The Barnstable Harbor Shellfish Recruitment Enhancement Project (BHSREP)

A Final Report compiled by:

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Executive Summary:

Soft shell clam recruitment onto tidal flats is a poorly understood phenomenon that is thought to be dependent on physical, chemical, and biological factors in the environment. In Barnstable Harbor, a number of sites have undergone a substantial change in their ability to attract and support soft shell clam sets. Many sites in the harbor have a history of promoting clam sets but inspection of these sites today reveals a lack of harvestable resources. How do we manage these flats to bring them back to their historical levels of clam production?

Two methods were proposed by a collaborative group consisting of the Barnstable Shellfishermen's Association, the Town of Barnstable Division of Natural Resources, and shellfish biologist Dale Leavitt (Sea Grant Program at Woods Hole Oceanographic Institution). The first proposed method to enhance soft shell clam recruitment was to physically turnover the sediment using a disk harrow. This technique has been used previously for soft shell clam recruitment and is thought to change sediment structure, reduce predators, change sediment chemistry, and increase bottom roughness on a short-term basis. The second proposed technique was to place suspended tents of plastic netting over the flats. This technique has also been previously used to promote clam recruitment and is thought to be effective due to changing the hydrodynamics across the flats and by excluding predators of small clams.

Five replicated treatments were administered at four sites within Barnstable Harbor. The sites were Huckins Island, The Cove, Green Point, and Eel Grass Cove and the treatments were no manipulations, mechanical cultivation, netting over a cultivated area, 5/16 inch mesh plastic netting, and 1/4 inch mesh plastic netting. The flats were sampled for sediment characteristics and/or clam density and size at four time intervals during the experiment, including before manipulating, two weeks post-manipulation, in the Fall of 1995, and in the Fall of 1996. In addition, data were collected on money and time expended to complete the project.

Equipment costs for placing clam tents on the flats was approximately $2,363 per acre. Labor costs for placing the nets on the flats were defrayed by using volunteer labor so that the time expended for the complete project of approximately 45 acres cultivated and 3.5 acres netted equaled 814 hours of volunteer help, 293 hours of salaried help, and $5,230 for net retrieval. The total cost for completing the program was approximately $3,900 per acre.

Although summer 1995 is suspected to have been a very poor year for soft shell clam recruitment in Massachusetts Bay, the results from the present study allow for guarded optimism in the efficacy of using human intervention to promote soft shell clam recruitment in Barnstable Harbor. Cultivation of the sediment did not prove to be effective during this study but more research is suggested to finally conclude that this technique is not appropriate for Barnstable Harbor. On the whole, the density of clams in the areas covered with clam tents did not change following tenting although two areas netted at one site (Green Point) did receive a significant set of clams due to the tents. The density of young of the year soft shell clams at Green Point under the 1/4 inch mesh netting increased from 26 clams per ft^2 before the treatment to 109 clams per ft^2 by Fall of 1995. This set resulted in a final density of 12 legally harvestable soft shell clams per ft^2 in the fall of 1996 compared to no legally harvestable clams in control areas. The economic return associated with the soft shell clam production achieved under the nets at Green Point approaches $37,925 per acre resulting in an economic gain of up to $113,775 per acre to the Town of Barnstable.

Background and Justification for the Project:

The recruitment of bivalve larvae onto intertidal and subtidal flats is a poorly understood phenomena. Studies dating back into the 1800's have investigated and speculated on what factors influence the distribution of young bivalves on the mud flats. To this day, although much is now known about bivalve settling behavior, the complete story is not fully understood. It is generally accepted that three general categories of environmental factors play a role in regulating the set of young clams. These categories include physical, chemical, and biological factors.

The soft shell clam (*Mya arenaria*) spawns primarily in the spring (May - July) and sometimes a second time in the fall (Sept. - Oct.) depending on the local environmental conditions at the flat. Following fertilization of the egg, the developing larvae will spend a short time, two weeks to a month, swimming in the water column while continually being transported by the prevailing wind and currents. As the larvae become ready to metamorphose to a bottom dwelling lifestyle they become negatively buoyant and start making excursions to the bottom looking for suitable habitat to settle on. Because clam larvae are very weak swimmers, the location of their settlement is largely at the mercy of the hydrodynamics of the water body they are resident in. Yet the competent, i.e. ready to settle, larvae demonstrate some selective capacity by controlling their height off the bottom, by way of swimming, thereby either promoting contact with the bottom or taking advantage of local water currents to move the larvae over different bottom conditions..

As stated above, the distribution of clam settling is generally thought to be controlled by a combination of three factors, the chemical, biological, and physical components of the environment. Many researchers have noted the influence chemical properties within the flats may have on settling clam spat. Properties such as salinity, temperature, level of organic content of the substrate, light, and possible chemical cues from resident adults are all thought to play a role in clam settling. The actual importance of chemical cues to bivalve recruitment are thought to be relatively minor once the basic life requirements for the clam are met. For example, clams will not be resident in flats that are routinely flushed with freshwater, yet if the salinity stays within an acceptable range, approximately 5 parts per thousand (ppt) up to 35 ppt, then salinity will not influence settling behavior and post-set survival. Clams also will not survive if the flat should experience any interval where the oxygen level drops below a critical level. Low ambient oxygen is a common cause of seed clam mortality and low recruitment during the summer months in some of Cape Cod's enclosed bays and estuaries.

Both the biological and the physical characteristics of the flats play a significant role in the distribution of settling spat. For biological properties, the most important consideration is predation on the young clams. Soft shell clam populations totally disappeared in the Annapolis Basin in Nova Scotia, Canada in the early 1980s, following the installation of a tidal power generating facility upstream from the flats. Rowell (1992) reported that the disappearance of the clam population was due, in part, to heavy predation on existing clam populations by the ribbon worm (*Cerebratulus lacteus*). The authors did not associate the presence of the nemertean worm with the construction of the power plant. Other researchers have also documented the role that predators play in controlling soft shell clam populations following settlement.

At the conclusion of a study investigating the role biotic factors played on soft shell clam recruitment, Beal (1990) stated his "results suggest that previously accepted models employing simple biotic mechanisms to explain recruitment patterns of intertidal marine bivalves are not sufficiently adequate and must be modified *to include physical parameters* such as sedimentary dynamics." The most important factor in controlling clam settlement distributions is thought to be the physical characteristics of the site. Two characteristics appear to be important - the water movement patterns and the sand grain size distribution. Turner (1953) suggested that enhanced clam recruitment could be expected where there was a decrease in water flow velocity. This is supported by reports of clam settlement patterns along slack water gradients or within eddies (Newell and Hidu 1986). In a recent Sea Grant funded study in Buzzards Bay, MA, Garland and Mullineaux (1992) concluded that coastal eddies do appear to concentrate late stage bivalve larvae except during periods of high wind stress. Coastal eddies, formed on the lee side of headlands, were first theorized to be sinks for bivalve larvae in 1903 (Kellogg 1903), where he described the phenomena as similar to tea leaves gathering in the middle of a swirling cup.

Other physical factors that impact water velocity near the bottom and could influence bivalve settlement include tidal current asymmetry and bottom roughness.

Sediment composition has also been implicated in playing a role in clam settlement. In addition to predation by the ribbon worm, Rowell (1992) demonstrated that the water flow patterns had changed in the Annapolis Basin following installation of the tidal power plant with the end result being the bottom becoming covered with a 1-2 inch layer of watery fine sediments. This layer effectively blocked the settling soft shell clam larvae from getting access to the bottom. Phil Schwind (1977) observed that "slimy bottom will prohibit the setting of clam seed, and soft mud containing hydrogen sulfide or other organic acids caused by decaying vegetation will prohibit growth and erode shells."

Within Barnstable Harbor, a number of sites have undergone a substantial change with respect to their ability to attract and support clam sets. Sites such as next to Mussel Point in The Cove and Green Point traditionally recruited large sets of soft shell clams but today are totally non-productive. These sites fit the hydrodynamic model for optimal clam recruitment by being probable eddy areas. Other currently non-productive sites within the harbor, such as Huckins Island, and Eel Grass Cove, also have a history of promoting clam sets and may have potential for clam recruitment. Inspection of many of these sites today reveals that the sediment is covered with a fine silt-clay mud and there are high numbers of ribbon worms, moon snails, and other predators. The question that needs to be asked is how do we manage these flats to bring them back to their historical levels of clam productivity?

One method that repeatedly appears in the scientific and management literature is cultivation of the flats. Schwind (1977) reports that flat cultivation was practiced over 100 years ago as a means to maintain clam flat productivity but is not currently used. It has been suggested by Rask (1986), Schwind (1977), MacKenzie (1979), Kite and Chew (1975), Pfitzenmeyer (1972), and many others as an acceptable means to promote clam recruitment. How does it promote recruitment?

Cultivation of the flats promotes clam recruitment through a number of different means. The first is that cultivation changes the grain size distribution of the sediment. It reduces the proportion of the fine silt-clay fraction thereby increasing the grain size of the sediment (Rask 1986, Haven 1970, Godcharles 1971). In Maine, Kyte (1975) found that sediment cultivation increased clam recruitment while in the Chesapeake region cultivation had no effect on clam recruitment (Haven 1970, Pfitzenmeyer 1972). MacFarlane (1983) observed fewer "seed" clams on cultivated flats, although her definition of "seed" was anything less than 1.5 inches, not really addressing the young of the year, and the cultivation took place during the peak period of clam settlement, thereby interrupting the primary settlement event in the spring. She reported increased settlement on the tilled flats the following year, probably representing the fall set which occurred immediately post-cultivation.

Cultivating the flats may reduce the density of predators through physical disturbance of the flats during the interval when the clams are settling. This will give the newly settled clams a chance to grow to a size where predators cannot prey on the clam.

Turning over the flats potentially resuspends and releases some of the organic material that may be contributing to both the level of organic acids as referenced by Schwind (1977) and the biological or chemical oxygen demand (BOD or COD) within the sediment. BOD and COD can deplete oxygen levels in the clam's microenvironment. Less sediment organic content has also been reported to support increased growth rates of soft shell clams (Belding 1930).

A second technique to enhance bivalve recruitment onto intertidal flats is through the use of "clam tents". This technique entails placing a relatively fine mesh plastic netting (1/8 to 1/2" mesh size) over the tidal flats and suspended above the sediment water interface. Clam tents have been used with varying degrees of success at many sites on Cape Cod and are currently popular tools to promote soft shell clam recruitment on aquaculture leases in the town of Wellfleet and at other sites on Cape Cod.

The mechanism of action whereby these tents promote clam recruitment is largely unknown although it is suspected that hydrodynamics may be a key factor. As outlined above, hydrodynamics plays several roles in distributing soft shell clam larvae during the free-swimming stage and the early post-set. During the larval stage, distribution of clam veligers is primarily controlled by water movement. Recent research suggests that immediately post-set and up to a valve length of 5mm, juvenile soft shell clams are routinely transported by water currents as a component of the bedload. The placement of netting, in the form of a suspended cover over the sediment and in the same plane as the bedload transport vector, will reduce water movement at the sediment surface therefore allowing particles entrained in the water current, such as larval or juvenile clams, to settle onto the sediment.

Clam tents may also physically inhibit crabs and other surface moving predators from gaining access to the newly settled clams. Because predation is thought to be the primary mechanism for loss of newly settled bivalve larvae, any obstruction to the predators will significantly increase the probability of juvenile clam survival post-set. Clam tents establish an appropriate microenvironment to promote the settlement, survival, and growth of soft shell clams in the intertidal flats.

Both types of flat manipulation, flat cultivation and clam tents, have potential to re-establish soft shell clams onto flats in Barnstable Harbor Although many of these flats have traditionally supported populations of clams large enough to allow commercial harvesting, they no longer do so. We propose to experimentally test the efficacy of these two flat manipulation techniques to promote soft shell clam recruitment at selected locations in Barnstable Harbor.

Experimental Methods:

We proposed to investigate how effective flat manipulations, in the form of flat cultivation and/or net tents, are in promoting soft shell clam recruitment in Barnstable Harbor. To achieve this objective, we established ten experimental squares at each of four sites within Barnstable Harbor (Figure 1). The 50 by 50 foot experimental squares (2,500 ft^2) were established at:

1) Huckins Island (Plot #2),
2) The Cove (Plot #4),
3) Green Point (Plot #5), and
4) Eel Grass Cove (Plot #6).

This research effort was part of a larger effort undertaken by the Barnstable Shellfishermen's Association and the Barnstable Department of Natural Resources to enhance soft shell clam recruitment within the Harbor.

At each experimental plot, randomly selected replicated squares were assigned to be manipulated by the following techniques:

1) control (no manipulation),
2) mechanical cultivation by disk harrow,
3) 510tt-brand plastic netting over cultivated sediment,
4) 510tt-brand plastic netting (5/16 inch mesh),
5) Plurima-brand plastic netting (1/4 inch mesh).

The experimental deployments at each plot are identified in the plot schematics in Figures 2 through 5. Each experimental square consisted of a 50 by 50 foot square with a 25 foot buffer strip between any two adjoining squares. Each square was demarcated by wooden corner stakes to allow repeated sampling during the experimental time period.

Prior to the application of the prescribed treatment at each square, one sediment core (two inch diameter) within each of the ten squares was collected for sediment analysis. The depth of the anaerobic horizon was recorded and the sediment cores were divided into two subsections consisting of the top one inch of sediment as subsection A and the next one inch of sediment as subsection B. The sediment samples are archived, by freezing at -10°C, for grain size analysis dependent on the outcome of the experimental manipulations. To analyze for faunal composition in each the experimental squares, one core (one ft^2) was collected at each of the ten squares, the core contents were sieved on site through a 2 mm sieve, and all living soft shell clams were collected for measurement of size class distribution prior to treatment. Size, in millimeters, was measured as the longest length of the valves along the anterio-posterior axis.

