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An Examination of Potential Conflict between SAV and Hard Clam Aquaculture in the Lower Chesapeake Bay

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AN EXAMINATION OF POTENTIAL CONFLICT BETWEEN SAV AND HARD CLAM AQUACULTURE IN THE LOWER CHESAPEAKE BAY

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ABSTRACT

Natural resource mangers may find themselves in a conflict of interest over the management of shallow subaqueous bottom when they attempt to promote both hard clam (*Mercenaria mercenaria*) aquaculture and the growth of submersed aquatic vegetation (SAV) (*Zostera marina* and *Ruppia maritima*). This project examines the issue of bottom use conflict along the Lower Eastern Shore of the Chesapeake Bay in a managerial and scientific context in an attempt to develop a solution to this conflict. First, it examines historical trends in clam aquaculture and SAV growth in the study area. Habitat suitability models are then developed to predict optimal habitat for clam aquaculture and SAV and through these, potential conflict between these resources. Comparable Western Shore sites are used for validation of ceratin models. The laws and policies of Virginia and the neighboring states of Maryland and North Carolina are then examined to understand the political reasons for this conflict. Finally, the historical, scientific, and political information is summarized and potential solutions to this conflict are recommended. Results show bottom use by clam aquaculture in Cherrystone Creek along the lower Eastern Shore of the Chesapeake Bay often increased between 1989 and 1997. SAV beds were also generally expanding during this time both in Cherrystone Creek as well as in creeks north of cherrystone where no clam culture was occurring. Habitat models, incorporating biological factors (SAV spreading rates, exposure tolerance, and light requirements) and management factors (water depth and bottom hardness for tending clams, exposure to prevent smothering of clam nets) show large areas of both suitable clam and SAV habitat in the lower portions of the study creeks. Consequently, conflict models show large areas of potential conflict in study creeks where these habitats overlap. Study of the policies, laws, and regulations of Virginia and adjacent states shows that none of these states have adequately addressed this issue. The primary management recommendation of this project is to annually define existing SAV beds and a 50 meter buffer surrounding these beds and restrict use of this area to clam aquaculture. Habitat models which placed "no clam" buffers of 50, 100, 150, and 200 meters around an SAV bed suggested a 50 meter buffer would adequately protect SAV bed expansion while minimizing areas legally restricted but otherwise suitable for clam aquaculture.

INTRODUCTION

1.0 Background

Hard clam (*Mercenaria mercenaria*) aquaculture is a growing and thriving industry. In 1997 in the Commonwealth of Virginia alone, it was worth nearly $10 million dockside (Virginia Agricultural Statistics Service, 1998). This, and other aquaculture industries, are promoted by mangers as a sustainable fishery with important economic ramifications citizens. As such, aquaculturists are permitted to benefit at minimal cost from a variety of public resources including public bottom land and the public water column.

Submersed aquatic vegetation (SAV) is an important habitat for fish and invertebrates (Marsh, 1973; Orth, 1973; Heck and Orth; 1980, Orth and Heck, 1980; Heck and Thoman 1984; Orth and Montfrans,1987; Heck, 1989; Perkins-Visser et al. 1996; Pile et al., 1996; Mattila et al.,1999; Pardieck et al., 1999) as well as a food source for waterfowl (Wilkins, 1982; Perry and Uhler, 1988; Erwin, 1996; Adair et al., 1996). As such, the Commonwealth of Virginia has made it a policy to protect and promote the growth of SAV (Chesapeake Bay Agreement, 1987) and has written such policy into subsequent regulation (eg. 4 VAC 20-335-10 ET SEQ., 4 VAC 20-1010-10 ET SEQ). Unfortunately, the growth of SAV and development of aquaculture can be mutually exclusive uses of the bottom land.

Hard clam aquaculture utilizes large areas of bottom for clam grow-out. The clams are spawned in a hatchery and then placed on the estuary bottom in covered trays in high salinity shallow waters for several months. They are then transferred to larger grow out areas where they are placed directly on the bottom sediments. Large nets, approximately 4m x 15m, are placed over top of the clams and then anchored to the bottom with sand bags. Both the nets and the covered trays are designed to protect the clams from predators such as crabs and sting rays. The maintenance of these nets kills existing SAV and excludes the growth of SAV into the area on which the nets are placed in the shallow littoral zone.

Serious concern has arisen about the incompatibility of clam aquaculture and the growth SAV. In the lower Chesapeake Bay SAV, consisting primarily of eelgrass, *Zostera marina*, and widgeon grass, *Ruppia maritima*, often inhabit areas of bottom desired by aquaculturists who raise hard clams. SAV proponents argue that SAV and potential SAV habitat should be protected since SAV provides critical habitat for many of the species of the Commonwealth's natural fisheries. Clam aquaculture proponents argue that hard clam aquaculture is a sustainable fishery and lucrative industry which greatly benefits an economically depressed region of the Commonwealth. They furthermore argue that the presence of their clams in the vicinity of SAV beds may actually promote SAV growth by altering sediment and water quality.

2.0 Submersed Aquatic Vegetation

2.1 Chesapeake Bay Agreements

In 1983 the first Chesapeake Bay Agreement was signed by representatives of Maryland, Virginia, the District of Columbia, and the EPA. This agreement formally acknowledged the environmentally degraded state of the Chesapeake Bay and established the Chesapeake Bay Executive Council to study this problem (Chesapeake Bay Commission, 1983). In 1987 the second Chesapeake Bay Agreement was signed (this time with the added signatory of Pennsylvania) which established eight goals, 40 objectives, and 29 priority commitments for managing various programs. One of those primary goals was the restoration and protection of living resources including SAV (Chesapeake Executive Council, 1987). In 1989 the Chesapeake Executive Council created the Submersed Aquatic Vegetation Policy for Chesapeake Bay and Tidal Tributaries which committed to achieving a net gain in SAV distribution, abundance, and species diversity (Chesapeake Executive Council, 1989). Following this, an Implementation Plan (Chesapeake Executive Council, 1990) and Habitat Requirements Technical Synthesis (Batiuk, 1992) were developed . The Bay Agreement was amended in 1992 to include the use of SAV distribution and abundance as an indicator of the progress of restoring living resources and enhancing water quality (Chesapeake Executive Council, 1992). In 1993 the Chesapeake Executive Council agreed to set quantitative restoration criteria based upon historical distribution estimates and established an interim restoration goal of 114,000 acres of SAV baywide (Chesapeake Executive Council, 1993). The criteria which was thereafter developed broke SAV restoration into three tiers.

Tier I goal: To restore or establish SAV in areas of historic (1971 to 1990) distribution.

Tier II target: To restore or establish SAV in potential habitats to a depth of 1 meter.

Tier III target: To restore or establish SAV in potential habitats to a depth of 2 meters.

The Executive Council's interim goal of 114,00 acres corresponded to the Tier I goal. Following this, in 1995 the Submerged Aquatic Vegetation Workgroup of the Living Resources

Subcommittee of the Chesapeake Bay Program published the Guidance for Protecting Submerged Aquatic Vegetation in Chesapeake Bay from Physical Disruption (Chesapeake Bay Program, 1995) which outlined physical disturbance threats to SAV and methods of protecting this resource within the Chesapeake Bay.

