the benthic environment underpins a body of scientific enquiry that has been conducted over the course of at least the last 30 years. This review seeks to explore the peer-review literature dealing with the experimental and historical analysis of these impacts, with a particular emphasis on European case studies, and has been expanded to include to the some of the more relevant articles from the Mediterranean, Australia and New Zealand.

5.2 Review Methodology

A systematic review of the scientific literature on bottom contact fishing impacts was carried out using Thomson Reuters Web of Science (WOS). Several searches (criteria specified below) yielded a total of 482 papers that were then manually reviewed for relevance in terms of themes, topic and geographic area to focus primarily on Europe, and also include a limited range of material on other locations outside of North America and Canada. Three main searches were conducted, all of which were inclusive over time periods 1970-2014. The first search was conducted on keywords 'fishing', 'impact', 'seabed' which returned 217 results including nine review articles, only two of which were directly relevant. The second search was based on keywords 'fishing', 'disturbance', 'benthos' which returned 177 results including five review articles. The third search was based on the terms 'physical', 'disturbance', 'seabed' and this returned 88 results, two of which were review articles. There was a degree of duplicity in the results uncovered that led to a reduction in the overall number of articles examined. References from the compiled review articles were examined for further links to suitable research articles to broaden the remit of the search. The top 10 results for each WOS search are displayed below (Figure 1) based on authorship and lead author institution in an attempt to try and refine the review criteria based on geography. The top contributing authors for the three searches (Prof. Michael Kaiser [Bangor University] and Prof. Chris Frid [University of Liverpool]) were explored in more detail through their respective Institutional Repositories, ResearchGate (https://www.researchgate.net) and Google Scholar (http://scholar.google.co.uk) profiles. In terms of the order the articles are presented and discussed, following examination of existing review articles on the subject, we have organised discussion of the outputs initially on geographic region and then further on the basis of chronology. The last section of the review (1.7) focuses on studies that are novel or have anomalous results in terms of comparison to the existing literature.

5.3 Existing Review Articles

Early reviews on the environmental impacts of trawling describe attempts to try and isolate specific drivers of the changes observed in the benthos to try and understand and reduce the term

[3] *Contributed by The Fisheries, Aquatic Science, & Technology (FAST) Laboratory at Alaska Pacific University, Director - Brad Harris, Ph.D.*

A more recent review highlights the methods by which most contemporary analysis of the impact of trawling takes place (Løkkeborg 2005), either by experimental trawling and assessing the impacts, or through analysis of historic data (e.g. Bradshaw et al. 2002; Callaway et al. 2007). This critical reflection of experimental methodologies describes the main difficulties of temporal and spatial aspects of experimental trawling, caused by using narrow corridors of impact to simulate the effects of commercial fishing.

