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A Comparative Evaluation of the Habitat Value of Shellfish Aquaculture Gear, Submerged Aquatic Vegetation and a Non-Vegetated Seabed

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A Comparative Evaluation of the Habitat Value of Shellfish Aquaculture Gear, Submerged Aquatic Vegetation and a Non-Vegetated Seabed

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A COMPARATIVE EVALUATION OF THE HABITAT VALUE OF SHELLFISH AQUACULTURE GEAR, SUBMERGED AQUATIC VEGETATION AND A NON-VEGETATED SEABED

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ABSTRACT The habitat value of modified rack and bag, shellfish aquaculture gear (SAG) used for the grow-out phase of the American oyster, *Crassostrea virginica*, submerged aquatic vegetation (SAV), *Zostera marina,* and a shallow nonvegetated seabed (NVSB) was comparatively evaluated over a 1-year period in Pt. Judith Pond, a tidal estuary in Southern Rhode Island. Enclosure gear was used to sample the three ecotypes, and organisms (>5 mm) were identified, enumerated, and measured to the nearest millimeter. Abundances of marine organisms and species diversity indices were used as measures of the habitat value of these ecotypes within each season. Environmental and geological parameters were not significantly different between the habitats. Emergent surface area ($cm^2\ m^{-2}$ of seabed) within each ecotype was estimated, and used to evaluate its role in providing habitat. The SAG habitat had a significantly greater surface area than either the SAV or NVSB habitats during all seasons. The physical structure of the SAG habitat protects juvenile fish from predators and provides substrate for sessile invertebrates that serve as forage for fish and invertebrates. The SAG habitat supported a significantly higher abundance of organisms per m^2 of seabed throughout the year. Species richness was also significantly greater in the SAG habitat compared with the SAV and NVSB habitats. A 2-way ANOVA indicated significant differences in species diversity (Shannon-Weiner index) between habitats. Tukey's HSD test indicated that the SAG habitat had significantly higher species diversity than the NVSB habitat, but no significant difference in species diversity was found between the SAG and SAV habitats. These findings indicate that shellfish aquaculture gear provides habitat for many organisms throughout the year, and is especially beneficial to ecosystems that support native species of recreationally and commercially important fish and invertebrates in their early life history stages. Therefore, we conclude that shellfish aquaculture gear has substantially greater habitat value than a shallow nonvegetated seabed, and has habitat value at least equal to and possibly superior to submerged aquatic vegetation.

KEY WORDS: shellfish aquaculture, habitat value, submerged aquatic vegetation

INTRODUCTION

Habitat is the place where an organism lives (Odum 1971). This simple definition is the basis for most ecologic studies involving habitat quality or value. Other considerations regarding the definition of habitat are that an organism at any particular life stage has only one habitat and that an organism's spatial distribution defines its habitat (Minello 1999). The characteristics of habitat that have been identified as being beneficial to organisms include physical structure, provision of food, substrate, hydrodynamics, and hydrology, and these must be specified to quantify habitat utilization by a particular species (Minello 1999). Physical structure is provided by submerged aquatic vegetation (SAV) or man-made structures like artificial reefs. The terms habitat "value" or "quality" when pertaining to fishery resources is defined as a habitat's ability to support a fishery resource (finfish, crustaceans, molluscs, and all other forms of marine animal and plant life). Studies that describe fishery resource habitat value primarily use species density or abundance data (Able, 1999). The purpose of this study is to comparatively evaluate the habitat value of modified rack and bag, shellfish aquaculture gear (SAG) used for the grow-out phase (Rheault & Rice 1995) of the American oyster, *Crassostrea virginica*, submerged aquatic vegetation (SAV), *Zostera marina,* and a shallow nonvegetated seabed (NVSB) over a 1-year period in Pt. Judith Pond, a tidal estuary in southern Rhode Island. The SAG habitat uniquely supplies an abundance of substrate due to the wire racks and rigid, plastic bags, in addition to the shell of the cultivated oyster.

In a study designed to estimate relative habitat value, Smith et al. (1989) used mark-recapture data and estimated densities of scallops (*Argopectin irradians*) to compare a recently transplanted eelgrass (*Zostera marina*) bed to a natural eelgrass bed. In a similar study, Fonseca et al. (1996) used abundances of shrimp, fish, and crab species to assess habitat value of the replanted eelgrass as compared with nonvegetated areas and naturally occurring eelgrass meadows. Recent studies involving oyster reefs have used similar criteria to determine relative habitat value by sampling nekton densities within the reefs. Coen et al. (1999a) conducted a long-term study comparing the habitat value of oyster reefs in the southeastern United States by measuring several parameters, including water quality and abundances, of resident and transient fauna. Faunal densities were used to compare species richness between natural and experimental reefs. Carr and Hixon (1997) compared fish assemblages and abundances to determine species richness on natural and artificial reefs. O'Beirn et al. (2001) investigated the organisms associated with oysters cultured in floating systems by measuring the number of macro-faunal species inhabiting these floating culture systems, so as to determine the species richness of this unique habitat.

Natural oyster reefs have been identified as essential fish habitat because not only do they support the oysters themselves but a myriad of other fishery resources. There is abundant evidence that indicates these reef communities are extremely diverse and show differences in species abundances as compared with adjacent nonvegetated, sand flat habitats. Oyster reef habitats are not only highly diverse but include species absent in adjacent soft-bottom environments (Coen et al. 1999b). In addition to obligate oyster reef residents, a variety of transient species occupy the reef in a facultative way (Posey et al. 1999). Grass shrimp, blue crabs, and other fish were observed utilizing the reefs possibly for foraging or refuge purposes. Breitburg and Miller (1998) reported that resident finfish populations are dependent on oyster reef habitats due to the physical extent of the reefs, their suitability as refuges from predators, and abundance of prey for consumption. These characteristics influence the abundance, growth, and reproduction of these resident finfish, thus demonstrating that oyster reefs enhance fish production. There is evidence that the 3-dimensional structure of oyster reefs affect the spatial distribution of various fish and perhaps the overall abundances. Striped bass and other predatory fish have

been observed to hover near reefs utilizing them as foraging sites Breitburg 1999).

