EFFECTS OF LARGE PREDATORS ON THE FIELD CULTURE OF THE HARD CLAM, *MERCENARIA MERCENARIA*[1]

Individuals in the clam industry have used fences to keep the cownose ray, *Rhinoptera bonasus*, out of planted areas (Lewis[2]; Burton[3]). Tiller et al. (1952) indicated losses due to skates in planted holding areas and stated that "One man reported the loss of 600 bushels of small clams in two nights during 1948. . . ." Merriner and Smith[4] stated that cownose ray predation is a serious problem on oyster and clam grounds in Chesapeake Bay. From these observations it is clear that such large predators could be a significant deterrent to the culture of clams from Delaware Bay southward along the Atlantic coast.

The present study continues a program designed to evaluate methods of protecting areas seeded with young *Mercenaria mercenaria*. The initial portion of the study outlined the interactive effects of pens, gravel, current baffles and crab traps on the first year's growth and survival (Kraeuter and Castagna 1977). The results of the second year study on the interactive effects of these manipulations are recorded below. The data indicate effectiveness of efforts to prevent predation on clams surviving the first year's plantings.

## Methods

Details of the experimental design were presented in the previous paper (Kraeuter and Castagna 1977) and are briefly discussed below.

Four contiguous intertidal sites were marked by pushing stakes into the muddy substrate and two of the four sites were enclosed by 10 mm mesh plastic net 2.3 m high stretched around the 38 m circumference. The two remaining sites were left open (Figure 1). Crab traps were placed within one of the penned and one of the unpenned (no net) sites to assess the predatory effects of the blue crab, *Callinectes sapidus*. In addition, within each site, areas to be seeded were marked and designated to be treated with or without combinations of metal framed current baffles and crushed granite gravel. Current baffles 0.6 m high were constructed to decrease the scouring effects of currents. Since average tidal amplitudes are 1.2 m, the baffles did not prevent entrance of fish or crabs into the plots. Each baffle was about 1.5 m long and 12 baffles were set in an array forming four squares (Figure 1). Clam seed (about 2 mm) was planted in all sites at 3,000/m$^2$.

Clams were sampled in each site with a 7.4 cm diameter corer. A 0.6 m$^2$ grid was placed over each treatment and 10 random samples were removed in July 1977. This is a continuation of the previous year's sampling. For final sampling (October-November 1977), all sites were harvested using a suction sampler with an attached mesh bag. Four quadrats corresponding to the squares formed by placing current baffles in squares were sampled as discrete units (Figure 1). Where no baffles were utilized for the treatment, squares were marked by stakes and sampled as though the baffles had been present. All clams removed from the plots were brought to the laboratory, counted, and the percent commercial size (1 in (25.4 mm) thick New York legal limit) was determined. The data (counts) were transformed by $\log_{10}$ and compared by a factorial analysis of variance design (ANOVA).

## Results and Discussion

Results from the first year sampling (through September 1976) indicated that baffles and gravel in combination were superior to any other treatment. Plots were sited in an area where predaceous echinoderms were not present, and although pens were not effective in preventing crab predation, no discernable damage could be attributed to other predators (Kraeuter and Castagna 1977).

The statistical summaries (Table 1) are a continuation of the table presented by Kraeuter and Castagna (1977), and, as in that paper, it is important to emphasize that the sampling results from one period to the next were not independent. The final data represent the cumulative effects of all environmental and biotic interactions on clams planted in fall 1975.

The July 1977 results mirrored those of earlier sampling periods (Kraeuter and Castagna 1977) with the exception that the pen × trap and pen × baffle × trap interactions were significant at the 0.05 level. This was due, in part, to the higher level of predation in the penned area without traps (18

[1]Contribution No. 924 from Virginia Institute of Marine Science.
[2]J. H. Lewis, seafood shipper and packer, Saxis, VA 23427, pers. commun. Nov. 1976.
[3]L. L. Burton, seafood shipper and packer, Burton's Seafood, Chincoteague, VA 23336, pers. commun. Sept. 1976.
[4]Merriner, J. V., and J. W. Smith. 1979. Gear feasibility study for the cownose ray, *Rhinoptera bonasus*. Va. Inst. Mar. Sci., Spec. Rep. Appl. Mar. Sci. Ocean Eng. 227, 27 p.

