

# The Performance and Environmental Effects of a Hydraulic Clam Dredge

THOMAS L. MEYER, RICHARD A. COOPER, and KENNETH J. PECCI

## Introduction

The Northeast Fisheries Center (NEFC), National Marine Fisheries Service, NOAA, has conducted annual surveys since 1965 (excluding 1968, 1973, and 1975) to establish the distribution and abundance of the surf clam, *Spisula solidissima* (Dillwyn), along the inner continental shelf from Cape Hatteras, N.C., northward to Nantucket, Mass. Hydraulic clam dredges with 0.76 m and 1.2 m (30 and 48 inch) wide blades were used during these surveys (Serchuk et al., 1979). The efficiency of these dredges and the general effect of dredging on the substrate and the macrobenthic fauna is unknown. This paper presents the re-

sults of a diver-conducted study to estimate the dredge efficiency of the NEFC's 1.2 m hydraulic clam dredge and to assess the effect of dredging on bottom substrate and fauna.

## Study Area

The study area off Rockaway Beach, southwestern Long Island, N.Y., (Fig. 1) was selected because of the high density of surf clams reported by Franz (1976). The area was closed to commercial clamming, except for a relatively small bait fishery, in April 1974, by the U.S. Food and Drug Administration because of high levels of bacterial pollution (Verber, 1976). High densities of clams occurred at shallow water depths (10-15 m) and in substrate relatively undisturbed by dredging or other bottom-fishing operations. The area represented an ideal location for making in situ diver

observations and collections. The study area is characterized by high substrate mobility (Harris, 1976) with bottom sediment consisting of fine-medium sands at depths of 0-5 m, and silty-fine sands at depths of 5-30 m (Swift et al., 1976). Bottom currents generally flow in an easterly direction parallel to the Long Island shore (Charnell and Hansen, 1974).

## Materials and Methods

### Dredge Performance and Efficiency

During NEFC cruise DE-77-10, 17-25 August 1977, the NOAA Ship *Delaware II* made 60 tows using NEFC's 1.2 m hydraulic clam dredge (Fig. 2), 58 to experiment with various fishing techniques for maximizing the catch of clams and minimizing clam breakage, and two 2-minute tows to estimate dredge efficiency. Scientists equipped with scuba worked from the *Delaware II* during tows numbered 1-19 and 21-59.

The following dredge settings were varied in fishing the dredge as divers visually observed: Direction and speed of towing, scope of topline, attachment point of topline to dredge, scope of the water hose, size of digging and blowback nozzles, water pressure and flow rate to water manifold, depth and angle of cutting blade, size of cutting blade hold-down springs, and distance between blade and water manifold. Because of limited vessel and diver time, dredge efficiency was not estimated during these 58 experimental tows. Scientists equipped with scuba worked from the *Delaware II* and the NOAA Ship *Rorqual* during tows number 20 and 60 (hereafter referred to as tows #1 and #2) to observe and film dredge performance, to estimate dredge efficiency, and to make observations on the effects of dredging on the bottom substrate and fauna. Table 1 presents the dredge settings during the two dredge efficiency tows.

Dredge performance was recorded on film with a Hydro-Products' (Model 125)

The authors are with the Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543.

**ABSTRACT**—The efficiency of a 1.2 m hydraulic clam dredge in a surf clam, *Spisula solidissima* (Dillwyn), population was demonstrated by diver scientists to be sensitive to factors such as: Speed of towing, scope of tow line and water hose, and distance between cutting blade and water manifold. When these operational specifications were near optimum, the dredge removed 91 percent of the available clams; when below optimum, efficiency was 80 percent. When dredge performance was low, larger clams, which burrowed deeper into the sediment, suffered mortalities as high as 92 percent; when high, mortalities decreased to 30 percent.

In high clam density areas ( $>1,000/m^2$ ), the dredge filled with clams after approximately 10 m of towing. Once filled, the dredge action was analogous to a snowplow as it pushed and blew clams and sediment to the sides.

Initially, the dredge track was conspicuous with a smooth track shoulder, sharply angled walls, and a flat floor. The track rapidly deteriorated through slumping and biological activity until by 24 hours it appeared more like a series of shallow depressions.

Predators were more abundant inside the dredge track than outside and were divided into two categories: 1) Ones which fed on the remains of damaged clams, and 2) those which preyed on undamaged clams. The most abundant predator feeding on damaged clams was the lady crab, *Ovalipes ocellatus*, which reached a density of  $1,500/100 m^2$ . The starfish, *Asterias forbesi*, was the most abundant predator of undamaged clams, reaching a density of  $30/100 m^2$ . After 24 hours, predator density had returned to predredging levels except for the moon snail, *Lunatia heros*, which was the only predator to increase in abundance after the 2-hour estimate.

<sup>1</sup>Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Dredge settings during the two dredge efficiency tows.

