Title: HARD CLAM (*Mercenaria* spp.) AQUACULTURE IN FLORIDA, USA: GEOGRAPHIC INFORMATION SYSTEM APPLICATIONS TO LEASE SITE SELECTION

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Application Tool: GIS.

Main Issues Addressed: Lease site selection for hard clam aquaculture.

The general problem, or aim of the study, and the contribution of GIS, remote sensing and/or mapping to the solving the problem: Hard clam (*Mercenaria*) aquaculture is a rapidly growing industry in Florida waters, and new coastal areas are continually being utilized for this activity. Our goal was to develop a data driven method for identifying areas most suitable for hard clam aquaculture and that included consideration of biology, logistics, management, and compatibility with alternative uses. Because hard clam aquaculture also is developing in other areas of the USA, and because similar bivalve aquaculture operations are developing or in operation in various areas throughout the world, our methodology was designed to be easily transferred to other areas and other species. Ultimately, an integrated and GIS-based approach to lease site selection should be considered a prerequisite for all marine aquaculture operations.

The successful development of a hard clam lease site selection model required the acquisition and interpretation of data from a variety of sources. Of fundamental importance was the incorporation of long-term data sets, because leases are generally granted for a minimum of five years and typically ten years. For parameters such as salinity and dissolved oxygen, mean values were effectively useless because the extremes dictate the survival of the organism. Thus, long-term minimum values for those parameters were integrated with other parameters (e.g. harvesting area classification, seagrass distribution, boat ramps) using ESRI Arc/View GIS software. Using the Spatial Analyst component of Arc/View, we were then able to query the database to identify areas of the Indian River Lagoon on the Florida east coast and Charlotte Harbor on the Florida west coast to identify sites that met our classification criteria. An additional advantage of the GIS system that we used was its flexibility, which allowed us to modify our classification criteria almost instantaneously. This provided a tremendous advantage during user-group meetings, because it allowed us to respond to requests from the user-group representatives for modifications to the criteria and to illustrate the outcome of those changes in a responsive and immediate manner.

Main Environments: Coastal bays and estuaries, and nearshore shallow-water habitats.

Culture Systems: Adult hard clams are induced to spawn in a hatchery setting and the resultant offspring raised to approximately 5 mm shell height (SH = maximum distance from umbo to ventral margin) in nursery raceways. The seed clams are then planted in mesh bags that are anchored to the bottom in intertidal and shallow subtidal habitats. The clams are allowed to grow to about 50 mm SH, which requires 1–1.5 years depending upon site, then harvested for eventual consumption on the half-shell.

Organism Divisions: Mollusca/Bivalvia, but these techniques are applicable to many sedentary aquaculture operations.

Genera and Species: *Mercenaria mercenaria* or hybrids of *M. mercenaria* and *M. campechiensis* are the target species for hard clam aquaculture in Florida waters. Pure-species *M. campechiensis* are a common constituent of natural clam assemblages in Florida, but that species is not suitable for aquaculture due to its short life span when held out of water. Because hard clams are consumed on the half-shell, and therefore must be alive and healthy when prepared for consumption, post-harvest survival is a critical consideration. Hybrid and *M. mercenaria* clams can survive post-harvest for up to two weeks, whereas pure *M. campechiensis* only survive for several days.

Target Country: The study was conducted in Florida, USA waters but has applicability throughout the world.

Target Audience: Coastal managers, natural resource managers, scientists, aquaculture industry participants.

Duration of the Study and Year Begun: The impetus for this work originated during field surveys for hard clam lease sites that were initiated during the early 1990s. At that time, lease sites were evaluated manually and on a case-by-case basis, and the aquaculturist was required to choose a site with little prior knowledge of the local environment and little guidance from resource managers. Baseline data sets for salinity and dissolved oxygen included information collected as early as 1984 and extending through 1998. The process of data consolidation, integration, and analysis required approximately six months.

Personnel Involved:
Fisheries Ecologist who conceived, planned, and coordinated the study. This scientist was involved part-time throughout the duration of the study and authored the summary publication.