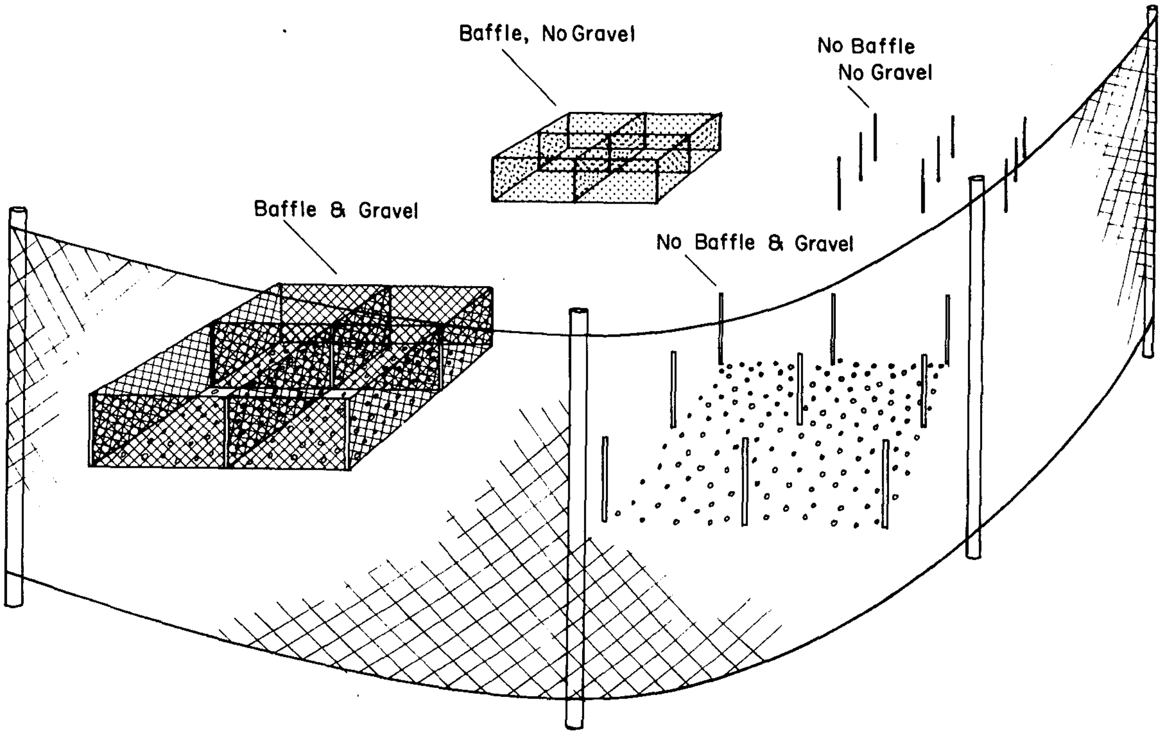


FIGURE 1.—Diagram of one site of the experimental design indicating the presence of each plot and the net for protection of juvenile *Mercenaria mercenaria*. Included in one site with a net would be a crab trap (not illustrated). The net was pushed into the substrate.

TABLE 1.—ANOVA table for survival of hard clam, *Mercenaria mercenaria*, juveniles with tests of pens, baffles, gravel, and traps and their interactions. Identical SS in the July data were caused by clams being absent in all sites with no baffle and no gravel.

| | July 1977 | | | | October-November 1977 | | | |
|---|---|---|---|---|---|---|---|---|
| Source of variation | df | SS | MS | *F* | df | SS | MS | *F* |
| Total | 159 | 7.91 | | | 63 | 54.64 | | |
| Pens (P) | 1 | .02 | 0.02 | | 1 | 4.31 | 4.31 | 114.31*** |
| Baffles (B) | 1 | 1.44 | 1.44 | 63.17*** | 1 | 32.17 | 32.17 | 853.37*** |
| Gravel (G) | 1 | 1.56 | 1.56 | 68.27*** | 1 | 10.21 | 10.21 | 270.89*** |
| Traps (T) | 1 | .01 | .01 | | 1 | .39 | .39 | 10.43** |
| P × B | 1 | .05 | .05 | | 1 | 1.16 | 1.16 | 30.64*** |
| P × G | 1 | .03 | .03 | | 1 | 2.76 | 2.76 | 73.30*** |
| P × T | 1 | .09 | .09 | 4.08* | 1 | .94 | .94 | 24.90*** |
| B × G | 1 | 1.12 | 1.12 | 49.02*** | 1 | .07 | .07 | |
| B × T | 1 | .00 | .00 | | 1 | .01 | .01 | |
| G × T | 1 | .001 | .001 | | 1 | .42 | .42 | 11.12** |
| P × B × G | 1 | .08 | .08 | | 1 | .04 | .04 | |
| P × B × T | 1 | .09 | .09 | 4.05* | 1 | .001 | .001 | |
| P × G × T | 1 | .07 | .07 | | 1 | .01 | .01 | |
| B × G × T | 1 | .004 | .004 | | 1 | .17 | .17 | 4.61* |
| P × B × G × T | 1 | .07 | .07 | | 1 | .16 | .16 | 4.20* |
| Residual | 144 | 3.29 | .02 | | 48 | 1.81 | 0.04 | |