Setting	Tow #1	Tow #2
Speed over bottom	1½-2 knots	½-1 knots
Towline length	37 m	33 m
Water hose length	46 m	76 m
Digging nozzle (hose nipple) size	16 mm	16 mm
Blowback nozzle size	19 mm	19 mm
Blade depth	22-23 cm	22-23 cm
Blade springs	Heavy duty	Heavy duty
Distance between water manifold and blade	22 cm	91 cm
Towing time	2 minutes	2 minutes
Diesel pressure	1,400 rpm	1,400 rpm

television camera with a 250-watt thallium iodide light source by divers riding the dredge. Dredge efficiency (in terms of percent removed from track) was calculated by comparing the track density (no./m<sup>2</sup>) of clams within sample quadrats inside the dredge track to the mean density (no./m<sup>2</sup>) found in samples from the undisturbed "adjacent area" outside of the track (Table 2, Fig. 3). Divers collected six samples (¼ m<sup>2</sup> quadrat) inside the dredge track and six samples in the undisturbed "adjacent area" on each side (north and south) of the track during the first tow, and six samples inside and five samples outside of the track on each side during the second tow. Samples were collected down to a depth of about 23 cm at approximately 10 m intervals along the 60 m track and adjacent area starting at the 5 m mark. Sampling inside the track was random between spillage areas and included clams that were buried along with ones which were discarded by the dredge (Fig. 3). Sampling in the adjacent area included only the clams that were buried.

### Dredge Track, Adjacent Areas, and Windrows

Photographic records (35 mm and video tape) and visual observations were made on: 1) Distribution of clams partially or entirely uncovered, 2) substrate type, 3) dredge track configuration, 4) breakdown of the dredge path, 5) clam behavior, 6) clam mortality, and 7) predation. Divers swam along and on each side of the dredge paths documenting the above. These in situ examinations were made immediately after

Figure 2.—1.2 m hydraulic clam dredge.

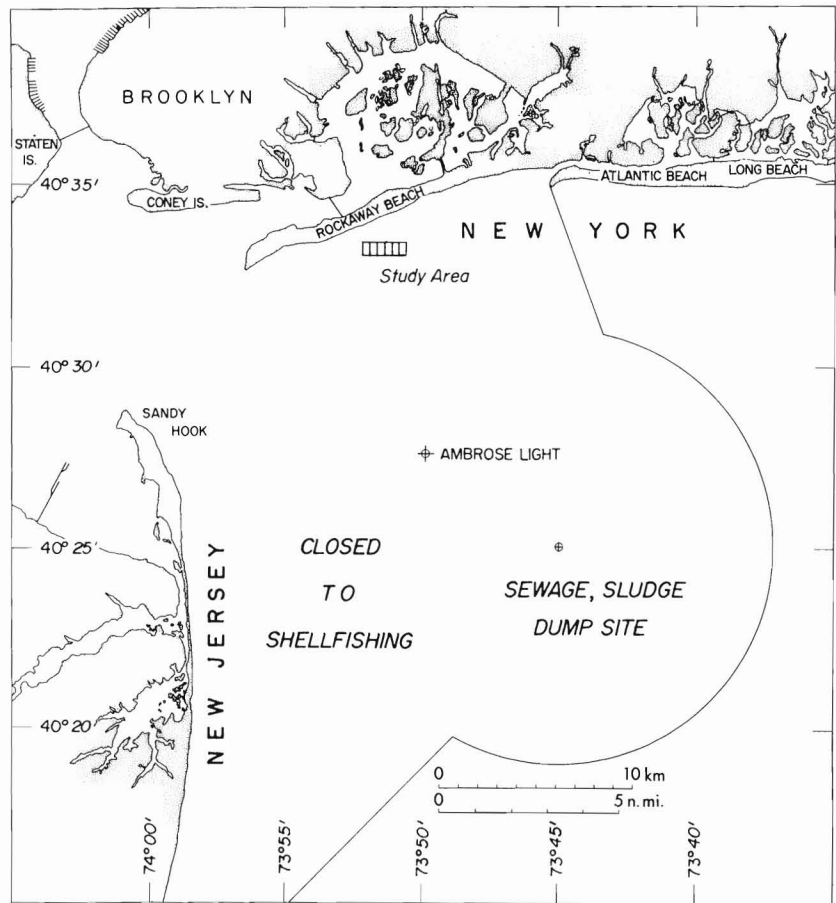
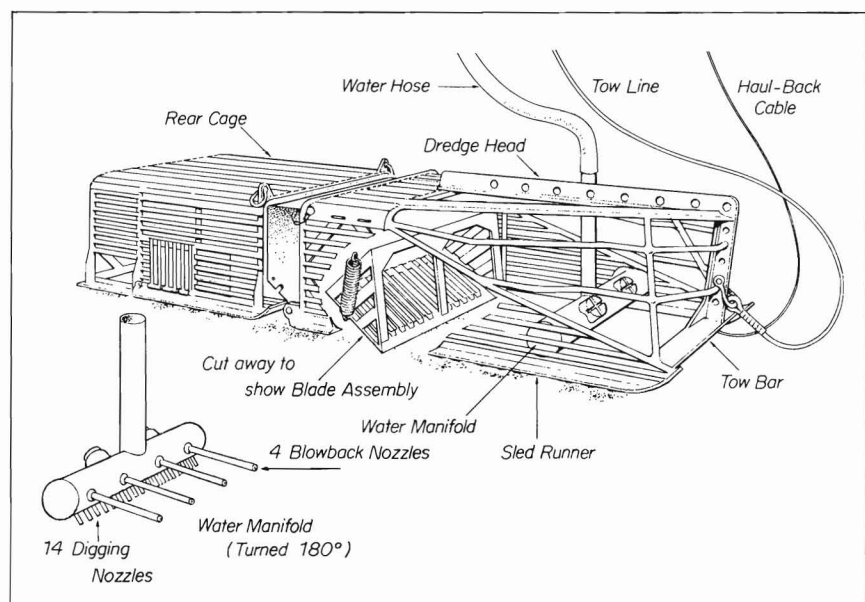


Figure 1.—Study area.