2.2 Habitat Requirements

In 1992 the EPA Bay Program published its first SAV Habitat Requirement and Restoration Target Synthesis (Table 1; Batiuk, et al, 1992). This book incorporated the work of a multitude of scientists from the Chesapeake Bay region who defined five parameters (TSS, Chlorophyll, DIN, DIP, and light) which they found to influence SAV growth and survival. These scientists studied four Bay regions and classified their work by four salinity regimes. Each of the four regions studied incorporated at least two of the salinity regimes so the results were not site specific. The results were derived by:

1. Using transplant experiments and bay-wide distribution surveys to define suitable habitat.
2. Measuring water quality characteristics along large scale transects that spanned regions of different SAV habitat suitability.
3. Combining water quality characteristics and SAV suitability data to establish minimum water quality levels which would support SAV.

The resulting correspondence analysis was supported with multi-year data sets of meteorological and hydrological conditions and their corresponding effects on SAV. Validation of this work supported the use of all five of these water quality characteristics (TSS, Chlorphyll, DIN, DIP, and light) to determine SAV habitat suitability. It also showed that no single characteristic was a perfect predictor of SAV presence. It concluded that SAV presence could be inhibited when as few as two of the SAV habitat criteria were not met.

2.3 Lower Chesapeake Bay SAV Species

The species of SAV which were considered in this study were *Z. marina* and *R. maritima*. Both species are found in the lower Chesapeake Bay in waters typically less than 2 meters (Moore et al. 2000; Orth and Moore, 1988).

Z. marina grows primarily in cool high salinity waters of the northern hemisphere (Thayer et al 1984). In the Chesapeake Bay *Z. marina* is most abundant in the high salinity rivers and shallows of the lower bay but can be found in the middle and occasionally the upper Bay (Moore et al. 2000). It is temperature sensitive and experiences peak biomass in June and July and a leaf shedding event in July and August (Orth and Moore, 1986). This sensitivity to temperature also restricts *Z. marina* to cooler waters (Wetzel and Penhale, 1983; Orth and Moore 1988). In the Chesapeake Bay *Z. marina* seeds germinate from late October through November (Moore et al 1993) and mature in two years. Mature plants begin flower development in February with pollen being released in mid-April and seeds produced between May and June (Silberhorn, et al, 1983). Reproductive shoots are often released from the plants and float on the surface of the water and may be carried by winds and currents before dropping their seeds (Harwell, 2000). *Z. marina* beds also spread vegetatively although free floating rhizomes cannot reroot themselves (Ewanchuk and Williams, 1996).

R. maritima is found worldwide and can live in a wide variety of conditions. It can grow in highly saline or purely fresh water and is more heat tolerant than *Z. marina* (Wetzel and Penhale, 1983, Evans et al, 1986). As a result, *R. maritima* can grow in freshwater ponds, shallow marsh guts (Silberhorn et al 1996), and areas close in to shore (Orth and Moore, 1988). Generally, *R. maritima* grows in monospecific beds in very shallow water (often <0.3 meters, MLW). As water depth increases, both species co-occur (0.3-0.6 meters, MLW). In deeper water (>0.6 meters, MLW), *Z. marina* is found in monospecific bedshowever, where *Z. marina* is not present in some areas of the Chesapeake Bay, *R. maritima* can grow to depths greater than one meter at mean low water (Orth, 1977; Wetzel and Penhale, 1983; Orth and Moore 1988). *R. maritima* can be either annual or perennial, can reproduce vegetatively or through seeds, and can exhibit morphological diversity based upon environmental conditions (Richardson, 1980). *R. maritima* seeds germinate in spring and flower in the late spring and summer with a peak in June and July (Silberhorn et al.,1996).

3.0 Hard Clams, *Mercenaria mercenaria*

3.1 Habitat Requirements

The hard clam, *M. mercenaria*, is naturally distributed along the Atlantic Coast of North America from the Gulf of St. Lawrence to Florida and the Gulf of Mexico. In the Chesapeake Bay it is found in greatest abundance in the high salinity waters of Virginia at depths greater than 5meters (Mann, 1991 in Funderburk).

M. mercenaria requires salinities greater than 12 psu and is found in abundance only in salinities greater than 18 ppt. Larval metamorphosis requires salinities of 17 psu or greater. Lower salinities also slow adult growth (Davis, 1958; Mann, 1991 in Funderburk).

Warm water and food availability stimulates *M. mercenaria* growth and thus *M. mercenaria* exhibits latitudinal variations in growth rate (Mann and Castagna, 1989 in Funderburk and Mann, 1991 in Funderburk). In the Chesapeake Bay, greatest growth occurs in the spring and fall when warm water temperature coincides with high food availability. Water temperatures of 10° C or greater stimulate gametogenesis (Eversole, 1987). Optimal growth of adult clams occurs between 21° and 31° C (Tenore et al, 1973). In optimal conditions in the Chesapeake Bay, clams may grow to market size (1 inch in shell length) within 2 years. In areas to the south of the Chesapeake Bay, growth rates may be much higher.

Turbidity may play an important role in *M. mercenaria* growth and development. While adult clams can tolerate some suspended sediment, exceptionally heavy amounts may impede clam feeding (Bricelj and Malouf, 1984). Larval clams are particularly susceptible to growth and development impediment caused by high levels of suspended sediments (Davis, 1960; Bricelj et al, 1984).

Substrate may affect the settling of *M. mercenaria* larvae as larvae prefer sandy bottoms over muddy, organic rich sediments (Thorson, 1955) however, discussion with clam aquaculturists suggests that sediment type plays only a limited role in the growth of adult cultured clams.

3.2 Life Cycle

M. mercenaria is a protandrous, consecutive hermaphrodite (Eversole, 1987). *M. mercenaria* experiences a short juvenile phase at a few months of age where it exhibits a bisexual gonad but functions as male (Coe,1943a; Manzi and Castagna, 1989). This phase is followed at approximately two years of age by an adult phase where the clam becomes either distinctively male or distinctively female (Loosanoff, 1936; Manzi and Castagna, 1989). Spawning is affected by food availability and temperature with Southern latitudes affording longer spawning periods (Eversole, 1987). In the Chesapeake Bay, spawning occurs from May through October (Chanley and Andrews, 1971).

M. mercenaria releases very large numbers of gametes directly into the water column where fertilization occurs. Young larvae are planktonic and planktotrophic. Rate of development of the blastula, gastrula, trochophore, straight-hinged, umboned, and pediveliger stages is dependent upon environmental conditions and food availability and may last for a week or longer. (Chanley and Andrews; 1971; Eversole, 1987). Pediveligers swim and crawl along the bottom searching for appropriate substrate before anchoring themselves. From there, the larvae develop into mature clams, after which they will only travel short distances (Mann, 1991 in Funderburk).

3.3 Feeding Mechanisms and Rates

M. mercenaria primarily resides beneath the sediment with only their siphons reaching into the water column. To feed, a clam forces water through its inhalant siphon and out of its exhalant siphon using a pumping force created by internal cilia. These cilia draw the current of water through the siphon and to the gills and mucus strings which trap material suspended in the water. The labial palps then sort the material by size. Material of suitable size is ingested while material of unsuitable size is ejected from the clam as pseudofeces (Funderburk, 1991).

Filtration rates and efficiencies of *M. mercenaria* are dependant upon a variety of factors including particle concentration, species of algae present, water temperature, and current velocity (Walne, 1972; Tenore and Dunstan, 1973). In general, both filtration rates and efficiencies increase with increasing particle concentration but efficiencies reach a maxima and eventually decrease with increased food concentration (Tenore and Dunstan, 1973). Optimum algal density for hard clam filtration is 2×10^5 cells ml^{-1} with clams having been observed to assimilate 71.2-77.3% of the ingested food (Tenore et al 1973 and Tenor and Dunstan 1973).