Two weeks following the completion of the plot manipulations, sediment cores were taken as described above and preserved for sediment grain size analysis, as outlined above.

The squares were experimentally manipulated during the time interval of 22 April to 27 June 1995, prior to the predicted soft shell clam spring recruitment event in Barnstable Harbor.

The squares were allowed to sit untouched during the summer. During November 1995, from each of the ten squares at each experimental site, one core (two inch diameter) was collected for sediment grain size analysis as described above, one core (two inch diameter) was collected for total sediment organic content analysis, and one core (eight inch diameter) was collected and sieved, as described above, for faunal analysis.

One year following the Fall 1995 sampling period, a second series of replicated cores (eight inch diameter) were collected (8 October 1996) at all experimental squares that showed visual evidence of soft shell clams.

Results and Discussion:

Overall:

The timeline for the flat manipulations, including the associated research sampling effort, is presented in Table 1. The experimental deployments at each of the plots are diagrammed in Figures 2 through 5 and also included are the plans for the complete net deployments at each plot.

Summaries of the total amounts of areas netted and estimated costs of materials for each site are included in Tables 2 and 3. These data include all areas covered with clam tents, including the research squares. The areas netted and the estimated costs of materials at each site are 0.9 acres netted at Huckins Island at a materials cost of $2,324 (Table 2a); 0.3 acres of The Cove netted at a cost of $747 (Table 2b); 1.4 acres of Green Point netted at a cost of $2,335 (Table 3a); and 0.9 acres of Eel Grass Cove netted at a cost of $2,218 (Table 3b). The mean cost of materials per acre netted is approximately $2,363.

An estimate of total effort, both volunteered and salaried, for cultivating the flats and deploying the nets are included in Table 4. A total of 814 person-hours were volunteered for starting this project, in conjunction with 123 hours of salaried DNR employee time.

As of the 20 December 1995, a large amount of netting remained deployed on the flats due to a lack of volunteer effort in removing the netting. Because this was a breach of the "Order of Conditions" placed on the project and because the volunteer support diminished to the point where no help was forthcoming, the Barnstable DNR instituted a bounty system for net retrievals to expedite net removal from the flats. Due to the bounty system there was a large effort to remove the remaining nets, including all of the remaining nets associated with the research program, and this was completed as of 21 March 1996. The costs associated with the net bounty program was $5,230 and these are itemized in Table 5. In addition to the bounty program, Barnstable DNR committed 170 hours of salaried time for net removal (Table 4).

The total cost for deploying and removing clam tents on the four flats in Barnstable Harbor can be calculated in two different ways, depending on how one handles the labor volunteered in the beginning of the program. If the 810 hours of volunteer labor is charged off at $15.00 per hour then the total cost per acre for placing clam tents on the four plots and removing them, including materials costs, was approximately $7,500. If the volunteer labor is not charged off then the cost per acre is approximately $3,900. These costs are rough estimates due to the fact that included in the labor tally is the time volunteered to cultivate the flats as well as the time dedicated to placing tents. The record keeping did not differentiate between labor commitments based on each task completed.

A listing of general observations made for each of the experimental sites is included in Table 6. In general, observations indicated that sediment deposition beneath the netted areas occurred at all plots except Eel Grass Cove. This could be an indication of the relative levels of water movement at each of the sites, where Eel Grass Cove was an area of relatively quiescent water. Sediment deposition was observed as an increase in sediment elevation beneath the netted areas, sometimes approaching a maximum of 6-8 inches of new sediment. This suggests that bedload transport of sediment, and potentially other particles such as small clams, occurs routinely in many areas within Barnstable Harbor. The presence of the net tents succeeded in reducing sediment movement at the netted sites and enhanced particle deposition on site. As a follow-up to these observations, a WHOI scientist (Dr. Lauren Mullineaux) has had a Sea Grant proposal funded to investigate the potential for bedload transport as an important mechanism in soft shell clam dispersal in Barnstable Harbor, scheduled to begin in 1997.

The Research Component:

The results of the research component of the Barnstable Harbor Shellfish Recruitment Enhancement Project are summarized and discussed as follows.

The sediment structure was monitored throughout the experimental time period. Samples were collected to measure changes in the depth of the anaerobic horizon, changes in the particle size composition of the sediment at the sediment surface and at one inch depth, and changes in the total organic content of the surface layer of sediment within each of the experimental plots at each of the four sites. The samples collected for sediment particle size analysis and for organic analysis are currently archived in a freezer at -10°C at Woods Hole Oceanographic Institution. At present, there are no compelling reasons to expend the time to analyze the sediment characteristics. The only site to actively recruit soft shell clams was a site where the treatment was to apply a net tent with no sediment manipulation. Therefore, the sediment characteristics within this treatment would have minimally changed during the course of the experiments. Because analyzing the sediment characteristics is a labor intensive procedure, the results of this study does not warrant this expenditure of time.

The one sediment character that was routinely monitored was change in the depth of the anaerobic horizon due to the experimental flat manipulations. The results from this analysis are summarized in Table 7. The depths of the anaerobic horizon were compared between sites, between times, and between treatments using a three-way analysis of variance (ANOVA) technique. Significant differences were noted in the depth of the horizon when comparisons were made between locations (Table 7-B1), times (Table 7-B2), and a two-way interaction between location and time (Table 7-B4). Due to variability in the sediment composition and water flow patterns at each site, it is not surprising that differences were noted between locations. It is interesting to note, although not unexpected, that the plots with the highest tidal flow rates (Huckins Island and Green Point) had the deepest anaerobic horizons. Differences in the horizon between times of measurement may be the result of changes in ambient temperature, although the largest difference is between the start of the experiments and two weeks following treatment. One would be tempted to prescribe the observed differences in depth of the horizon as the result of the manipulations to the flats but this is not supported by analysis of the data. No differences were noted between treatments (Table 7-B3; $p=0.258$) or between the interaction of time and treatment ($p=0.157$). These data further support the conclusion not to carry on with the analyses of the sediment characteristics. Because no treatment differences were observed, it is unlikely that changes in sediment characteristics influenced the one successful set of clams observed. The interpretation of the results concerning differences in the depth of anaerobic horizon between sites and times would require a more complete study to ascertain why these differences were observed.

Changes in soft shell clam density throughout Barnstable Harbor due to experimental manipulations of the clam flats are summarized in Table 8. Clam densities at the start of the experimental period were low at all sites, averaging 4.5 clams per ft^2, with a range from 1.7 clams/ft^2 at Eel Grass Cove to a high of 9.9 clams/ft^2 at The Cove. Massachusetts Division of Marine Fisheries sets a criteria of a minimum of three clams per ft^2 as a threshold for a productive flat. The average density for all sites during the Fall 1995 sampling time was 3.1 clams per ft^2, probably not significantly different from densities at the start of the experiment (4.6 clams/ft^2), based on the variability in the observed density. The density in the Fall of 1995 ranged from a low of 0 clams/ft^2 at Huckins Island and The Cove to a high of 12.2 clams/ft^2 at Green Point. After one and one-half years post-treatment, the average density of soft shell clams at all of the sites was 0.7 clams/ft^2, significantly lower than that observed the previous year. The range at this time was from a low of 0 clams/ft^2 at Huckins Island, Eel Grass Cove, and The Cove to a high of 2.7 clams/ft^2 at Green Point. On the whole, none of the treatments appeared to have an effect on promoting recruitment and survival of young of the year soft shell clams. The one exception to these observations was noted at Plot # 5 - Green Point in squares one and eight and this will be discussed below.

The size frequency distribution of the clams sampled at the start of the experiments at all four sites were very similar (Figure 6). Therefore the size frequency data from all sites were combined (Figure 7) to demonstrate the size composition of the clam population in Barnstable Harbor prior to this experiment. As demarcated in Figure 7, the population structure of soft shell clams in the smaller valve size ranges (5-18 mm) can be identified as two specific recruitment events during the previous year, corresponding to a spring and a fall set in 1994. Individual cohorts of clams can routinely be identified shortly after recruited but, as the clams grow, the individual variability in growth rates results in the lose of one's ability to follow the cohort as it grows beyond the first or second year post-set.

The size distribution presented in Figures 6 and 7 demonstrate an important consideration when investigating soft shell clam recruitment in Barnstable Harbor. It is very interesting to note that no clams larger than a valve length of 30 mm were found at any of the sites sampled, even though none of the sites had been commercially or recreationally harvested in the recent past. For some unexplained reason clams were not surviving long enough at these sites to grow to legal size (slightly larger than 50 mm). A number of theories could be put forth to explain this phenomenon, including inadequate food resources or high predation pressure, but the important point to note is that although the clam densities met the MaDMF criteria as productive flats, the reality is that the productivity of the flats sampled proved to be zero based on producing a harvestable resource, for none of the resource grew to a harvestable size.

Sets of bivalves, other than soft shell clams, were observed at many of the sites. For example, high densities of the false angel wing clam (*Petricola pholadiformis*) were observed under netting at The Cove, as was a large set of the jellybean clam (*Solemya velum*). Also a large set of blue mussels (*Mytilus edulis*) was observed on the netting at Huckins Island.

As noted above, on the whole there was no net increase in the population densities of soft shell clams in any of the experimental manipulations. A lack of young of the year clams throughout Barnstable Harbor (T. Marcotti, personal observation) suggests that 1995 was a poor year for soft shell clam recruitment on the Massachusetts Bay side of Cape Cod. This has subsequently been confirmed by town shellfish biologists throughout Cape Cod. In an attempt to confirm a lack of a strong recruitment year within Barnstable Harbor, core samples were collected within the *Spartina* island located next to the experimental site on Huckins Island during the Fall 1995 sampling interval. The *Spartina* islands on Huckins Island routinely accumulate clam set if one occurs within the harbor. As can be observed in Figure 8, there were no small clams found in the *Spartina* bed on Huckins Island when sampled in November 1995 (solid black bars) although many small clams were present during sampling of this area in the Spring of 1995 (open white bars) prior to the start of the experiment. The size distribution within the *Spartina* bed in the Fall 1995 started at the 40mm size range and progressed up into larger legally harvestable clams. The larger clams sampled in Fall 1995 reflect the anticipated growth rate of the 1994 year class identified during the Spring 1995 sampling. The soft shell clam set for 1995 was not apparent in the *Spartina* islands of Huckins confirming that the last good year for soft shell clam recruitment in Barnstable Harbor was 1994.

The one exception to the observation of a lack of strong soft shell clam recruitment in Barnstable Harbor in 1995 was detected under the Plurima netting on experimental square eight at Green Point during the Fall 1995 sampling period and squares one and eight during the Fall 1996 sampling period. A large set of clams under the tents on square eight resulted in approximate clam densities of greater than 109 clams per ft^2 in Fall 1995. This population of clams sustained itself during the ensuing year resulting in a final density of more than 12 clams/ft^2 in Fall 1996 (Table 8). In addition, during the Fall 1996 sampling interval, an parallel occurrence of the same set was detected under the Plurima netting deployed in square one at Green Point. For unexplainable reasons, the set on square one was not detected during the Fall 1995 sampling interval. The sampling protocol during Fall 1995 was single cores at each experimental square unless clams were detected during a preliminary visual inspection and this may have contributed to missing the set during the initial evaluation.

The size frequency distribution for the soft shell clams sampled by replicated cores in square eight at Green Point during the one and one-half year sampling period is reported in Table 9 and Figure 9. The cohort of clams observed within experimental squares one and eight at Green Point originated from one recruitment event during the summer of 1995, probably the first (spring) set in May-June immediately after setting the tents. This observation is based on the relative size of the clam set as related to the time of sampling and compared to the size frequency distribution of the clams collected at the beginning of the experiment (Figures 6 and 7). The clams in the cohort observed at Green Point in Fall 1995 (Figure 9A) and proposed to be from the Spring 1995 set were the same size as the clams observed in the May 1995 sampling and determined to be from the Fall 1994 set.

The size frequency distribution measured on the same cohort of clams one year later, Fall of 1996, shows some startling results (Figure 9B). The mean valve length of this cohort is now greater than 71 mm in length, growing from a mean length of 6.3 mm, eleven months prior to this collection (Table 9). This indicates that the clams recruited onto Green Point during the spring of 1995 had grown to a harvestable size (greater than 50 mm) in approximately one year. This growth rate for soft shell clams is the fastest rate of growth the authors have observed in soft shell clam populations anywhere within the Cape Cod region.

Conclusions:

Overall, the results from the present study allow for guarded optimism in the efficacy of using human intervention to promote soft shell clam recruitment in Barnstable Harbor. Although, on the whole, 1995 is suspected to have been a poor year for soft shell clam recruitment throughout the Massachusetts Bay side of Cape Cod, we were able to significantly enhance the set of soft shell clams at one site in the harbor due to flat manipulation. The replicated sample manipulation that used the Plurima-type plastic netting, with a 1/4 inch mesh size, enhanced the set of soft shell clams at one site in Barnstable Harbor. In addition, the population of clams that recruited under the clam tent were able to grow to a harvestable size within one year. Although the clams' growth rate was very fast at the experimental site, this was not a result of the experimental manipulations; but it does indicate the site is very good for sustaining clam growth if recruitment can be realized.