**Table 2. — Diver estimates of percent removal, breakage, mean size, and density of small and large clams sampled from within and adjacent to two clam dredge tracks.**

Population characteristics related to dredge efficiency and performance		Tow #1: Sample location — diver				Tow #2: Sample location — diver			
		With-in path	North of path	South of path	N & S Combined	With-in path	North of path	South of path	N & S Combined
Removal (%) before dredge full	Small	80	—	—	—	90	—	—	—
	Large	68	—	—	—	92	—	—	—
	All	80	—	—	—	91	—	—	—
Removal (%) after dredge full	Small	89	—	—	—	72	—	—	—
	Large	76	—	—	—	83	—	—	—
	All	88	—	—	—	73	—	—	—
Mean size (mm)	Small	29	32	31	31	31	32	32	32
	Large	107	112	113	113	112	110	111	111
Mean density (no./m <sup>2</sup> ) before dredge full	Small	258	1,312	1,368	1,320	120	1,112	1,140	1,126
	Large	12	32	42	37	4	44	56	50
Mean density (no./m <sup>2</sup> ) after dredge full	Small	270	1,344	1,410	1,357	124	1,156	1,196	1,176
	Large	6	33	31	32	10	30	46	38
Mean density (no./m <sup>2</sup> ) entire track	Small	82	1,153	1,211	1,182	420	1,006	1,145	1,075
	Large	137	1,171	1,243	1,207	293	1,003	1,107	1,055
Breakage (%) before dredge full	Small	145	1,204	1,278	1,241	300	1,036	1,155	1,095
	Large	18	1	1	1	17	1	1	1
	All	83	2	4	3	7	1	1	1
Breakage (%) after dredge full	Small	21	1	2	2	14	1	1	1
	Large	26	1	1	1	28	1	1	1
	All	92	2	4	3	30	1	1	1
Breakage (%) windrow area	Small	29	1	2	2	28	1	1	1
	Large	—	2	2	2	—	2	2	2
	All	—	35	35	35	—	20	20	20

the tow and again at 2 and 24 hours. For the first 3 hours after the tow, the beginning of the dredge path was marked by a buoy and the end by the dredge. After 3 hours, the dredge was brought aboard and a buoy was positioned in its place at the end of the path.

### Treatment of Samples

The diver-collected samples were placed in 4 mm nylon mesh bags and returned to the *Rorqual*. Clams ranged in size (shell length) from 22 to 132 mm with no individuals within the 45-85 mm size range. Standard shell length measurements were made along the longest linear dimension to the nearest millimeter. A representative sample of 50 clams less than 45 mm (hereafter defined as small clams) and all clams greater than 85 mm (defined as large clams) were