3.4 Ecology and Ecological Consequences of Hard Clam Aquaculture

M. mercenaria in natural populations may benefit from relationships with rooted vascular macrophytes (SAV). Such clams are often found growing within beds of SAV in concentrations much greater than in adjacent sand flats (Irlandi, 1997). Several factors likely account for this discrepancy, including increased larval deposition (Peterson, 1986) and decreased predation (Peterson, 1982). Clam growth may also be affected by occurrence within an SAV bed although this relationship is still unclear. Some studies have shown increased growth of clams in SAV as opposed to sand flats, while others have shown decreased clam growth in SAV beds (Kerswill, 1949). This discrepancy may be caused by factors that sporadically assist clam growth such as increased food quantities in SAV beds (Judge, et al., 1993) or sub-lethal predation such as siphon nipping which is decreased in areas where clams are protected by dense SAV (Cohen and Heck, 1991; Irlandi, 1994)

As filter feeders, *M. mercenaria* assist in benthic-pelagic coupling processes by removing phytoplankton and sediment from the water column and depositing them into the sediment. Nutrient regeneration rates, especially nitrogen, are high for clams compared with other shellfish (Tenore et al, 1973) however, water column nutrient levels may remain low (Mojica and Nelson, 1993) suggesting nutrient sequestration in sediments or rapid uptake rates in some cases. This benthic-pelagic coupling may also alter sediment composition by increasing organic and fine particle components, especially in intense aquaculture conditions (Mojica and Nelson, 1993).

How high densities of hard clams, such as are found in aquaculture operations, affect SAV is still in question. Some studies on other filter feeding bivalves have suggested improved light availability and increased sediment nutrients which would increase SAV growth (Reusch et al, 1994; Phelps, 1994). Other studies of intense shellfish aquaculture operations showed increased levels of eutrophication which may produce increased macro-algal growth and harm SAV growth (DeCasabianca, 1997). At present, there are no published studies, either lab or field based, showing positive or negative effects of clam filter feeding on SAV growth.

4.0 Habitat and Conflict Models

Spatial habitat models, often based upon habitat suitability indices (HSIs), have been developed for a variety of different purposes and for a variety of different regions. An HSI ranks factors which contribute to habitat value for a given species and combines these ranks to predict habitat quality for that species. A spatial habitat model then integrates and displays this information graphically. Hill et al. (1990) developed a spatial habitat model based upon HSIs to predict the best locations for pond aquaculture in Louisiana. Battista (1998) recently developed a model to predict the best locations for optimal oyster growth based upon food availability and disease prevalence in the Chesapeake Bay. A similar model is currently being developed to predict potential SAV habitat to help target restoration efforts in Maryland (Goshorn et al., 1998).

A large scale spatial model was developed earlier to investigate potential SAV and aquaculture conflicts by predicting suitable habitat for each use (Grignano, 1994); however, this current project examined this issue at a much smaller scale. Grignano's model had a scale of kilometers and looked at large areas within the entire lower Chesapeake Bay. The models that were developed in this project focused application to several creeks in a very small area of the Bay. The completed models predicted the degree of potential conflict between the bottom land uses, growing SAV and planting clams, on a scale of meters. This smaller scale is much more practical for managers who are trying to manage small areas of bottom leased by individual aquaculturists.

5.0 Project Overview

This project was designed to study potential conflict between bottom land use by SAV and hard clam aquaculture, and to provide a management approach that could be used to minimize this conflict. This was accomplished by a three fold approach. First, the historical trends in SAV growth and aquaculture bottom use in this region were examined statistically and geographically to provide historical context of the problem. Second, a spatial GIS model was developed based upon the habitat requirements for SAV survival as well as industry requirements for clam aquaculture, respectively to quantify potential conflict in the study region. Third, to provide political insight towards implementation, a legislative review was be performed to examine the current regulation and policy regarding clam aquaculture in Virginia and compare it with that of the neighboring states Maryland and North Carolina.

The goal of this project was to develop a habitat suitability model which can be used by mangers to better predict which areas of bottom land are most suitable for SAV or clam aquaculture as to allow them to optimize bottom land allocation. This project also provided suggestions as to how to best utilize such an index based upon the historical, scientific, and political information which was compiled and analyzed. The outcome of this project is a solution to help managers to minimize impact of aquaculture on SAV so that the

Commonwealth's objectives of promoting SAV recovery and aquaculture activities can be realized as much as possible.

Objectives

Objective A: To examine and quantify the historic trends in Virginia of hard clam aquaculture bottom land use and SAV distribution in the study areas

Objective B: To develop and validate clam aquaculture and SAV habitat suitability indexes and spatial models to predict use conflict in the study areas

Objective C: To examine the legal framework regulating on-bottom aquaculture in Virginia and adjacent states to provide the political framework needed to understand the policies which have led to this conflict and to create new policies to minimize this conflict..

Objective D: To utilize the output of the spatial models as well as the synthesized historical and policy information to develop potential solutions to this conflict.

MATERIALS AND METHODS

Objective A: Examination and Quanitification of Historic SAV and Clam Aquaculture Trends

1.0 Historical Trends Study

1.1 Approach

Historical trends in clam aquaculture in Cherrystone Creek and SAV in Cherrystone and Neighboring Creeks were studied and analysis was performed to test the theory that increased clam culture was spurring the growth of surrounding SAV beds.

1.2 Study Sites

The Cherrystone Creek System, a high salinity creek system on the Eastern Shore of the Chesapeake Bay, was selected for primary analysis in this study. Clam aquaculture sites appear in aerial photographs of this region dating back to 1989. *Z. marina* and *R. maritima* are the SAV species present in this area. Comparison creek systems (of similar size and surrounding land use) without clam aquaculture were located to the north of Cherrystone Creek and had similar size, location, and surrounding land use (Figure1).

1.3 Analysis

SAV geographic distribution data was obtained from the VIMS SAV mapping program. Area calculations were made of SAV and clam beds within the creeks using Arc Info® software. Clam geographic distribution data was obtained from aerial photographs

(1:24,000) from the VIMS SAV aerial photography archive. Photographs, scanned at 600 dots per inch, were rectified using USGS digital ortho quarter quads. Active clam beds, visible as rectangular underwater structures, were digitized on screen with Imagine® software. Area calculations of active clam beds (those upon which nets were visible) were determined from resulting coverages with Arc Info® software. GIS coverages of SAV and clam beds within this creek system were plotted and visually compared. A multiple regression was then preformed to test for a relation between yearly SAV coverage and yearly clam beds coverage from 1989 to 1997 within the Cherrystone creek system and between yearly SAV coverage in Cherrystone creek system (with aquaculture present) and yearly SAV coverage of four creeks without clam operations.

Objective B: Development of SAV and Clam Aquaculture Suitability Indexes and Spatial Models

2.0 Clam Aquaculture Models

2.1 Approach

The clam aquaculture index was based upon a combination of the biological requirements of hard clams and the industry requirements for growing clams. Clam aquaculturists place clam grow-out nets in high salinity (preferably 25-35psu) waters (Oesterling 1996). Areas with hard, sandy sediments and shallow waters (1m or less at mean low water) are selected to allow aquaculturists to tend the clams. Macro algal fouling of the nets is common much of the year and the aquaculturists must be able to clear the nets of algae and harvest the clams without sinking into the sediments while wearing chest waders (Pierson pers. comm.). For these reasons, the factors selected for the clam models to be discussed were salinity, sediment type, and bathymetry (Table2).