Habitats that exhibit structural complexity have been shown to support higher numbers of species as compared with barren nonvegetated bottom types (Orth & Heck 1980). Orth et al. (1984) concluded that an increase in habitat complexity due to eelgrass density should increase refuges for prey species. Man-made structures have also been shown to increase abundances of fishery resources (Carr & Hixon 1997). Man-made structures or "artificial reefs" may be specially constructed and consist of concrete rubble (Kelch et al. 1999) used for the purposes of creating habitat for fish. Grossman et al. (1997) hypothesized that if habitat is limiting, new artificial reefs can potentially increase fish production through 3 mechanisms: (1) an increase of foraging habitat for adult, juvenile, and/or newly recruited fishes; (2) an increase in breeding habitat; and (3) an increase in predator refuge or resting habitat. Therefore, shellfish aquaculture gear may serve as an artificial reef habitat by virtue of its inherent structural complexity and extensive time spent on the seafloor throughout the year, thereby increasing the fish production in the ecosystem.

MATERIALS AND METHODS

Study Area

Three habitats (SAG, SAV, and NVSB) were sampled in Pt. Judith Pond, Rhode Island, a shallow 6 km tidal estuary that discharges into Block Island Sound. The 1.0 h aquaculture lease site contained over 600 oyster cages, each consisting of a 1.8 m × 0.6 m × 0.6 m wire cage that held 12 mesh bags of shellfish on shelves. The oyster cages were placed 2.4–6.1 m apart on the seabed in 2.4–3.0 m of water. The SAV and NVSB habitats were located approximately 1.5 km south of the aquaculture lease in Pt. Judith Pond at similar depths of water.

Experimental Design

The research design was a four (season) by three (habitat type) factorial design with three replicates within each habitat. Three habitats (SAG, SAV, and NVSB) were seasonally sampled in replicate between December 2000 and October 2001 so as to evaluate the following habitat characteristics: macro-epibenthic fauna community structure, and the physical, chemical, and geological environmental conditions. All three habitats sampled using enclosure type gears to maximize the efficiency and consistency of sampling (Rozas & Minello 1997).

Field and Laboratory Methods

Moonstone Oyster Company cultivates the American Oyster (*Crassostrea virginica*) in cages that are cleaned every 4–6 months. We selected cages for sampling that had been cleaned 4–6 weeks prior to each seasonal sampling so that they would have a representative seasonal fouling population. Lift-nets (2.1 m × 0.9 m with a 2-mm mesh) were placed beneath three randomly selected SAG units 2 weeks before sampling to allow sufficient time for swimming organisms to return to the cages following the disturbance of lifting the cage to place the lift nets underneath.

A scuba diver deployed the lift-net so that it completely enclosed the oyster cage during recovery. All free swimming epifauna >5 mm were recovered from the lift net enclosure along with three randomly selected oyster bags, and were taken back to the laboratory for analysis. Each oyster cage was also randomly sampled in five locations with a 0.022 m^2 (15 cm × 15 cm) quadrat to assess sessile invertebrate growth. The oyster cages are constructed of 5.1 cm mesh, vinyl-coated, 2 mm diameter wire. Percent cover of each biofouling organism within each quadrat sample was assessed to the nearest class and/or phylum. The percent cover of sessile invertebrate growth on the oyster bags was determined in a similar fashion. Total biomass of sessile invertebrates on the cages and bags was estimated for the entire surface area of the cages and bags by extrapolating mean sample values to the total surface area. A random subsample of 10 oysters was taken from each of three bags taken from each cage. Oyster length and width was measured to the nearest millimeter using vernier calipers and the surface area of the oysters and sessile invertebrate growth on both sides was estimated to the nearest square centimeter. Results were averaged within seasons and extrapolated over an average of 200 oysters per bag or 2,400 oysters per cage. The total surface area and sessile invertebrate coverage (cm^2) for each oyster cage consisted of the sum of the surface area of the oyster cage, the 12 oyster bags, and the seasonal average surface area of the 2,400 oysters. These sums were divided by the area enclosed by the lift net used to sample the SAG habitat (1.95 m^2). Thus, surface area and invertebrate growth are referenced to area (m^2) of the seabed.

The SAV and NVSB habitats were sampled on the same day within a few hours of noontime during each of the seasons. These habitats were randomly sampled using a 2-mm mesh drop-net (2.13 m × 0.92 m) and a venturi-driven suction dredge deployed from a small skiff. The animals were collected in a 2 mm-mesh catch bag and returned to the laboratory for analysis. The emergent portion of the SAV habitat was randomly subsampled with a 0.25 m^2 quadrat (3 replicates) each season. The eelgrass blades within each quadrat were clipped at the base and measured to the nearest 100 cm using vernier calipers. Sessile invertebrate growth (cm^2) on the SAV was similarly estimated. The NVSB habitat was devoid of emergent substrate and attached sessile invertebrates.

All free swimming organisms >5 mm in length collected from each of the three habitats were identified to the genus and species, and measured to the nearest millimeter using vernier calipers. Temperature, salinity, and dissolved oxygen were seasonally measured during each sampling event in each habitat. Sediment from each habitat was collected seasonally using a 7.5-cm diameter ×15.2-cm deep corer. Mean sediment grain size was determined by dry sieve analysis (Folk 1968).