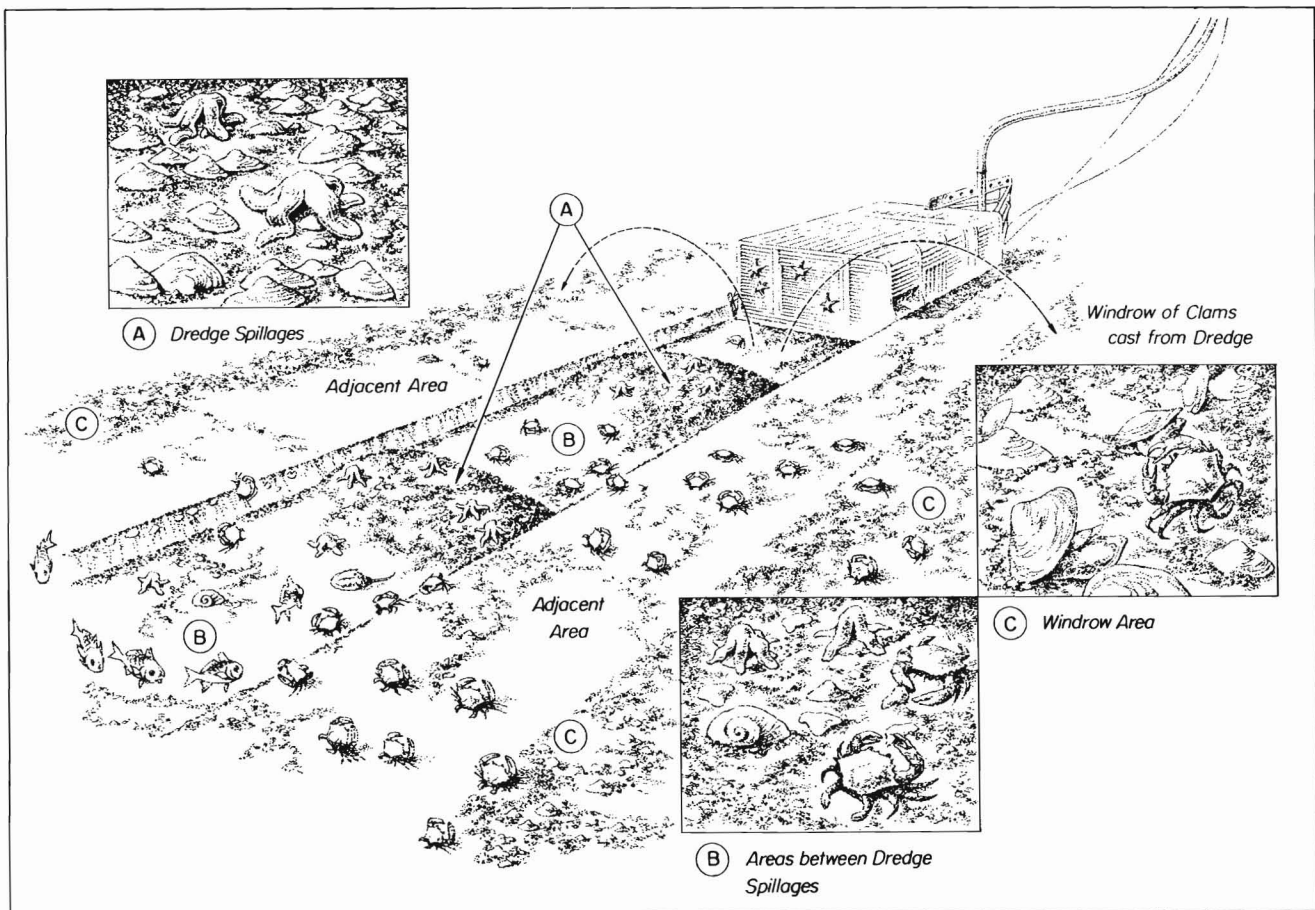


Figure 3. — Artist's rendition of a 2-hour-old clam dredge path.

measured for shell size. Diver-collected samples were divided into small and large clam categories because of the bimodal size distribution (Fig. 4) and to determine the catch efficiency of the dredge on the larger commercially valued clams. After measuring the sample, the remaining small clams were counted and added to the above totals for a measure of clam density. All damaged clams (broken shells, severed feet, and/or siphons) were counted and grouped by size category.

The dredge catch during tows #1 and #2 were hauled aboard the *Delaware II*. A representative 1-bushel sample of clams was measured and counted; the total catch was estimated by prorating the 1-bushel sample to the total number of bushels of clams in each tow. The numbers of damaged clams and other invertebrates were recorded for each sample.

## Results and Discussion

### Dredge Performance

#### First Tow

Tow #1 was made in a westerly direction in calm seas at a depth of 11 m. Bottom currents were negligible in the study area immediately after the tow. Underwater visibility was 2-3 m on the bottom. The dredge did not consistently dig to the same depth, but periodically "hung up" and then "surged ahead." Divers noticed that water from the digging nozzles did not penetrate the substrate as deep as the cutting blade (Fig. 2). This surging action was accentuated by the elasticity of the polypropylene towing line.

After approximately 10 m of towing, the dredge filled sufficiently to cause spillage of some clams from the rear cage onto the blade assembly during a surge (Fig. 2). They passed through the 33 mm slits between the angle stock of the blade assembly or washed under the cutting blade to form the dredge "spilling areas" inside the path (Fig. 3A). The dredge then refilled until another surge caused more spillage. These spillage areas were approximately 2-4 m apart, the full width of the deep path, and 1-3 clams thick. Hundreds of small clams

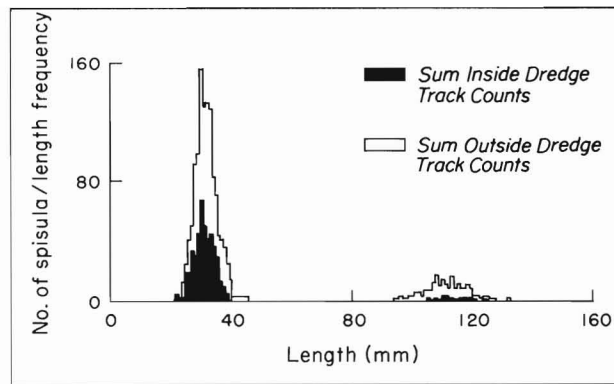


Figure 4.—Size distribution of clams in the study area.

were deposited at each spillage site. The blade assembly appeared to act like a strainer, selectively spilling the smaller clams.

As the rear cage became full, the filtering of water through the cage slits was restricted, creating a back pressure wave from the rear cage toward the dredge head. The pressure wave in conjunction with the normal turbulence created by the dredge moving over the bottom and the pressure exerted by the digging and blowback nozzles resulted in clams being blown out through the sides and the top of the dredge head and rear cage areas. This dredge action is analogous to a snowplow pushing and blowing everything to the sides.

Divers visually estimated that 60 percent of the discarded clams were deposited 1-2 m outside the dredge path forming a "windrow of clams" (Fig. 3C). Windrows were 1-2 m wide and extended the last 50 m of the dredge path. An estimated 2 percent of the discarded clams were deposited in the "adjacent area" with the remaining portion evenly distributed inside the dredge path between spillage areas (Fig. 3B).