GIS Analyst who assisted part-time throughout the duration of the study and who was responsible for data input and verification, data integration, plotting, and spatial analyses.

GIS Modeller who was involved intermittently to oversee the activities of the analyst, verify procedures, provide guidance as to available tools, and evaluate the outcome.

Aquaculture Manager who was involved intermittently to assist with the selection of sites and parameters.

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Introduction

Whereas the information base for the husbandry and marketing of aquaculture products is considerable, much less information is available for selecting appropriate sites for the conduct of aquaculture operations. Selection of an appropriate site for aquaculture activities will influence the long-term success of the aquaculture operation, both biologically and politically. We have developed a GIS-based hard clam aquaculture lease site model that will assist in this critical phase of industry development.

Methods and Results

Parameters incorporated into the model included hard clam density (raster), 10-year minimum salinity and dissolved oxygen (raster), seagrass distribution (raster), bathymetry (vector), shellfish harvesting zone classification (vector), location of navigable channels (vector), and the location of boat ramps (vector). Shellfish harvesting zones were ranked according to their suitability for harvest. Boat ramps were ranked based upon distance from the proposed lease site. Salinity was ranked with areas exhibiting minimum salinity < 12.5 psu deemed unsuitable, areas exhibiting minimum salinity between 12.5 and 17.5 psu deemed marginal, areas exhibiting minimum salinity between 17.5 and 20.0 psu deemed acceptable, and areas exhibiting minimum salinity > 20.0 psu deemed ideal. Areas with minimum dissolved oxygen below 1.0 mg/l, seagrass present, navigable channels within 30 m, or clam densities exceeding 5 m^{-2} were deemed unacceptable for hard clam aquaculture.

Resultant data were integrated using ESRI ArcView GIS software at a resolution of 1 ha. ArcView Spatial Analyst software was then employed to query the database for the identification of sites that met the above criteria. For the Indian River Lagoon, those sites are depicted in Figure 1.