Data Analysis

Seasonal environmental parameters (temperature, salinity, and dissolved oxygen) were analyzed by 2-way analysis of variance (ANOVA) without replication (EXCEL 1997) between habitat and season. The environmental dependent variables for each season were also analyzed using 1-way analysis of variance (ANOVA). Tukey's honest significant difference (HSD) test was used to compare treatment means when an F-test indicated significant treatment effects (SPSS vs.10 1999). Sediment type data for each habitat was characterized according to percent gravel, sand, and silt-clay using a 2-way ANOVA without replication (EXCEL 1997) between habitat and season. This analysis was repeated after subtracting the gravel component from the oyster cage habitat to compensate for the presence of shell hash from the aquaculture operations. Physical habitat complexity was measured in terms of emergent surface area within each habitat. The average surface area within each of the replicates for each habitat was log transformed

($\ln(cm^2)$) to satisfy the homogeneity of variance assumption for an analysis of variance (Zar 1984). The average surface area was compared with a 2-way ANOVA (SPSS vs.10 1999) between habitats and seasons, and Tukey's HSD test (SPSS vs.10 1999) was used to compare treatment means when an F-test indicated significant treatment effects.

The community structure was analyzed using Ecological Methodology (Krebs 1989) statistical software (Exeter Software 2000). The raw data used in the statistical software consisted of species abundances (3 replicates) within each habitat for each season. Species richness was determined by the Jackknife method for quadrat counts (Heltshe & Forrester 1983). Shannon-Weiner species diversity and Smith and Wilson species evenness indices were generated using Ecological Methodology statistical software (Exeter Software 2000). The indices of species richness, diversity, and evenness within each habitat were each analyzed using a 2-way ANOVA (SPSS vs.10 1999) between habitat and season. Tukey's HSD test (SPSS vs.10 1999) was used to compare treatment means when an F-test indicated significant treatment effects.

Species abundance data within each habitat were compiled into 5 categories for analysis; total abundances of all organisms sampled, fish, crustacean, mollusk abundances, and total surface covered by sessile invertebrates. The abundance data were log transformed (ln(X)) to satisfy the homogeneity of variances assumption (Zar 1984) and analyzed using a 2-way ANOVAs (SPSS vs.10 1999) between habitat and season for each abundance category. Tukey's HSD test (SPSS vs.10 1999) was used to compare treatment means when an F-test indicated significant treatment effects. Correlation analysis (EXCEL 1997) was used to investigate the relationship between the total abundance of animals observed in each habitat and season, and the emergent surface area found in each habitat and season.

RESULTS

Environmental Parameters and Sediment Characteristics

There were no significant differences in temperature, dissolved oxygen, or salinity between sites ($P < 0.05$) in any given season. Temperature varied seasonally from 3.0 to 23.7 °C; salinity was influenced by rainfall and ranged from 25.0 ppt to 34.6 ppt; and dissolved oxygen peaked in winter/spring at 11.9 mg/L and was lowest in spring/summer at 6.4 mg/L. The three sampling sites had a similar grain size composition, dominated by sand (mean 93.5%) and silt-clay (mean 6.5%), however there was a substantial gravel component (4.27%) in the SAG site that was comprised primarily of oyster shell fragments. After removing this fraction, the sediments from the three sites were not significantly different from each other ($P < 0.05$).

Habitat Structure

Habitat structure, described in terms of emergent surface area (cm^2) per m^2 of seabed, varied as a function of habitat type and season (Fig. 1). The log transformed average emergent surface area varied significantly both between sites and between seasons ($P < 0.001$). There were significant differences ($P < 0.05$) between each of the 3 habitats (SAG>SAV>NVSB), and significant differences ($P < 0.01$) between each of the seasons (except between spring/summer and winter/spring). The SAG habitat, due to the cages, bags, and oysters, provided an average of more than 60 times the emergent surface area per square meter over the course of the year than the SAV habitat. The SAV habitat had mean shoot densities of $554/m^2$ in the spring/summer and summer/fall seasons and $224/m^2$ in the fall/winter and winter/spring seasons. The NVSB habitat was devoid of emergent surface area during all seasons.

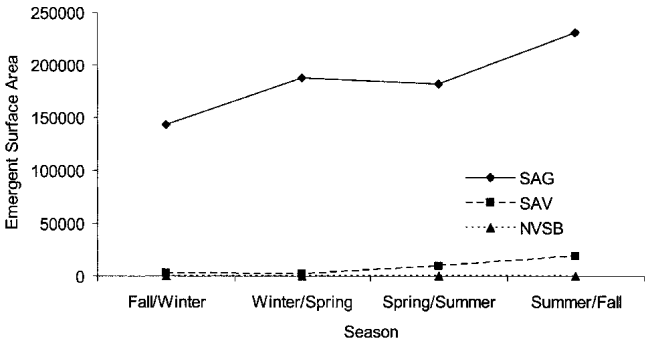

Figure 1. Emergent surface area (cm^2/m^2 of seabed) for each habitat and season.