#### Gear Changes After Tow #1

During the first tow, the blade was not cutting consistently beneath the clam bed, but periodically rode up into the bed causing considerable damage. Practice hauls (tows 21-59) made after the first diver assessment tow demonstrated that three factors affected the cutting depth: 1) Water manifold pressure, 2)

distance between the water manifold and the blade, and 3) dredge nose not tending bottom. When the water pressure reaching the manifold was low, blade penetration into the substrate was too shallow. At high water manifold pressures, clams were damaged by either colliding with one another or hitting parts of the dredge before reaching the rear cage. An increase in the distance between the blade and the water manifold from 22 to 91 cm improved performance by allowing the digging nozzles a longer time to soften up the sediment in front of the advancing blade. The problem of the dredge nose lifting off the bottom was corrected by decreasing the length of the tow line from 37 to 33 m, by increasing the length of the water hose to the water manifold from 46 to 76 m, and by decreasing the towing speed from 1.5-2 knots to 0.5-1 knot; and these specifications were used for tow #2 (Table 1).

#### Second Tow

Tow #2 was made in a westerly direction in calm seas at a depth of 11 m. A 0.25 knot westerly bottom current was found in the study area immediately after the tow. Underwater visibility was 1-1.5 m on the bottom. The surging motion observed by divers during tow #1 was greatly reduced by the various gear changes made between assessment tows (Table 1). The decrease in surging probably contributed to a 15 percent reduction in the number of clams in the spillage area after tow #2. With these

improvements, the dredge remained hard on the bottom with the blade cutting a consistent 23 cm deep trench. After approximately 10 m of towing, the dredge filled sufficiently for windrow and spillage areas to develop. The distribution of discarded clams inside and outside the path was the same as in the first tow.

### Comparisons Between Tows

The discarding of clams to form the spillage and windrow areas was probably more a function of the high clam density, which averaged from 1,095 to 1,241 clams per square meter (Table 2), than the actual dredge performance. Although few clam beds average over 1,000 clams/m<sup>2</sup>, with longer towing time in a less dense area there is a possibility of filling a dredge. Once a dredge is brought aboard and determined to be filled, there is no way of determining at which point during the tow the dredge was full. When the dredge was fished during practice hauls (tows 21-59) in areas where clam densities were less than 100 clams per square meter, dredge spillage and windrow areas did not develop based on diver observations. The average catch during normal NEFC survey tows does not exceed 500 clams for a 4-minute tow using a 1.2 m hydraulic clam dredge (Murawski and Serchuk<sup>2</sup>).

### Dredge Efficiency

#### First Tow

The percentage of small clams in the quadrat samples during tow #1 was 97.3±1.0 at a 95 percent confidence interval: A uniform distribution throughout the dredge tow area. The dredge removed an average of 80 percent of the small clams and 68 percent of the large clams in the first 10 m of the dredge track (Table 2). After approximately 10 m of towing, the dredge was full of clams and although it continued to remove clams, it immediately discarded them. The removal percentages for the re-

maining 50 m of the path were 89 percent for the small clams and 76 percent for the large clams. The average size of clams remaining in the dredge path after the tow was 29 mm for small and 107 mm for the large; outside the track small clams averaged 31 mm and large averaged 113 mm. Mean clam densities measured inside the dredge path after the tow were 137/m<sup>2</sup> for the small and 8/m<sup>2</sup> for the large. Densities measured outside the path were 1,207/m<sup>2</sup> for the small clams and 34/m<sup>2</sup> for the large clams.

Twenty-two bushels of clams (16,170 individuals) were caught in the dredge of which 96 percent were small clams (Table 3). The average size of the clams caught in the dredge was 24 mm for the small and 115 mm for the large.

#### Second Tow

The percentage of small clams in the quadrat samples during tow #2 was 96.1±0.7 at a 95 percent confidence interval: A uniform distribution throughout the dredge tow area. The dredge removed an average of 90 percent of the small clams and 92 percent of the large clams in the first 10 m of the dredge track, and 72 percent and 83 percent of the remaining 50 m. The average size of clams remaining in the dredge path was 31 mm for the small and 112 mm for the large; outside the track small clams averaged 32 mm and large ones averaged 111 mm. Mean clam densities measured inside the dredge path after the tow were 293/m<sup>2</sup> for the small and 7/m<sup>2</sup> for the large. Densities measured outside the path were 1,055/m<sup>2</sup> for the small and 40/m<sup>2</sup> for the large clams.

Again 22 bushels of clams (11,946 individuals) were caught in the dredge of which 76 percent were small clams (Table 3). The average size of the clams caught in the dredge was 29 mm for the small and 108 mm for the large.

### Comparisons Between Tows

Dredge efficiencies (in terms of percent removed from track) calculated before the dredge was filled showed an increase from tow #1 to tow #2: Small clams from 80 to 90 percent and large clams from 68 to 92 percent. The apparent increase in dredge efficiency during tow #2, for the first 10 m of dredge track, was probably related to improvements in the cutting blade depth previously described in the dredge performance section. Once the dredge filled, removal of small clams from tow #1 to tow #2 decreased from 88 to 73 percent and increased for large clams from 76 to 83 percent. The dredge was more efficient during the first 10 m of the second tow, and also captured more clams during the last 50 m, but these were immediately discarded. A higher number of these discarded clams landed inside the dredge path which was seen by the 82 clams/m<sup>2</sup> in the dredge path for the first tow compared with 420 clams/m<sup>2</sup> for the second tow (Table 2).