Cultivating the sediment as a means to promote soft shell clam recruitment did not prove to be effective during this study. Neither did the use of a larger mesh size plastic netting (510tt netting) or combining the 510tt netting with substrate cultivation. It can not be irrefutably concluded that these techniques will not work to promote shellfish recruitment as on the whole soft shell clam recruitment was so poor in 1995. More research should be conducted to confirm the lack of efficacy of substrate cultivation and other types of plastic netting as a means to reintroduce and promote clam stocks in the harbor.

MacKenzie (1979) has suggested that for a management procedure to be incorporated into a management program it must meet five criteria. These criteria are:

1) it must meet an urgent need,

2) it must be technically and operationally feasible,

3) it can offer no damaging risks to the flats,

4) it can't impinge on other interests,

5) it must yield a return that exceeds the primary investment.

Flat manipulation to promote recruitment of the soft shell clam potentially fulfills each of these five criteria. It may be an appropriate choice as a component of the Town of Barnstable's shellfish management program

Given the history of soft shell clam harvests in Barnstable Harbor relative to the present rate of commercial harvesting, it is evident that there is an urgent need to understand and enhance clam recruitment within the harbor (criteria 1). Areas of the harbor that have supported extensive harvesting efforts during the 1940's through the 1960's are now barren. The commercial shellfishing industry in Barnstable needs technical and managerial assistance to allow the industry to thrive in the town rather than subsist.

The data presented to date adequately demonstrates the technical and operational feasibility of projects such as cultivation and "tenting" the clam flats (criteria 2). Although the program was not ideal during this initial attempt, the regulatory and technical managers have demonstrated that a flat manipulation program can be organized and undertaken within the community. Relying on strictly volunteer labor will require rethinking but is not completely out of the question. A combination of volunteer efforts and paid assistance, as the present program has evolved into, may be the more appropriate means to undertake enhanced recruitment efforts for the Town of Barnstable.

No adverse environmental impacts were noted in the short-term during the initial cultivation and net deployment steps (criteria 3). There was nothing observed that suggests these techniques offer any long-term risk to the flats or the surrounding environment either. There were no reported incidents of impact on other organisms, such as the endangered diamondback terrapin nor did the flat manipulations seem to change the overall faunal structure of the flats. The one major concern with respect to environmental insult revolves around removing the deployed clam tents expeditiously in the fall. It is evident that relying on volunteer labor is inappropriate for this type of project. It is imperative that the netting be removed before the winter months as ice and winter storms can wreak havoc on the netting by moving it all around the harbor. Therefore, if this type of flat manipulation is to be incorporated into a clam management program, careful attention must be paid to planning for guaranteed net removal during the late fall and ensuring that it occurs.

Flat manipulations, such as those tested in this study, are relatively innocuous techniques that have very little possibility of impinging on other user interests (criteria 4). This statement is supported by the observation that little to no user conflicts occurred during the manipulations in the present study. The only known interaction between the flat manipulations and other users was minor damage done to the nets on two experimental squares at Huckins Island due to a recreational boater cutting across the flats at too shallow a tidal stage. This damage was inconsequential to both the experimental project and the recreational boater.

The economic success of the project is unmeasured at this point (criteria 5). We have observed enhanced recruitment at one site and the clam population survived and grew to a harvestable size. Using a back of the envelope calculation, based on the recruitment data observed during this study (Table 8), one could argue that the technique of placing clam tents on the flats may provide significant economic benefit in terms of harvestable returns to the shellfish industry in the Town of Barnstable (Table 10). If recruitment could be enhanced routinely in a predictable way then the economic return per acre of manipulated flat would be $ 37,925. Given an economic multiplier of three, representing the cost benefit of the income derived on the flats to the town in increased business and derived from a recent economic analysis of the soft shell clam fishery in Casco Bay, Maine, the economic benefit to the Town of Barnstable per acre of flat netted could reach $ 113,775.

Using clam tents as a means to promote soft shell clam recruitment in Barnstable Harbor has been shown to have potential as a management tool. However, more research will be needed to understand where and how this technique can be used most effectively in the harbor. It is obvious that the scale of manipulations attempted during the present program was far beyond that needed to test the effectiveness of flat manipulations to recruit soft shell clams. In an attempt to fine tune the manipulation techniques, the authors would like to recommend that these techniques should continue to be tested on a much smaller scale. Any research effort should be directed primarily at testing the engineering and placement of clam tents although more work is required to justify dismissing substrate cultivation as an alternate means for restocking clams.

In closing, we have included a document published by the Merrimack Valley Planning Commission in November 1995 that outlines a shellfish enhancement research project that was instituted in the towns of Ipswich and Gloucester. The North Shore Shellfish Enhancement Project is a near mirror image to the Barnstable Harbor Shellfish Recruitment Enhancement Project (even the names are similar) and was conceived and undertaken entirely independent to the BHSREP. A classic example of convergent evolution of shellfish management programs.

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List of Tables:

Table 1:
Barnstable Harbor Shellfish Recruitment
Enhancement Project (BHSREP)
Timeline of Project

01-31-95	Meeting at W.H.O.I between Peter Jasin and Dale Leavitt conception of BHSREP.
02-08-95	Dale Leavitt met with Barnstable DNR to discuss BHSREP.
02-14-95	DNR filed N.O.I. with Conservation Commission.
02-21-95	DNR filed N.O.I. with Ma D.E.P.
02-28-95	Meeting at DNR to discuss project.
04-04-95	Surveyed (5) BHSREP field sites with Grant Kelly, A.C.O.E; Dale Leavitt, W.H.O.I.; Darcy Munson, Con. Comm.; Peter Jason, B.S.A.; a representative from N.M.F.S.; Thomas Marcotti, D.N.R.; Mark Forrest, Rep. Studd's office.
04-08-95	Prepared approx. (54) 50ft. nets.
04-11-95	Met with Barnstable Conservation Commission.
04-19-95	Prepared bridges, staples and floats. Met with Barnstable Shellfish Association at Sturgis Library.
04-20-95	Prepared nets, bridges, staples and floats.
04-21-95	Prepared nets, bridges, staples and floats.
04-22-95	**Huckins Island Flat (Plot #2)**: Harrowed; (20) sediment cores obtained on (10) expt'l squares (sample H-I); fauna sampled; expt'l squares #1 and #3 netted.
04-23-95	**Huckins Island Flat (Plot #2):** Expt'l squares #4, #6, #8, and #10 netted; (22) other nets deployed. **Green Point Flat (Plot #5):** (10) sediment cores obtained on (10) expt'l squares (sample G-I); fauna sampled; expt'l squares #1, #2,#8 and #10 netted.
04-25-95	Prepared nets, bridges, staples and floats.
04-26-95	Prepared nets, bridges, staples and floats.
04-28-95	Prepared nets, bridges, staples and floats.
04-29-95	Prepared nets, bridges, staples and floats. **Green Point Flat (Plot #5):** Harrowed.
04-30-95	Prepared nets, bridges, staples and floats.
05-03-95	Prepared nets, bridges, staples and floats. **Huckins Island Flat (Plot #2):** (19) 50ft. nets deployed. **Eel Grass Cove Flat (Plot #6):** Expt'l squares surveyed and staked.
05-06-95	Prepared nets, bridges, staples and floats. **Huckins Island Flat (Plot #2):** (10) sediment cores obtained on expt'l squares (sample H-II). **Eel Grass Cove Flat (Plot #6):** Harrowed, (10) sediment cores obtained on (10) expt'l squares (sample E-I); fauna sampled. **Green Point Flat (Plot #5):** (10) 50ft. nets deployed.

05-07-95	**Eel Grass Cove Flat (Plot #6):** (18) 50ft. nets deployed on expt'l squares.
05-17-95	**Green Point Flat (Plot #5):** (10) sediment cores, collected on (10) expt'l squares (sample G-II); A.E.T. netting deployed.
05-19-95	Prepared nets, bridges, staples and floats.
05-20-95	**The Cove Flat (Plot #4):** Harrowed, sample squares surveyed and staked. **Green Point Flat (Plot #5):** A.E.T. netting deployed.
05-27-95	**Eel Grass Cove Flat (Plot #6):** (10) sediment cores obtained on expt'l squares (sample E-II).
06-17-95	**The Cove Flat (Plot #4):** Harrowed, (10) sediment cores obtained on (10) expt'l squares (sample C-I); fauna sampled; (2) expt'l squares netted.
06-18-95	**The Cove Flat (Plot #4):** (2) expt'l squares netted.
06-27-95	**The Cove Flat (Plot #4):** (2) expt'l squares netted.
07-02-95	**The Cove Flat (Plot #4):** (10) sediment cores obtained on (10) expt'l squares (sample C-II).
-weekly-	Visited field sites to check on integrity of net systems.
11-19-95	**Huckins Island Flat (Plot #2):** (10) sediment cores obtained on (10) expt'l squares (sample H-III), fauna sampled.
11-30-95	**The Cove Flat (Plot #4):** (10) sediment cores obtained on (10) expt'l squares (sample C-III); fauna sampled. **Green Point Flat (Plot #5):** (10) sediment cores obtained on (10) expt'l squares (sample G-III); fauna sampled.
12-12-95	Met with Barnstable Conservation Commission to discuss progress of BHSREP.
12-17-95	**Eel Grass Cove Flat (Plot #6):** (10) sediment cores obtained on (10) expt'l squares (sample G-III); fauna sampled.
01-01-96	Barnstable DNR established bounty system to expedite net removal from flats.
01-09-96	Preliminary report submitted to Barnstable DNR.
03-21-96	Last net removed from flats in bounty program.
10-08-96	Visited field sites to check on clam densities: replicated cores at squares 1 and 8 at **Green Point Flat (Plot #5)** for faunal analysis.
11-15-96	Draft final report submitted to Barnstable DNR.
01-17-97	Final report submitted to Town of Barnstable.

Huckins Island Flat (Plot #2) Equipment Costs and Acreage Netted

Equipment Type	#Units	Equipment Type/Cost		Total Cost
15ft. end rods	118	1/4in. mild steel	@ $0.0555/ft.	$98.24
15ft. bridge rods	246			$204.80
34in. bridge supports	246			$36.41
27in. rod staples	806			$100.65
30in. wire staples	2,360	9 gauge wire	@ $0.0324/ft.	$191.16
7.5 oz. floats	324	7.5 oz. floats	@ $0.26 each	$84.24
510tt430(14'X50'net)	37	510tt430 net	@ $0.0362/sq. ft.	$937.58
Plurima (13'X50'net)	22	Plurima net	@ $0.0469/sq. ft.	$670.67
		Total Cost		$2,323.75

Acreage Netted:			
	510tt430 net	25,900 sq. ft.	0.595 acres
	Plurima net	14,300 sq. ft.	0.328 acres
	Total	40,200 sq. ft.	0.923 acres

The Cove Flat (Plot #4) Equipment Costs and Acreage Netted

Equipment Type	#Units	Equipment Type/Cost		Total Cost
15ft. end rods	36	1/4in. mild steel	@ $0.0555/ft.	$29.97
15ft. bridge rods	141			$117.38
34in. bridge supports	87			$13.68
27in. rod staples	216			$26.97
30in. wire staples	720	9 gauge wire	@ $0.0324/ft.	$58.32
7.5 oz. floats	54	7.5 oz. floats	@ $0.26 each	$14.04
510tt430 (14'X50'net)	12	510tt430 net	@ $0.0.362/sq. ft.	$304.08
Plurima (13'X50'net)	6	Plurima net	@ $0.0469/sq. ft.	$182.91
		Total Cost		$747.35

Acreage Netted:			
	510tt430 net	8,400 sq. ft.	0.19 acres
	Plurima net	3,900 sq. ft.	0.09 acres
	Total	12,300 sq. ft.	0.28 acres

Green Point Flat (Plot #5) Equipment Costs and Acreage Netted

Equipment Type	#Units	Equipment Type/Cost	Total Cost
15ft. end rods	46	1/4in. mild steel @ $0.0555/ft.	$38.30
15ft. bridge rods	190		$158.18
34in. bridge supports	171		$26.89
27in. rod staples	350		$43.71
30in. wire staples	4,368	9 gauge wire @ $0.0324/ft.	$353.81
7.5 oz. floats	828	7.5 oz. floats @ $0.26 each	$215.28
510tt430 (14'X50'net)	16	510tt430 net @ $0.0362/sq. ft.	$405.44
Plurima (13'X50'net)	6	Plurima net @ $0.0469/sq. ft.	$182.91
(13'X205'net)	1		$124.87
A.E.T.6155(10'X100'net)	1	A.E.T.6155 @ $0.0189/sq. ft.	$18.90
(10'X275'net)	3		$155.93
(10'X300'net)	4		$226.80
(10'X312'net)	2		$117.94
(10'X375'net)	1		$70.88
(10'X475'net)	1		$89.78
(10'X560'net)	1		$105.84
		Total Cost	$2,335.46

Acreage Netted:			
	510tt430 net	11,200 sq. ft.	0.257 acres
	Plurima net	6,565 sq. ft.	0.151 acres
	A.E.T.6155 net	41,590 sq. ft.	0.955 acres
	Total	59,355 sq. ft.	1.363 acres

Eel Grass Cove Flat (Plot #6) Equipment Costs and Acreage Netted

Equipment Type	#Units	Equipment Type/Cost	Total Cost
15ft. end rods	64	1/4in. mild steel @ $0.0555/ft.	$53.28
15ft. bridge rods	254		$211.46
34in. bridge supports	254		$39.94
27in. rod staples	416		$53.87
30in. wire staples	2,272	9 gauge wire @ $0.0324/ft.	$184.03
7.5 oz. floats	144	7.5 oz. float @ $0.26 each	$37.44
510tt430 (14'X50'net)	18	510tt430 net @ $0.0362/sq. ft.	$456.12
Plurima (13'X50'net)	6	Plurima net @ $0.0469/sq. ft.	$182.91
(13'X205'net)	8		$998.96
		Total Cost	$2,218.01

Acreage Netted:			
	510tt430 net	12,600 sq. ft.	0.289 acres
	Plurima net	25,220 sq. ft.	0.579 acres
	Total	37,820 sq. ft.	0.868 acres

Table 4:
Estimates of total labor used in the Barnstable Harbor Shellfish Recruitment Enhancement Project (BHSREP).

