Florida Sea Grant Program Development

FINAL REPORT
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Initial Assessment of Mechanical Harvesting Bottom-planted Hard Clams *Mercenaria mercenaria* on Shellfish Aquaculture Leases in Florida

Investigators:

Leslie N. Sturmer, Statewide Shellfish Aquaculture Extension Agent IV
  Cooperative Extension Service, Florida Sea Grant, IFAS University of Florida
L. Rex Ellis, Research Assistant Professor
  Soil and Water Science Department, IFAS University of Florida
Todd Z. Osborne, Research Assistant Professor
  Soil and Water Science Department, IFAS University of Florida

ATTAINMENT OF RESEARCH PROJECT OBJECTIVES

Summarize Project Results

OBJECTIVE 1. To examine production characteristics of hard clams cultured using bottom plants with cover nets.

Pasta-sized hard clams *Mercenaria mercenaria* (n=30,000) were bottom planted in triplicate under cover nets (8' x 10', 80 ft^2) and in 9-mm mesh polyester growout bags (5 bags belted per replicate, 16 ft^2 per bag or 80 ft^2 per belt) during January 2013. Each culture method was stocked at a density of 62/ft^2 (4,985 per bottom plant, 997 per bag or a total of 4,985 per belt). The bottom cover netting consisted of two layers (9-mm mesh polyester and ½" mesh high-density polyethylene), the perimeter of which was staked to the bottom and further secured with ½" rebar. A sample (n=50) of hard clams at plant was measured and averaged 33 mm in shell length, 17 mm in shell width, and 11 grams in total weight. The field trials were conducted at the UF management agreement (38-MA-1106) located within the Dog Island High-density Lease Area near Cedar Key. Permission was obtained from the Florida Department of Agriculture and Consumer Services (FDACS), Division of Aquaculture, to evaluate the use of mechanical harvesting on the experimental lease.

Harvesting of the three replicated bottom plants and bottom bag belts began the last week in July and continued through August (2013), allowing a six to seven-month culture period for the hard clams to reach a market size of ~50 mm SL (littlenecks). Due to the amount of effort involved with water quality sonde (n=7) deployment, retrieval and maintenance for each replicate, the harvests were scheduled biweekly to coincide with spring or neap tides. The last harvest occurred during the last week of August. At harvest, live hard clams from each culture method were counted to obtain survival estimates as well as sorted on bar graders (1, 7/8, and ¾") to determine market size frequencies. Growth characteristics measured for hard clams from each culture method included shell length, shell width and total weight. Fifty hard clams from each bag and 250 hard clams per bottom plant were used for each parameter measured. Presence of predators and fouling organisms was also noted during harvest. Survival and growth data were analyzed using appropriate statistical tests after testing data for underlying assumptions. Percentage values for survival and grading sizes were arcsine transformed prior to analyses. Overall averages for the two culture method treatments were compared with a t-test analysis and statistical differences were considered if $p<0.05$.

Survival of hard clams was statistically different ($p=0.04$) between the culture methods. Average survival of clams cultured in bottom bags was 94.9%, while the average survival of clams cultured in bottom plants was 82.2%. Although these values are considered commercially acceptable, the lower clam survival obtained from the bottom plants may have been attributed to our inexperience in using this culture method as well as the harvesting device. For example, broadcasting seed in subtidal conditions prior to deploying cover netting at plant could have resulted in some clams falling outside the designated culture area. Further, adjusting the pump throttle after the first replicate harvest of bottom-planted clams may have improved the recovery of clams as survival increased from 75% to 79 and 91% in the second and third replicate harvests, respectively. Moon snails were the dominate predator observed in both culture methods.