2.2 Study Sites

The clam models and the validation of the clam models were done using the Cherrystone Creek System consisting of Cherrystone Creek and Kings Creek and the Hungars Creek System consisting of Hungars Creek, Matawoman Creek, and The Gulf (Figures 1 and 2, Table 2).

2.3 Analysis - Clam Aquaculture Model I:

A preliminary bathymetric and sediment ground survey was conducted in the study areas but the spatial resolution of the collected data proved inadequate for this study. Sediment type in the shallow waters was therefore derived from aerial photography using visual gray scale comparisons (shallow sandy areas appeared light in color) and digitally plotted. Bathymetry was interpolated from NOAA data (Wilcox, unpublished data) with the exception of offshore sandbars. Off-shore sandbars were digitized from photographs because of their dynamic nature to create a more recent representation of bathymetry than was available from bathymetric soundings data. Exposure coverage estimates were made using best professional judgement, taking into account fetch and exposure breaks from off shore sand bars and land masses (Hershner, unpublished data). Moderate exposure areas were designated behind offshore sandbars and near creek mouths while high exposure areas were designated outside of the creeks in areas without shoreline or sandbar protection. Salinity was appropriate at all locations studied for clam culture.

The above data sets were then entered into a Geographic Information System (GIS). Areas with a shallow, hard, sandy (light colored) bottom, up to one meter in depth at mean low water (MLW), and with a low north-west exposure, were designated as having a high probability of supporting clam aquaculture. Areas with a shallow, hard, sandy (light colored) , up to one meter in depth at MLW, and with a moderate north-west exposure were designated as having a moderate probability of supporting clam aquaculture. All other areas were designated as having a low probability of supporting clam aquaculture (Table 3).

2.4 Validation - Clam Aquaculture Model I:

The model was validated by comparing recent (1997) locations of hard clam operations with predicted locations, because none of the data used in generating this suitability model was dependent upon actual distribution of hard clam aquaculture operations (Table 2). Since hard clam aquaculture continues to expand in this region, it can be assumed that not all areas appropriate for hard clam aquaculture have been exploited. Therefore, this model was tested by comparing the amount of hard clam area in use that is within the predicted zones with that which is outside of the predicted zones. Degree of error was estimated as the amount of clam area which lay outside of the predicted zones.

2.5 Analysis - Clam Aquaculture Model II:

The hard clam aquaculture model I was then refined. The original prediction factors of bottom type, exposure, and water depth were retained but additional data pertaining to bottom hardness and hydrodynamic exposure were incorporated into the second version of this model.

Bottom type contours were refined with sediment type data which were collected in the field. The firmness of the shallow water habitat was tested with a pole. A GPS unit was used to record sampling locations and the bottom was classified as either "hard" or "soft." These data points were then plotted using a GIS and contours were drawn by adjusting the original bottom type coverage with the new data.

An additional study was performed to quantify "hard" and "soft" classifications. For this study a 5lb weight was affixed to a 10ft x 5/8in metal pole and the depth of penetration was measured. A sediment sample was taken at each of these measurement sites and a grain size analysis was performed.

The exposure model was then updated to incorporate a quantifiable, reproducible method. As with the original method, this new method created a classification scheme which took into account protection of a point from northwest winds by land masses and sandbars within 1km of the point. (Koch, pers. comm.). A program was written which divided areas of water within 1km of the shoreline or a sand bar into grid cells 0.1km by 0.1km in size. For the center point of each grid cell, the computer drew nine 1 km radials in the North to West directions and at increments of 11.25 degrees (a total of 90 degrees). A numerical value was assigned to each radial. Radials which intersected land or land and a sand bar were assigned a value of 3. Radials which intersected sand bars were assigned a value of 2. Radials which did not intersect land or sandbars were assigned a value of 1. The sum of the radials was then assigned to the point and its corresponding grid cell. These values were then incorporated into the aquaculture suitability model such that areas with a hard bottom and exposure value of 9-14 were designated as a low exposure, 15-20 as a moderate exposure, and 21-27 as a high exposure (Figure 3).

2.6 Validation - Clam Aquaculture Model II:

As with the initial model, the refined model was validated by comparing current (1997) locations of hard clam operations with predicted locations and comparing the area of hard clam aquculture within the predicted zones with that outside of the predicted zones. Degree of error was measured by the amount of clam area which lay outside of the predicted zones.

2.7 Analysis - Clam Aquaculture Model III:

A third clam model was created because of the decreased accuracy of clam model II which was attributed to the problems with the second exposure component. This model used the all of the same components as clam model II, with the exception of the exposure component. The exposure component created for clam model I was used in clam model III (Table 2). Validation was performed in the same manner as clam Models I and II.

<u>3.0 Development of SAV Suitability Index and Spatial Model</u>

3.1 Approach - SAV Model I:

To develop a suitability index and model for SAV, an approach utilizing water quality parameters to predict SAV habitat was employed.

3.2 Study Sites - SAV Model I:

SAV model I was created using the SAV distribution data from the Cherrystone and Hungars Creek systems on the lower eastern shore of the Chesapeake Bay. Validation of this model was accomplished by comparing model predicted SAV distributions to actual SAV distributions in Back River and the Poquoson River creek systems located in Virginia along the western shore of the Chesapeake Bay (Table 2). These two areas both support the same species of SAV as the Cherrystone and Hungars systems although they do not currently support intensive clam aquaculture.

3.3 Analysis - SAV Model I:

Literature on SAV habitat requirements including Technical Syntheses I and II (Batiuk, 1992; Batiuk et al., http://www.chesapeakebay.net), were reviewed and experts were consulted regarding the habitat requirements of the SAV species *Z. marina* and *R. maritima* (Moore, pers comm.). From this information, the principal factors influencing habitat suitability for SAV in the lower Chesapeake Bay were determined to be water quality, depth, and exposure. Several methods were determined for ascertaining appropriate water quality for SAV. These were ranked by estimate of accuracy. Data required for each method were noted

(Table 4).

All available water quality data for this region was collected and light attenuation, in the form of secchi depth measurements, was determined to be the best available measurement for use in determining required SAV water quality. Although the accuracy of using only light attenuation to determine required water quality for SAV is ranked as the lowest of the methods described, no other data sets were available with the needed spatial resolution to utilize either of the other two methods. For light attenuation, a large data set, covering a wide variety of locations and dating back many years is available from the Virginia Department of Health, Division of Shellfish Sanitation. Supplemental secchi depth data for this region was also available from Dr. Al Kuo of the Virginia Institute of Marine Science. The combined data set allowed for a first order approximation of light levels in these creek systems with high spatial definition.

Median secchi depth during the SAV growing season, March through November (Batiuk et al,, 1992), was then calculated, geographically plotted, and interpolated. Based on the observation that secchi depth decreased upriver, the secchi depths at the observed upriver SAV growth limits were used as the secchi depth limits for predicting SAV occurrence. Since the SAV limits were at slightly different secchi depths in the two creek systems, the two limits were used as the limits for "a moderate probability of supporting SAV" and "a high probability of supporting SAV."

Data pertaining to the other factors in question, depth and exposure, were also entered into the GIS (Table 2). Since clam aquaculture is restricted by the harvest techniques employed to the one meter MLW or less, and most SAV in the region grows within this same depth range (Orth and Moore, 1988), this model was designed to predict SAV at one meter or less, MLW. Areas with good or moderate light levels within the one meter interval were designated as follows (Table 5).

3.4 Validation - SAV Model I:

To validate this model, the developed criteria was applied to Back River and the Poquoson River creek systems (Table 2). The percent of actual SAV within and outside of the predicted SAV habitat was then compared between the 4 systems.