Task	average number of volunteers per day	total volunteer hours	total salaried hours
1) Prepare nets, bridges, staples and floats (12 days)	7.4	278	34
2) Huckins Island - tilling and netting (3 days)	20.0	290	17
3) Green Point - tilling and netting (4 days)	6.0	91	7
4) The Cove - tilling and netting (4 days)	4.0	56	24
5) Eel Grass Cove - tilling and netting (3 days)	6.0	66	8
6) Sample collection (11 days)	1.0	33	33
SUBTOTAL		**814 h**	**123 h**
7) Collection of net from the flats	2.0	*220**	170
TOTAL		**814 h**	**293 h**

* collected under bounty system

Table 5

"BHSREP" NET RETRIEVAL BY "PUBLIC VOLUNTARY BOUNTY"

50 ft. net/staples/rods: $20
200 ft. net/staples/rods: $50
00 ft. plus net: $50/200 ft. + $20/50 ft. after the first 200 ft.

NAME	Date Retrieved	Sites from which nets, rods and staples were retrieved, as reported by volunteers: Plot #2	Plot #4	Plot #5	Plot #6	Paid
Scott Korkuch			**13** (50 ft. 510tt)			$260
John Nawoichik	1/28/96				**.25** (205 ft. Plur)	
Rob Ashworth						
Chris Woods	1/18/96	**7** *(50 ft. 510tt)*			**1** *(205 ft. Plur)*	
	1/22/96	**3.5** *(50 ft. mix)*	**6** *(50 ft. Plur)*		**2** *(205 ft. Plur)*	
	1/23/96			**10** *(50 ft. mix)*	**1.5** *(205 ft. Plur)*	
	1/24/96				**5** (50 ft. mix)	
	1/25/96	*8 (50 ft. mix)*				
	1/26/96				**.75** (205 ft. Plur)	
					7 (50 ft. mix)	
	1/29/96				**4.5** (50 ft. mix)	
	1/30/96			**14** (50 ft. sec. A.E.T.)		
				3 (50 ft. 510tt)		
	2/1/96			**17** (50 ft. sec. A.E.T.)		
	2/2/96			**20** (50 ft. sec. A.E.T.)		
						$2,580
Rob Ashworth @ $130/day	3/7/96	(510tt, Plur.)rods, staples		(A.E.T., Plur, 510tt) rods, staples		
Chris Wood @ $130/day	3/11/96	"		"	"	
	3/12/96	"		"	"	
	3/13/96	"		"	"	
	3/14/96	"		"	"	
	3/15/96	"		"	"	
	3/18/96	"		"	"	
	3/19/96	"		"	"	
	3/20/96	"		"	"	
						$2,340
	3/21/96			**2.5** (50 ft. sec.)		$50
Total						**$5,230**

Table 6:

Barnstable Harbor Shellfish Recruitment Enhancement Project (BHSREP): General Observations

1) *Illyanassa* congregated on nets at all sites - potential predator?

HUCKINS ISLAND FLATS

1) squares 1, 3, & 4 collected coarse grained sediment under nets without being buried (3-4" build-up)
2) sedimentation pattern continued in the extra squares all along south edge
3) early in season minor build up of drift algae (primarily *Codium*) - snagged by nets
4) squares 8 & 10 (plurima netting) had mussel (*Mytilus edulis*) set on them without much sedimentation but with brown alga (>1mm first Aug => approximately 40 mm in mid Nov.)
5) bamboo worms (*Clymenella* spp.) colonized under extra plots similar to pattern of sedimentation
6) Minor damage to two nets - cut by local boat traffic

THE COVE

1) *Ruppia* growing under nets on north side of experimental squares during August
2) sedimentation occurring mid-Sept. onward (1" build-up)
3) diatoms (microalgae) observed on all nets by end of August which collected fine particles in matrix - occluded net
4) no macroalgal build-up
5) *Petricola* set in squares 5 & 10 (northern most plots in *Ruppia* area)
6) *Solemya velum* set in square 8
7) historically productive area with large numbers of 3-5" boxes

GREEN POINT

1) no macroalgal build-up

2) sedimentation on NE end and most extreme SE end (1-2" in Aug =>2-3" in Nov.), fine grained

3) sedimentation in square 1 was coarse grained under netting (4-5")

4) high current area obvious

5) square 8a (Plurima w/ floats) had clam set under it

6) microalgae build-up similar to THE COVE on all nets (particularly on bridged nets)

7) historically productive area

EEL GRASS COVE

1) minimal sedimentation at all sites

2) net maintenance easiest (low flow area)

3) dispersed brown macroalgal build-up usually where net in contact with substrate - started here the earliest (late July)

4) *Enteromorpha* in early July around edges and gone by Sept.

Table 7

Barnstable Harbor Shellfish Recruitment Enhancement Project

A) Anaerobic Horizon Data

Square	Treatment	Start depth horizon (inches)	2 Weeks depth horizon (inches)	Fall depth horizon (inches)
Plot # 2: Huckins Islan		22 April	6 May	19 Nov
1	510tt	2.50	0.75	0.50
2		1.75	0.75	1.00
3	510tt	1.38	0.75	1.25
4	T + 510tt	1.63	0.88	2.00
5	Tilled	1.25	0.38	1.00
6	T + 510tt	1.38	1.00	0.63
7	Tilled	1.13	0.38	0.63
8	Plurima	0.88	0.75	2.00
9		0.75	0.38	0.75
10	Plurima	1.07	0.88	0.50
Plot #4: The Cove		17 June	2 July	30 Nov
1	Tilled	0.50	0.50	0.75
2	Plurima	nd	0.38	0.38
3	T + 510tt	0.38	0.25	0.75
4	510tt	0.25	0.88	1.00
5	510tt	0.88	0.63	0.63
6	Tilled	0.50	0.50	0.63
7		0.25	0.75	0.50
8	T + 510tt	0.50	0.50	1.00
9		0.50	1.00	0.50
10	Plurima		0.50	0.50
Plot #5: Green Point		23 Apr	17 May	30 Nov
1	Plurima	nd	1.75	0.50
2	510tt	nd	1.00	0.50
3	T + 510tt	1.25	1.25	1.25
4	Tilled	1.50	1.25	1.00
5	T + 510tt	1.00	0.50	nd
6		1.50	1.63	0.75
7		2.00	1.25	1.00
8	Plurima	1.00	1.63	1.00
9	Tilled	1.00	1.13	0.50
10	Plurima	2.00	1.25	nd
Plot #6: Eel Grass Cov		6 May	27 May	17 Dec
1	Plurima	0.75	0.50	0.75
2	Plurima	0.50	0.63	0.50
3		0.38	0.50	0.63
4	T + 510tt	0.38	0.38	0.50
5	Tilled	0.88	0.63	0.50
6	T + 510tt	0.75	0.50	0.50
7	510tt	0.50	0.38	1.00
8	510tt	1.13	0.50	1.25
9		0.88	1.00	1.00
10	Tilled	0.63	0.75	0.50

B) Anaerobic Horizon Data Summary

Level	Mean Depth (inch)	Std Dev
1) by Plot	[different (p<0.001)]	
Huckins Island	1.03	0.52
The Cove	0.58	0.22
Green Point	1.17	0.43
Eel Grass Cove	0.65	0.24
2) by Time	[different (p=0.019)]	
Start	0.98	0.54
2 weeks after	0.78	0.38
Fall, 1995	0.80	0.38
3) by Treatment	[not different (p=0.258)]	
control	0.89	0.46
tilled	0.77	0.32
tilled + 510tt	0.83	0.46
510tt	0.95	0.53
Plurima	0.82	0.46

4) by Plot and Tim [different (p<0.001)]

Plot => Time	Start Mean [Std Dev]	2 wks Mean [Std Dev]	Fall, 1995 Mean [Std Dev]
Huckins Island	1.37 [0.50]	0.69 [0.23]	1.02 [0.57]
The Cove	0.47 [0.20]	0.59 [0.23]	0.66 [0.21]
Green Point	1.41 [0.42]	1.26 [0.36]	0.81 [0.29]
Eel Grass Cove	0.68 [0.24]	0.57 [0.19]	0.71 [0.28]

Table 8

Barnstable Harbor Shellfish Recruitment Enhancement Project
Summary of clam density data

Site	value	Before Exp't (23 April 1995) mean # clams (#/m^2)	mean # clams (#/ft^2)	n	Fall 1995 (30 November) mean # clams (#/m^2)	mean # clams (#/ft^2)	n	Fall 1996 (8 October) mean # clams (#/m^2)	mean # clams (#/ft^2)	n
Huckins Island	mean	28.2	2.6	10	0.0	0.0	10	0.0	0.0	visual
(Plot #2)	stds	28.1	2.6							
Green Point	mean	43.1	4.0	10	166.2	12.2	10	37.0	2.7	visual
(Plot #5)	stds	85.4	7.9		498.5	36.6		78.3	5.7	+2
square 1 only	mean	43.1	4.0	1	0.0	0.0	1	200.4	14.7	2
	stds							21.8	1.6	
square 8 only	mean	279.9	26.0	1	1495.6	109.8	2	169.6	12.4	2
	stds				937.6	68.8		63.5	4.7	
Eel Grass Cove	mean	18.3	1.7	10	3.4	0.3	10	0.0	0.0	visual
(Plot #6)	stds	14.4	1.3		9.4	0.7				
square 1 only	mean	43.1	4.0	1	30.8	2.3	1	0.0	0.0	visual
	stds									
The Cove	mean	106.6	9.9	10	0.0	0.0	10	0.0	0.0	visual
(Plot #4)	stds	72.6	6.7							
All Sites	mean	49.0	4.6	4	42.4	3.1	4	9.3	0.7	4
	stds	39.7	3.7		82.5	6.1		18.5	1.4	

Table 9

Barnstable Harbor Shellfish Recruitment Enhancement Project
Green Point Experimental Site

Initial clam survey
(23 April 1995)

Core sample area (rectangular sample)
D = 0.305 m 1.00 ft
A = 0.093 m^2 1.00 ft^2

Expt'l Square	# clams /core	mean # clams (#/m^2)	mean # clams (#/ft^2)	Valve Length (mm)
1	4	43.1	4.00	18.99
				18.93
				16.87
				15.68
2	0	0.0	0.00	
3	4	43.1	4.00	14.87
				8.15
				7.63
				6.97
4	0	0.0	0.00	
5	1	10.8	1.00	25.33
6	1	10.8	1.00	24.07
7	4	43.1	4.00	24.00
				23.13
				21.89
				19.07
8	26	279.9	26.00	18.71
				16.01
				15.18
				14.57
				14.40
				13.80
				13.79
				13.48
				13.08
				12.54
				12.15
				7.25
				6.79
				6.65
				6.31
				6.03
				5.89
				5.81
				5.65
				5.29
				5.15
				5.02
				4.95
				4.77
				4.65
				4.55
9	0.00	0.0	0.0	
10	0.00	0.0	0.0	
squares 1 and 8 combined				
mean	15.0	161.5	15.0	10.43
stds	15.6	167.4	15.6	5.15
all squares				
mean	4.0	43.1	4.0	12.20
stds	7.9	85.4	7.9	6.50

Fall 1995
(30 November)

Core sample area (small core)
D = 0.203 m 0.75 ft
A = 0.032 m^2 0.442 ft^2

Expt'l Square	# clams /core	mean # clams (#/m^2)	mean # clams (#/ft^2)	Valve length (mm)	Valve length (mm)
1		NOT SAMPLED			
8a	27	832.6	61.1	24.71	5.46
				11.27	5.42
				8.58	5.10
				8.10	4.77
				7.54	4.74
				7.11	4.43
				6.35	4.40
				6.24	4.34
				6.22	4.24
				6.17	4.16
				6.04	4.03
				6.04	3.96
				5.85	3.44
				5.58	
8b	70	2158.5	158.4	40.27	5.46
				15.17	5.39
				10.10	5.38
				8.83	5.27
				8.76	5.25
				8.24	5.20
				7.87	5.20
				7.58	5.20
				7.55	5.18
				7.49	5.13
				7.44	5.09
				7.23	5.02
				7.18	4.95
				7.04	4.92
				6.99	4.80
				6.93	4.71
				6.62	4.68
				6.51	4.59
				6.51	4.58
				6.46	4.54
				6.41	4.54
				6.31	4.47
				6.27	4.38
				6.26	4.21
				6.22	4.20
				6.15	4.16
				6.12	4.14
				6.01	3.93
				5.98	3.82
				5.91	3.78
				5.91	3.68
				5.63	3.60
				5.57	3.42
				5.56	3.41
				5.53	3.31
square 8					
mean	48.5	1495.6	109.8	6.33	
stds	30.4	937.6	68.8	4.35	

Fall 1996
(8 October)

Core sample area (small core)
D = 0.203 m 0.75 ft
A = 0.032 m^2 0.442 ft^2

Expt'l Square	# clams /core	mean # clams (#/m^2)	mean # clams (#/ft^2)	Valve length (mm)
1a	6	185.0	13.6	72.97
				69.44
				68.78
				68.70
				62.00
				58.34
1b	7	215.9	15.8	81.76
				78.28
				74.70
				74.12
				73.88
				71.90
				71.90
square 1				
mean	6.5	200.4	14.7	71.29
stds	0.7	21.8	1.6	6.18
8a	5	154.2	11.3	79.62
				79.14
				74.02
				68.38
				57.78
8b	4	123.3	9.1	78.01
				75.03
				71.90
				71.90
square 8				
mean	4.5	138.8	10.2	72.86
stds	0.7	21.8	1.6	6.77
squares 1 and 8 combined				
mean	5.5	169.6	12.4	71.11
stds	2.1	63.5	4.7	25.19

Table 10: A back of the envelope estimate of the economic return for placing clam tents on Green Point, based on the observed recruitment success at the site in the Fall 1996 (conversion constants taken from Newell 1983).