Growth characteristics of hard clams differed significantly ($p<0.05$) between the two culture methods. Average (± standard deviation) shell length (SL) and shell width (SW) of hard clams harvested from the bottom plants were 49.3 (±0.5) mm and 25.6 (±0.3) mm, respectively, resulting in clams slightly larger than those harvested from bottom bags (46.8 ± 0.7 mm SL, 24.6 ± 0.5 mm SW). Hard clams were also graded at harvest, which is a function of shell width. On average, almost half, or 47%, of the clams harvested from bottom plants were retained on a 1" bar grader, whereas 29% of the clams harvested from bottom bags were retained. Conversely, almost half, or 47% of the clams harvested from bottom bags were retained on a 7/8" bar grader, whereas 40% of the clams harvested from bottom plants were retained. This is of importance to growers as littleneck-size (1" SW) clams bring a higher dockside price than smaller grade sizes. Differences in harvest weights were also observed between the two culture methods. Average (+S.D.) total weight (TW) of clams harvested from the bottom plants was 37 grams (12/lb), resulting in clams 13% heavier in total weight than those harvested from bottom bags (average 33g TW [14/lb]). Yields were calculated based on average survival and total weight of the clams harvested per culture method and equalized per unit of culture area (square foot). Yields were not significantly different between the two culture methods ($p=0.66$). Higher survival of clams in bottom bags and heavier clams harvested from bottom plants resulted in similar yields (1.95 versus 1.88 kg/ft^2).

OBJECTIVE 2. To determine the effects on soil physiochemical properties resulting from the use of a pump-driven harvester to harvest bottom-planted hard clams as compared to harvesting clams cultured in bottom bags.

To determine if effects on water and soil physiochemical properties resulting from harvesting bottom-planted hard clams with a pump-driven device were similar or less disruptive to those associated with harvesting clams in bottom bags, water quality, soil elevation, and soil properties were monitored during three comparative harvest replicates.

Water Quality Monitoring

To investigate potential differences between water quality disturbances associated with the two clam harvest methods, seven YSI 6600 sondes were deployed in cardinal directions five feet from the perimeters of both the bag and bottom plants with one sonde placed midway between the culture units, which were planted 10 feet apart. Multiple parameters (dissolved oxygen, turbidity, pH, salinity, and water temperature) were measured continuously for a period spanning 48 hours pre- and post-harvest. Measurements were recorded every 15 minutes for the first replicate harvest and every minute for the second and third replicates. Harvest replicates were treated as independent evaluations as ambient conditions (tide, current, wind, and background turbidity levels) were different under each harvest activity.

When sondes were retrieved, a post-calibration check was performed and data from probes failing calibration or which had animals (e.g., crabs, fish) or debris lodged inside the probe covers were excluded from analyses. In all harvests, there was no statistically relevant change to dissolved oxygen, temperature, salinity, and pH at any sonde location, indicating that neither harvesting method imposed any disturbance on these water quality parameters. The only observed changes induced by harvesting were in the form of turbidity, which is a measurement of water clarity. YSI probes measure turbidity with an optical sensor that detects how much light scatters off particles in the water, following the nephelometric technique of measurement. Values are expressed in nephelometric turbidity units (NTUs).

Turbidity values were analyzed (mean, standard deviation, minimum, maximum) for all sondes and a background level of turbidity determined for each sonde by calculating a mean ambient turbidity (95% confidence interval) for the one-hour period prior to initiation of harvest. Return to background condition was considered to be the point at which the turbidity values after harvesting activities reached the mean background (ambient) level (±5%). This return to background condition was observed to be variable and likely heavily dependent on environmental conditions, such as tidal currents and wind. In each harvest, the sondes that captured the maximum turbidity values for each treatment were compared to ensure that the highest disturbance recorded were used in the comparison.

In the first harvest replicate, bags were harvested from 7:50-8:40 am followed by the bottom plant harvest from 9:00-10:30 am. Low tide occurred at 9:20 am, thus currents were considered low for the duration of activities. The shared sonde (middle, between the two culture methods) captured the most impacting turbidity measurements for both activities and was used in the analysis. Background turbidity was determined as 28.9 ± 1.5 NTU. The maximum observed turbidity value for the bag harvest was 39.9 NTU and the return interval to background was 6 minutes. The maximum observed value for the pump harvester was 126 NTU and the observed return interval was 75 minutes.