3.5 Approach - SAV Model II:

Since the objective of this project was not only to develop a model with best possible accuracy and precision, but to develop a model which can be used by managers with minimal expense and readily available data, SAV model II was actually a new SAV model that was more simplistic than the original model. Based on the observation that SAV grows best where it already exists and is most likely to expand in areas immediately adjacent to existing beds (Moore, pers. com.), the impact of using only SAV geographic data sets (e.g. Orth et al., 1999) to predict SAV habitat was tested.

A regulation based on this theory might set aside existing SAV beds and a buffer zone of a set size around existing beds as being off limit to clam production for one year at which point, SAV distribution would be reevaluated. This would be similar to the existing policy for protecting SAV beds and a 200 meter buffer around SAV beds from clam dredging within the Commonwealth (Regulation: 4 VAC 20-1010-10).

3.6 Study Sites - SAV Model II:

SAV model II was created using SAV distribution data from the Cherrystone and Hungars Creek systems on the lower eastern shore of the Chesapeake Bay (Orth et al.). Validation of this model was accomplished by comparing predicted distributions of SAV in Back River and the Poquoson River to the actual mapped distributions in a manner similar to SAV model I validation.

3.7 Analysis - SAV Model II:

To test the hypothesis that the use of existing SAV beds perimeters plus a fixed buffer would provide a useful prediction of SAV distribution during the next growing season, buffer zones of 50, 100, 150, and 200 meters were developed for each SAV bed mapped in the Cherrystone and Hungars creek systems from the early 1980's to the late 1990's. These various buffer sizes were tested by comparing them against actual SAV distribution in that same area during the following year (Figure 4, Table 6). A 50 meter buffer was then selected as a result of this analysis and used to predict SAV growth in the Eastern Shore study areas. Areas within these SAV and 50 meter buffer zones were predicted to have a high and moderately high probability of supporting SAV the following year.

3.8 Validation - SAV Model II:

This model was validated by comparing the 1997 SAV bed and 50 meter buffer locations Back River and Poquoson River with the 1998 distribution of beds in the same location (Table 2). Error was defined as the amount of SAV area which lay outside of the predicted zones and the amount of predicted SAV zone which was not occupied by SAV the following year.

4.0 Development of Potential Bottom Allocation Conflict Models

4.1 Approach:

Reasoning that habitat suitable for both clam aquaculture and SAV would possess the potential for resource use conflict, the clam aquaculture and SAV model were combined to create a conflict data set.

4.2 Study Sites:

Cherrystone and Hungars Creek Systems were used to create the conflict models (Table 2).

4.3 Analysis:

The hard clam model I and SAV model I predicted distributions were overlaid using GIS to predict degrees of overlap and therefore degrees of conflict (Table 7). Similarly, SAV model II and clam model II predicted distributions as well as SAV model II and clam model III predicted distributions were combined to create conflict models II and III, respectively (Table

2).

The conflict categories of high, moderately high, moderately low, and low are rankings and do not possess a numerical value. Instead, they are used simply as a tool to assist managers who wish to strive for minimum conflict between resource users. In this case, areas of low conflict are areas which this model predicts will likely be mutually exclusive for either SAV, clam aquaculture, or both. Areas ranked as a moderate or high degree of conflict are areas with a greater probability of being capable of supporting both SAV and clam aquaculture (although not concurrently). In these areas managers should expect a greater chance of resource competition occurring. These are the areas where management may need to be the most active to avoid user conflict.

4.4 Validation:

The accuracy and precision of these models is dependant upon the accuracy and precision of the hard clam and SAV models. No validation is possible (Table 2) without additional data such as clam beds moved by regulatory oversight from encroaching SAV beds.

Objective C: Examination of Policy and Regulation Concerning Aquaculture in Virginia and Neighboring States

A review was conducted of the policies and regulations regarding clam aquaculture, SAV, and bottom leasing structure in Virginia and the neighboring states of Maryland and North Carolina. A review of similar policies in Florida which has a well developed clam aquaculture industry was also attempted. Unfortunately, Florida's bottom land management structure was in the midst of major reorganization at the time of this writing. The study performed was completed by reviewing the written regulations of Virginia, Maryland, and North Carolina and interviewing state shellfish managers. The results provide regulatory and policy background for this study as well as insight as to how three different states currently manage this problem.

Objective D: Synthesis and application of material to policy and regulation

Policy and regulatory suggestions for managers were generated based on the historical data, scientific models, and policy information developed in this study. These suggestions incorporate the annual application of the developed SAV habitat model, and constitute tools that may minimize conflict in these areas.

RESULTS

1.0 Historic Trends in Hard Clam Aquaculture and SAV Distribution

Active clam aquaculture, depicted by algal fouled nets, was first documented in aerial photography in the Cherrystone Creek System in 1989 (1988 data was not available). It was later documented in the Hungars Creek System. Clam aquaculture in this entire region continuously increased from 1989 through 1994 with a decrease in 1995. A continuous increase was present from 1995 through 1997 (Figure 5).

Analysis of the Cherrystone area SAV coverage shows SAV generally increasing from 1989 to 1994 with a sharp decline in 1995. SAV area then rebounds between 1995 and 1998 (Figure 5). SAV in nearby creeks follows a similar pattern but with a sharp decline in 1994 (Figure 6).

While visual inspection of trends might suggest a relationship between SAV and clam area over time (Figure 7), multiple regression analysis indicates that this is not a significant relationship ($P=0.061$, adj $r^2= 54\%$). A relationship between SAV in Cherrystone and SAV in surrounding creek systems is significant ($P=0.023$, Table 8, Figure 8). Initial analysis of the data also notes 1994 as an outlying data point when a general decrease in SAV is noted but clam aquaculture continues to increase. Removal of this point yields a significant relationship for near-by SAV ($P=0.001$) and but not for clams ($P=0.027$) with Cherrystone SAV and a higher adjusted r^2 value (86%).

2.0 Clam Aquaculture Models

2.1 Clam Aquaculture Model I

Hard clam aquaculture model I predicted 4,218,606 square meters of good clam aquaculture area and 963,065 square meters of moderate clam aquaculture area in the creeks studied (Table 9). Hard bottom areas of a depth 1 meter or less, as predicted from aerial photographs, occurred along the shorelines of the creeks. Sediment had the highest sand content near the mouths of the creeks (Figure 9). Exposure (Figure 10) was designated as lowest in the middle and upper portions of the creeks. Moderate exposure areas were designated behind offshore sandbars and near creek mouths. High exposure areas were designated outside of the creeks in areas without shoreline or sandbar protection. A high exposure area was also designated in the mouth of the Hungars Creek System because of it's lack of protection by sandbars or shoreline from Northwest winds. The completed clam aquaculture suitability model, which incorporated these factors with bathymetry, predicted the best clam aquaculture areas would be along the shorelines in the middle and upper portions of the creeks. The widest areas suitable for clam aquaculture were in the middle portions of the creeks. Moderate clam aquaculture areas were located near the mouths of the creeks where they received protection only from offshore sandbars (Figure 11).

Clam aquaculture model I matches up fairly well with the actual locations of clam aquaculture sites. Of the 306,218 square meters of clam aquaculture sites, 219,158 square meters were located in areas ranked as "good clam habitat" and 31,482 square meters were located in areas ranked as moderately suitable. Only 55,578 square meters of clam beds were located in areas depicted as not suitable. While 95% of area ranked as suitable clam habitat was not being used for clam aquaculture, only 18% of clam beds were not located in area ranked as suitable for hard clam aquaculture (Table 9, Figure 11).