1) If all of the netted areas at Green Point (1.36 acres) recruited clams at densities observed in squares 1 & 8 (13.5 clam/ft^2; Table 8)

then: with 100% survival = 807,840 clams
with 50% survival = 403,920 clams

2) If the clams grew such that the population structure resulted in 15% less than 2.0 inches,

70% @ 2.0-2.16 inches, and
15% @ 2.16-2.32 inches

then: with 100% survival = 566 harvestable bushels
with 50% survival = 283 harvestable bushels

3) At 60 pounds per bushel

then: with 100% survival = 33,966 pounds
with 50% survival = 16,980 pounds

4) At $1.25 per pound average for the commercial market

then: with 100% survival = $ 42,458
with 50% survival = $ 21,225

5) Estimated cost of materials for netting Green Point

(Table 2) - $ 2,335

6) Estimated cost of labor for netting Green Point

(91 volunteer hours @ $10.00/h)	- $ 910
(7 hours salaried time @ 14.00/h)	- $ 98

7) Estimated cost to retrieve netting

(22 small nets @ $20/net)	- $ 440
(15 large nets @ $50/net)	- $ 750

Total Credit	with 100% survival	= $ 42,458
	with 50% survival	= $ 21,225
Total Debit		- $ 4,533
Estimated Profit	with 100% survival	= $ 37,925
	with 50% survival	= $ 16,692

List of Figures:

BARNSTABLE HARBOR S 'SHELL CL
RECRUITMENT ENHANCEMENT PROJEC
SITES

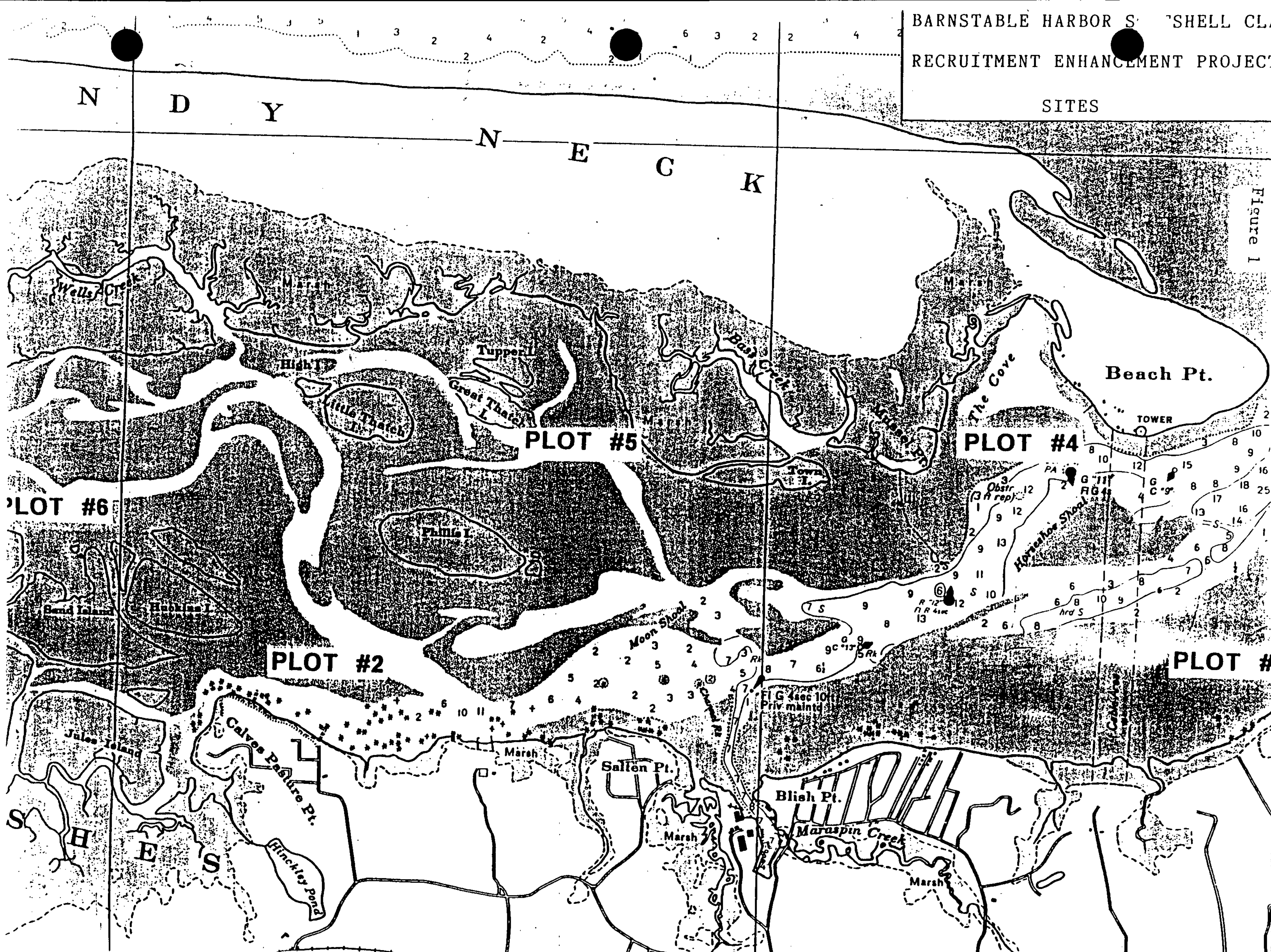
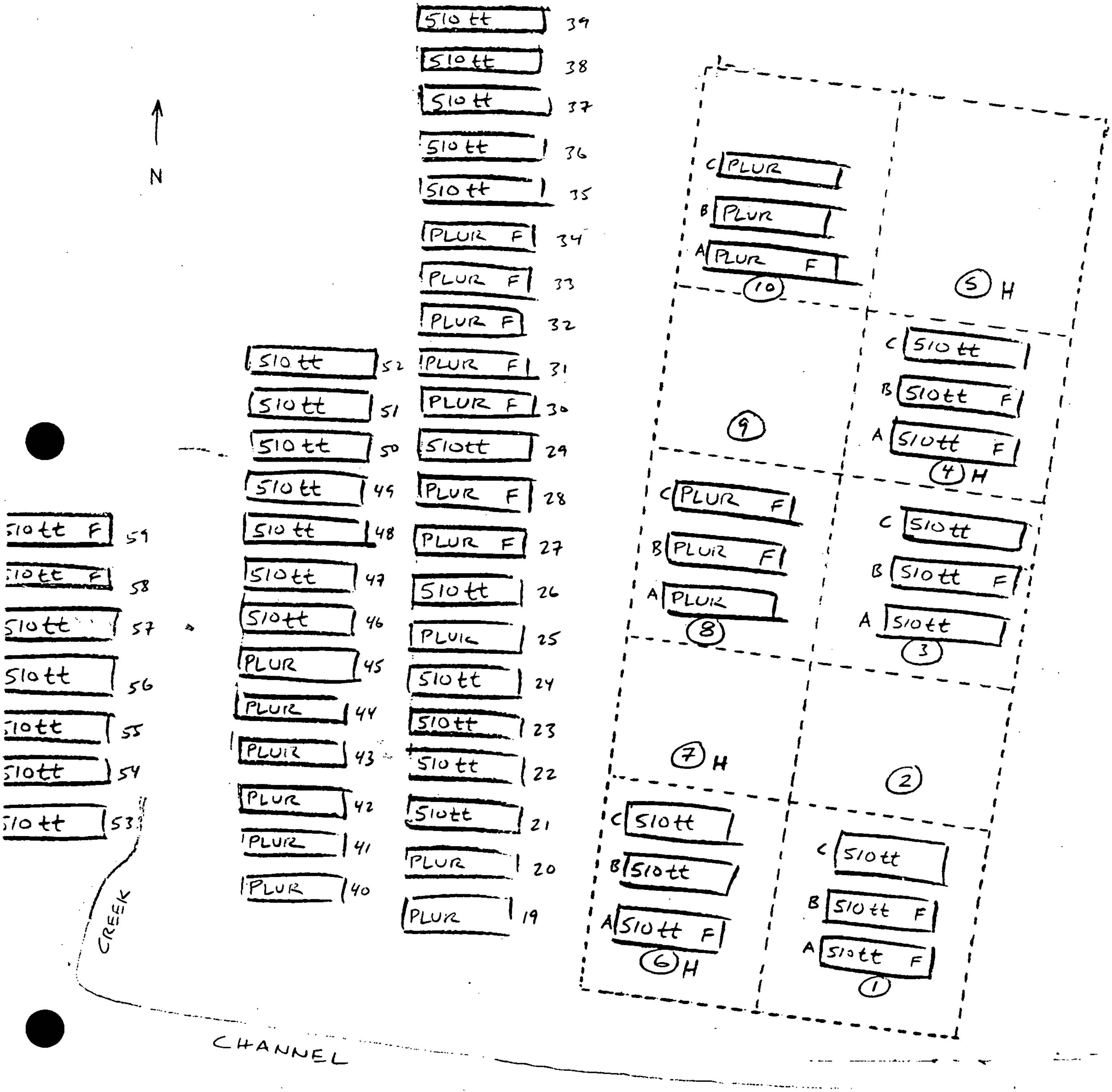


Figure 2

HUCKINS ISLAND FLAT (PLOT #2)



THE COVE FLAT (PLOT #4)

Figure 3

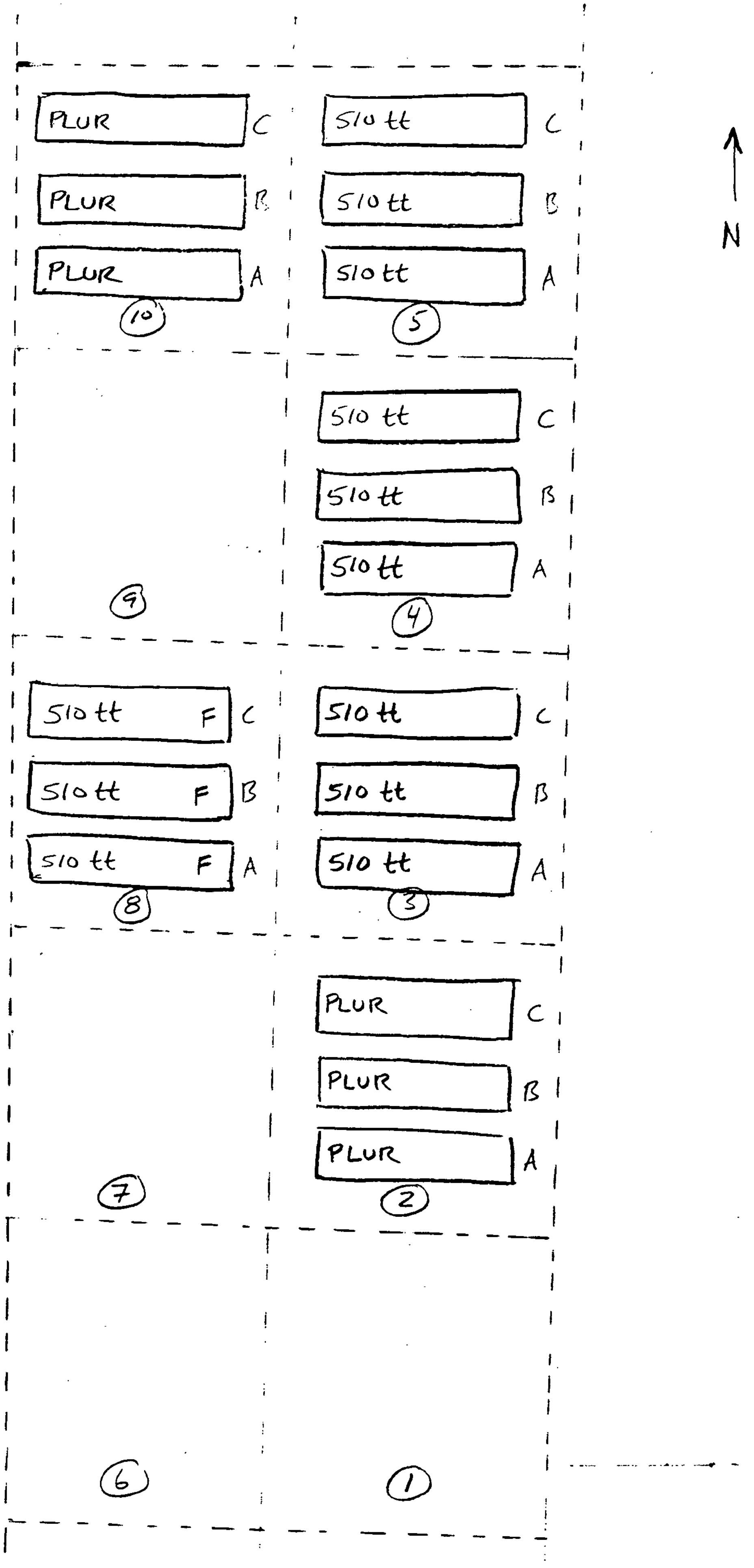


Figure 4

G EN POINT FLAT (PLOT #5)

