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CLAM DREDGE FRAMEWORK ADJUSTMENT

Appendix B: Effects of hydraulic clam dredge fishing gear on benthic habitats

History of gear effects determinations

Amendment 12 SC/OQ FMP – MAFMC 1998

Cited three publications published in the 1980s that were included in review of habitat effects of fishing gears by Auster & Langton (1998) and concluded that hydraulic clam dredges could potentially have an adverse impact on EFH, but since "The Council feels strongly that very little evidence was provided [in A&L] relative to identifiable adverse effects to EFH in FMPs managed by this Council, [therefore] it would be premature to propose gear management measures at this time. It is simply not practicable to impose unwarranted management measures that are unjustifiable."

In April 1999, the Regional Office disapproved the fishing impact evaluations and adverse impact EFH determinations of three MAFMC amendments, including Am12 SQ/OC, because a) "they lacked a complete assessment of the potential adverse effects on EFH of the gears used in each fishery" and b) "there is insufficient discussion to justify the Council's conclusion that it is not practicable to take measures to minimize these effects." Additional, more detailed comments were provided for the SC/OQ amendment.

NE Region Gear Effects Workshop – 2001 - NEFSC Ref Doc 02-01

The results of 12 studies of the benthic habitat effects of hydraulic dredge were summarized in a "white paper" that was distributed to workshop participants in advance of the meeting. Conclusions reached by the peer review panel were based on peer-reviewed scientific information, unpublished reports, and the professional judgment of the participants. A revised and expanded version of the white paper was published in 2004 as NOAA Tech Memo 181 (see below).

The panel concluded that the habitat effects of hydraulic dredging were limited to sandy substrates, since the gear is not used in gravel and mud habitats (Table 3). Two effects -changes in physical and biological structure – were determined to occur at high levels. The temporal scale of the effects varies depending on the background energy of the environment. Recovery of physical structure can range from days in high energy environments to months in low energy environments, whereas biological structure can take months to years to recover from dredging, depending on what species are affected.

Table 1 – Impacts of Clam Dredges on Benthic Habitat

TYPE OF IMPACT	DEGREE OF IMPACT	DURATION	TYPE OF EVIDENCE	COMMENTS
MUD				
Removal of Major Physical Features	N/A			
Impacts to Biological Structure	N/A			
Impacts to Physical Structure	N/A			
Changes in Benthic Prey	N/A			
SAND				
Removal of Major Physical Features	Unknown			
Impacts to Biological Structure	XXX	Months - Years[1]	PR, GL, PJ	[1] Dependent upon species composition (eg. Amphipod tubes < 1 yr recovery)
Impacts to Physical Structure	XXX[2]	Days - Months	PR, GL, PJ	[2] Represents major alteration to regime for soft bodied organisms
Changes in benthic prey	Unknown			
GRAVEL				
Removal of Major Physical Features	N/A			
Impacts to Biological Structure	N/A			
Impacts to Physical Structure	N/A			
Changes in benthic prey	N/A			

KEY: X = Effect can be present, but is rarely large; XX = Effect is present and moderate; XXX = Effect is often present and can be large; N/A = Effect is not present or not applicable; Unknown = effects are not currently known; (H) = High energy environment; (L) = Low energy environment; PR = Peer reviewed literature; GL = Grey literature; PJ = Professional judgement. For definitions of Substrate Type and Type of Impact see Appendix D.
NOTE: Ongoing Canadian studies for clam dredges are near completion and will contribute substantially to this discussion.

The panel agreed that hydraulic dredges have important habitat effects, but even in a worst case scenario, where there were known to be severe biological impacts, only a small area is affected and therefore this gear type is less important than other gear types like bottom trawls and scallop dredges which affect much larger areas. It was also pointed out, however, that even though the effects of dredging (at least for surfclams) are limited to a relatively small area, localized effects of dredging on EFH could be very significant if the dredged area is a productive habitat for one or more managed fish resources. A major question for this gear is "what are its long-term biological impacts" *i.e.*, how, and to what extent, are benthic communities altered in heavily dredged areas, particularly the prey organisms, and how long does it take for them to recover once dredging ceases?

Management actions that could be taken to minimize adverse impacts to benthic habitat:

- Since the two resources are underfished, reductions in effort are probably not practicable. Therefore spatial area management seems to be the only practicable approach to minimizing gear impacts, if necessary.
- Hydraulic dredges are designed to operate in sandy substrate and could be very destructive if fished in the wrong sediment type or in structured environments like gravel beds. The gear should not be used in sediment types where it would cause more damage. Areas of known structure-forming biota should be mapped and set aside as a priority.
- Since we really do not know what the effect of this gear is to soft-bodied benthic organisms, a possible precautionary measure would be to restrict the fishery to areas of high clam productivity.

Amendment 13 SQ/OQ FMP – MAFMC 2003

The fishing impact evaluation/determination was updated based on a complete review of hydraulic dredge impact studies made available to participants at the 2001 Northeast Region Gear Effects Workshop and the conclusions in the workshop report (see below). Based on the workshop report, the Council concluded that "there may be some impacts but…they are short term and minimal." Acting on advice from NMFS that management measures should still be considered in light of the uncertainty of this conclusion, the Council considered nine closed area alternatives, but after analyzing the costs and benefits of four of them, selected the No Action alternative as their preferred alternative. NMFS approved the EFH portions of Amendment 13 in August 2003.