In the second replicate harvest, bags were harvested from 9:58-10:24 am followed by the bottom plant harvest from 11:17-11:57 am. Low tide occurred at 11:55 am (at the end of the belt harvest) and wind conditions were light (mean 4.8 knots E), thus similar current directions were experienced in each harvest. Two sondes were determined to capture reliable measurements and results of both are reported. The shared sonde had a background turbidity of 16.9 ± 0.85 NTU. The bag harvest had a maximum turbidity of 35.8 NTU and returned to background in 24 minutes, while the pump harvester was observed to reach 141 NTU but returned to background rapidly (19 minutes). A second sonde, located at the southern end of the bag site, also captured discrete curves for each harvest method. The bag harvest reached a maximum of 15 NTU and returned to background level of 12.7 ± 0.7 NTU within 8 minutes. The pump harvester reached a maximum of 329 NTU and returned to background in 20 minutes.

The third harvest replicate began with bags harvested between 7:15-7:42 am followed by the bottom plant harvest from 8:30-10:04 am with a short break from 8:45 to 9:11 am due to a medical emergency. Low tide occurred at 9:08 am and wind conditions were moderate from the east (mean 11.4 knots, gusts 11.7-15.2 knots). Wind conditions combined with a low tide had confounding effect on environmental conditions that resulted in gradually increasing turbidity at all sites, even at those not within the turbidity plume created by harvest activities. The mean turbidity at the south bottom plant sonde for the hour prior to harvest was 23.0 ± 3.8 NTU pre-harvest and did not return to background after the bag harvest or bottom plant harvest. The mean turbidity post-harvest (60 minute period) was 39.0 ± 4.9 NTU. While a rapid return to baseline was expected, it was not observed for either harvest method due to the gradual increase of turbidity throughout the day. Graphical display of the turbidity data indicate the expected return to background condition in the form of a rapid decline in turbidity after the cessation of harvesting activity; however, because the background condition was gradually increasing throughout the day, a definitive return interval was not determined.

In all cases, the magnitude of turbidity was greater with the pump-driven harvester. In the first harvest, the difference in turbidity caused by each harvest method was not statistically significant due to high variability (t-test, p=0.075); however, this difference was significant (p=0.048) in the second harvest replicate. In the third harvest replicate, the difference between the two harvest methods was significant for both portions of the bottom plant harvest (p<0.001). These results suggest that the pump-driven harvester produces greater turbidity than the bag harvest method. However, when viewed within the context of natural disturbances, both of these methods are relatively inconsequential with respect to production of turbidity.

Perhaps the most valuable observation made during these harvest replicates was that of high variability in turbidity in the 48 hours of monitoring data collected prior to harvesting activities. The highest observed turbidity caused by the pump-driven harvester (when a sonde was located 5 feet from the harvester) was 329 NTU compared to the highest turbidity value of 327 NTU recorded during the 48 hours of background monitoring. This observation suggests elevated turbidity conditions (above that caused by clam harvest techniques) are common within the study area and that common natural events can induce turbidity conditions similar to or higher than harvest activity. The results of this initial study suggest that while there is a trend for harvesting of bottom-planted clams to have a greater impact to turbidity than traditional harvest methods (bottom bags), the duration is very short and does not approach the magnitude of natural disturbances, which create larger turbidity pulse events.

Soil Physiochemical Properties

Prior to planting, nine soil cores (3 cores per replicate) were collected to establish baseline condition for soil particle size distribution (sand, silt, and clay), organic matter content, and bulk density. For this study, silt and clay size fractions of sediments were grouped together and referred to as fines. Additional soil cores were collected repeatedly at 0, 2, and 4 weeks post-harvest to evaluate potential changes in soil properties. For each sampling period, three cores (total of nine) were collected at the bag and bottom plant sites, as well as at unfarmed reference sites located between the culture sites. To determine if changes had occurred over the six- to seven-month culture period, soil properties of the unfarmed areas at plant and harvest were averaged and then analyzed using a t-test. Soil property values were also averaged for each harvest method and reference sites and analyzed by repeated measures ANOVA. Least square differences tests were used to detect significant variation in soil property means between culture and reference sites. Soil particle size (sand and fines contents) values were not normally distributed and were arcsine transformed prior to analysis. Bulk density data were not normally distributed, but multiple transformations of the data did not achieve normality.