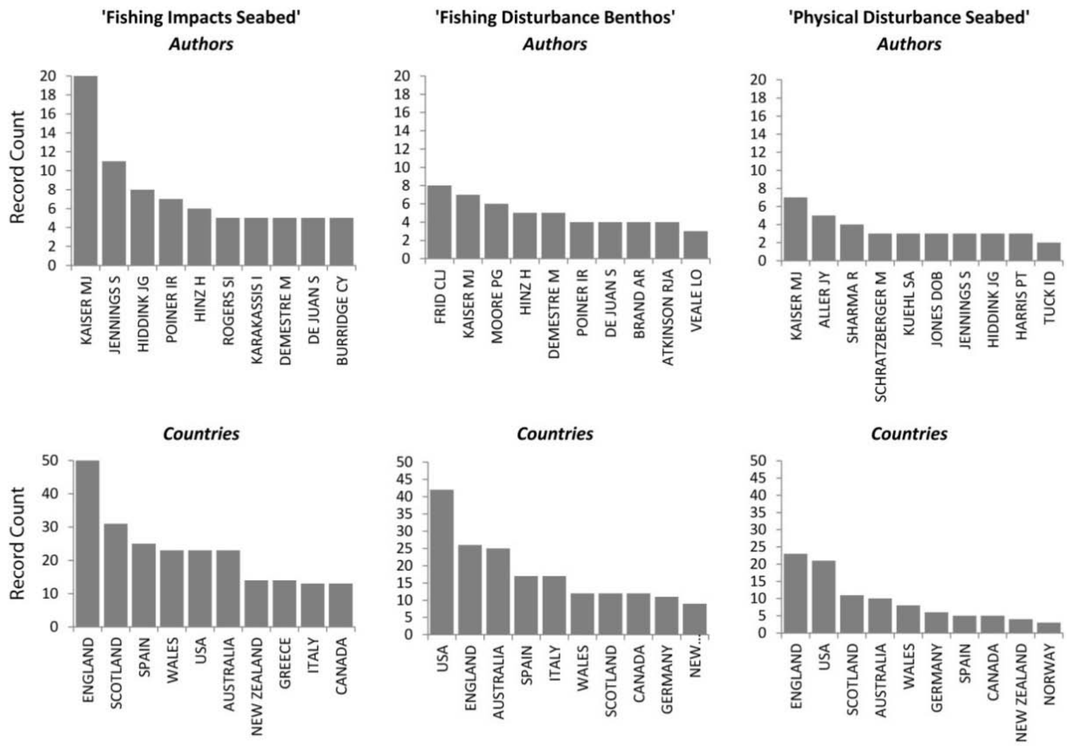

Figure 1: Results of systematic review on keywords detailed on each inset. Keyword search terms (left) ‘fishing, impacts, seabed’; (centre) ‘fishing, disturbance, benthos’; (right) ‘physical, disturbance, seabed’. Source of data: Thompson Reuters Web of Science. Top 10 results and proportion of total results per search.

impact of confounding variables (Jones 1992; Watling and Norse 1998; Kaiser 1998; Jennings and Kaiser 1998; Thrush and Dayton 2002).

Inter-annual variability also has the capacity to confound the results of before and after controlled impact type (BACI) studies if it is not adequately incorporated into the experimental design of the research (see the discussion of Collie, Escanero, and Valentine 1997 and 2000 above). The use of historical and opportunistic data to describe trends is common practice, but it is also limited in terms of its utility due to inherent bias in sampling effort, wider spatial and temporal variations and natural variations in recruitment etc. This has been acknowledged as a limitation in several of the studies, which were the subject of this review (e.g. Garcia et al. 2006).

Gray et al. (2006) summarises Løkkeborg’s (2005) position that no general conclusions may be drawn about the effects of trawling based on the degree of variability in the way studies have been conducted. This position is taken on the basis that benthic assemblages are complex and exhibit a large degree of temporal and spatial variability; furthermore, variations in the way the reviewed studies were conducted (fishing gear, disturbance regime, bottom type, natural disturbance) mean they are not strictly comparable, and finally that large variations in the experimental design in terms of sampling strategy would compromise their integrity. Gray et al. (2006) strongly refute this position on the basis of over 100 manipulative experiments in the literature at the time of the article that provides significant evidence to the contrary.

Dounas et al. (2007) examined the effects of bottom trawling on shelf in the Eastern Mediterranean, around Crete, using a 3D ecosystem model to examine primary productivity responses to bottom trawling. These modelled data revealed pulses of nutrient input related to bottom trawling occurring in addition to productivity pulses from the natural seasonal cycle.
Other work in the Mediterranean includes that of De Juan et al. (2007; 2011), who explored the role of functional changes in the benthos as indicators of trawling disturbance by contrasting disturbed and undisturbed reference sites (20 years without fishing) . The disturbed site had a higher incidence of burrowing epifaunal scavengers and motile burrowing infauna, in contrast to the undisturbed site that had a higher abundance of surface infauna, predatory fish and suspension feeders. Demestre et al. 2008 examined how benthic communities in the Mediterranean would respond to seasonal closures for the purposes of ecosystem-based management. Short-term benefits were apparent, but overall faunal abundance decreased after resumption of fishing activity.

Beginning from a global overview, Puig et al. (2012) experimentally demonstrated how displacement and sediment reworking effects of demersal trawling were modifying the upper continental slopes globally by homogenising fine scale variation in geomorphology.
Mangano et al. (2013) recently highlighted the impacts of otter trawl fisheries on epifaunal assemblage structure in the Central Mediterranean. Similarly to Diesing et al. (2013), this study also utilised VMS data to good effect, to study the impacts at a wide variety of depths across the continental shelf down to the meso-bathyal plain. Untrawled areas displayed significantly higher abundances of fragile and emergent fauna, whilst exploited areas had a greater number of scavengers.