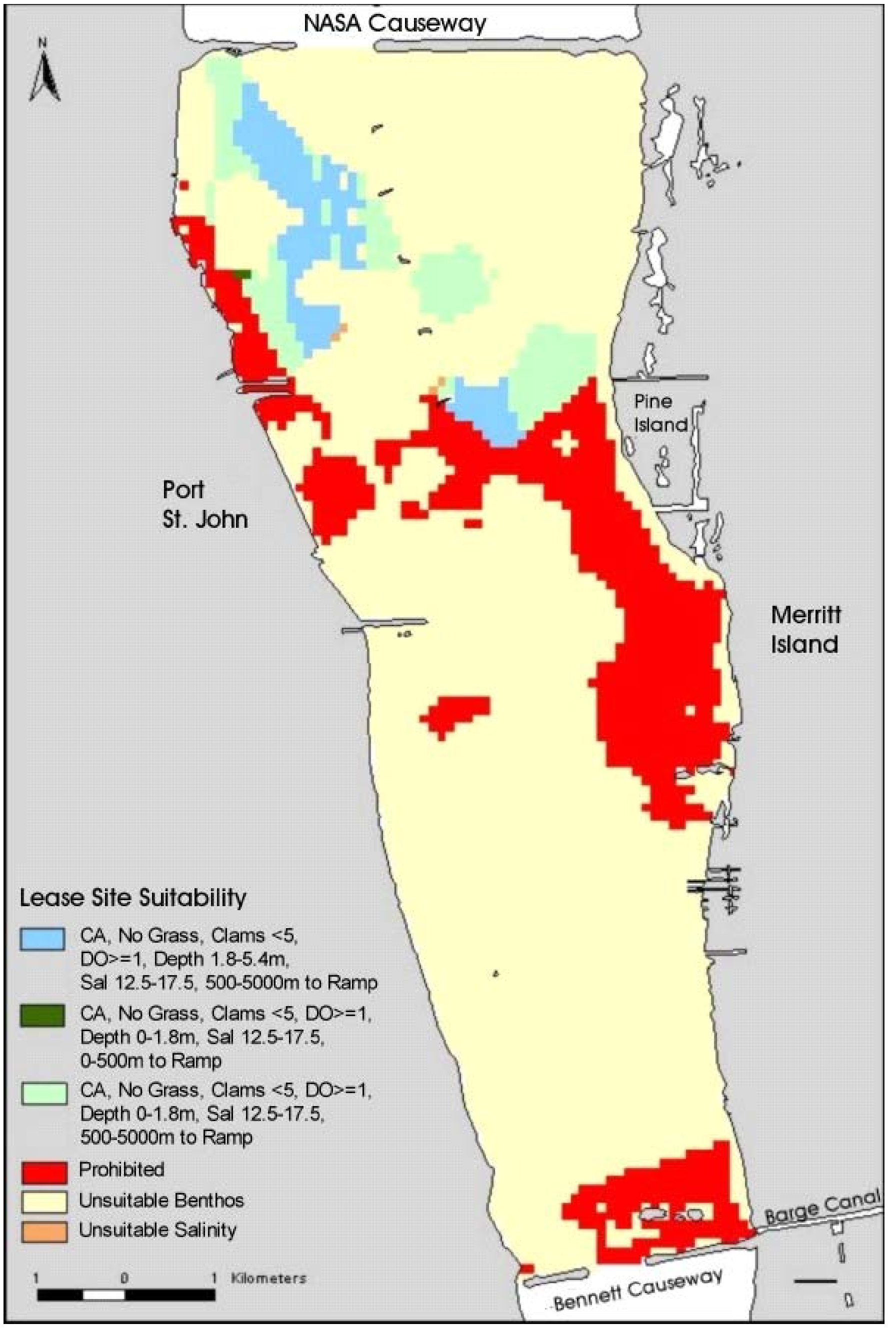

Figure 1 Areas suitable for hard clam aquaculture leases in Shellfish Harvesting Area C of the Indian River lagoon, Florida. Areas categorized as unsuitable are not appropriate for hard clam aquaculture due to the presence of seagrass, high density clam populations recorded during our 1994 survey, low levels of dissolved oxygen recorded between 1987 and 1998, excessive water depth or the proximity of navigable channels, or low salinity conditions inimical to clam survival. Of the remaining area, those cells classified as prohibited (= Prohibited or Conditionally Restricted classification) do not meet shellfish harvesting water quality standards.

In the legend, CA = Conditionally Approved shellfish harvesting area; DO = dissolved oxygen (mg/l); Sal = salinity (ppt); range in metres represents water depth (first) or distance to the nearest boat ramp (second).

A similar effort was applied in Charlotte Harbor, although hard clam density was not available for that estuary. Results for the Charlotte Harbor lease site identification exercise are depicted in Figure 2.