Some of the statements made in Amendment 13 to support the minimal impact conclusion are worth restating here:

- There is sufficient information that clam dredges could have an effect on EFH if the gear is fished improperly or in the wrong sediment type (e.g., if such gear were used in a stable, fragile, structured, environment like a coral reef or a SAV bed).
- However, clam resources are concentrated in high energy sandy sediment…where natural events have more effect on the benthic community.
- There may be large, localized impacts to biological and physical structure [in these environments], however, the recovery time is relatively short (hours to months) [and] the adverse impacts…can be considered temporary.
- Also, because these impacts are potentially affecting a small portion (approx. 100 square nautical miles) of all the high energy sand habitat on the continental shelf – much less than scallop dredges or bottom trawls - they can be considered minimal.

Tech Memo 181 – 2004

Originally prepared to provide background information to participants at the 2001 Northeast Region Gear Effects Workshop (see above), the Tech Memo (Stevenson et al. 2004) included a summary of the results of 12 individual studies published through early 2002, seven of which were relevant to the hydraulic clam dredge fishery for surfclams and ocean quahogs in the region. Physical and biological effects were described for each gear and substrate type combination and included information relating to recovery times. The Tech Memo also included a qualitative evaluation of habitat vulnerability (high, moderate, and low) for all the managed species and life stages in the region. Five additional studies published after 2002 were added to the literature review between 2004 and 2014, bringing the total number of relevant studies to twelve.

Amendment 15 SC/OQ FMP – MAFMC 2009 (never completed)

The gear effects analysis for this fishery was up-dated in 2009 as part of the 5-year review of the EFH provisions of MSA, but was never carried through to adverse impact determinations because the more controversial portions of Amendment 15 caused a delay and MAFMC and the Regional Office subsequently decided to drop EFH from the amendment. Four new references were added to the seven relevant studies that were reviewed in NOAA Tech Memo 181 (see below) and a revised gear impact evaluation was written, but no conclusions were drawn. The gear impact analysis also included a section on the effects of the "dry dredge" fishery for small ocean quahogs in eastern Maine.

Amendment 13 to the Multispecies FMP & Amendment 10 to the Atlantic Scallop FMP – NEFMC 2003/2004

Results of the seven studies that were relevant to the SC/OQ fishery in the region and summarized in TM181 were included as part of the fishing effects determinations for these two management actions and for a later amendment to the NEFMC/MAFMC monkfish FMP. Six of them were conducted in sandy habitats and one in mixed substrates. Seven habitat management areas totaling 3,710 square miles that prohibited the use of mobile, bottom-tending gear (bottom trawls, scallop dredges, and hydraulic clam dredges) were implemented by these two actions. The following adverse impact conclusions are excerpted from Amendment 13.

Distribution of Fishing Activity: Hydraulic clam dredging activity was much less intensive during 1995-2001 than for either of the other two major types of mobile gear. Hydraulic clam dredging took place in SNE and the MA, generally in shallower shelf waters than scallop dredging and trawling. A cluster of TMS off the New Jersey coast was heavily fished, as were other TMS further out toward the edge of the shelf, south of Long Island, and in SNE waters. Clam dredges do not operate on GB because ocean quahogs on the bank contain red tide-causing micro-organisms and cannot be harvested. Hydraulic clam dredging is restricted to sandy and muddy sand substrates because the gear can be damaged in hard bottom areas. For this reason, hydraulic dredges are not used in the GOM.

Potential Adverse Impacts of Fishing Activities: Gears That Could Adversely Impact Groundfish EFH: Of the five gear types that are either used to harvest the 15 species of groundfish that are managed under the NEFMC Multi-Species FMP, or which are capable of catching groundfish (i.e., as by-catch), or which are used in other federally-managed fisheries, there are three that could adversely affect benthic EFH for the 15 groundfish species listed below. These are bottom otter trawls, scallop dredges, and hydraulic clam dredges.

Effects and Recovery Times of Hydraulic Clam Dredges on Sand Substrate in the Northeast Region as Noted By Authors of Six Gear Effect Studies: Adverse and potentially adverse habitat impacts from hydraulic clam dredging occur primarily in the Mid-Atlantic and secondarily in southern New England on sand substrates. Clam dredges only impact sandy substrates and are used in a much smaller area than scallop dredges or trawls.

Hydraulic Clam Dredges: The use of hydraulic clam dredges may have an adverse effect on the following species (and life stages) EFH as designated in Amendment 11 to the Northeast Multispecies FMP (1998):

Atlantic cod (A), black sea bass (J, A), clearnose skate (J, A), little skate (J, A), ocean pout (E, L, J, A), red hake (J), rosette skate (J, A), scup (J), silver hake (J), winter flounder (A), winter skate (J, A), and yellowtail flounder (J, A).

Note: The habitat management areas that were established in 2004 overlap to a large extent with groundfish management areas that were already in place. The groundfish management areas prohibit the use of all gears capable of catching groundfish, but "fishing with or using dredge gear designed and used to take surfclams or ocean quahogs, provided that there is no retention of regulated species and no other gear on board capable of catching NE multispecies" is allowed in the Nantucket Lightship Closed Area, Cashes Ledge Closed Area, and Western Gulf of Maine Closed Area. Clam dredges are not exempt from Closed Area I or Closed Area II.