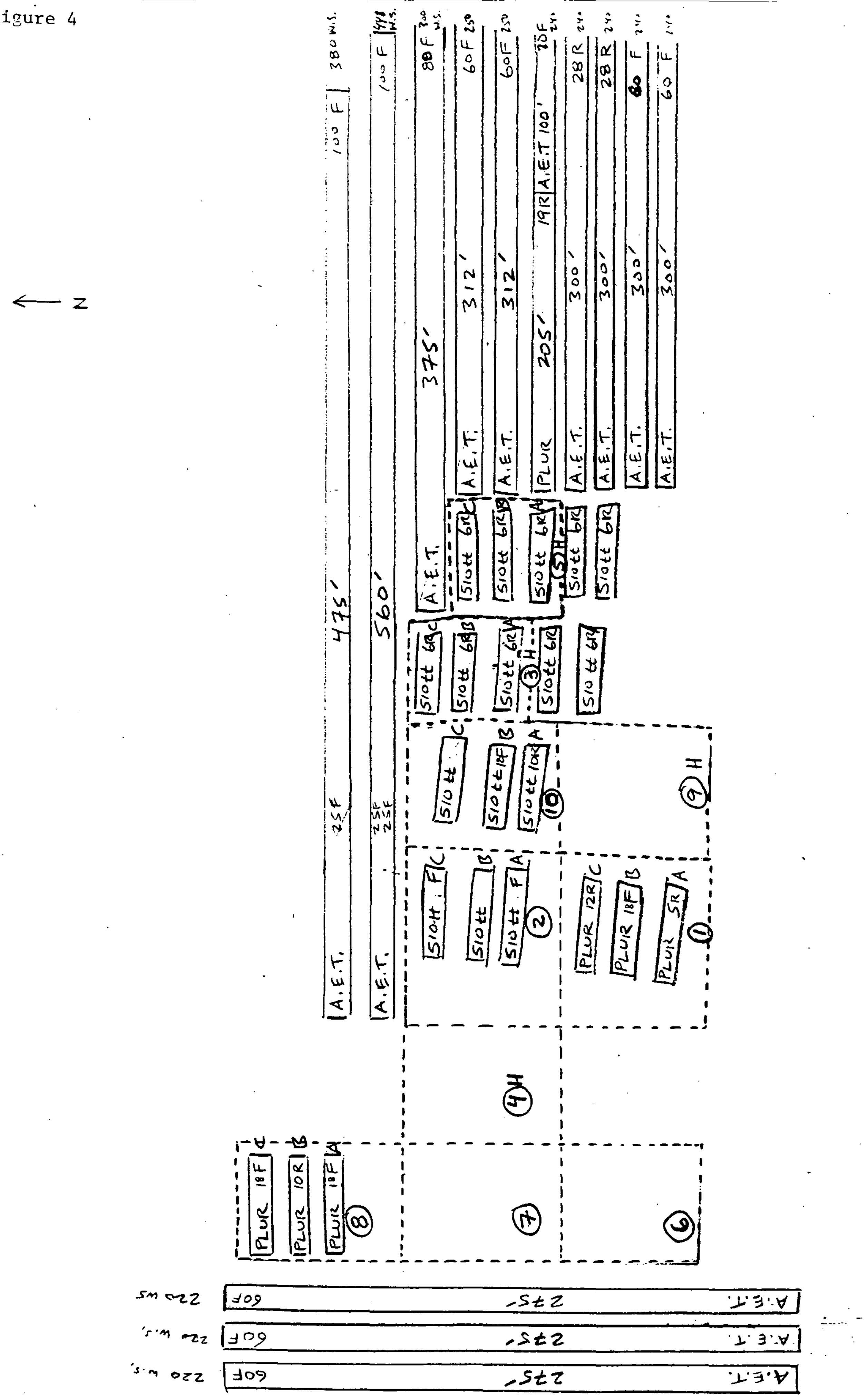


Figure 5

EEL GRASS COVE FLAT (PLOT #6)

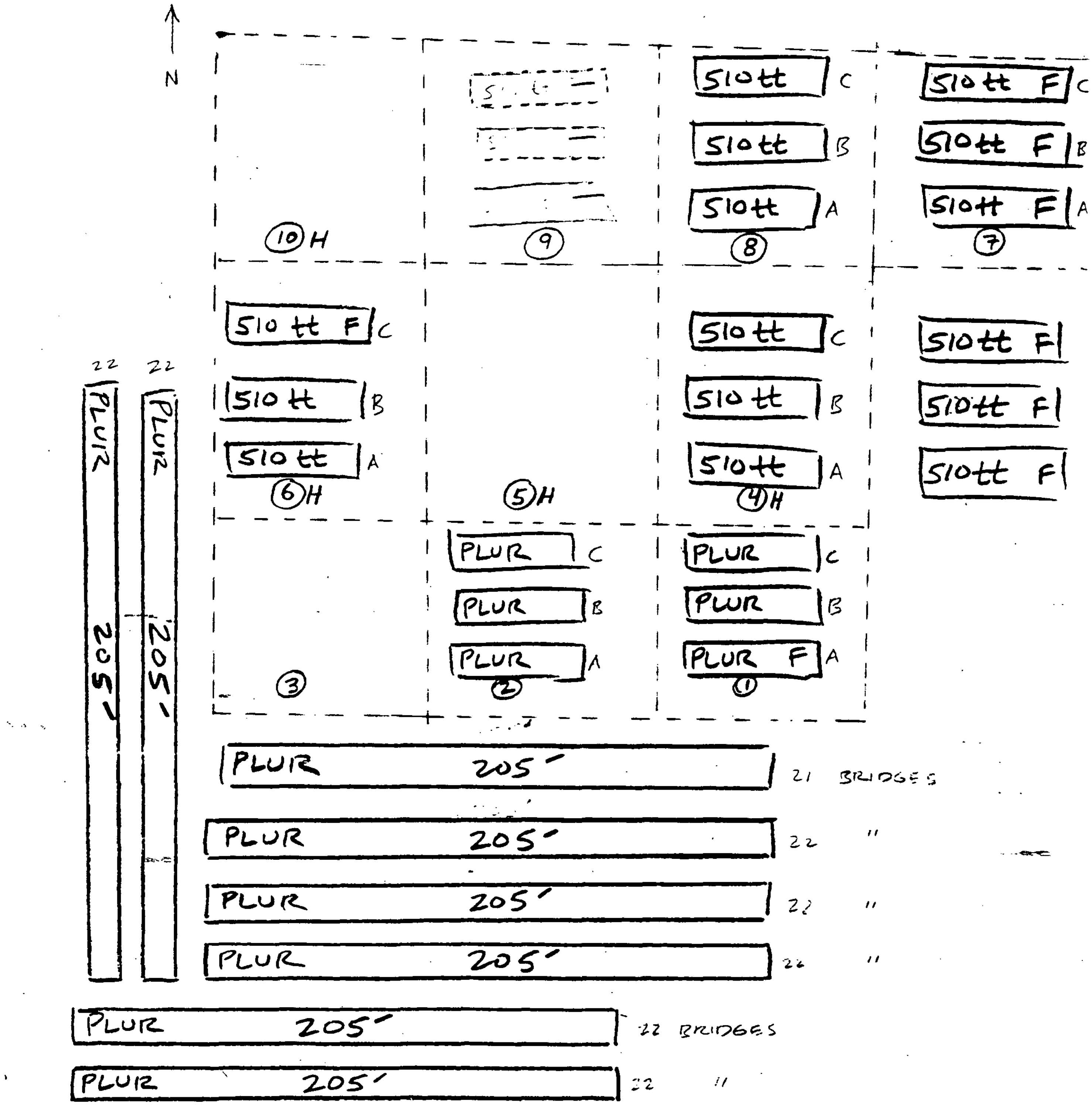
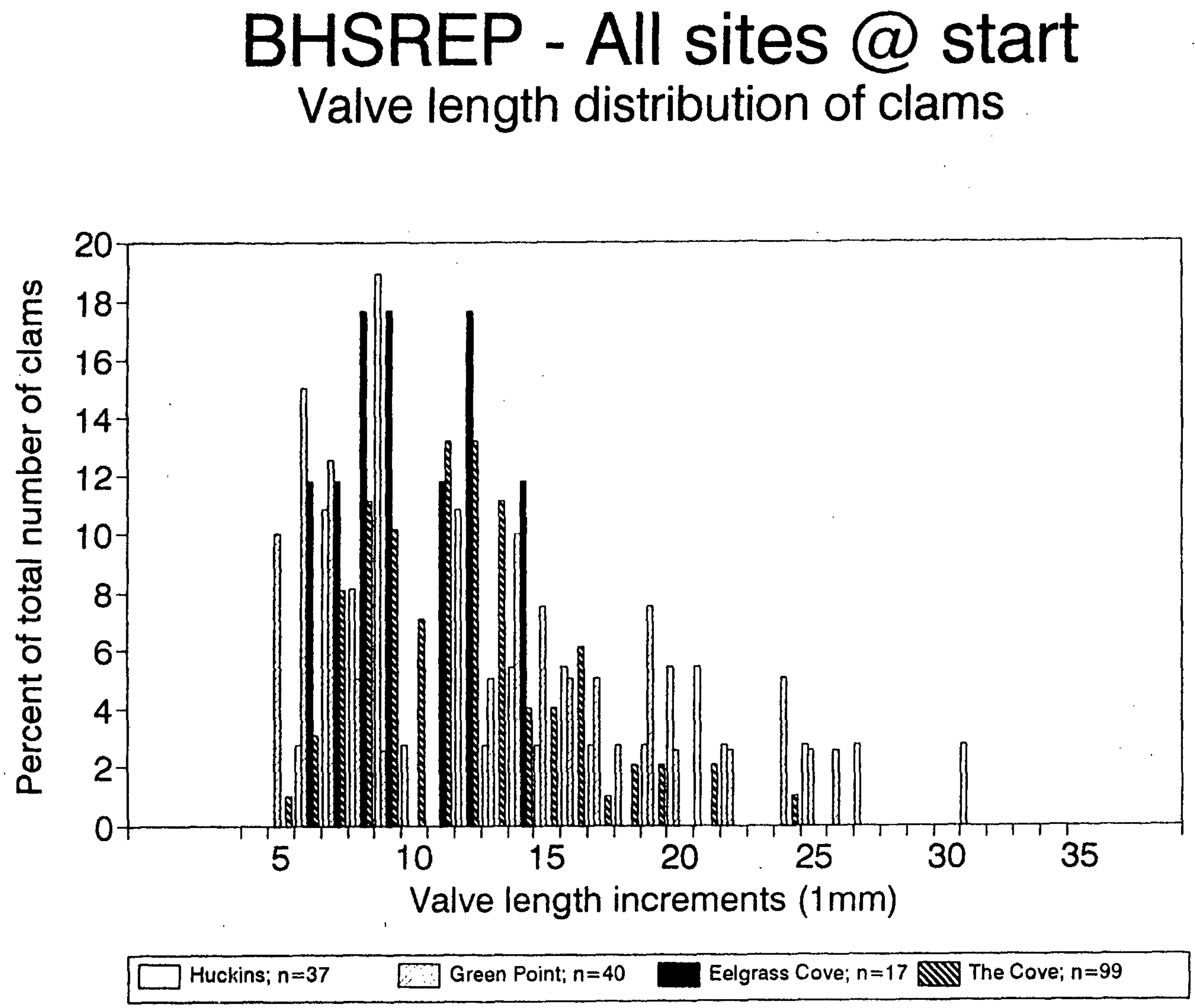
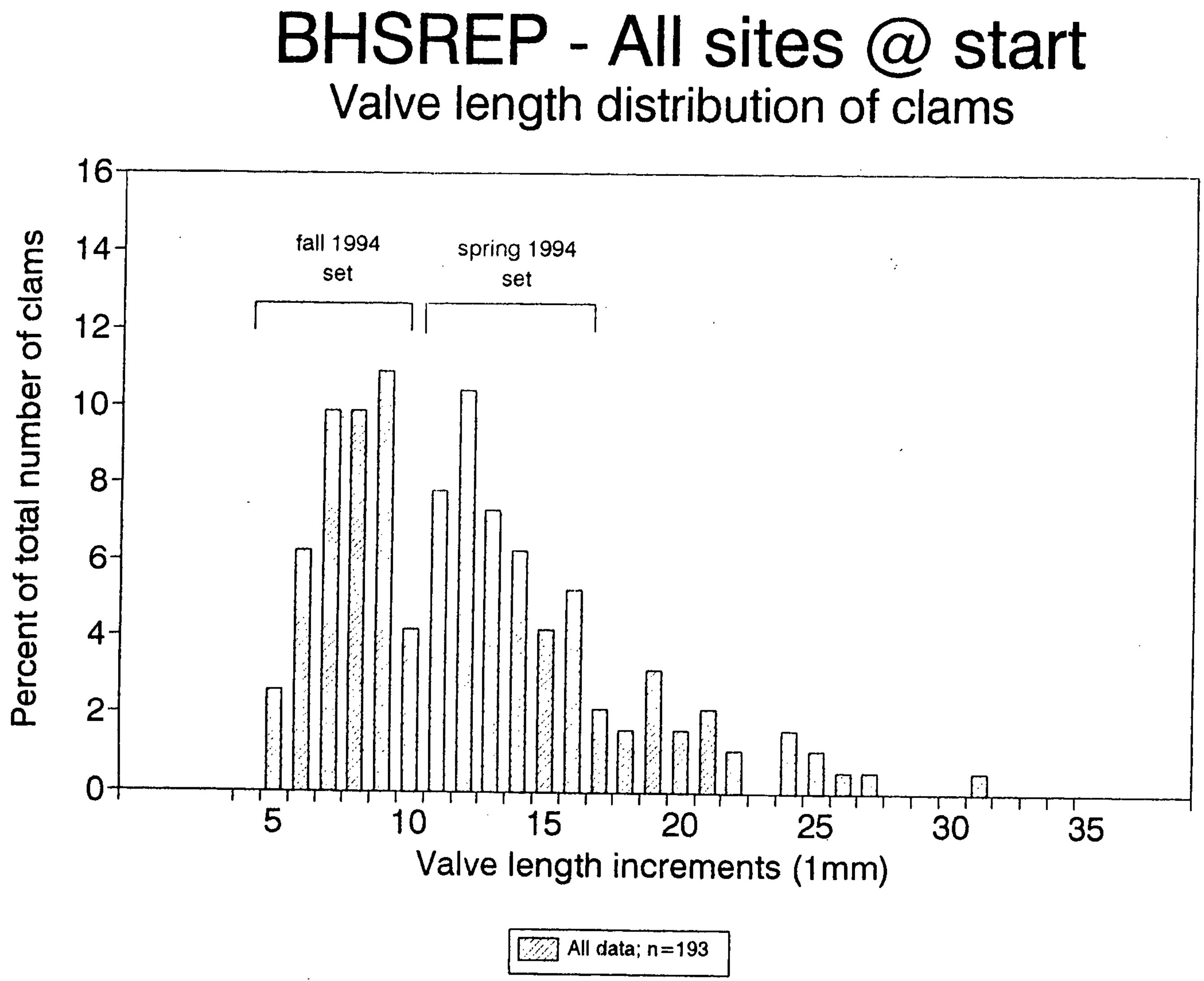