***$P<0.001$, **$P<0.01$, *$P<0.05$.

clams sampled vs. 31 clams sampled in penned areas with traps), and, in part, to predation at the no pen no trap site, 23 clams sampled vs. 15 clams at the no pen plus trap site. These data indicate that trapping is essential in penned areas, but that when pens are absent crab trapping is of no benefit.

Within 2 wk following the July sampling, inspection of the sites revealed that clams 1.5-4.0 cm high had been crushed. These shell fragments were the result of large predators. The shells were clean and some were mixed within the surface layer on the bottom. In addition, the predators had created pits 50 cm in diameter and 6-10 cm deep in the aggregate and substrate which had been covering the clams.

To eliminate effects of losses due to predation during the first year's study and concentrate on the effects due to these predators, we have utilized the estimate of the mean number of clams from the July 1977 samples as 100% of those present for further predation. The estimated numbers of clams in each experimental plot for July 1977 are given in Table 2, and the number of clams remaining for the corresponding treatments from the October to November 1977 sampling are given in the same table. Several important aspects not evident from the ANOVA table are apparent. A combination of baffles, gravel, pens, and traps was essential for high survival. Pens were significant only because of the predation between July and October. The percentage survival between these two sampling periods seemed to indicate that gravel somehow negatively interacted with the baffles (compare percent survival B + G and B + NG, Table 2) when pens were absent. This was not the case, but resulted from heavy predation in the baffle + gravel sites with no pens. Since there were more clams in these areas in July, the percent survival was lower, but total survival was better than in the baffle + no gravel sites (Table 2). The higher survival in the baffled sites was due to the protection the baffles offered the clams when the predators entered the area. Almost all clams found in these areas were close to, or beneath, the cross rods supporting the bottom of the baffle. This same shadow effect was the cause of the nonsignificant baffle + gravel interaction in the October-November ANOVA table. If more clams had been present in the B + NG sites, the clams would have been in the center of the plot and thus vulnerable to predation.

The impact of predation to the mariculture of clams can be seen by comparing survival inside and outside the penned sites (Table 2). Estimated survival inside a penned area was always more than 76%, and the average survival for both penned sites was 94% from July to October-November. Average survival for the same period in the unpenned sites was 8.75%. The greatest survival in the unpenned areas was 65% but, as explained above, was due to protection provided by baffle frames. These data indicate that at least 85-90% of the observed losses in the unpenned sites were due to predation. The importance of these data is amplified when the size of the clams is considered.

The average size of clams in July 1977 was 3.2 cm and by October was 3.9 cm (hinge to lip). The percentage marketable clams (1 in (25.4 mm) thick) was the same for both the penned and unpenned sites (58.5 and 58.6%) in October. This indicates no size selection of clams, but that clams of all sizes were consumed. The loss of such large clams represents 2 yr of work and a product of market size.

Flounders, known to prey on young *Mercenaria mercenaria* and to selectively eat the neck of adult clams, have been eliminated as potential predators because they are not capable of crushing the shell of 3 cm high hard clams. Of the seven species of fish capable of forming pits and crushing the shell of 3 cm size hard clams (Table 3), only two are known to be common away from the inlets and near the planted areas (Richards and Castagna 1970; Musick 1972). These two species, *Dasyatis centroura* and *Rhinoptera bonasus*, are prime suspects for causing the destruction in our unprotected plots. The former cannot be eliminated be-

TABLE 2.—Total number of clams estimated from mean number per sample (July 1977), total counts (October-November 1977), and the percent mortality between the sampling dates. — = not calculated because of 0 estimate in July. P = pens, T = traps, G = gravel, B = baffle. The prefix N = absence; NP = no pen, etc.