Re-opening of a Portion of the PSP Area on Georges Bank – NMFS 2012

Following the approval of an at-sea testing protocol for paralytic shellfish poisoning developed by the clam industry and tested aboard commercial clam dredge vessels for two years in the Cultivator Shoals area of the bank, the FDA removed the prohibition on clam harvesting in the Georges Bank PSP closure area which had been in place since 1990. Subsequently, the MAFMC requested that NMFS re-open the area. GARFO completed work in November 2012 on an EA that opened 5,423 square miles of the closed area and in 2013 an area of 958 square miles was added to it. The habitat impact analysis concluded that the adverse impacts of renewed clam dredging on Georges Shoal would be minimal and/or temporary as long as dredging was confined to the shallower, more dynamic sandy bottom habitats which were the only areas where it was believed that the gear could be operated (see excerpts below).

Conclusion (for alternative that included Georges Shoal): There would be adverse habitat impacts of hydraulic dredging in this area. In the sandy substrate that is inhabited by surfclams – and where most dredging activity is expected – these impacts would be minimal and/or temporary due to the extreme effects of bottom currents and storm- generated waves. However, if dredging extended into the coarser sediment areas (the gravel troughs between the sand ridges), the impacts could be more than minimal.

One of the mitigating factors noted in the analysis is the fact that the density of surfclams on Georges Bank is much higher than on the traditionally-fished grounds in the Mid-Atlantic. Landings per unit effort data from the two vessels that participated in the PSP testing program in 2011 were over seven times higher than LPUE from the Mid-Atlantic for the same year, thus, as long as total catch remains the same, shifting effort from the Mid-Atlantic to Georges is expected to significantly reduce the area swept by clam dredges in the fishery. Also, hydraulic clam dredges are prohibited in Closed Areas I and II, including within the habitat closures.

Omnibus EFH Amendment 2 – NEFMC 2017

A number of candidate habitat management areas on Georges Bank and in the Gulf of Maine were considered and preferred alternatives were selected in April and June 2015. To facilitate the selection of appropriate habitat management areas, the Habitat PDT developed a spatially explicit model (SASI = Swept Area Seabed Impact) for estimating habitat vulnerability that incorporated gear-specific susceptibility (S) and recovery (R) scores for a number of geological and biological habitat features in mud, sand, granule-pebble, cobble, and boulder-dominated substrates. S and R scores were based on a review of 97 published gear impact studies that were judged to be relevant to gears used and habitat types that occur in the region. The literature review for hydraulic clam dredges included the seven publications that were summarized in Tech Memo 181 plus five studies that were published after 2002. The vulnerability assessment methods and results are also described in Grabowski et al. (2014).

Based on the results of the SASI model (see Figures 1 and 2), the PDT recommended that all mobile bottom-tending gears be prohibited in any habitat management area (HMA) selected by the Council. Additional management measures were added by the Council, including an exemption for hydraulic clam dredges in many of the HMAs. In taking final action on this amendment, the Council's preferred alternatives for Georges Bank-Nantucket Shoals included a provision that a clam dredge exemption would remain in effect for a year after implementation of OHA2 to allow time for the Council to consider creating access areas within two of the areas included in the alternatives.

Excerpted from Appendix D to the DEIS

Hydraulic clam dredges can be operated in areas of large-grain sand, fine sand, sand with small-grain gravel, sand with small amounts of mud, and sand with very small amounts of clay. Most tows are made in large-grain sand. <u>Surfclam/ocean quahog dredges are not fished in clay, mud, pebbles, rocks, coral, large gravel >0.5 in (> 1.25 cm), or seagrass beds</u>.

<u>Susceptibility and recovery are only evaluated for hydraulic clam dredges for sand and granule-pebble substrates because this gear cannot be operated in mud or in rocky habitats (NEFSC 2002, Wallace and Hoff 2005)</u>. This is because hydraulic dredges harvest clams by injecting pressurized water into sandy sediments to a depth of 8-10 inches, rather than dragging over the sediment surface like bottom trawls and scallop dredges. Water pressures vary from 50 lbs per square inch (psi) in coarse sand to 110 psi in finer sediments (NEFSC 2002). <u>In the absence of much published information on the degree to which benthic habitat features are susceptible to this gear, professional judgment relied on the presumption that these dredges have a more severe immediate impact on surface and sub-surface habitat features than other fishing gears used in the Northeast region</u>.

<u>Across all gears, geological and biological features are generally most susceptible to impacts from hydraulic dredges as compared to other gear types (average scores for all features in a particular substrate and energy environment ranged from 2.5-2.8 out of 3).</u> Average otter trawl

and scallop dredge S scores ranged from 1.0 to 2.0. Higher S scores reflect a higher proportion of features with >25% encountered estimated to have a reduction in functional habitat value. For trawls and scallop dredges, there was a larger proportion of high S scores (S=2 or 3) for geological features, especially in mud and cobble, than for biological features; for hydraulic dredges, however, there was very little difference between feature classes.

Geological feature recovery values are slightly higher (i.e., recovery times are longer) for hydraulic dredges than for the other two mobile gears fished in similar habitats (sand and granule-pebble). Average recovery values are more similar for biological features across the three mobile gear types, although in a few cases estimated recovery times are longer for hydraulic dredge gear. This was due to differences in gear effects associated with hydraulic dredges as compared to scallop dredges or otter trawls.

Figure 1 – Susceptibility of geological and biological features to hydraulic dredge impacts according to substrate and energy. Percentages = average percent loss in functional value of all habitat features after one pass of the gear. Green = high energy granule-pebble, purple = low energy granule-pebble.