Community Structure

Species richness was also consistently higher in the SAG habitat (Fig. 2a). There were significant differences ($P < 0.01$) between habitats, and between seasons ($P < 0.05$). Species richness was significantly different between each habitat (SAG>SAV>NVSB) and between fall/winter and summer/fall seasons. The mean Shannon-Weiner Index values of species diversity were highly significantly different between habitats ($P < 0.001$) and between

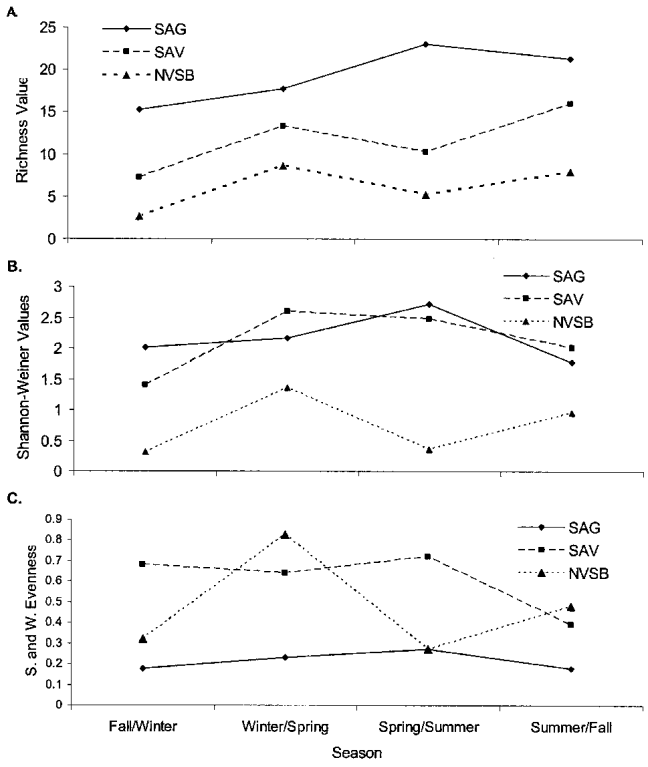

Figure 2. A. Species richness values for each habitat and season, B. Mean Shannon-Weiner values for each habitat and season, C. Mean Smith and Wilson measure of evenness values for each habitat and season.

seasons ($P < 0.01$). The SAG habitat was not significantly different from the SAV habitat ($P > 0.05$), however both of these habitats were highly significantly different ($P < 0.01$) from the NVSB (see Fig. 2b). Significant differences ($P < 0.05$) in species diversity were also found between the fall/winter and winter/spring sampling and between fall/winter and spring/summer. The SAG habitat showed consistently lower Smith and Wilson species evenness values than either the SAV or NVSB because a few species tended to dominate this habitat (see Fig. 2c). There were highly significant differences in species evenness between habitats ($P < 0.001$), but not between seasons ($P > 0.05$). The SAG habitat was significantly lower in species evenness than either the SAV or NVSB habitats ($P < 0.05$).

Species Abundances

The SAG habitat consistently supported far greater abundances of organisms than either the SAV or the NVSB habitats throughout the year (Fig. 3). There were highly significant differences ($P < 0.001$) between habitat and seasons for the species abundance data. There was a highly significant difference ($P < 0.001$) in species abundance between each habitat (SAG>SAV>NVSB). There was also a significant difference ($P < 0.05$) in species abundances between all seasons except winter/spring and spring/summer sampling periods showed no significant differences ($P > 0.05$). A strong correlation ($r = 0.94$) was found between the total abundance of organisms in each habitat and season and the emergent surface area available in corresponding habitat and season (Fig. 4).

Ten fish species were identified inhabiting one or more of the three habitats sampled during the course of the study (Fig. 5), and individual fish species abundances are shown for each habitat and season in Figure 6. There were highly significant differences ($P < 0.001$) in fish abundances between habitats and seasons. The greatest fish abundances ($P < 0.01$) occurred in the SAG habitat followed by the SAV habitat and then the NVSB habitat. The summer/fall sampling period had significantly higher ($P < 0.01$) fish abundances compared with any other season. With two exceptions, the SAG habitat supported higher abundances of fish than either SAV or NVSB habitats. The Northern Pipefish (*Syngnathus fuscus*) in the spring/summer and summer/fall and the Winter Flounder (*Pleuronectes americanus*) in the summer/fall were unique to the SAV. There were many species of fish that were unique to SAG including the American eel (*Anguilla rostrata*), oyster toadfish (*Opsanus tau*), rock gunnel (*Pholis gunnellus*), and Atlantic tomcod (*Microgadus tomcod*). Several fish species were sampled throughout each season in the SAG, which included the seaboard goby (*Gobiosoma ginsburgi*), grubby (*Myoxocephalus aenaeus*), tautog (*Tautoga onitis*), and cunner (*Tautogalabrus adspersus*). The SAG habitat was the only habitat sampled that supported one or more fish species year-round.

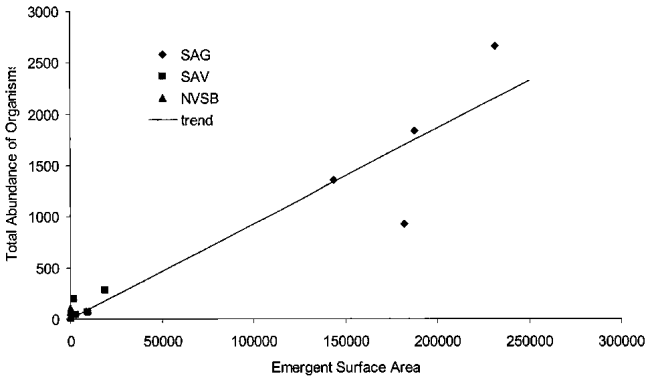

Figure 4. Correlation of total abundance of organisms (abundance) and emergent surface area (surface area cm^2/m^2 of seabed).

Thirteen crustacean species were identified to inhabit one or more of the three habitats sampled during the course of the study (Fig. 7), and individual crustacean species abundances are shown for each habitat and season in Figure 8. There were highly significant differences ($P < 0.01$) in crustacean abundances between habitats and seasons. The greatest abundances occurred in the SAG habitat followed by the SAV habitat and then the NVSB habitat. The summer/fall sampling period had significantly higher ($P < 0.01$) crustacean abundances compared with any other season. The American Lobster, *Homarus americanus*, was the only crustacean unique to the SAG habitat (5 observed individuals). The average carapace length was 6.3 cm (S.E. ± 0.88), which places these lobsters in the juvenile phase of their lifecycle (Hudon 1987).