Bulk density was significantly lower (t-value =-3.23, *p*-value=0.032) prior to planting (1.47 g cm^{-3}) than at harvest (1.60 g cm^{-3}). A similar trend, although not significant (*p* =0.084), occurred in sand content, which increased 1.6% between plant and harvest. Consequently, fines (range 2.64-4.25%, *p*=0.084) and organic matter (range 0.89-1.11%, *p*=0.281) content decreased. Variation in bulk density was greater prior to planting (coefficient of variation=0.05) than at harvest (coefficient of variation=0.01). The significant difference between the bulk densities was due to differences in natural variation.

There was no significant difference in sand content of soils of the bag treatment and reference in week 0 (*p*=0.489), week 2 (*p*=0.390), or week 4 (*p*=0.323). There was no significant difference observed between sand content of soils of the bottom plant and bag treatments in week 0 (*p*=0.343), week 2 (*p*=0.313), or week 4 (*p*=0.267) nor was there a significant difference observed between sand content of soils of the bottom plant treatment and reference in week 0 (*p*=0.770), week 2 (*p*=0.858), or week 4 (*p*=0.073). It is important to note that the *p*-values associated with bag and reference site soils were lower than those of bottom plant and reference sites suggesting a higher degree of similarity between bottom plant and reference site soils. There was no significant difference observed in organic matter content of soils from the bag and bottom plant methods in week 0 (*p*=0.210), week 2 (*p*=0.291), or week 4 (*p*=0.680). Further, there was no significant difference observed in organic matter content of soils from the bag method and reference in week 0 (*p*=0.431), week 2 (*p*=0.166), or week 4 (*p*=0.330) or of soils from the bottom plant method and reference in week 0 (*p*=0.571), week 2 (*p*=0.658), or week 4 (*p*=0.196).

The similarity between soils occurring within the bag footprint and adjacent reference (unfarmed) site is encouraging given the extent to which bags are used in Florida clam aquaculture. Soils from this study were greater than 95% sand and less than 2% OM. Based on these findings, it is likely that sandier soils are unaffected by bag removal given their coarser particle size and lower propensity to resuspend and erode. The higher p-values of the bottom plant soil to reference comparisons suggest these soils were more similar to the reference than bag soils. Therefore, while harvesting of bags does not alter soil properties significantly, there is a greater chance for change in soils using this culture method. These findings were repeated at weeks 0, 2, and 4 suggesting that soils in these areas were not affected by harvesting methods. Finally, the variability in observations after harvest indicated natural disturbance in these areas and support the findings that these harvesting methods have little or no impact on aqueous soil resources when compared to the magnitude of common natural disturbances.

Soil Elevation Changes

Cross-sectional soil elevation profiles were monitored to capture tracks created by bag and bottom plant harvest activity. To accomplish this, rows of PVC pipes extending past tracks were pushed into the soil to a given depth (approximately 2 feet), perpendicular to the track direction following harvest. Each row of pipes was positioned so that three PVC pipes were located within the depressions created by bottom bag harvesting and eight pipes within the tracks created by the pump-driven harvester. Reference pipes were located in unfarmed areas, 1.5 feet outside of the tracks to either side. Two rows of pipes were deployed at each bottom bag and bottom plant replicate site. Soil elevations were monitored over time (0, 2, 4, and 8 weeks post-harvest) by measuring the length of PVC pipe exposed above the soil surface. To create the soil elevation profile immediately post-harvest, the height of each pipe in a row was subtracted from the height of the eastern reference pipe. Differences in height between the eastern reference pipe and other pipes within the row represented topography changes immediately post-harvest. Beginning with week 2, the amount of soil infill or loss (differences between week 0 and subsequent sampling efforts) was added to week 0 soil elevations to determine values at 2, 4, and 8 weeks post-harvest. The difference between reference and treatment elevations within a row were then averaged by replicate for each week (n=3/replicate/week). Data were analyzed with repeated measures ANOVA and results considered significant at $p<0.05$. Least squared differences tests were used to detect changes in soil elevations between harvesting methods by week. Bottom plant values were not normally distributed but multiple transformations of the data did not achieve normality.