The size composition of clams retained by the dredge was 96 percent small for the first tow, and 76 percent for the second tow, a highly significant difference ( $\chi^2=2.512$ ;  $P\{\chi^2_1>10.8\}=0.001$ ). The number of large clams in a bushel sample was 27 and 130 for the first and second tow, respectively (Table 3). After the gear changes made between tows, the dredge became more efficient at removing the larger clams during tow #2.

Medcof and Caddy (1971) conducted a similar gear study to observe the performance of three types of clam dredges. In their study area a uniform density of 30-40 clams/m<sup>2</sup> was found at depths of 7-12 m. Their commercial hydraulic clam dredge, when "skillfully controlled," was 92 percent efficient in catching ocean quahogs, *Arctica islandica* (L.), on a sandy bottom. Although the

Table 3. — Analysis of clams captured by the dredge during the two dredge-efficiency tows.

Tow	Individuals captured	Bushels collected	Percent caught		Average (mm)		Percent breakage		
			Small clams	Large clams	Small clams	Large clams	Small clams	Large clams	Overall
#1	16,170	22	96	4	24	115	15	0	14
#2	11,946	22	76	24	29	108	21	18	20

<sup>2</sup>Murawski, S.A., and F.M. Serchuk. 1979. An assessment of offshore surf clam, *Spisula solidissima*, population off the Middle Atlantic coast of the United States. Woods Hole Lab. Ref. 79-13, 36 p.



Clam spillage area in dredge track.

clam density measured  $1,095/m^2$  in our study area during tow #2 in comparison with 30-40 clams/ $m^2$  during Medcof and Caddy's study. dredge efficiencies were similar: 91-92 percent, respectively. If the dredge is fished skillfully, the clam density does not become a factor in dredge efficiency until the dredge is filled with clams.

#### Track Configuration and Breakdown

The path left by tow #2 was selected for examination of the track configuration and breakdown over a 24-hour period. The fine to medium sand in the study area was covered by a 75 mm thick silty layer. During the tow, the dredge created a cloud of silt 0.5-1.5 m in height. The silt settled evenly within 4 minutes of the tow. The dredge track was conspicuous with smooth and sharply angled walls and a flat floor. The dredge track was 1.2 m wide and 60 m long. Substrate penetration depth by the dredge increased gradually down to 20 cm in the first 3 m, remained relatively constant at a depth of 23 cm for the next 54 m, and then returned to 5 cm in the last 3 m. Depths up to 30 cm were measured in areas where the dredge passed

over small depressions on the bottom. The walls varied in slope from  $20^\circ$  to  $45^\circ$ , depending on the amount of sediment resettlement, the amount of slumping, the strength of the alongshore transport system, and clam predator action.

During the tow, the dredge pushed sediment off to the sides, forming heaps called the track shoulder. The track shoulder was 15-35 cm wide and 5-15 cm high when measured against the undisturbed sediment outside the path. The area of slumping varied from 5 to 15 cm into the track shoulder. Many clams were found half embedded along the slope and were an aide in distinguishing the path when visibility was poor. Slumping along the walls of the path began immediately after the tow and became more apparent with time. The clams, which were half embedded in the dredge slope, soon began spilling onto the floor of the path.

In the 2-hour-old track, slumping of the walls created a more rounded depression. The walls of the path varied in slope from  $15^\circ$  to  $35^\circ$ . The track shoulder was now 10-25 cm wide and 5-10 cm high. The area of slumping now var-

ied from 5 to 20 cm into the track shoulder. Unburied clams had a silty film on their shell surfaces.

The 24-hour-old track lacked the well-defined shoulder seen immediately after the tow and at 2 hours. The path appeared more like a series of shallow depressions with  $5^\circ$ - $10^\circ$  sloped walls. The dredge path blended in with the general bottom features and was difficult to recognize.

#### Mortality

Mortality, as deduced from direct observations, occurred when damage to the clam shells resulted in parts of their viscera, or other soft-bodied tissues, being exposed. Two categories of dredge-induced mortalities were observed by divers as the dredge moved through this tightly compacted area: 1) Cut clams and 2) crushed clams. Damage of either type is considered to lead to mortality.

Cut clams were found whenever the dredge blade was not penetrating the bottom to at least 20 cm. Large clams, which burrowed deeper into the sediment, suffered the greatest damage. Many of these had their foot muscle

severed. These feet were observed on or floating near the bottom within the dredge path and reached densities up to  $2/m^2$ . A small number of severed siphons were observed from both size categories. The majority of the crushed clams were found after the dredge had filled. Clams were crushed by passing through the blade assembly or under the blade, by coming in contact with the inside of the sled runners, or by striking parts of the dredge or other clams while being discarded. Clam mortality due to crushing was highest among the larger clams.

#### *First Tow*

After tow #1, mortalities among the clams remaining in the dredge track for the first 10 m were 18 and 83 percent for the small and large clams, respectively. After approximately 10 m of towing, the dredge had filled and mortalities appeared to increase to 26 and 92 percent. Mortalities measured outside the dredge track in the adjacent area were 1 and 3 percent for small and large clams; in the windrow areas 2 and 35 percent for small and large clams. Divers visually estimated that 5 percent of all small clams in the spillage areas were damaged. The remaining damaged small clams were found evenly distributed inside the dredge track and outside the track in the windrow areas (Fig. 3). Divers estimated that 60 percent of all large damaged clams were found near the sides of the trench or on the slope. The remaining individuals were evenly distributed inside the dredge track between spillage areas and outside the track in the windrow areas. Divers estimated that 60 percent of all damaged clams were crushed and 40 percent were cut.