Seven mollusk species were identified to inhabit one or more of the three habitats sampled during the course of the study (Fig. 9), and individual mollusk species abundances are shown for each habitat and season in Figure 10. There were highly significant differences ($P < 0.01$) in mollusk abundances between habitats and seasons. The greatest abundances occurred in the SAG habitat followed by the SAV habitat and then the NVSB habitats. The winter/spring sampling period had significantly higher ($P < 0.01$) crustacean abundances compared with any other season.

Sessile invertebrate species were present in both SAG and SAV habitats (Fig. 11). The NVSB habitat was devoid of surface and hence the absence of sessile invertebrates. Statistics were not performed to detect differences between habitats due to the high variability of sessile invertebrate abundances.

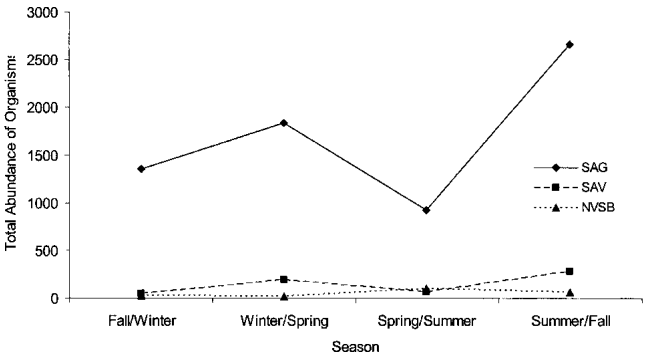

Figure 3. Total abundances of organisms collected within each habitat and season.

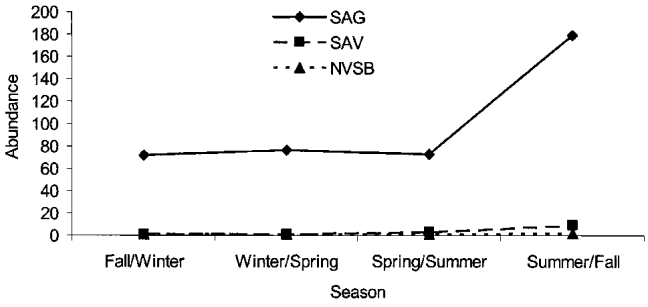

Figure 5. Total fish abundances found within each habitat and season.

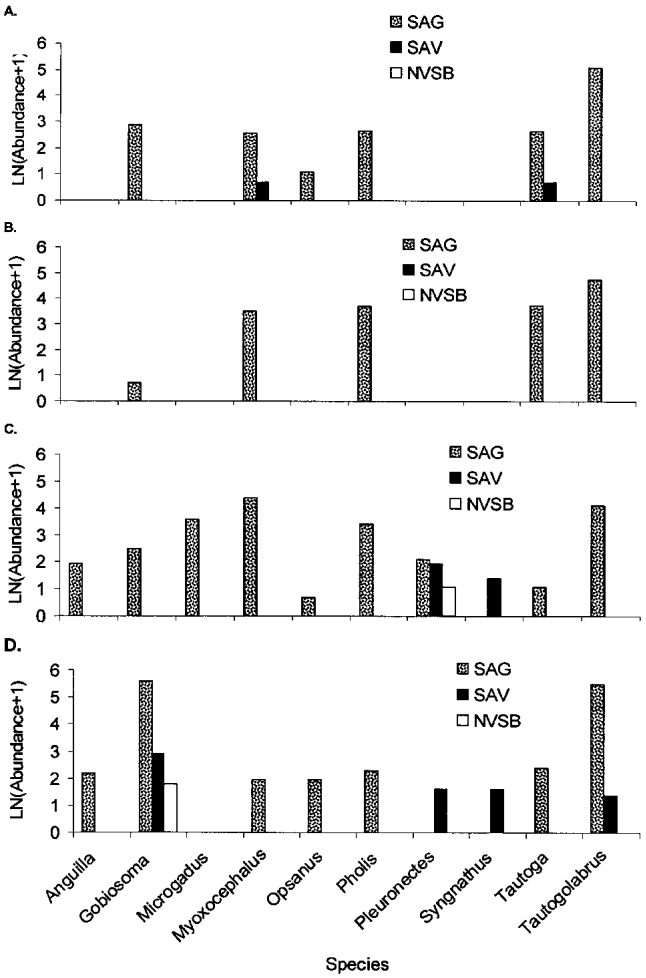

Figure 6. Total abundances (ln(abundance+1)) of individual fish species found within each habitat during: A. fall/winter, B. winter/spring, C. spring-summer, and D. summer-fall sampling periods for the following species: *Anguilla rostrata*, *Goliosoma spp.*, *Microgadus tomcod*, *Myoxocephalus aenaeus*, *Opsanus tau*, *Pholis gunnellus*, *Pleuronectes americanus*, *Syngnathus fuscus*, *Tautoga ontis*, *Tautogolabtrus adspersus*.