Tracks created by the pump harvester were deeper (ranging from -3.65 cm at week 0 to -2.55 cm at week 8) than depressions at bag sites (ranging from -0.92 cm at week 0 to -0.62 cm at week 8). Soil elevations at bottom plant sites increased by 1.10 cm from week 0 to week 8. Infill (0.30 cm) also occurred at bottom bag sites from 0 to week 2, but then decreased from week 2 to week 8 (loss of 0.39 cm soil). However, no significant differences between or within culture/harvest methods were observed ($p>0.05$). Thus, changes in soil elevation caused by the use of a pump-driven harvester to recover bottom-planted clams were similar to those caused by the culture and removal of bottom bags. Changes in soil elevation occurring in the weeks after harvest were most likely caused by natural variation and/or processes (e.g., currents or wave action), which transport material, leveling local topography over time. As no significant difference was observed between the methods with respect to soil elevation, we contend that the methods are equivalent with respect to disturbance. The data further suggest that harvest method disturbance is within the range of normal disturbances observed for subaqueous soils in this open-water environment.

OBJECTIVE 3. To assess the product quality of hard clams harvested by these two methods.

Product quality of hard clams was assessed to determine the effects of both culture and harvest methods on shell breakage and shelf life. In our literature review, damage to hard clams harvested by a hydraulic rake was reported to be low (<5%). To quantify shell breakage associated with harvesting bottom plants and bags, hard clams observed to be chipped, cracked, or crushed were counted. Breakage was expressed as a percentage of the total number of live clams per culture and harvest method. The average breakage of hard clams harvested from bottom bags was 0.5%, while the breakage of hard clams harvested from the bottom plants was similar (0.4%). Thus, use of a small (5Hp) pump-driven device to harvest hard clams from bottom plants should not result in increased damage to the clams.

Molluscan shellfish are typically shipped as live shell stock and adequate shelf life is an important product attribute. Federal and state regulations require that live molluscs be placed in refrigerated storage within a predetermined time/temperature harvest matrix in order to reduce probable levels of *Vibrio* bacteria. For these reasons, shelf life of hard clams harvested by both methods was investigated to assure product quality. Post-harvest, three samples of 100 live hard clams from a bottom plant and an equal number of samples from the combined harvest of five bottom bags were packaged in polyethylene harvest netting. The samples were obtained from similar sized clams after sorting on a 1" bar grader. Samples were tempered at ~70-72°F for approximately 6 hours, then transferred to a refrigerated cooler and maintained at the customary storage temperature of ≤45°F. Each sample bag was checked for survival and gaping every other day for 10 days. Shelf life evaluations were conducted for each replicate harvest (n=3) in July and August (2013), when ambient water temperatures at harvest were 81, 87, and 82°F, respectively. Survival and gaping data per culture method were averaged and analyzed using repeated measures ANOVA. Percentage data were not transformed and statistical differences were considered if $p<0.05$. A post hoc test was employed to compare treatment means.

Survival of hard clams in refrigerated storage from each culture method during the first eight days was high (99-100%). At the end of the evaluation period (10 days), survival of hard clams averaged 95% for each treatment. Visual judgments were used to assess gaping of hard clams during the shelf life evaluations. Gaped hard clams were considered alive when they responded by closing their shells to specified agitation, or tapping, after the clams were held for a short time at room temperature. Throughout the shelf life evaluations, gaping was high and increased over the evaluation period. Differences in gaping between the two culture methods were observed on day 2 (bottom bags, 28%; bottom plant, 44%; $p=0.01$) and on day 4 (bottom bags, 47%; bottom plant, 59%; $p=0.04$). By day 10, gaping of hard clams from both the bottom bags and bottom plants was alike (70%). Although the majority of hard clams were alive, their organoleptic properties would have rendered them unacceptable for consumption. These results were similar to those obtained in previous shelf life evaluations of hard clams harvested during summer months from Florida waters.