In the Northwestern Mediterranean, Palanques et al. (2014) conducted a series of monitoring experiments on the benthic environment, covering periods of differing trawl intensities and incorporating data from a closed season. Morphology of the area was examined using side scan sonar (SSS) and suspended sediment was determined using CTD+turbidity hydrographic profiles, moored turbidometers and current meters. The results support the position that the seabed is strongly affected by the action of the bottom trawling in this region. The finer fraction of the sediment that is resuspended is winnowed and leads to increases in sediment flux. Bottom trawling was also determined to lead to an increase in the organic carbon content of the benthic environment in the study area.

5.4 Anomalous findings and novel approaches

Several studies emerged that had particularly novel methodological approaches or interesting results in terms of their deviation from the findings in the main body of literature.
In a methodological study, MacDonald et al. (1996) explored the development of sensitivity indices for fishing disturbance based on habitat (or seabed) types in order to focus and prioritise efforts for marine conservation objectives. They studied the effects of a wide range of fishing gear and assessed the theoretical sensitivity of a variety of species that could have potential to be utilised as candidate

indicator species. This study suggested that slow recruiting animals are most vulnerable to disturbance, whereas those fast growing species with good recruitment have the least sensitivity.

Tuck et al. (1998) explored the effects of physical trawling disturbance in an unfished Scottish sea lough. In contrast to many of the previously mentioned studies this was a low-energy depositional environment. They undertook extensive and repeated experimental trawling over an 18-month period in an area that had been closed to fishing for over 25 years. During the study, the number of species and individuals increased, while Shannon's exponential and Simpson's reciprocal and evenness decreased. The physical effects of the impact of bottom contact were examined using side scan sonar (SSS) and acoustic ground discrimination system (AGDS) (RoxAnn); these were able to be determined immediately after the impacts, but after 18 months they were almost indistinguishable from the control sites (Tuck et al. 1998).

Ball et al. (2000) conducted research into the long- and short-term impacts of trawl fishery for *Nephrops norvegicus* in the Irish Sea, using pseudo-control sites from close proximity to shipwrecks as a proxy for unfished populations. This study examined offshore and inshore sites over a variety of timescales, and suggested that the main observed impacts were due to intensity of fishing rather than the direct impact of bottom contact. The impact and value of this study was significantly reduced by a lack of quantitative pre-impact reference information. Løkkeborg (2005) also details this position, describing the use of wreck sites as pseudo-controls, however these may act as artificial reefs/ fish aggregation devices and as such not reflect the benthic diversity of the surrounding area.

The effects of disturbances caused by experimental trawling were tested in a Swedish fjord by Lindegarth et al. (2000). This was conducted based on sampling within replicated trawl and control areas before and after trawling taking place. This paper made inference as to the validity of many experiments in the literature around the same time that had poor degrees of (or no) replication. The authors described differences in fauna frequently occurred between control sites, and that from the analysis using all sites that there were no consistent effects of trawling on any of the taxa researched. In doing so, the researchers drew attention to the capacity for spatial confounding in areas with insufficient degrees of replication.

A novel study in the Isle of Man physically deployed divers immediately after an area was experimentally scallop dredged (Jenkins et al. 2001). This study explored the impacts on captured and non-captured organisms using a four-point scale modified for each taxonomic group. Mean damage levels to megafauna that were in the dredge tracks were assessed and demonstrated to be the same for most species. These results suggested that the majority of damage from scallop dredging occurs in the non-captured benthos rather than in the bycatch.
The majority of reviewed studies focus on the impacts of trawling for macro- and megafaunal species associated with the benthos. Schratzberger et al. (2002) examined the short-term impacts on the diversity, biomass and structure of meiofauna assemblages using a BACI design in the southern North Sea. The study showed no short- to medium-term trawling impacts on diversity or biomass, but there were mild effects on community structure. Their findings suggest that the meiofauna have a greater ability to withstand the effects of bottom trawling than the macrofauna in a comparable environment. These ideas were further developed in Schratzberger et al. (2009), where six independent datasets from large scale surveys of markedly different environments were combined with the results from small scale laboratory based observations on the effects of seabed disturbance on nematodes. These results suggested that the genus composition of nematode assemblages came together with an increasing level of anthropogenic disturbance.