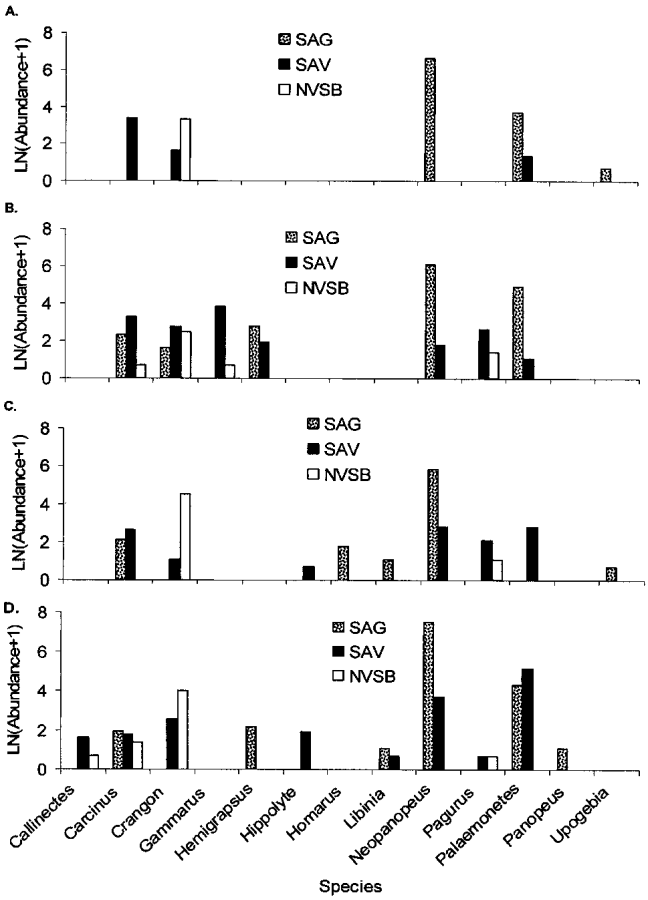

Figure 8. Total abundances (ln(abundance+1)) of individual crustacean species found within each habitat during: A. fall/winter, B. winter/spring, C. spring-summer, and D. summer-fall sampling periods for the following species: *Callinectes sapidus*, *Carinus maenus*, *Cragnon septemsoinosa*, *Gammarus spp.*, *Hemigrapsus sanguineus*, *Hippolyte spp.*, *Homarus americanus*, *Libinia emarginata*, *Dyspanopeus sayi*, *Pagurus longicarpus*, *Panopeus spp.*, *Upogebia affinis*.

DISCUSSION

Habitat is the place where an organism lives during any part of its lifecycle (Odum 1971). The ecologic value of habitat is inferred by quantifying the resident and transient marine organisms associated with a particular habitat. Consequently, the greater the abundance and diversity of fish in a particular habitat, the greater its habitat value (Able 1999). SAV and natural oyster reefs have been identified as important fish habitats not only because of shelter they provide to resident and transient marine organisms, but also because of the ecologic services they provide to the surrounding environment. The objective of our study is to comparatively evaluate the habitat value of SAG, SAV and NVSB in a small estuary. The SAV habitat sampled in this study is typical of other SAV

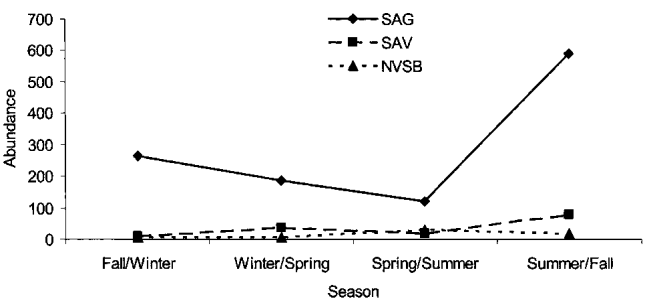

Figure 7. Total crustacean abundances found within each habitat and season.

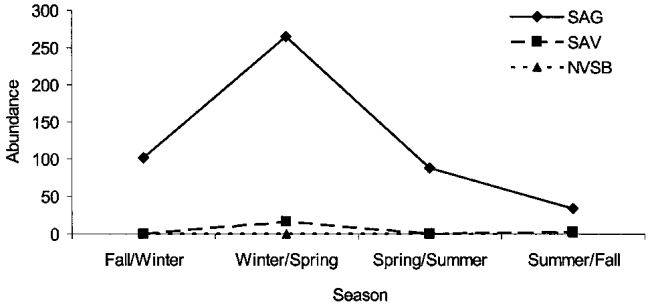

Figure 9. Total mollusk abundances found within each habitat and season.