| Month or period | Item | B + G | NB + G | B + NG | NBNG |
|---|---|---|---|---|---|
| July 1977 | P + T | 6,670 | 230 | 230 | 0 |
| | P + NT | 4,140 | 0 | 0 | 0 |
| | NP + T | 2,760 | 460 | 230 | 0 |
| | NPNT | 4,830 | 230 | 230 | 0 |
| Oct.-Nov. 1977 | P + T | 6,723 | 174 | 352 | 2 |
| | P + NT | 3,228 | 23 | 126 | 2 |
| | NP + T | 257 | 17 | 75 | 2 |
| | NPNT | 248 | 13 | 148 | 5 |
| % survival | P + T | 101 | 76 | 153 | — |
| July to Oct.-Nov. | P + NT | 78 | — | — | — |
| | NP + T | 9 | 4 | 33 | — |
| | NPNT | 5 | 6 | 65 | — |

TABLE 3.—Potential fish predators on 3 cm hard clams in Virginia. Information from Richards and Castagna (1970) and Musick (1972).

| Scientific name | Common name |
|---|---|
| *Dasyatis americana* | Southern stingray |
| *D. centroura* | Roughtail stingray |
| *D. sayi* | Bluntnose stingray |
| *Myliobatis freminvillei* | Bullnose ray |
| *Aetobatus narinari* | Spotted eagle ray |
| *Rhinoptera bonasus* | Cownose ray |
| *Pogonias cromis* | Black drum |

cause of its large size and overall abundance within the area and the latter because of its schooling behavior. Schools of *R. bonasus* often destroy large areas of eelgrass and other habitats in search of clams, their primary food (Orth 1975, 1977). Burton (footnote 3) used hog wire fencing to keep schools of cownose rays from his beds of inventoried and replanted market size *Mercenaria*. Because of the suddenness of the disappearance (<2 wk) and the presence of crushed clam shell in this and other plantings, we believe the most likely predator was a school of *R. bonasus*.

Our data indicate that losses, due to such predation, would be unpredictable, but it would be financially devastating to the clam grower. The use of a fence or some other device to protect the clams is essential for successful field culture in areas where large predators occur. These fences can be removed during the winter to prevent ice damage, but along the Virginia coast they should be kept in place and maintained at all times from late March to early November.

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## A DIRECT METHOD FOR ESTIMATING NORTHERN ANCHOVY, *ENGRAULIS MORDAX*, SPAWNING BIOMASS

Two methods exist for estimating spawning biomass, the total weight of mature fish, from abundance of spawning products. The first, or direct, method (Saville 1963) consists of dividing an estimate of egg production by the product of batch fecundity and the proportion of females in the mature stock. Saville safely assumed spawning frequency to be unity. The second method is indirect (Murphy 1966; Smith 1972) and utilizes information from two different species. Smith illustrated the second method, using information on the Pacific sardine, *Sardinops caerulea*, and northern anchovy, *Engraulis mordax*. Sardine spawner biomass is estimated from landings data and cohort analysis; anchovy spawner biomass is estimated by multiplying the estimated sardine spawner biomass by the product of the anchovy-to-sardine ratio of larval abundance and the sardine-to-anchovy ratios of fecundity, and spawning frequency. Computation was facilitated by assuming the unknown spawning frequencies to be equal, making the ratio of spawning frequencies unity. Up to the present only the second method has been used for the northern anchovy. This paper presents estimates derived from the first.

Computation of spawning biomass is simplified for the direct method when spawning occurs but once and for the indirect method when both species spawn with equal frequency. Difficulties arise when spawning is continuous and when it cannot be safely assumed that all mature fish spawn with the same frequency. This is the case with the northern anchovy. Spawning products are present all year, with a maximum abundance occurring in the late winter and early spring and a minimum during late summer and early fall. Abundance of and seasonal pattern of spawning products give no clue as to the number of spawnings by size and age, or even to the average number of spawnings.

Under the following conditions spawning frequency can be estimated from examining the spawning condition of females: 1) females can be examined for a characteristic that indicates when spawning takes place; 2) the length of time such a characteristic remains detectable can be estimated; 3) the spawning rate remains relatively constant over the sampling interval.

The spawning fraction, or frequency, is the