An interesting observation of hard clams harvested from each culture method was noted but not quantified. Shell coloration of hard clams cultured using the bottom plant method was lighter and devoid of orange tones typically associated with hard clams cultured in bottom bags in the Cedar Key area. Several wholesalers, who were asked to comment on the appearance of hard clams harvested in this study, found the bottom-planted clams to be more attractive. This external characteristic could possibly be used in marketing efforts to distinguish the product. A sensory evaluation of hard clams produced by bottom plant culture methods should be considered.

Problems Encountered

The harvesting protocol developed was to pull the bottom bag belt first, which took about 10 minutes. Then, we proceeded to take soil samples and install elevation pipes for measuring the depression (or track) in the bottom substrate created by removing the bags. After which, we assembled the pump-driven harvester, removed the bottom nets, and proceeded with harvesting clams from the bottom plant replicate. The time interval between harvesting the two culture methods was about 55 minutes, resulting in differences in ambient water quality conditions at harvest due to tidal changes. This protocol was redefined for the Florida Department of Agriculture and Consumer Services-funded project with the bottom-planted clams harvested immediately after pulling the bottom bags.

In the third replicate, about 15 minutes into harvesting the bottom-planted clams, the PI was hit by a stingray. Harvesting was halted for another 30 minutes as the PI was returned to Cedar Key for medical attention.

RESEARCH PROJECT ACCOMPLISHMENTS

Summary

Eliminating regulatory barriers that serve as constraints to establishing alternative culture and harvesting technologies for the commercial production of hard clams *Mercenaria mercenaria* in Florida was the focus of this initial study. Clam growers are considering incorporating bottom planting into their business plans, but are reluctant to do so because of harvesting constraints. The prohibition of mechanical harvesting on shellfish aquaculture leases has clam growers limited to manual methods (hand raking) that are not commercially viable or acceptable to the industry.

The production characteristics of hard clams cultured using bottom plants with cover nets was evaluated and compared to clams grown in bottom bags, the typical method used by Florida growers. Both methods resulted in commercial acceptable survival and growth. However, survival of clams in bottom bags was significantly higher (95%) than bottom-planted clams (82%) and may have reflected the investigators' inexperience in using this method. Growth characteristics differed between the two methods as bottom-planted clams were larger than those in bottom bags. Almost half (47%) of the clams harvested from bottom plants were retained on a 1" bar grader, while 29% of the clams harvested from bags were retained. Product quality characteristics of hard clams harvested by both methods were similar. Shell breakage associated with harvesting bottom bags and plants was low (<1%). Further, survival of hard clams in refrigerated storage averaged 95% for both culture/harvest methods after 10 days.

To provide science-based information to the Florida Department of Agriculture and Consumer Services for consideration in approving the use of small pump-driven harvesters on shellfish aquaculture leases, the effects on water quality and soil physiochemical properties from harvesting bottom-planted hard clams were examined and compared to harvesting clams in bottom bags. Water quality parameters were measured continuously 48 hours prior to harvest, during harvest, and 48 hours post-harvest. Values for dissolved oxygen, water temperature, pH, and salinity did not differ during harvests of the two culture methods. Turbidity was higher during the harvest of bottom plants (maximum value of 329 NTU) as opposed to harvest of bags (maximum value of 40 NTU). However, impacts of harvesting activities to the water column were short-term as turbidity values returned to background levels within 6 to 75 minutes. Subaqueous soils were sampled prior to planting, then repeatedly post-harvest at 0, 2, and 4 weeks to evaluate soil properties and changes in soil elevations. Soil particle size, organic matter content, and bulk density did not differ between harvest or reference (unfarmed) sites at any time. Although tracks created by the pump harvester were deeper than depressions created by harvesting bags, no significant differences between or within the harvest methods were observed. These findings suggest that the pulse disturbance created by harvesting activities does not approach the magnitude of natural and normal disturbances observed in shallow coastal environments.

To advance the shellfish aquaculture industry in Florida, the environmental effects of using a pump-driven harvester to recover bottom-planted hard clams was initially assessed. If the agency that administers the leasing program for the state approves the use of these harvesters, than a different culture method for hard clams and other bivalve species will be available to the industry. Development of alternative farming technology would have a positive impact by improving production, mitigating production and market risks, diversifying revenue streams, and increasing cash-flow for clam farmers and ancillary businesses, thereby enhancing economic stability and continued growth.