In the 1-bushel sample from the dredge catch, 15 percent of the small clams were damaged. Of the nine large clams measured, all were undamaged.

#### *Second Tow*

After the second tow, mortalities among the clams remaining in the dredge track for the first 10 m were 17 and 7 percent for small and large clams, and increased to 28 and 30 percent for the remaining 50 m. Mortalities measured outside the dredge track in the ad-

acent area were 1 percent for the small and large clams; in the windrow areas 2 and 20 percent for small and large clams. Clam mortality in the spillage areas and distribution of clams inside and outside the path in the windrow areas were the same as in the first tow. Divers visually estimated that 85 percent of all damaged clams were crushed, and 15 percent were cut.

In the 1-bushel sample from the dredge catch, 21 percent of the small clams and 18 percent of the large clams were damaged.

#### *Comparisons Between Tows*

Clam mortalities among the small clams remaining in the dredge track for the first 10 m were 18 and 17 percent for the first and second tows, respectively, 83 and 7 percent for the large clams. After 10 m of towing, the dredge had filled and small clam mortality increased to an estimated 26 and 28 percent, and 92 and 30 percent for the large clams. Dredge induced mortalities outside the dredge track in the adjacent area for both size categories remained less than 2 percent, while in the windrow areas small clam mortality remained approximately 2 percent and large clams demonstrated an apparent decrease of 35-20 percent (Table 2).

The most significant improvement between tows was the substantial decrease in large clam mortality throughout the dredge path. This decrease was a result of improvements in cutting blade depth which led to a reduction in the amount of cut clams from 40 to 15 percent from the first to second tow.

Medcof and Caddy (1971) found that their dredge broke the shells of more than 80 percent of the uncaught clams, but less than 20 percent of those caught; however, shell length measurements and the number of tows were not presented. For comparison purposes, mortalities from our second tow were used since the dredge efficiencies were similar. Before the dredge was full, our dredge broke the shells of 14 percent of the uncaught clams in the dredge path; windrows had not developed yet. Mortality increased to 28 percent for the clams in the dredge path after the dredge was filled. In addition, 2 percent of the

small clams and 20 percent of the large clams discarded outside the path were damaged. Mortality to the clams caught by the dredge during tow #2 was 20 percent, the same as found by Medcof and Caddy (1971). Fishing mortality, as defined by Medcof and Caddy (1971), was the average number of broken clams per square meter divided by the average density of clams per square meter. The breakage to clams caught by the dredge was not included in this percentage. Medcof and Caddy (1971) found their fishing mortality to be about 10 percent. During our second tow, fishing mortality was 2 percent before the dredge was filled and about 12 percent after it was filled.

#### **Clam Behavior**

In this dense clam population, large clams were found living at a depth (measured to uppermost posterior end) of 10-12 cm below the sediment water interface with their siphons projecting between the small clams burrowed to a depth of 2-4 cm.

During and after both tows, the behavior of discarded undamaged clams was observed. In the first 2 hours after the tow, discarded small clams were more vulnerable to predators than the large clams. Some reburrowed immediately, but others remained immobile, apparently suffering from some form of dredge induced shock which lasted from 1 to 24 hours. Divers estimated that 99 percent of all clams in the dredge spillage areas were small. They were piled 1-3 clams thick and those on the upper layer were using their "leaping escape" response, previously described by Ropes and Merrill (1973), to propel themselves from the clam piles. Once they were clear, the average reburrowing time was approximately 1.5-2 minutes. The large clams had the most difficulty reburrowing; many remained on their sides and were being covered over by a silty film; some were extending their foot in an attempt to right themselves, but because of their large size could not apparently get enough leverage. Some of the larger clams may have suffered internal damage, i.e., foot severed, hinge dislocation, or damage to adductor muscles, making reburrowing impossible.

Dredge induced shock to the larger clams was noted in a few cases. For example, one large apparently undamaged clam was found upside down with its foot extended up into the water column.

In the 2-hour-old dredge path, approximately 80 percent of the undamaged small clams located in the dredge path between spillages and in the wind-row areas had reburrowed (Fig. 3B, C). Small clams visually counted in the dredge spillage areas numbered approximately 150 individuals, about one-fourth of their initial population level. An estimated 20 percent of all large undamaged clams in the study area had reburrowed.

In the 24-hour-old dredge path, approximately 95 percent of all small undamaged clams in the study area had reburrowed. Small clams in the dredge spillage areas now numbered 50 individuals. An estimated 80 percent of all large undamaged clams in the study area had either been consumed by predators or had reburrowed. The few that remained were covered by a thin layer of sediment.