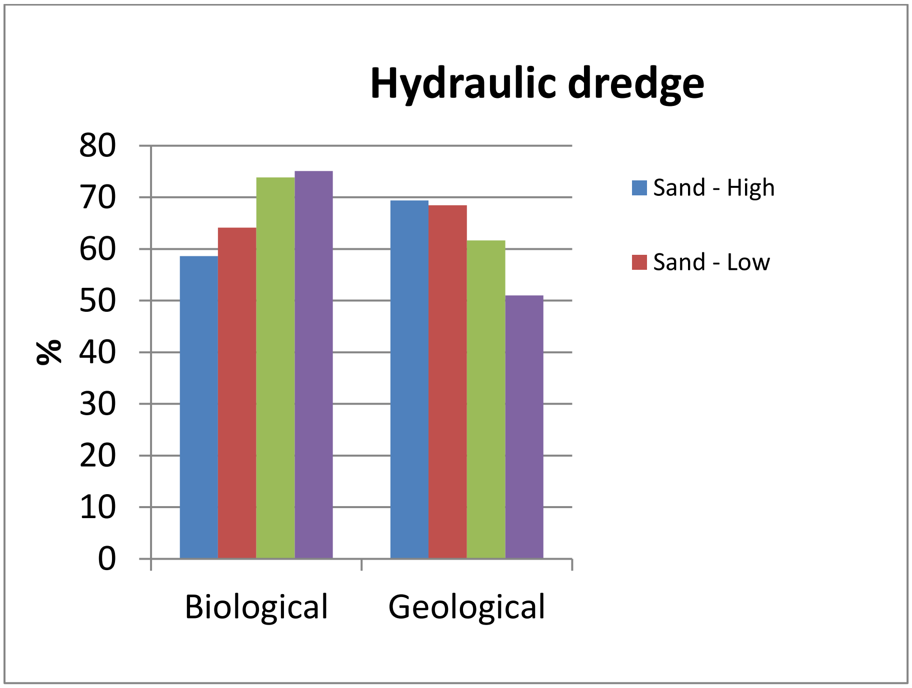
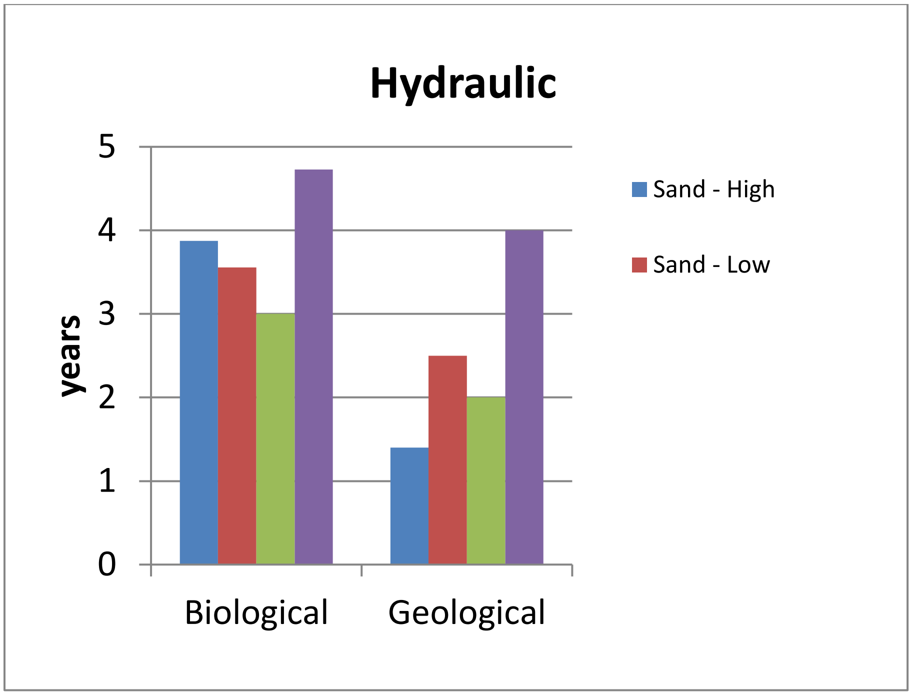
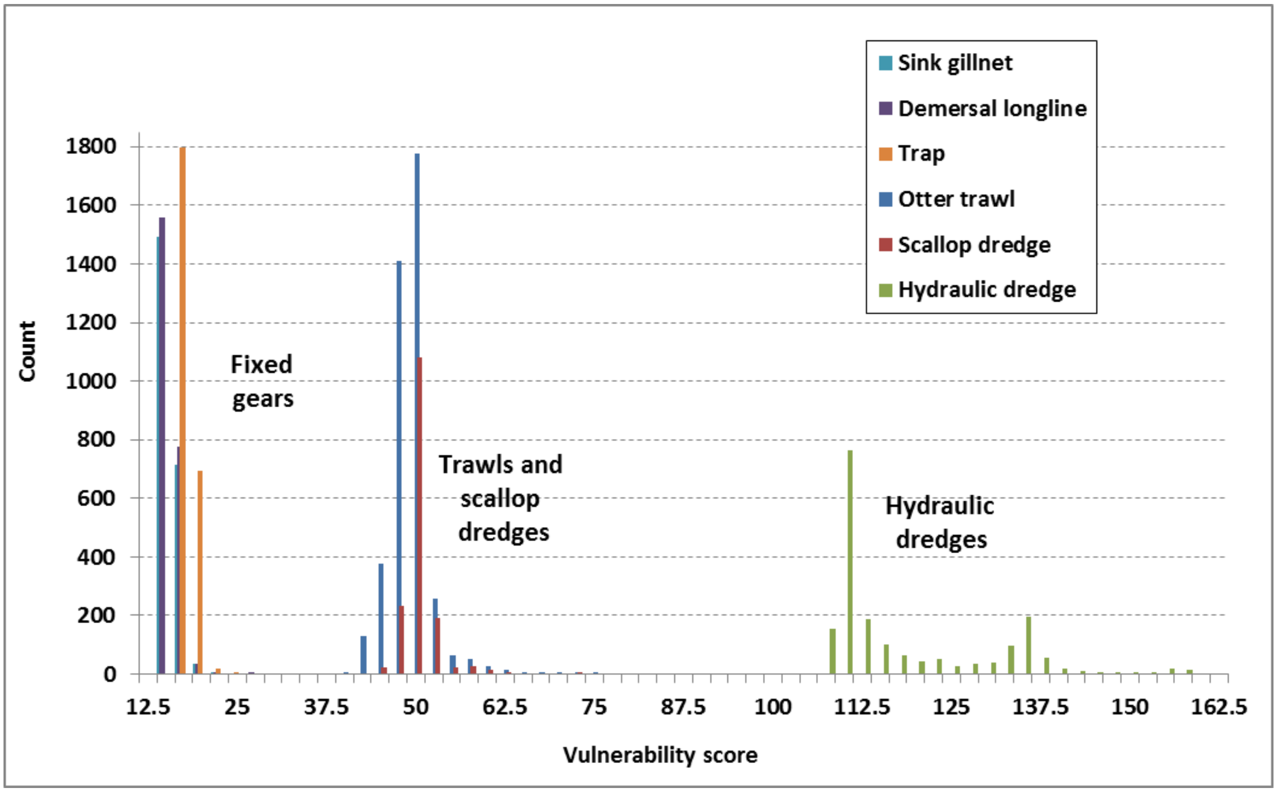