PROGRAMMATIC OUTCOMES AND IMPACTS

Production characteristics of hard clams cultured using bottom plant methods

Commercially acceptable production of hard clams was attained using a bottom plant method with cover nets. However, survival was lower (82%) using this method than for hard clams cultured in bottom bags (95%), the typical method used by Florida clam farmers. Growth was higher in the bottom-planted clams (37 gram total weight) versus clams cultured in bags (33 g). Yields between the two culture methods did not differ (1.9 kg ft^{-2}).

Product quality of bottom-cultured hard clams harvested with a pump-driven device

Product quality of hard clams was assessed to determine the effects of both culture and harvest methods on shell breakage. In a literature review, damage to hard clams harvested by a hydraulic rake was reported to be low (<5%). In this study, the average breakage of hard clams harvested from bottom bags and bottom bags was similar and low (0.4-0.5%). Thus, use of a small (5Hp) pump-driven device to harvest hard clams should not result in increased damage to the clams.

Effect of hard clam harvesting methods on water quality parameters

Turbidity was the only water quality metric observed to change during harvesting of clams. Salinity, temperature, dissolved oxygen and pH remained unchanged during harvest activities. The magnitude of turbidity was greater with a pump-driven harvester in two of the three replicate harvests. In the first two harvests, turbidity conditions returned to background levels within 6-75 minutes post-harvest. High variability in ambient water quality suggest elevated turbidity conditions are common within shallow coastal waters and that natural events can and do induce turbidity conditions equal to or higher than harvester activity.

Effect of hard clam harvesting methods on aqueous soil properties

Hard clam harvesting methods had no significant effect on soil properties when compared to unfarmed reference soils. At harvest (week 0), the range of soil properties (96.7-97.7% sand, 3.3-2.3% fines, 0.7-1.1% organic matter, and 1.57-1.61 g cm^{-3} bulk densities) from both bottom bag and bottom plant culture sites were similar to the unfarmed reference soils (97.4% sand, 2.6% fines, 0.9% organic matter, and 1.60 g/cm^3 bulk density). However, soil bulk density was significantly higher at bottom plant sites (1.61 g cm^{-3}) than bottom bag culture sites (1.57 g cm^{-3}). There were no lasting effects to soil properties due to harvesting clams from bags or bottom plants. Changes that occurred post-harvest were due to normal soil dynamics. At two and four weeks post-harvest, the range of soil properties (96.8-97.7% sand, 2.3-3.2% fines, 0.7-0.9% organic matter, and 1.6-1.7 g/cm^3 bulk density) from both bottom bag and bottom plant culture sites were similar to the unfarmed reference soils (96.8-97.5% sand, 2.5-3.2% fines, 0.7-0.9% organic matter, and 1.6-1.7 g/cm^3 bulk density). However, a significant increase (0.12 g cm^{-3}) in bulk density occurred from week 0 to week 2 within bag culture sites. By week 4, soil bulk density values returned to reference site values.

Effect of hard clam harvesting methods on soil elevations

The average depth of tracks created by a pump-driven harvester was not statistically different from depressions created by harvesting hard clams in bottom bags. These tracks/depressions were starting to fill when soil elevations were measured two weeks post-harvest. By weeks 4 and 8, the depth of the tracks continued to diminish at bottom plant sites, while depressions at bag sites increased slightly in depth, potentially due to natural dynamic processes. The average depth of tracks created by the pump harvester was relatively small (-3.65 cm) when considering the depth that the harvester was able to effectively extract hard clams from bottom sediments (>5 cm). This may have been due to the high sand content of the soils (average >95%), as heavier sand particles settled within or near the tracks.

Initial assessment of harvesting bottom-cultured hard clams on shellfish leases

This study designed to assess the use of a small pump-driven device to harvest bottom-cultured hard clams found that the impacts on water and soil physiochemical properties were short term, reversible, and due to the limited scale of the activity, unlikely to have significant adverse impacts to shellfish aquaculture leases located in shallow coastal environments.