Figure 6



BHSREP - All sites @ start
Valve length distribution of clams
Percent of total number of clams
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30
35
Valve length increments (1mm)
Huckins; n=37
Green Point; n=40
Eelgrass Cove; n=17
The Cove; n=99

Figure 7



BHSREP - All sites @ start
Valve length distribution of clams
Percent of total number of clams
Valve length increments (1mm)
fall 1994
set
spring 1994
set
0
2
4
6
8
10
12
14
16
5
10
15
20
25
30
35
All data; n=193

BHSREP - Huckins Island

Valve length distribution of clams

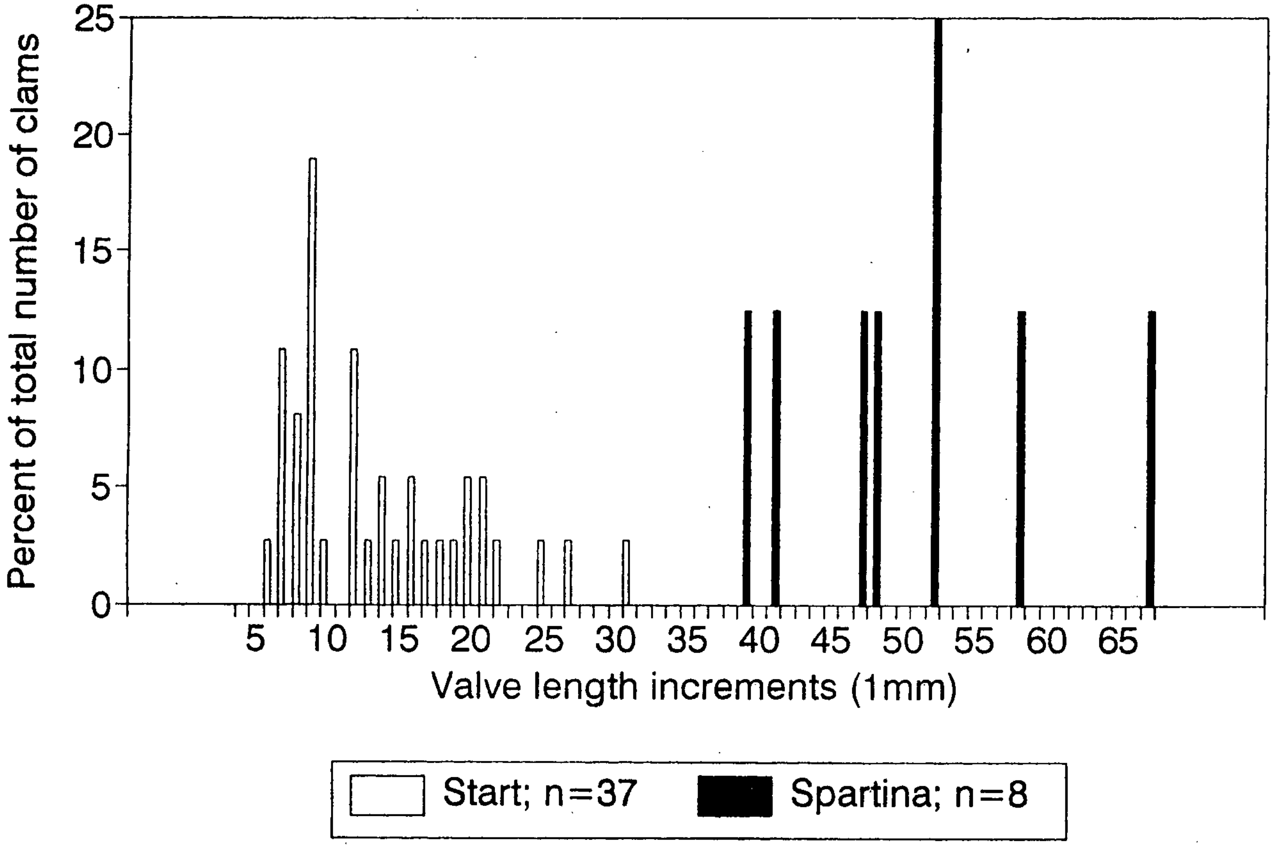
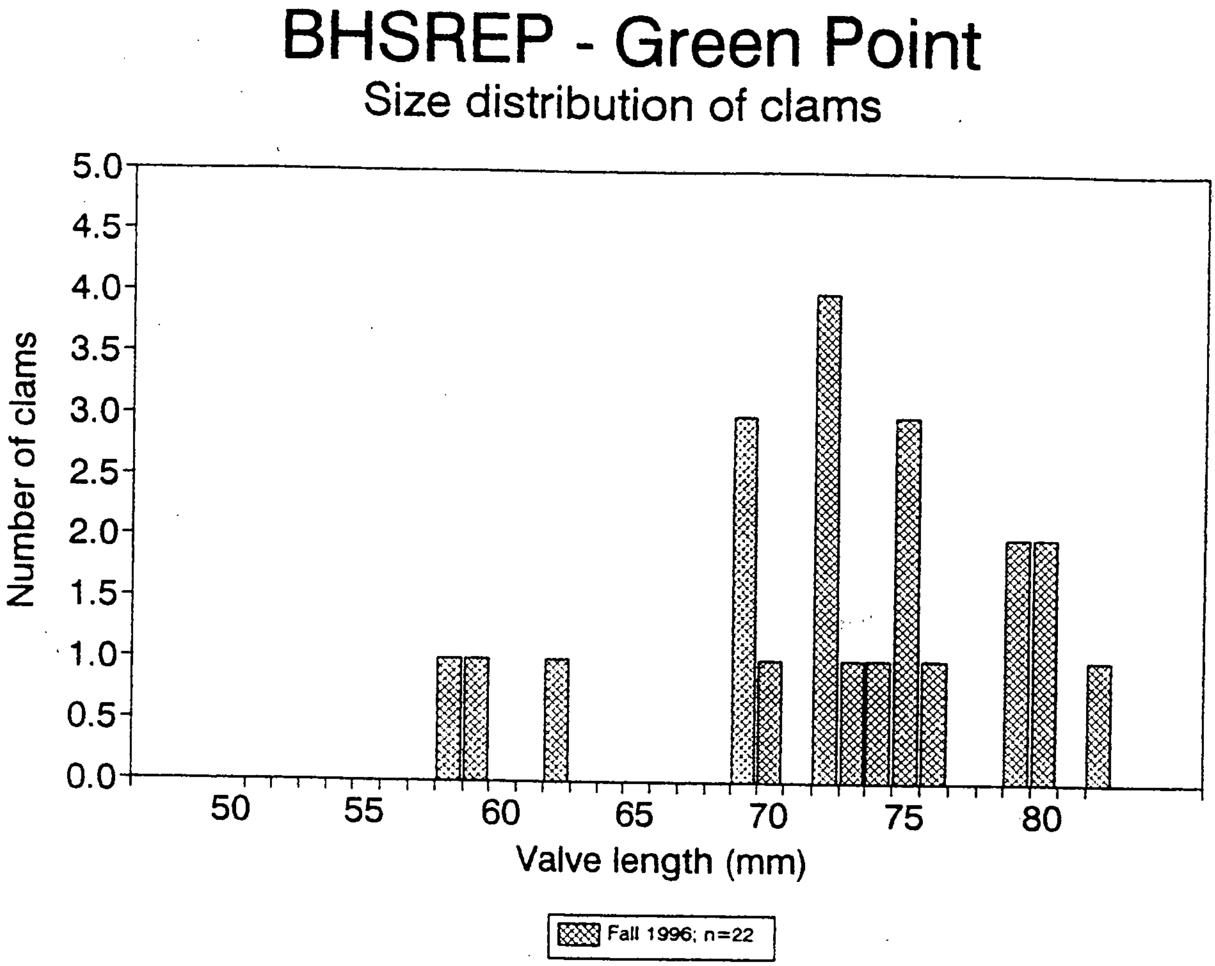


Figure 8

Figure 9


BHSREP - Green Point
Size distribution of clams
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Number of clams
50
55
60
65
70
75
80
Valve length (mm)
Fall 1996; n=22

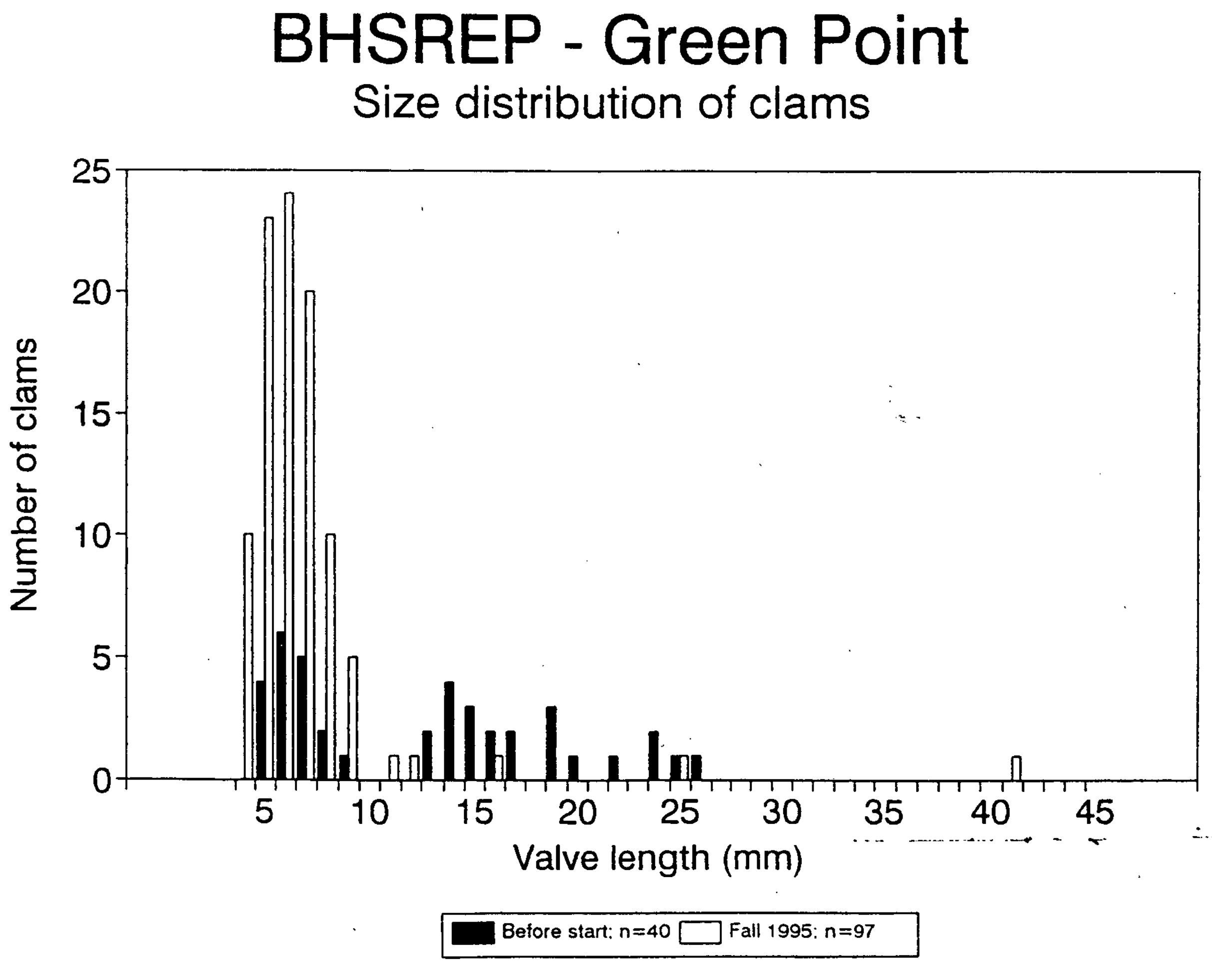

BHSREP - Green Point
Size distribution of clams
25
20
15
10
5
0
Number of clams
5
10
15
20
25
30
35
40
45
Valve length (mm)
Before start; n=40
Fall 1995; n=97