Another novel approach was conducted based on the use of sediment profile imagery (SPI) to examine the effects of otter trawling in two areas of the Aegean Sea (Smith et al. 2003). Control and impact areas were determined across commercial fishing areas and experimentally trawled areas. The results indicated that the degree of penetration and roughness were not good indicators of disturbance. Furthermore the small sampling window means that a limited area can be sampled in comparison to other techniques (SSS, video, stills imagery), although this may be aided by the incorporation of more replicates in a tiered imaging approach (Smith et al. 2003).
A modelling-based approach to the study of the impacts of demersal trawling was carried out by Allen and Clarke (2007). This approach was based on a physical-ecological model for stratified and unstratified water columns in the North Sea. The work was underpinned by a meta-analysis of mortality of benthic fauna from more than 100 trawling disturbance experiments. The findings suggested that with the complete cessation of demersal trawling, most analogous systems would return to their original state within a period of 5 years.

The effects of bottom trawling on ecosystem functioning were explored by Olsgard et al. (2008), who examined nutrient fluxes and levels of bioturbation in benthic sediments. Based on these mesocosm experiments and field observations, the research was able to demonstrate the potential for bottom trawling to affect nutrient balances in continental shelf and coastal seas.

Another interesting study that is more specifically relevant for aggregate extraction discusses the differential responses of the meio- and macrofauna to in-situ burial (Whormersly et al. 2009). This was experimentally tested using a replicated block design and by spreading 4 cm of anoxic mud on each experimental plot at two different intensities. In general, macrofauna were found to be more sensitive to physical disturbance than meiofauna nematodes, although these may have been more sensitive to the initial impacts of the disturbance (Whomersley et al. 2009).

Recently, a novel quantitative technique was proposed by Diesing et al. (2013) for assessing the extent of effects of demersal trawling in comparison to the effects of natural disturbance. Here, the authors use a method incorporating vessel monitoring systems (VMS) and models of natural disturbance (tidal forcing, wave base) to generate maps of an area of the Greater North Sea. In achieving this, they attempt to define a metric that can determine where fishing disturbance exceeds natural disturbance. Their findings suggested that from 2006-2008, almost half of the English sector of the North Sea (45.1% or 70, 552 km^2) is more affected by natural disturbance than fishing, most specifically related to areas of coarse sediments, with high shear stresses and frequent levels of natural disturbance (Diesing et al. 2013). Gerritsen et al. (2013) also make used of VMS data to try and quantify the spatial extent of the impacts of trawling in the Celtic Sea. Harris et al. (2014) provide an excellent review article on physical disturbance in shelf and deep-sea sedimentary environments and the broader implications for species distribution modelling and other biophysical analysis.

Scriberras et al. (2013) conducted a series of underwater television surveys (UWTV) to assess the benthic community response to scallop dredging. This was conducted in Cardigan Bay in the UK over a period of 23 months, comparing details of the benthos between areas that experience seasonal closures and permanently closed control sites. This study was specifically focused on examining scallop densities and epibenthic community structure; changes they observed were attributed to seasonal variability at the site, with the role of natural disturbance being a more significant structuring agent that the impact of the dredging.

Another novel approach to modelling the impact of bottom contact disturbance was recently developed (Van Denderen et al. 2013). This study created a simple model of an ecosystem consisting of benthiverous fish and two food populations (benthos) that were both susceptible and resistant to trawling. The findings appear to suggest that the ecosystem response to the effect of trawling depend on whether the benthos is bottom-up or top-down controlled. In this model, fishing was demonstrated to have the capacity to lead to higher fish abundance and higher maximum sustainable yield (MSY) when the benthos were also more resistant to the effects of trawling, however, this was not the case when the benthos were susceptible to the effects.