2.2 Clam Aquaculture Model II

The quantitative study of "hard" and "soft" classifications showed a fairly distinct difference in penetration values between hard and soft sediments. "Hard" sediments had no penetration values greater than 2 inches. Hard sediments generally possessed a higher sand content (median = 92%) than did soft sediments (median = 72%, Table 10).

Hard clam aquaculture model II predicted 3,567,575 square meters of good clam aquaculture area and 1,217,746 square meters of moderate clam aquaculture area in the creeks studied (Table 11). Depiction of sandy areas 1 meter or less in depth was refined with ground-truth data with most of the corrections occurring near the heads of creeks (Figure 12). As in model I, moderate exposure areas were designated behind offshore sandbars and near creek mouths while high exposure areas were designated outside of the creeks in areas without shoreline or sandbar protection. Unlike model I, on model II moderate to high exposure areas were sometimes designated on the southeastern shore on the wider creeks (Figure 13). The refined clam aquaculture suitability model, which incorporated these factors with bathymetry, predicted the best clam aquaculture areas would be along the shorelines in the middle and upper portions of the creeks, especially along the north western shorelines (Figure 14).

The clam aquaculture model II does not match up well with the actual locations of clam aquaculture sites. Of the 306,359 square meters of clam aquaculture sites, 83,752, or 27%, were located in areas ranked as good clam habitat and 64,403, or 21%, were located in areas ranked as moderate clam habitat. As much as 158,204 square meters, or 52% of clam aquaculture sites, were located in areas labeled as not suitable to support clams. Ninety seven percent of the area ranked as suitable for clam aquaculture was not being used for such (Figure 14, Table 11).

2.3 Clam Aquaculture Model III

Hard clam aquaculture model III predicted 4,090,743 square meters of good clam aquaculture area and 926,361 square meters of moderate clam aquaculture area in the creeks studied (Table 12). Clam aquaculture suitability model III, predicted the best clam aquaculture areas would be along the shorelines in the middle and upper portions of the creeks (Figure 15).

The clam aquaculture model III matches up fairly well with the actual locations of clam aquaculture sites. Of the 306,374 square meters of clam aquaculture sites, 213,813, or 70%, were located in areas ranked as good clam habitat and 31,541, or 10%, were located in areas ranked as moderate clam habitat. About 61,020 square meters, or 20% of clam aquaculture sites, were located in areas labeled as not suitable to support clams. Ninety seven percent of the area ranked as suitable for clam aquaculture was not being used for such (Figure 15, Table 12).

3.0 SAV Models

3.1 SAV Model I

The SAV model I predicted 1,837,337 square meters of good SAV area and 6,256,892 square meters of moderate SAV area in the Eastern Shore creeks studied (Table 13). Light levels were highest at the mouths of the creeks/rivers and decreased towards the heads of the creeks/rivers (Figure 16). The same exposure model was used for SAV model I as was used for the clam aquaculture model I (Figure 10). The completed SAV model I, which incorporated these factors with bathymetry, predicted the best SAV areas would be located in the shallow areas near the mouths of Hungars Creek, Mattawoman Creek and the Gulf. Moderate SAV areas would be located in the upper portions of Hungars Creek, Mattawoman Creek, and the Gulf as well the lower portion of Cherrystone Creek and all of Kings Creek (Figure 17).

SAV model I was validated with small Western Shore tributaries, Back River and Poquoson River (Figure 1). Calculations could not be performed on certain small areas of the western shore rivers due to a lack of data in those areas. The validation model predicted 3,134,087 square meters of good SAV area and 10,090,749 square meters of moderate SAV habitat. The model for the occurrence of SAV was not robust in its ability to predict SAV in its actual locations. Of the 6,321,735 square meters of SAV in these rivers, only 1,164,663 square meters, or 18%, were located in areas ranked as good SAV habitat and only 2,860,247 square meters, or 45%, were located in areas ranked as moderate SAV habitat. Analysis showed 14,838 square meters, 0.2%, of SAV located in areas with no data. Further, 2,281,987 square meters of SAV, or 36% of SAV, were located in areas depicted as not suitable SAV habitat. As much as 1,969,424 square meters, or 63% of area ranked as good SAV habitat, was not being occupied by SAV and 8,311,719 square meters, or 82% of area ranked as moderate SAV habitat, was not occupied by SAV (Table 14, Figure 18).

3.2 SAV Model II

The results of the one year study of different SAV buffer sizes indicated that 50 meters was an appropriate buffer size which would maximize SAV protection while minimizing the amount of bottom land set as off limits to clam operations which does not actually support SAV within one year. An additional, using the same methods as the study of the annual buffer but for a two year period, also supported the 50 meter buffer.

SAV model II, which used the 50 meter buffer, showed 3,869,793 square meters of good SAV habitat and 1,548,086 square meters of moderate SAV habitat in the Eastern Shore creeks studied (Table 15). Most SAV and buffer areas were located towards the mouths of the creeks/rivers (Figure 19).

SAV model II was validated by comparing predicted SAV distribution with the actual SAV distribution in Back River and Poquoson River. The model predicted 6,150,399 square meters of good SAV habitat and 2,490,906 square meters of moderate SAV habitat. SAV predictions in these validation areas match up well with the actual locations of SAV. Of the 5,321,293 square meters of SAV in these rivers, 5,145,843 square meters, or 97%, were located in areas ranked as good SAV habitat and 169,242 square meters, or 3%, were located in areas ranked as moderately suitable. Only 6,207 square meters of SAV, or 0.12% of SAV, was located in areas depicted as not suitable. Analysis showed 1,004,556 square meters, or 16% of area ranked as good SAV habitat, was not being occupied by SAV and 2,321,664 square meters, or 93% of area ranked as moderate SAV habitat, was not occupied by SAV (Table 16, Figure 20).

4.0 Conflict Models

4.1 Conflict model I

Conflict model I predicted 1,077,637 square meters of high conflict area, 1,596,036 square meters of moderately high conflict area, and 955,243 square meters of moderately low conflict area. The model also predicted that 4,349,679 square meters will support SAV only and that 1,437,323 square meters will support clam aquaculture only (Table 17). High conflict areas were located in the lower portions of Hungar Creek, Mattawoman Creek, and the Gulf. Moderately high and moderately low conflict areas were located near the mouths and mid sections of all of the creeks. Areas which only supported clam aquaculture were located in the upper portions of the Cherrystone along the shoreline. Areas which only supported SAV were located in the upper portions of all creeks except Cherrystone Creek (Figure 21).

4.2 Conflict model II

Conflict model II predicted 1,372,411 square meters of high conflict area, 1,276,210 square meters of moderately high conflict area, and 113,320 square meters of moderately low conflict area. The model predicted 2,678,732 square meters which would support only SAV, and 1,872,619 square meters would support only clam aquaculture (Table 18). High and moderate conflict regions were located in the lower portions of the creeks near the shorelines. Areas which only supported clam aquaculture were located in the upper portions of creeks along the shorelines. Areas which only supported SAV were located predominantly in the lower portions of creeks in scattered pockets where high exposure had been predicted which excluded clam operations. (Figure 22)

4.3 Conflict model III

Conflict model III predicted 820,520 square meters of high conflict area, 1,249,240 square meters of moderately high conflict area, and 88,930 square meters of moderately low conflict area. The model predicted 2,474,526 square meters which would support only SAV, and 2,027,460 square meters would support only clam aquaculture (Table 19). High and moderate conflict regions were located in the lower portions of the creeks in the shallow areas. Areas which only supported clam aquaculture were located in the upper portions of creeks along the shorelines. Areas which only supported SAV were located predominantly in the lower portions of creeks in areas too deep for clam aquaculture. The area at the confluence of Hungars and Mattawoman creeks also supported a large area of exclusive SAV habitat (Figure 23). Approximately 43, 400 square meters or 14% of clam beds were located in the area of potential SAV growth. Approximately 500,000 square meters or 20% of potential currently available "good' clam grounds were located in the potential SAV area .