Figure 10

MERRIMACK VALLEY PLANNING COMMISSION

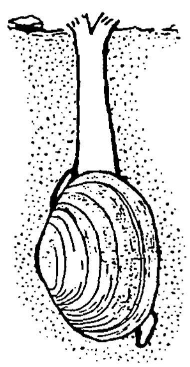
NORTH SHORE

Shellfish Enhancement Project

November 1995

Progress Report

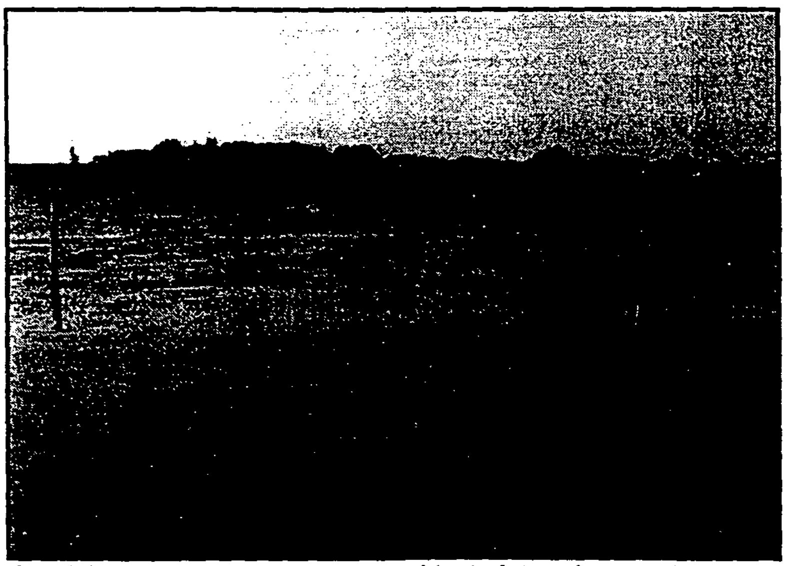
The Merrimack Valley Planning Commission (MVPC), in partnership with the Town of Ipswich and the City of Gloucester, has embarked on an exciting shellfish enhancement demonstration project for the North Shore. Funded by the U.S. Economic Development Administration and MVPC, this two-year project will assess the feasibility of profitably culturing soft-shell clams (*Mya arenaria* L.) on unproductive tidal flats. To accomplish this, MVPC's environmental staff is evaluating the costs and success rates of a variety of different aquaculture techniques that are intended to attract and anchor clam larvae ("spat") while controlling natural predators, such as green crabs, which feed on seed clams.



The project is a direct outgrowth of MVPC's affiliation and work with the *Eight Towns and the Bay Committee* (8T&B) and the Massachusetts Bays Program. Jerrard Whitten, MVPC Environmental Planner and field manager for the project, has worked closely with 8T&B's Wayne Castonguay and Dave Sargent, the Ipswich and Gloucester Shellfish Advisory Committees, Phil Kent and Robert "Stubby" Knowles (Ipswich and Gloucester Shellfish Wardens), and Dr. Brian Beal of the University of Maine (Machias) to design and implement the project.

In launching the project, the first challenge was to identify appropriate unproductive tidal flats. Through consultations with Division of Marine Fisheries (DMF) biologists and the local shellfish advisory committees, MVPC developed a series of specific site selection criteria and subsequently chose two promising test sites - Eagle Hill River flat (Ipswich) and Little River flat (Gloucester). The necessary regulatory permits were then applied for from DMF, the two municipalities, the bordering property owners, and the Army Corps of Engineers.

By mid July, all permits were in hand and set-up of

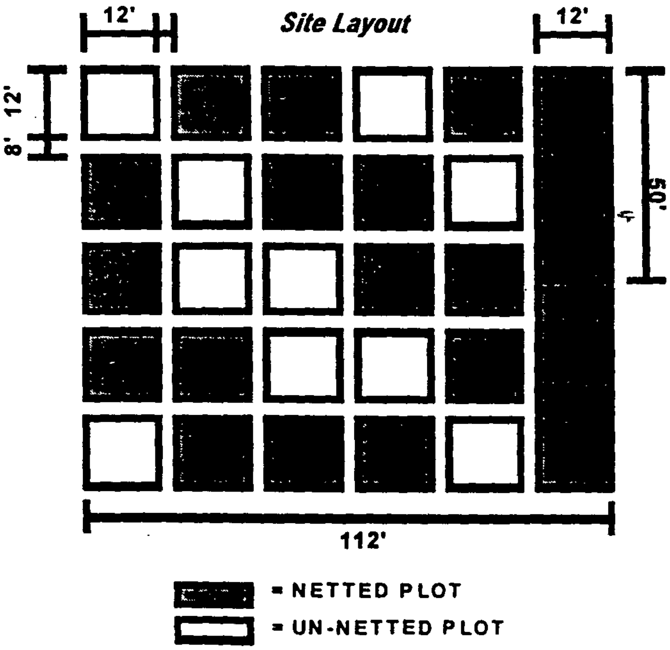


Ipswich: defining the study area and test plots using wooden stakes

the plots was initiated. In all, 54 plots (27 per site) were established. The plots were laid out using 4 foot wooden stakes marking the corner of each 12' x 12' study area. Prior to the application of individual aquaculture treatments, a preliminary inventory was made of existing site conditions and biology (species types, density, and distribution, including predators). To conduct this inventory, one sediment core was taken from each of the defined plots. The cores were then sieved on window screening (1.2 mm aperture). All benthic inhabitants retained on the sieve were identified and counted. This inventory will serve as the baseline for gauging productivity changes over time. Primary inhabitants of the benthos included duck clams (*Macoma balthica*), periwinkles (*Littorina littorea*), bamboo worms (*Clymenella torquata*), and clam worms (*Nereis virens*). Other inhabitants included an occasional moonsnail (*Lunatia heros*), blood worm (*Glycera dibranchiata*), and tape worm (*Cerebratulus lacteus*). Incidentally, only one legal-size clam (2 inches or greater) was found among all 54 core samples.

"Walking-in" the netting to exclude predators and shelter juvenile clams

Once the site inventory was completed, it was time to apply the individual aquaculture treatments and seed the flats. Approximately 58,000 seed clams were dispersed over 10 plots at each site. A total of five treatments are being evaluated: 1) net and seed; 2) net without seed; 3) net and cultivate; 4) seed without net; and 5) no net, no seed (control). Each treatment is replicated five times for a total of 25 plots at each site. Two larger plots measuring 12' x 50' also were established at each site. The purpose of these larger plots is to better simulate the area a commercial aquaculturist might use.

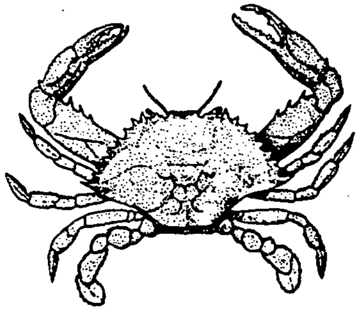


Sampling of the plots has begun, and will continue on a monthly basis until the end of the growing season. The sampling is performed both to assess clam survival and to monitor monthly growth. The presence and abundance of other species encountered during sampling also are being recorded. Preliminary results suggest that nearly all clams distributed over the *un*protected plots have suffered predation. Conversely, the clams protected by netting have shown excellent survival.

Gloucester: establishing two "commercial" plots adjacent to the scientific plots

In early December, the protective netting will be removed from the flats to avoid damage from ice. Although predator activity declines during periods of cold water, clams may still suffer mortality as a result of exposure to ice and scouring from winter storms. This information will become important when the overall costs and benefits are tallied for each treatment.

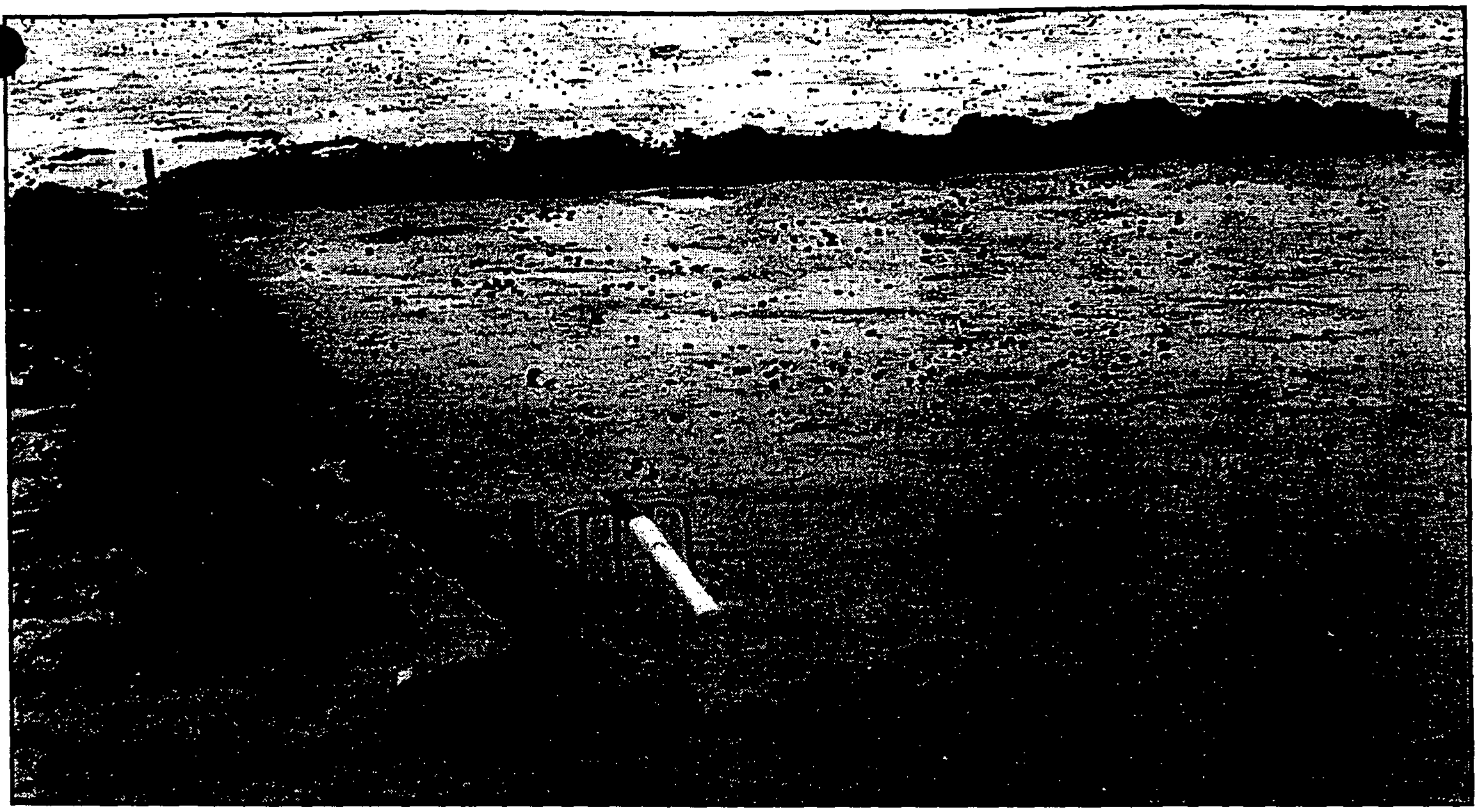
To date, the primary problem encountered has been mortality of clams due to green crab predation. Up until late July, juvenile green crabs were small enough to move freely in and out of the protective netting. However, once the crabs had increased sufficiently in size, they became trapped beneath the nets, and could be captured and removed using baited minnow traps.



The sampling will be resumed on the original 54 plots in the spring of 1996; in addition, 27 new plots per site will be established. Sampling at both sites will continue through the fall of 1996. Final sampling will be performed in the spring of 1997, at which point the cultured clam populations will be left in the care of the communities to harvest or manage as they deem appropriate. Project findings will be compiled and made available in an interim report in the winter of 1995/96 and in a final report in the winter of 1996/97. MVPC will be meeting with representatives of the shellfishing industry, interested municipal boards, and abutting landowners during the course of the project to apprise them of the project's progress, and will sponsor an informational workshop on North Shore aquaculture opportunities upon completion of the project in the spring of 1997.

For further information on MVPC's Shellfish Enhancement Demonstration Project, contact Jerrard Whitten at the MVPC offices (508/374-0519).

Step 1: Growing clams on unproductive tidal flats . . . digging trenches to secure protective netting



MERRIMACK VALLEY PLANNING COMMISSION

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