Figure 2 – Recovery of geological and biological features following hydraulic dredge impacts according to substrate and energy. Years = average recovery time for all habitat features following one pass of the gear. Green = high energy granule-pebble, purple = low energy granule-pebble.



The range of the vulnerability estimates varies by gear type; fixed gears, i.e. longlines, gillnets, and traps, have vulnerability scores that are about one third that of scallop dredges and otter trawls (see below). Hydraulic dredges have higher vulnerability scores than otter trawls and scallop dredges, and much higher vulnerability scores than the fixed gears. Vulnerability scores across all gear types except hydraulic dredges have a narrow, skewed distribution, with a single mode and outliers on the upper end (see Figure 3). The hydraulic dredge scores are distributed somewhat differently; they have a bimodal distribution with lower scores in higher energy areas, and higher scores in lower energy areas. The hydraulic dredge model is fairly different from the others because the assumption was made that hydraulic dredges can only operate on sand and granule-pebble substrates, so the model ignores other substrate types when they occurred in a particular grid cell.

Figure 3. Distribution of SASI habitat vulnerability scores by gear type



Summary of gear effects literature

This analysis includes the results of fourteen hydraulic dredge studies published in peer-reviewed and non-peer-reviewed literature between 1971 and 2015 (Table 2 – List of hydraulic dredge impact studies; Table 3 – Results of hydraulic dredge impact studies). All but one of them examined the effects of hydraulic cage dredges of the type used in the U.S. surfclam and ocean quahog fishery and one examined the effects of escalator dredges, which affect sandy bottom habitats similarly to cage dredges. All studies were conducted in sandy bottom habitats exposed to varying degrees of natural disturbance, depending primarily on depth. Four of them were published prior to 1990, two in the 1990s, and eight since 2000. Nine were performed in the Northwest Atlantic Ocean (five in the U.S. and four in Canada), one in the North Atlantic (Iceland), two in Italy (Adriatic Sea) and two in Scotland.

Nine studies were conducted in coastal waters in depths <12 m and five on the continental shelf, four at 70-80 m, one at 37 m, and one with no depth given. The four studies done at 70-80 m were all done on the Scotian shelf of Canada by the same group of researchers and examined the immediate and long-term effects (2-10 years) of hydraulic clam dredging on physical and biological habitat features. The three early studies in the Mid-Atlantic region and in Nova Scotia were limited primarily to before and after observations of the physical effects in shallow water. Two recent shallow-water studies in Long Island Sound focused on effects on benthic assemblages and sediment biogeochemistry. The Scotian shelf studies are the most relevant to the U.S. commercial clam dredge fishery currently operating in the Northwest Atlantic and will be described in more detail.

Seven of these studies were experimental in nature, meaning that they were controlled before and after experiments designed to evaluate impacts by comparing conditions in treatment (towed) and control (un-towed) areas. In these studies, recovery of affected habitat features was monitored for periods ranging from 40 days to 10 years. Three studies were limited to before and after observations of single dredge tows and four compared environmental conditions in areas where clam dredging was active with unfished areas. In one of the comparative studies, recovery in the dredged area was followed for two months and in the two Long Island studies, for 24 weeks and five months. The fourth one (McKenzie 1982) compared physical and biological features of actively, recently, and never fished locations off the New Jersey coast. One of the Italian studies (8) failed to detect any significant biological effects of dredging and the Long Island Sound studies (13,14) found no significant differences in the benthic communities or the biogeochemical properties of the sediments inside and outside of cultivated clam beds after harvesting