5.0 Summary of Policy and Regulation Concerning Aquaculture in Virginia and Neighboring States

(Please see Appendix 1 for more complete review.)

The study of Virginia's management program and that of neighboring states shows similarities and differences. The greatest similarity is that all of the states express concern for the protection of SAV but have a fairly reactive approach to SAV management. This is evident in that none of these states have laws protecting potential SAV habitat from aquaculture. Instead, their laws protect only existing SAV and SAV that has grown into an aquaculture site (although Virginia does protect a 200 meter buffer of area around SAV beds from commercial clam dredging). The states differ in the depth of their laws concerning SAV and aquaculture. In all states, the Army Corp of Engineers may regulate on bottom structures such as aquaculture nets, but they too offer a reactive management approach to this situation

The Commonwealth of Virginia has a subaqueous bottom leasing system which is very favorable to the continued development of commercial clam aquaculture in environmentally suitable areas such as the lower Chesapeake and coastal bays. The Virginia system allows for the leasing by both individuals and corporations of nearly all bottom which does not fall within the Baylor oyster ground surveys. A person may lease up to 5,000 acres in the Chesapeake Bay or 3,000 in one of the tributaries. With permits, leasee may use a wide variety of bottom and water column structures to assist with clam production. While Virginia aquaculture regulations protect existing SAV beds, they are favorable for the aquaculturist in that they do not provide for the expansion or movement of existing beds into aquaculture areas.

Many of North Carolina's aquaculture regulations are more restrictive than those of Virginia. In North Carolina, only individuals may lease bottom. The individual must also go through a fairly lengthy and expensive surveying and permitting process to lease a given area and keep that area posted. Specific SAV regulations regarding aquaculture in NC do not exist but permit applications may be denied if an applicant does not develop a management plan which will not harm existing SAV.

Maryland has not yet developed a clam aquaculture policy. This is in large part due to restrictive aquaculture laws designed to prohibit oyster aquaculture and therefore, theoretically, protect the public oyster fishery by allowing harvesting on almost all bottom. In part it is also due to the lack of suitable areas in MD for hard clam aquaculture as only Maryland's coastal bays are of high enough salinity to support hard clam aquaculture. Historically, Maryland's state-wide estuarine management policies were designed exclusively with Chesapeake Bay management in mind. Only recent continuing efforts have begun to separate Chesapeake Bay and coastal bay management issues in Maryland. Additionally, as of this writing, proposals are being put forth in Maryland to completely ban hydraulic harvesting of clams and possibly train commercial clammers to take up aquaculture. (Currently hydraulic clamming is only banned in existing SAV beds). Whether or not this happens, it is probable that with a lack of guiding policy in this area, Maryland may see use conflict issues arising in the coastal bays where SAV often grows abundantly, leasing is not restricted, and salinities are great enough to support a clam aquaculture industry.

In all of these states, the Army Corp of Engineers may regulate on bottom structures such as the nets used for clam aquaculture. The Corp is currently the acting management agency in Virginia because their regulations are more strict than those of Virginia. The Corp's regulations affect clam beds which are planted on barren bottom and later invaded by SAV. In such cases, the Corp may work with aquaculturists to move the individual clam beds which are most inundated by SAV.

DISCUSSION

Historic Trends Study

SAV trends in the Cherrystone Creek System indicate the fluctuating nature of SAV. This, coupled with the nearly continuous increase in clam aquaculture, points to the conflict which has arisen when aquaculture has expanded into areas where SAV has only temporarily diminished. Fluctuations in SAV in Cherrystone tend to mirror those of the SAV in near by creeks and, to a lesser degree, those of the clam areas. This is reflected in the statistical analysis which indicates a stronger relation between the two regions of SAV than between the Cherrystone SAV and clams however, the strong influence of the outlying data point suggests that sample size is too low to draw conclusions in this matter.

One difficulty of this study was determining the true nature of each clam bed. Not only was is sometimes difficult to tell if a clam bed was currently active, but it was impossible to determine the number or size of clams in a given bed. This made it impossible to quantify the filtering capacity or other impact of a clam bed. It was therefore assumed that all clam beds of equal size were approximately equal in their potential effects upon surrounding SAV.

This study examined this issue on a fairly large scale which may have biased it towards SAV. If clam aquaculture does influence SAV growth, the effects may be only in beds immediately adjacent to clam areas. Since this study examined SAV and clam beds in the creek as a whole, such site specific influences may not have been detectable at this scale.

Habitat and Conflict Models

Clam Models

Clam model I matched actual locations of clam beds fairly well (Table 9, Figure 11). Overall, only 18% of clam beds were not located in clam habitat. Since not all suitable clam areas have been exploited at the time of this study, it is impossible to tell if the model is overly liberal in predicting clam areas. The major downfall of this was the subjective nature of the incorporated exposure model. While based roughly upon the location of sandbars and land masses, it was very subjective in nature and relied heavily upon the professional judgment of the person creating it. Therefore, the primary change later made to clam model I was the incorporation of a quantitative, reproducible exposure model.

The clam model II did not match the actual locations of clams nearly as well as the original model. In fact, the clam model II did a very poor job in predicting appropriate locations for clam aquaculture and 52% of clam beds were located outside of areas deemed acceptable for such. While both the bottom substrate and exposure coverages were changed during the refinement of this model, a visual examination of the data (Figures 12, 13, and 14) shows that the loss of model accuracy can be assigned almost entirely to the change in the exposure coverage as nearly all of the clam beds fall within an area designated for hard bottom on the refined model.

Clam model III was created with the best components of clam models I and II, included the measured bottom hardness and estimated wave exposure. It matched the actual locations of clam aquaculture fairly well and with approximately the same accuracy as clam model I. While the size and location of some of the clam habitat did vary from clam model I, nearly all of the same clam beds were included in the clam habitat of clam model III as were included in the clam area in clam model I.

The exposure model component of the clam models and SAV model I was perhaps the most difficult part of this project. While the original exposure model component yielded better results when incorporated into model I, it lacked a quantifiable, reproducible method of the refined model. The second exposure model component succeeded in this respect, by incorporating fetch and energy attenuation by structures such as land masses and sand bars in a reproducible manner. Unfortunately, the results, measured through the results of the clam model II, did not reflect actual conditions.

The final exposure model should continue to be refined if it is to reflect actual exposure in a given location. Five ways in which this model might be refined include:

1. Exposure direction: Both the original and refined clam models were designed to only examine exposure to north west winds since local clam aquaculturists had suggested that these were the winds which typically wreaked havoc with their beds. Future models should explore exposure from other directions, especially in different locations such as creeks which open in different directions.

2. SAV presence: Aquaculturists suggested that SAV actually protects their beds from exposure damage. Future models may benefit from incorporation of SAV as a wave attenuation factor such as sandbars.

3. Fetch: An arbitrary fetch limit of 1 km was set for the first trial of the refined exposure model. The results of this model suggest that a greater fetch limit may need to be set to provide greater model accuracy. Areas with little to no protection from northwest winds within 1 km still supported clam aquaculture. This suggests that, land/sandbars were close enough to the clam sites to provide adequate protection for these clam beds.