### Predators

Predation was another form of clam mortality. Predators were more abundant inside the dredge track than outside and were divided into two categories: 1) ones which fed on the remains of damaged clams (i.e., lady crab, *Ovalipes ocellatus* (Herbst); rock crab, *Cancer irroratus* (Say); and spot, *Leiostomus xanthurus* (Lacépède)) and 2) those which preyed on undamaged clams (i.e., starfish, *Asterias forbesi* (Desor); horseshoe crab, *Limulus polyphemus* (L.); and moon snail, *Lunatia heros* (Say)). During the 2 hours after the tows, the abundance of predators feeding on clams damaged by the dredge increased sharply. These were the most mobile of the predators. Lady crabs were the most conspicuous, numbering 100/100 m<sup>2</sup> immediately after the tow, and 1,500/100 m<sup>2</sup> 2 hours later (Table 4). Lady crabs were observed ripping and tearing at the exposed clam flesh and severed clam feet and siphons. On numerous occasions, divers observed interspecific competition for the available food. The rock crab density was

constant at 2/100 m<sup>2</sup> throughout the 24-hour study period. Spot initially numbered about 15/100 m<sup>2</sup> and were observed in a small school of about 15 individuals nibbling on small pieces of clam flesh. Two hours later, spot abundance increased to 300/100 m<sup>2</sup> and a large school of 100 individuals was seen.

Predators of undamaged clams were slower to move into the study area. Starfish were the only predators observed to be preying on undamaged clams during the first 2 hours. They avoided, for the most part, the damaged clams and tended to concentrate on clams in the 25-45 mm size range, depending on the size of the starfish. Starfish initially numbered 10/100 m<sup>2</sup>, but increased to 30/100 m<sup>2</sup> within 2 hours after the tow. They were found climbing up the sides and rear of the dredge full of clams resting at the end of the track. After 2 hours, moon snails and horseshoe crabs had moved into the study area, reaching abundance levels of about 4/100 m<sup>2</sup>. They seemed to prefer feeding on small undamaged clams. Franz (1977) reported that moon snails favored clams less than 80 mm in shell length. In the diver collected samples, 7 small clams were found bored by moon snails during the first tow, and 11 during the second tow.

After 24 hours, the distribution and abundance of predators and discarded clams appeared to have returned to normal except for the broken and whole clam shells void of meat spread throughout the study area. The abundance of predators feeding on damaged clams had either returned to the predredging levels, as in the lady crab, or the predator was not observed, as in the spot. All available food from the damaged clams had been consumed. The abundance of predators feeding on undamaged clams showed that the starfish population had returned to the predredging levels, horse-

shoe crab population had decreased from 4 to 2/100 m<sup>2</sup>, and the moon snail abundance had increased from 4 to 6/100 m<sup>2</sup>. The moon snail was the only predator to increase in abundance after the 2-hour estimates.

In general, approximately 3 percent of the undamaged clams discarded by the dredge during both tows suffered predator-induced mortalities.

Predators captured by the dredge were 10 lady crabs, 26 starfish, and 1 horseshoe crab for the first tow, and 33 lady crabs, 22 starfish, and 1 moon snail for the second tow.

### Summary

Dredge efficiency was demonstrated to be sensitive to factors such as: Speed of towing, scope of towline and water hose, and distance between cutting blade and water manifold. When these operational specifications were near optimum, the dredge removed 91 percent of the available clams; when below optimum, efficiency was 80 percent. When dredge performance was low, the larger clams, which burrowed deeper into the sediment, suffered mortalities as high as 92 percent; when high, mortalities decreased to 30 percent.

Because of the high clam densities measured in the study area (1,095-1,240 clams/m<sup>2</sup> for a 2 minute tow), the dredge filled with clams after approximately 10 m of towing. Once filled, the dredge action was analogous to a "snowplow" as it pushed and blew clams and sediment to the sides. During this process, the majority of the clam mortality occurred. Although few clam beds average over 1,000 clams/m<sup>2</sup>, with longer towing time in a less dense area there is a possibility of filling a dredge. Once a dredge is brought aboard and determined to be filled, there is no way of determining at which point during the two the dredge was full.

Initially, the dredged track was conspicuous with a smooth track shoulder, sharply angled walls, and a flat floor. The track rapidly deteriorated through slumping and biological activity until by 24 hours it lacked the well-defined shoulder and appeared more like a series of shallow depressions. Divers found that the dredge track blended in with

Table 4.—Estimated abundance of predators by divers.

Predator	Initially	2 hours	24 hours
Lady crab	100/100m <sup>2</sup>	1,500/100m <sup>2</sup>	100/100m <sup>2</sup>
Rock crab	2/100m <sup>2</sup>	2/100m <sup>2</sup>	2/100m <sup>2</sup>
Spot	15/100m <sup>2</sup>	300m <sup>2</sup>	N.o. <sup>1</sup>
Starfish	10/100m <sup>2</sup>	30/100m <sup>2</sup>	10/100m <sup>2</sup>
Moon snail	N.o.	4/100m <sup>2</sup>	6/100m <sup>2</sup>
Horseshoe crab	N.o.	4/100m <sup>2</sup>	2/100m <sup>2</sup>

<sup>1</sup>N.o. = none observed.



general bottom features and was difficult to recognize.

Predators were more abundant inside the dredge track than outside and were divided into two categories: 1) Ones which fed on the remains of damaged clams and 2) those which preyed on undamaged clams. The most abundant predator feeding on damaged clams was the lady crab which reached a density of 1,500/100 m<sup>2</sup>. After 24 hours, predator densities had returned to predredging levels except for the moon snail which was the only predator to increase in abundance after the 2-hour estimate.

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