Physical effects

Hydraulic clam dredges create steep-sided trenches 8-30 cm deep with mounds of sediment along the edges of the trench (5) (Table 2). Hydraulic dredges also fluidize sediments in the bottom and sides of trenches (1,6,12), re-suspend and disperse fine sediment (3,4), and cause a re-sorting of sediments that settle back into trenches (1,2). In one study (6), sediment in the bottom of trenches was initially fluidized to a depth of 30 cm and in the sides of the trench to 15 cm, creating a condition "like quicksand." In deeper water on the Scotian shelf, dredging caused the loss of burrows, biogenic tubes, and shells in dredge tracks through destruction, burial, and the settlement of fine sediment (9). Differences in the acoustic properties of the sediment inside and outside the dredge tracks persisted for three years, indicating long-lasting effects on sediment structure. These effects were still detectable 5 and 10 years later even though they were no longer visible a year after dredging (see below).

Recovery times can only be estimated, based on how often and over what time period investigators returned to their study sites after the initial dredging disturbance. In shallow, sandy environments exposed to strong natural disturbance, they fill in rapidly. Trenches in one inshore location in Long Island Sound were nearly indistinct within 24 hours after dredging (4). In another high-energy environment (6), trenches were still longer visible after 5 days, but not after 11 weeks. However, after 11 weeks sand in the bottom of the trenches was still fluidized to a depth of 20 cm (6). In deeper water, dredge tracks in fine sediments filled in within several days and even more quickly in coarse sediments (7). Complete recovery of seafloor topography was noted after 40 days in a shallow, sandy environment that was exposed to winter storms (1). In a study done in a very shallow coastal lagoon in the Mediterranean (4) not considered relevant to the Mid-Atlantic surfclam and ocean quahog fishery, dredge tracks were still visible after two months. Silt clouds only last for a few minutes (3,4).

Physical impacts of experimental hydraulic clam dredging on the Scotian shelf in depths of 70-80 m were monitored for ten years (9,11). Although dredge tracks were no longer visible one year after dredging, they could still be detected with side-scan sonar after three and five years, and, to some extent, 10 years later. Examination of sonograms showed that after five years they were only partially degraded; after 10 years they had nearly disappeared over half their length. Degradation of the dredge tracks was attributed primarily to the effects of storm waves (height 11 m).

Biological effects

Benthic organisms are dislodged from the sediment, or damaged by the dredge, temporarily providing food for foraging fish and invertebrates (4,7,8,12). Hydraulic dredging caused an immediate and significant reduction in the total number of benthic organisms in four studies (1,5,6 and 12), reductions in biomass (5,10), and species diversity (5). There were also significant reductions in the number of infaunal species in one case, with significant increases (>50%) in abundance for some species (e.g., polychaetes) and decreases for others (e.g., amphipods) five days after dredging (6). In the Iceland study (12), total infaunal abundance was reduced by 46% immediately after dredging and 39% after three months. One study failed to detect any significant reduction in the abundance of any individual species (1), but there were significant reductions in the total number of infaunal organisms and the mean abundances of the ten most common species were all lower one day after dredging, with a significant difference in the abundance of the whole group (all ten species). Another study reported there were no impacts of experimental tows on the entire microbenthic community, only on the bivalves that were targeted by the gear (8). Evidence from the study conducted off the New Jersey coast indicated that the number of organisms and species, and species composition, were the same in actively dredged and un-dredged locations (2).

Recovery was monitored in all but one study. Total abundance and species diversity had fully recovered only five days after dredging in one location where tidal currents reach maximum speeds of three knots, although some individual species did not recover until 11 weeks after the initial disturbance (6). In the Venice lagoon study (5), densities recovered within two months, but biomass did not. Total abundance had recovered 40 days after dredging in another location exposed to winter storms, when the site was re-visited for the first time (1). In the Iceland study (12), crustaceans and bivalves recovered within three months, with full recovery of the entire species assemblage occurring sometime between sampling three months and a year after dredging. On the Scotian shelf (10) opportunistic species (polychaetes and amphipods) which decreased in abundance and biomass by more than 40% immediately after dredging were much more abundant a year later and were many times more abundant relative to pre-dredging levels after two years, indicating that colonization was still taking place.

Table 2 – List of hydraulic dredge impact studies

No.	**Reference**	**Location**	**Type of Study**						**Duration of study**
			Experimental		Obs	Comp	Fished	Unfished	
			Single tows	Multiple tows	Single tows				
1	Hall et al. 1990	Scotland		X				X	40 d
2	MacKenzie 1982	Mid-Atlantic				X	X	X	na
3	Medcof and Caddy 1971	Nova Scotia			X		X		2-3 d
4	Pranovi and Giovanardi 1994	Italy				X	X	X	2 mo
5	Meyer et al 1981	Mid-Atlantic			X			X	24 hr
6	Tuck et al 2000	Scotland	X						11 wk
7	Murawski and Serchuk 1989	Mid-Atlantic			X		?		several d
8	Morello et al 2005	Italy		X			X		18 d
9	Gilkinson et al 2003	Scotian Shelf		X				X	3 yr
10	Gilkinson et al 2005	Scotian Shelf		X				X	2 yr
11	Gilkinson et al 2015	Scotian Shelf		X				X	10 yr
12	Ragnarsson et al 2015	Iceland		X				X	5 yr
13	Goldberg et al 2012	Long Island Sound				X	X	X	24 wk
14	Goldberg et al 2014	Long Island Sound				X	X	X	5 mo