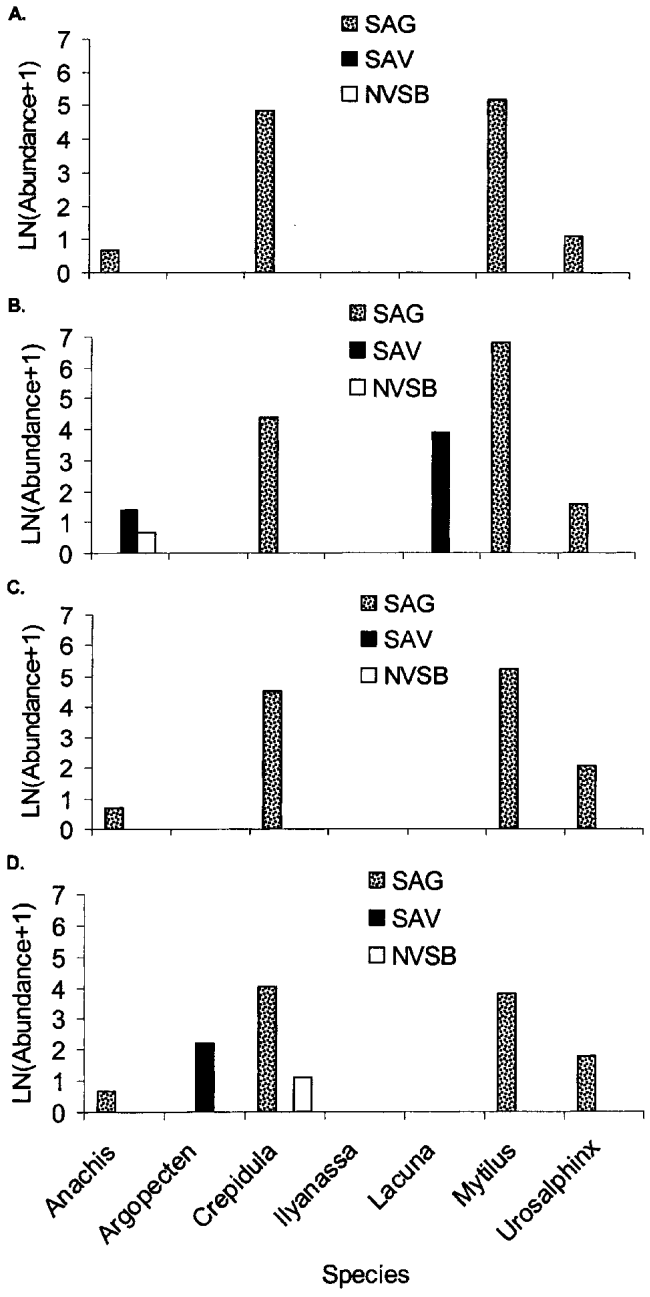

Figure 10. Total abundances (ln(abundance+1)) of individual mollusk species found within each habitat during: A. fall/winter, B. winter/spring, C. spring-summer, and D. summer-fall sampling periods for the following species: *Anachis spp.*, *Argopecten irradians*, *Crepidula fornicata*, *Ilyanassa trivattata*, *Lacuna vincta*, *Mytilus edulis*, *Ursalphinx cinerea*.

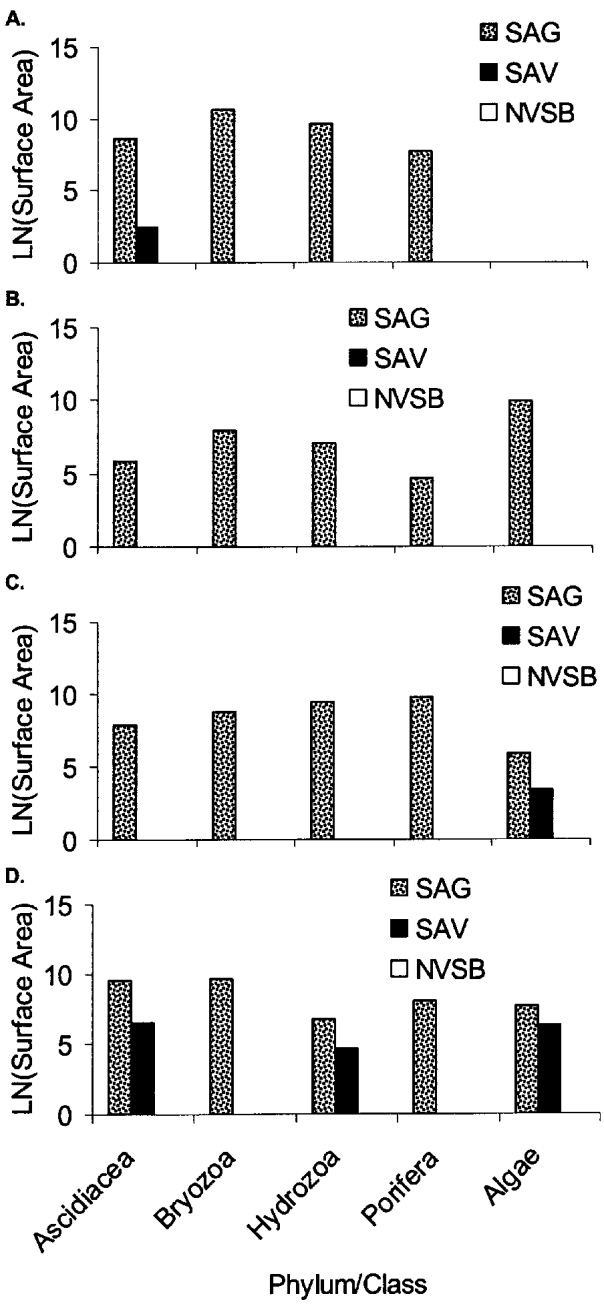

Figure 11. Total surface area (ln(surface area (cm^2)) of sessile species found within each habitat during: A. fall/winter, B. winter/spring, C. spring-summer, and D. summer-fall sampling periods for the following phylum/class groups: *Ascidiacea, Bryozoa, Hydrozoa, Porifera, Algae.*

habitats in New England and the mid-Atlantic regions based on eelgrass shoot density (Thayer et al. 1984),

The environmental parameters were relatively consistent among habitats within each season. No significant differences were observed between habitats for temperature, salinity, and dissolved oxygen, as was expected considering each habitat is contained within the same estuary. Also, as expected, the major differences among environmental parameters occurred between seasons. Sediment type between habitats was found to be similar after the gravel component was removed from the SAG site. The gravel component in the SAG site consisted of shell hash, which is a direct result of the aquaculture activities that take place over the seabed. The differences observed in species abundances and diversity between habitats are not likely to be related to environmental or geological parameters. Therefore, we believe that the observed differences in species composition and abundances are influenced by differences in habitat composition, structure, and complexity.