5.5 Conclusions on the European perspective

This review has identified the principal literature on the impacts of bottom contact fishing from a European context. As has been demonstrated throughout the articles examined, there are several challenges that unite these studies in attempting to determine the nature of the impacts from trawling and dredging from bottom contact fishing, and these occur irrespective of the specific geography of the studies. One of the main issues in northwest Europe is the lack of control sites that are truly un-impacted by some form of anthropogenic degradation – and even more specifically by fishing activities. Area based closures and marine protected areas may offer a form of solution, but it is not clear to what extent these systems may be reflective of an un-impacted environment bearing in mind the relatively short time scales over which they may have been in place. Beyond this limitation, the principal difficulties that have affected many of the earlier studies are to do with inadequacies of experimental design, poor degree of spatial and temporal replication, and inadequate controls. To a certain extent this has compromised the confidence of interpretation in some of these results and this has been discussed and presented at considerable length (Løkkeborg, 2005; Gray et al. 2006). The use of historical data to analyse trends has been demonstrated to cause a different set of problems, but remains a valuable exercise in terms of describing longer term trends in impacts and benthic community structure (Bradshaw et al. 2002; Callaway et al. 2007). In terms of the impacts themselves, there are clearly differences that are presenting themselves in the way these impacts are manifest in the benthic environment, differences in gear types, differences in sensitivity to impact and differences in recovery potential and time taken to reach this state. **Uniformly, the review would appear to suggest that habitats that have a high degree of stability are the most vulnerable to the impacts of bottom contact fishing, whilst mobile dynamic systems exhibit a limited (or lack of) obvious impact in the community response.** More recently, there is an emergent body of work that is seeking to reconcile these problems in a procedurally robust way – but this remains a considerable challenge.

Section 6. Recommendations[3]

The submerged lands around the Monomoy Refuge are recognized to be high-energy sand environments subject to extensive natural disturbance. In this regard, there are many similarities to nearby Georges Bank (see Stokesbury and Harris 2006, Harris et al. 2012) and perhaps some recommendations may be drawn from our work there.

1) *De novo assessment*: The "precautionary approach" can lead policy makers or scientists with limited understanding of the literature or of the fundamentals of experimental design to invoke disparate and weakly-related scientific studies to support a given policy. Unfortunately policy actions can create scientific tautologies (self-validating loops) that exert pressure on future management (see McGuire and Harris 2010). An area is protected because it is taken to be important and then assumed to be important because it is protected. We recommend that Refuge policy makers question carefully the applicability of previous fishing impacts research to the Monomoy Reserve and that they cautiously question the merits of the commonly employed management structures (e.g., closed areas, gear prohibitions) and weigh existing and new structures equally based on their merits (see #3 below).

2) *Adaptability***:** Ecosystem science is rapidly evolving and as such policy structures should be explicitly adaptable to new information with frequent accountability assessments (see McGuire and Harris 2010 and Brooks et al. 2002). We recommend that Refuge policy makers explicitly state the goals of the management structures they employ and set forth a research plan to determine if these are indeed achieved. These goals should directly inform testable hypotheses and include temporal and spatial expectations (when and where will SAV protections be realized) so as to guide future research.

3) *Precaution***:** Consider that our nascent understanding of the processes driving changes in the abundance and distribution of SAV means that rigid, "directional" policy structures (particularly spatial closures) are high-risk, not precautious, measures. Precaution is embodied in the frequency and scope of reassessment and adaption to new information. **It is significant (and often overlooked) that the most extensive assessment of fishing impacts conducted on the US east coast concluded that the removal of the three large marine protected areas on Georges Bank would *reduce* aggregate adverse impacts of fishing (NEFMC 2011).** Yet, the mechanism (highlighted by Hiddink et al. 2006a) is self-evident. Unless the area of fishery exclusion is much more vulnerable than surrounding areas the displacement and concentration of gear-benthos contact will increase outside the closures resulting in a net negative protection. This is particularly concerning where mobile avian species forage well beyond the boundaries of the Refuge. We recommend that Refuge policy makers enhance the process of establishing risk mitigation policies by developing ongoing research streams that directly address risks like the loss of SAV instead of rely on reviews of previous work.

4) *SAV Research*: Finally, given the paucity of information on the actual effects of fishing activities on SAV in the Refuge, we recommend the simple framework outlined by Stokesbury et al. (2011) for the initiation of a robust assessment program to elucidate the role of fishing impacts on SAV while accounting for local (e.g., storm events, run off) and regional (water temperature and pH) changes. However, given the hierarchical structure of benthic community data and the importance of controlling for potential pseudoreplication associated with replicate samples within study areas, we recommend using the Bayesian implementation of the generalized linear mixed models instead of traditional ANOVA for statistical comparisons.

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