Obs = observational; Comp = comparative; na = not applicable; d = days; hr = hours; wk = weeks; mo = months; yr = years

Table 3 – Results of hydraulic dredge impact studies

#	Reference	Location	Depth	Sediment	Sampling	Effects	Recovery	Approach
1	Hall *et al.* (1990)	Loch Gairloch, Scotland	7 m	Fine sand	5 treatment, 5 control plots 5, 10 cm cores taken per plot Sampled 1 day and 40 days* after dredging **only 7 plots (4 fished & 3 control) were sampled at 40 days*	Shallow trenches (25 cm deep) and large holes; sediment "almost fluidized"; median sediment grain size S higher in fished area; S reductions in numbers of infaunal organisms; no S effect on abundance of any individual species, but mean abundances of 10 most common species were all lower 1 d after fishing than in controls and difference for whole group was S; some mortality (not assessed) of large polychaetes and crustaceans retained on conveyor belt or returned to sea surface.	No detectable differences in total number of individuals or species after 40 days; some species were more abundant in dredged plots, some in controls, but all differences were NS, filling of trenches and holes accelerated by winter storms.	Experimental study in unexploited area to evaluate effects of simulated commercial escalator dredging activity; recovery evaluated after 40 days.
2	MacKenzie, 1982	East of Cape May, New Jersey, USA	37 m	Very fine to medium sand	Benthic grabs (0.1m^2): AF (8), RF (10), NF (12) 1 sampling event	Resorting of sediments (coarser at bottom of dredge track); no effect on total number of individuals or species, but S more polychaetes and S fewer mollusks at AF site. No S differences in mean number of invertebrates (annelids, arthropods, mollusks, and sand dollars) from samples collected in "evidently" dredged AF site and and un-dredged RF&NF sites.		Comparison of macrofauna in an area actively fished (AF) by commercial quahog vessels, an area recently fished for a year then abandoned 4 mos prior to sampling (RF), and a never fished (NF) area on the continental shelf.
3	Medcof and Caddy 1971	Southern Nova Scotia, Canada	7-12 m	Sand and sand-mud	No sampling	Smooth tracks with steep walls, 20 cm deep; sediment cloud.	Sediment plume lasted 1 min; dredge tracks still clearly visible after 2-3 days.	SCUBA and submersible observations during and after two tows with a cage dredge.
4	Meyer *et al.* 1981	South of Long Island, New York, USA	11 m	Fine to medium sand, covered by silt layer	No sampling	>20-cm-deep trench; sediment pushed into mounds 15-35 cm wide and 5-15 cm high on either side of trench; silt cloud, attraction of predators.	Slumping along walls of trench began immediately, trench nearly indistinct, and predator abundance normal, after 24 hr; silt settled in 4 min.	SCUBA observations during and following a single tow with a cage dredge in a closed area; effects evaluated after 2 and 24 hrs.

#	Reference	Location	Depth	Sediment	Sampling	Effects	Recovery	Approach
5	Pranovi and Giovanardi 1994	Venice Lagoon, Adriatic Sea, Italy	1.5-2 m	Sand	Paired dredge & control stations inside & outside fishing areas 4cm core sediment sampling 3 replicate 50x60x10cm benthic samples	8-10 cm deep trench; S decrease in total abundance, individual species abundance, biomass, and diversity of benthic macrofauna in fishing ground; no S effects outside fishing ground for number of species or biomass, but S decrease in individual species abundance.	After 2 mos, dredge tracks still visible; densities (especially of small species and epibenthic species) in fishing ground recovered, biomass did not. The number of specimens decreased over time outside the fishing grounds at the dredge plot and there was no recovery of individual species abundances over time.	Experimental dredging with a cage dredge (single tows) in previously dredged and undredged areas in coastal lagoon; recovery monitored every 3 wks for 2 mos.
6	Tuck *et al.* 2000	Sound of Ronay, Outer Hebrides, Scotland	2-5 m	Medium to fine sand	5, 10cm cores within and adjacent per track, plus 1 control core 2m from track	Steep-sided trenches (30 cm deep); sediments fluidized up to 30 cm; S decrease in number of infaunal species and individuals within a day of dredging; S decrease in proportion of polychaetes and S increase in proportion of amphipods 5 days after dredging; S increases in abundance of some species and S decreases in abundance of other species. Observed increase in crab abundance within tracks, but not tested.	Trenches still visible after 5 d, but not after 11 wk; sand still fluidized to 0.2m depth after 11 wk; "crust" developed on top of sediments; species diversity and total abundance recovered within 5 days; proportions of polychaetes and amphipods, and abundances of individual species, returned to pre-dredge levels after 11 wks.	Experimental dredging with cage dredge (individual tows at 6 sites) in area closed to commercial dredging, effects evaluated 1 day, 5 days, and 11 wks after dredging.
7	Murawski and Serchuk 1989	Mid-Atlantic Bight, USA	Not given	Sand, mud, and coarse gravel	No sampling	Trench cut; temporary increase in turbidity, disruption of benthic organisms in dredge path; attraction of predators.	Trenches filled quickly in coarse gravel but took several days in fine sediments.	Submersible observations following hydraulic cage dredge tows.