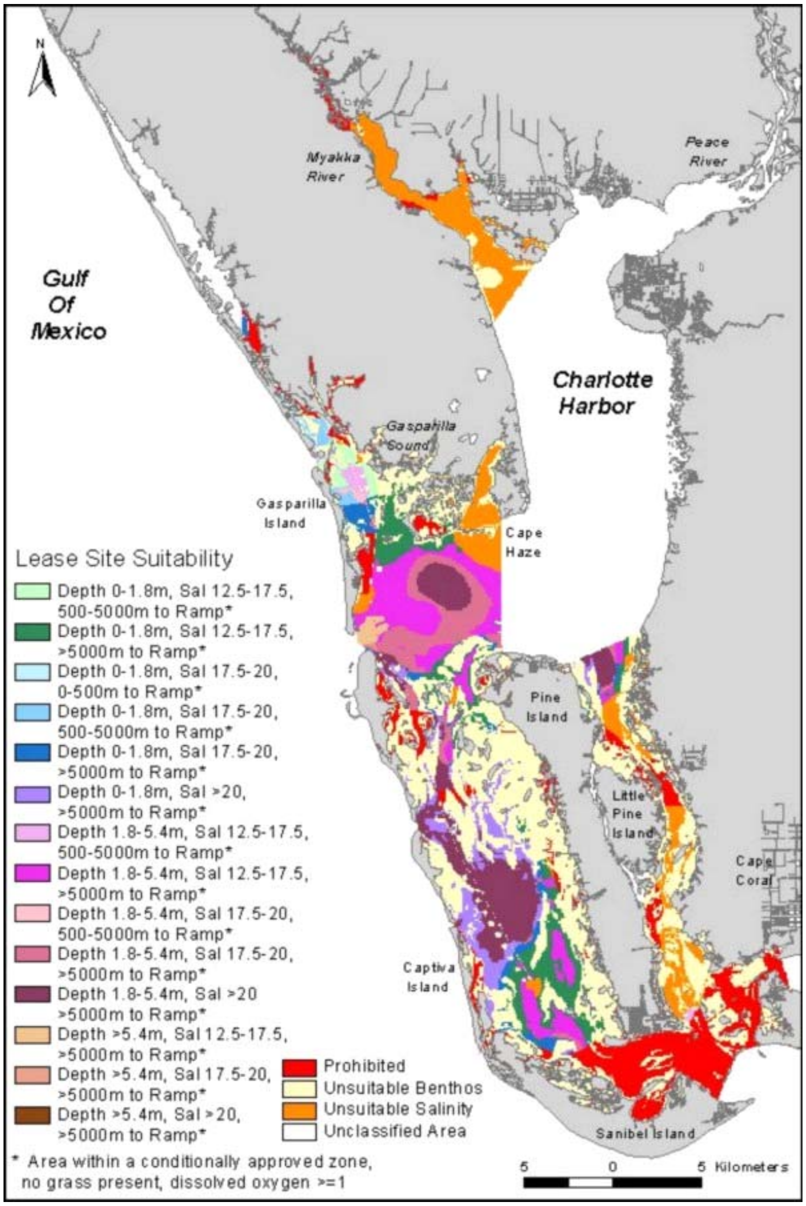

Figure 2 Areas suitable for hard clam aquaculture lease siting in Charlotte Harbor, Florida. Areas categorized as unsuitable are not appropriate for hard clam aquaculture due to the presence of seagrass, low levels of dissolved oxygen recorded between 1984 and 1998, excessive water depth or the proximity of navigable channels, or low salinity conditions inimical to clam survival. Of the remaining area, those cells not classified or classified as prohibited (= Prohibited or Conditionally Restricted classification) do not meet shellfish harvesting water quality standards.

In the legend, CA = Conditionally Approved shellfish harvesting area; DO = dissolved oxygen (mg/l); Sal = salinity (ppt); range in metres represents water depth (first) or distance to the nearest boat ramp (second).

No sites in the Indian River Lagoon were identified as being ideal for hard clam aquaculture, primarily because all sites experienced salinity < 20 psu during 1984–1998, but 281 ha were determined to be acceptable for clam aquaculture based upon the criteria that we employed. In Charlotte Harbor, we identified 1 844 ha that appear ideal for hard clam aquaculture and another 4 477 ha are acceptable.

Discussion

Our application of Geographic Information System technology to the selection of hard clam lease sites represents one of the first applications of this approach in nearshore marine waters. We incorporated information on biology, harvesting water quality and logistical support to identify areas that appear suitable for clam culture. The output from our model run is not intended to pre-determine the location of lease sites, but rather to provide guidance to the individual culturist in the preliminary selection of suitable sites. It is incumbent upon the individual culturist to carefully evaluate potential sites identified by our model with regard to their specific needs and requirements. This modelling method has the additional advantage that it is interactive, allowing for real-time evaluation of alternative interpretations. For example, one criterion we used in the model was relative distance to boat ramps. Sites that were too close to a boat ramp (< 500 m) were classified as being less than ideal because of the potential interference from boating activities. However, an individual culturist may consider a nearby boat ramp to be an advantage rather than a disadvantage. We can easily reevaluate our model output with that consideration in mind, thereby providing the culturist with an output tailored to his specific preferences.

We also identified two additional needs that must be met before we can consider this approach to be fully successful. First, the approach has not been as well-accepted by resource managers as we would have hoped. Second, and perhaps related to the first, field verification is needed. We have solicited funds to support a field verification effort, but to date such funds have not been forthcoming. We will continue to seek funds to support field verification and model tuning.

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