There was a highly significant difference in emergent surface

area (cm^2) between each habitat that was strongly correlated with abundance of organisms observed. The NVSB habitat supported significantly fewer organisms than either SAV or the SAG habitats throughout the year. The SAV emergent surface varied throughout the year due to seasonal growth and mortality patterns. The SAG emergent surface area varied seasonally as a result of the measured changes in the surface area of the oysters, whereas the surface area of the cages and bags remained constant. We believe that the higher abundances of species found in the SAG habitat throughout the year are related to the high surface area, the large numbers of spaces inside the cages that serve as refuge, and the prevalence of fouling organisms and forage. Structural heterogeneity was not considered when quantifying each habitat. The SAG habitat is constructed of 2-inch (5.08 cm) plastic-coated wire mesh. It can be assumed that the size of the wire mesh restricted many of the predator species of certain sizes and hence the cages became a refuge for many of the juvenile species of fish. These results are consistent with many studies that have recognized increased habitat complexity supports higher abundances of organisms due to increased predator protection (Orth et al. 1984, Ryer 1988, Beck 2000).

The high surface area within the shellfish aquaculture gear provides habitat not only for mobile fauna but also sessile biofouling invertebrates. Sponges, hydroids, bryozoans, and ascidians were found in both the SAG and SAV but the SAG habitat clearly displayed larger abundances of sessile invertebrate species. The SAV does support epiphytic and sessile invertebrate growth but not to the extent of the SAG. Although not intensively studied in this research, sessile invertebrate communities form the base of the food web for many artificial reef communities (Blancher et al. 1994). The high prevalence of sessile invertebrate communities on the SAG not only increases habitat complexity, but also increases food resources for the marine organisms inhabiting the aquaculture gear.

The SAG habitat shares many attributes and similarities with natural oyster reefs and artificial reefs. The oysters within the aquaculture gear are providing many of the same ecologic services as those found within naturally occurring oyster reefs. These ecologic services include but are not limited to particle clearance, nutrient removal and remineralization, benthic-pelagic coupling, and the creation of refuge from predators (Coen et al. 1999a, Dame 1999). The SAG also provides 3-dimensional structural complexity and many of the same benefits that artificial reefs provide in areas where habitat is limiting. Studies have shown and suggested that biologic services of artificial reefs include foraging habitat and predator refugia to resident and transient marine organisms (Blancher et al. 1994, Bohnsack 1989).

The abundance (organisms >5mm) and species richness exhibited in the aquaculture gear was greater than the eelgrass habitat, which in turn was greater than the unvegetated site, consistent with previous studies (Orth & Heck 1980, Mattila et al. 1999, Heck et al. 1995). This research clearly indicates more organisms inhabit the SAG habitat either SAV or NVSB habitats per square meter of seabed throughout the year. Species diversity levels were similarly higher in the shellfish aquaculture gear and the eelgrass ecotypes than in the unvegetated bottom consistent with findings of Marshall-Adams (1976), Mattila et al. (1999), Heise & Bortone 1999). Average species diversity in the SAG habitat was higher, but not significantly, than in the SAV habitat. The evenness measures varied greatly for each habitat throughout the year, however the SAG habitat had consistently lower evenness than the other ecotypes because of the hyperdominance of several species within the aquaculture gear (*Dyspanopeus sayi, Tautogalabrus adspersus, and Mytilus edulis*). In contrast, the SAV habitat was rarely dominated by a few species, but rather supported a more equal distribution of organisms. The NVSB habitat showed a greater fluctuation of evenness values directly affected by the abundances of the sand shrimp (*Crangon septemspinosa*) sampled during each season. The sand shrimp was by far the most dominant species in the NVSB habitat and accounted for 87% of the NVSB organisms sampled throughout the year.

The abundance and species diversity data elucidate the similarities and differences between each of the three habitats. The oyster cages supported much greater species abundances than eelgrass, but displayed similar species diversity (as shown by the Shannon-Weiner index). Eelgrass is a habitat known to provide many valuable ecosystem services and has been demonstrated to be a critical and essential habitat to many commercial and recreationally important species. The species abundance and diversity data from this study suggest that the shellfish aquaculture gear has similar habitat value for its inhabitants when compared with eelgrass. The species evenness data clearly shows that whereas the abundances may be greater in the SAG habitat, the SAG habitat is dominated by a few species.

The SAG habitat may also act as a predator refuge during early life stages of the lobster due to the limiting habitat within Point Judith Pond. In the spring and summer small lobsters are regularly found in the oyster cages and large predatory fish have been observed to frequent the aquaculture lease area including: the American shad (*Alosa sapidissima*), striped bass (*Morone saxatilis*), and winter flounder (*Pleuronectes americanus*). The American lobster supports an important fishery in the northeast United States therefore any habitat found to support the lobster should be considered commercially beneficial.

There is little research to date that describes the ecosystem services and benefits of aquaculture gear and its associated cultured product. The ecosystem services of the cultured bivalves and the benefits they provide to the marine ecosystem are fundamentally similar to those provided by wild stocks of bivalves. The aquaculture gear used to grow the cultured bivalves has intrinsic habitat complexity and shares many of the characteristics that artificial reefs possess. However, aquaculture gear is not a fixed structure, but it is periodically disturbed during maintenance and harvest operations. Most SAG habitat organisms are undoubtedly displaced during cleaning operations. Some of the sessile organisms are killed, but, the mobile species are probably able to quickly relocate to another of the 600 cages nearby when they are disturbed. The maintenance and cleaning of the aquaculture gear initiates recolonization of sessile invertebrate growth and inhabitance by motile organisms.

These findings indicate that shellfish aquaculture gear provides habitat for many native species of recreationally and commercially important fish and invertebrates in their early life history stages throughout the year. Therefore, we conclude that shellfish aquaculture gear has habitat value at least equal to and possibly superior to submerged aquatic vegetation. Future research should focus on growth, survival, and production of fish biomass within this habitat to further elucidate its habitat value.

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