#	Reference	Location	Depth	Sediment	Sampling	Effects	Recovery	Approach
8	Morello et al. 2005	Adriatic Sea (Italy)	6 m	Very fine sand	Each site sub-divided into 50 sub-plots, 0.25m^2 suction samples collected in 3 of them during each sampling visit (4 before and 4 after dredging)	No impacts of experimental tows on entire sampled macrobenthic community or on polychaetes, crustaceans, detritivores, or suspensivores, but abundance and biomass of mollusks (excluding target species of fishery) were S reduced by dredging; predators and scavengers S more abundant 1 day after dredging in dredged sites.	Abundance/biomass of mollusks had not recovered at end of experiment (18 days after dredging).	Experimental BACI study in small, heavily-dredged area; impacts evaluated 4,7,11 and 18 days after dredging (repeated 50 m tows) in two 3x50 m experimental sites and compared with two control sites.
9	Gilkinson et al. 2003	Banquereau Bank (Scotian Shelf), Canada	70-80 m	Sand	Sidescan sonar, 7x25x10cm sediment cores (9-20 per treatment), video, still photos (820 total)	Dredges cut deep (20 cm), wide (4 m) furrows in bottom; the loss of burrows, tubes, and shells through destruction or burial, and local sedimentation created a smooth surface; differences in patterns of acoustic reflectance between dredge furrows and the surrounding seabed indicate long-lasting effects on sediment structure; over time empty shells are trapped in dredge furrows; densities of large burrows were reduced up to 90% after dredging.	Margins of furrows were gradually degraded, likely through the combined actions of slumping, sediment transport and bioturbation and were no longer visible in video 1 year after dredging due to their low relief; however, in sidescan sonograms they persisted for 3 yr, while undergoing changes; no signs of recovery of large burrows after 3 yrs likely due to the high mortalities of clams that make them.	Three-year BACI study in previously un-dredged low-energy site; 12 overlapping experimental tows in 12 hrs using two commercial cage dredges fished at the same time in each of two 100x500 m treatment boxes.

#	Reference	Location	Depth	Sediment	Sampling	Effects	Recovery	Approach
10	**Gilkinson et al. 2005a**	Banquereau Bank (Scotian Shelf), Canada	70-80 m	Sand	Benthic grabs (0.5m^2, 180 total)	Immediately after dredging, most macrofaunal species (polychaetes and amphipods most common) decreased in abundance and biomass (abundance decreased on average >40%), with the greatest declines inside dredge furrows (which covered 53-68% of the area inside the dredged boxes).	Marked increases in abundance and biomass of polychaetes and amphipods after 1 year, decreased # of spp and body weight at 1 and 2 years, two years after dredging, abundances of opportunistic species were generally elevated by >> 100% relative to pre-dredging levels; authors conclude that the disturbed community was still in the colonizing phase 2 years after dredging.	BACI study in previously un-dredged low-energy location; experimental tows using a commercial cage dredge (see above), effects evaluated (video) immediately after, and 2 wks, 1 yr and 2 yr after dredging; dredged-only impacts compared with dredged + discards.
11	**Gilkinson et al. 2015**	Banquereau Bank (Scotian Shelf), Canada	70-80 m	Sand	Sidescan sonar	NA	Tracks only partially degraded after 5 years; after 10 yrs tracks had nearly disappeared over half their length but gravel/shell patches remained; winter storm waves (height 11 m) major cause of degradation at this depth; scattered, small shell patches appeared after 5 yrs.	Follow-up side scan sonar surveys 5 and 10 years after 1998 dredge impact study, includes obs of commercial dredge tracks and their degradation in nearby, shallower water and analysis of seabed recovery due to bottom currents and storm wave action.
12	**Ragnarsson et al. 2015**	Iceland	10 m	Fine sand	8 benthic 0.25m^2 cores collected to depth of 30 cm by divers in each dredge track and in 3 control areas on each occasion	Surficial sediments in tracks smoother and more fluidized than controls throughout study period; S reductions in number of indvs in dredged plots imm after (46%) and 3 mos after (39%) dredging, but not afterwards; results suggested long-term dredging effects on hydrozoans and 3 spp of polychaetes.	Erosion of tracks was rapid; surficial sediments in tracks; 12 of 15 most abundant taxa S affected by dredging, but after 3 mos most taxa had attained similar abundances as in the controls and all had done so after a year.	3 experimental cage dredge tows 150 m apart in unfished area, impacts and recovery of infauna assessed inside/outside dredge tracks imm after and 3 mos, 1,2, and 5 yrs after dredging.

#	Reference	Location	Depth	Sediment	Sampling	Effects	Recovery	Approach
13	**Goldberg et al. 2012**	Long Island Sound, US	5-6 m	Fine and very fine sand	3 treatment and 3 control plots sampled with a Smith-McIntyre grab at 1 or 2 wk intervals for 24 wks	No S differences between dredged and non-dredged treatments for benthic community as a whole or for any ecological measures, total molluscan or total annelid abundance; there were S differences related to plot and sampling date.		BACI study of benthic community effects of hydraulic dredges in a cultivated hard clam bed 2 yrs after most recent commercial harvesting.
14	**Goldberg et al. 2014**	Long Island Sound, US	3-5 m	Fine and very fine sand	3 treatment and 3 control plots sampled with a Smith-McIntyre grab at 1 or 2 wk intervals for 5 mos	Results of biological analyses same as in study #13. Similarly, there were no S differences between dredged and not dredged plots for any of the chemical parameters measured, only some differences related to shore position and/or sediment grain size.		BACI study of effects of hydraulic dredges on benthic assemblages and sediment biogeochemistry conducted a year after study #13 in a nearby cultivated hard clam bed.

S=statistically significant. All peer-reviewed except Murawski and Serchuk 1989 and Medcof and Caddy 1971.

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