4. Bathymetry Data: Several mathematical models exist to calculate wave energy but all depend upon accurate and precise bathymetry data which was not available for this project. By including such data, this model could be greatly refined.

5. Grid cell size: A smaller grid cell size would enhance the resolution of the exposure model.

While qualitative and subjective in nature, the refined bottom substrate sampling method which categorized bottom sediments into discrete categories of "hard" and "soft" worked well for this project. The resulting bottom hardness coverages which reflected actual clam beds locations and encompassed 99% of clam beds in the "hard" areas. The penetration measurements and grain size analysis reflected the quality of this simple approach in that nearly all "hard" measurements had a low penetration (0-2in) and high sand concentration (median = 92%) while nearly all "soft" measurements had a high penetration (2.5-12in) and low sand concentration (median = 72%).

It should also be noted that results of the refined bottom substrate coverages showed the original method (digitizing from aerial photos) to be most accurate in the sandy areas towards the mouths of the creeks and least accurate in the more muddy areas towards the heads of the creeks. This may reflect the color of the sediments and hence their visibility on aerial photographs.

It could be argued that all of the clam models should also include the factors of lease availability and health closures. Lease availability was not included because it depends on a multitude of factors ranging from owner willingness to transfer a lease to lease inundation with SAV. Health closures were not included since they change regularly, often seasonally, and it might be possible for an enterprising aquaculturist use a closed area if he were willing to depurate his shellfish.

SAV Models

SAV model I had many limitations to it, the greatest of which being data availability. While much has been written about predicting SAV habitat using water quality measurements, all methods assume the availability of appropriate data and the ability of metrics based on average or median measurements to adequately predict SAV responses. The methods presumed to be the most accurate (as reflected in TS1 and TS2) require the greatest amount of water quality data. In the case of this model, it was impossible to use most of these methods due to incomplete data availability in this area. The only usable method which employed water quality was interpolation of light penetration using secchi depth. This posed numerous sources of error, since secchi depth may be influenced by short term events such as rain storms, or may be specific to a very isolated portion of the creek. Additionally, the conversion of secchi depth values to light penetration values (Kd) is an imprecise one. Indeed, if interpolated secchi depth conversions are used with the light requirement values suggested in TS1, the results suggest that SAV should be able to grow in all areas of the study creeks! This is obviously not the case since SAV grows only up half the length of these creeks. Additionally, the secchi data suggests that SAV grows in more turbid waters in the Cherrystone creek system than in the Hungars creeks system. The secchi depth at the maximum depth of SAV in these creeks was used because of this to determine the light requirements of SAV for this model, with the lesser depth (at the upper extent of SAV in Cherrystone Creek) being the value considered for the limit of moderate SAV habitat and the greater depth (at the upper extent of SAV in Hungars and Mattawoman Creeks) being considered the limit for good SAV habitat.

The other major component of the SAV model was the exposure model. This was the same model that was used for exposure in the clam aquaculture model and faced the same challenges.

These limitations likely contributed to the inability of this model to accurately predict SAV habitat. The model validation using the Western Shore tributaries showed that a large amount of SAV (36%) grew outside of the areas which the model predicted were good SAV habitat and much of the area it suggested should support SAV (78%) did not.

It should also be noted that SAV model I also did not include temperature or seed dispersal limitations, which may be important factors limiting SAV distribution.

SAV model II did a much better job in predicting SAV habitat than SAV model I.

Less than 1% of the SAV grew outside of the area which the model predicted would support SAV. Like the original model, 38% of the area the model suggested would support SAV did not. In some ways this may be misleading if one is contemplating using these boundaries for aquaculture management. Since the first SAV model used bathymetry and predicted SAV areas only in 1 meter of water or less, the 38% of unvegetated SAV habitat was located in areas shallow enough for clam aquaculture. The second model did not take bathymetry into account, so much of the 38% of unvegetated SAV area is likely located in areas of water too deep to support clam aquaculture. Therefore, should the SAV habitat boundaries be used for clam aquaculture management, the second SAV model would have much less management impact on aquaculturists than the first model. Overall, SAV model II was a superior predictor of SAV habitat to SAV model I.

This is advantageous for management purposes since SAV model II requires only one data set, the SAV distribution data set, which is readily available in the Chesapeake Bay and many other locations. Should the "moderate" and "high" SAV boundaries be used to specially manage operations in certain locations, it would be easier for enforcement officials to mark off areas since they could simply measure a 50 meter distance from the perimeter of the SAV beds each year.

Conflict Models

It is impossible to measure conflict and therefore impossible to test the accuracy of the conflict models. It is reasonable to assume that their accuracy is directly dependent upon the accuracy of the clam and SAV components. It is reasonable to assume limited accuracy of the conflict models because of the deficiencies of some of the habitat models. None the less, the conflict models can provide some interesting insight into the potential conflict between SAV and clam aquaculture in the regions studied. The component models of conflict model III were believed to be the most accurate. Therefore, conflict model III will be considered the final conflict model and will be discussed.

In the Hungars Creek system, the areas of highest conflict were located the mid to lower sections of Mattawoman and Hungars Creeks, while areas below this were considered exclusive SAV habitat and areas above this were considered exclusive clam habitat. This is much the same in Cherrystone and Kings Creeks except that in these creeks, conflict areas extended to the mouths of the creeks with very limited areas exclusive to SAV. It was a series of photographs from this same area showing SAV invading clam beds which brought about this study.

The similarity in habitat requirements for SAV and clam aquaculture, likely have lead to the large areas of conflict depicted by this model in the mid and lower sections of these creeks. Clam aquaculture requires shallow water for clam aquaculturists to work in while SAV is dependant upon a large amount of light which is found in the shallows. Clam aquaculture requires hard bottom for clam aquaculturists to walk on. This hard bottom is generally located at the mouths of creeks, favored by SAV because of better light penetration. Both SAV and clam aquaculture require fairly low energy environments.

Areas exclusive to clam aquaculture are generally areas of hard bottom located in the upper portions of creeks. It should be noted that these may not be the optimal locations for clam aquaculture. Personal observation showed that even hard sediments in the upper portions of the creeks contained more mud and organic content than those at the mouths of the creeks. While there is little research on what affects this might have on cultured clam growth, anecdotal evidence suggests this may impair aquaculture operations. It should also be noted, that in years with particularly favorable environmental conditions, SAV could expand into some of these areas.

Some of the areas predicted as exclusive SAV habitat were those that were too deep to support clam aquaculture. It should be noted that these areas may be marginal for SAV growth and could possibly support clam aquaculture under certain conditions. The deep areas predicted as exclusive SAV habitat may only be suitable for SAV growth during years of particularly good water quality. Additionally, a change in aquaculture gear could allow aquaculture to expand into deeper waters.

Other exclusive SAV habitat areas were those that had too much exposure to support clam aquaculture. These areas are likely marginal for SAV since SAV cannot tolerate extremely high energy environments. There is also the possibility that these areas were incorrectly designated for exposure and could possibly support clam aquaculture as well as SAV. SAV and some clam aquaculture is present in many of these areas supporting this possibility.

Policy and Management Implications

While the Commonwealth of Virginia currently implements a reactive management strategy for aquaculture and SAV bottom use conflict issues and relying heavily on the Army Corp of Engineers to actually manage the situation, it should be applauded for establishing a system which both supports the development of aquaculture and for wishing to better address these conflict issues before they become problematic. Neither of Virginia's neighbors, North Carolina nor Maryland, have succeeded in either of these aspects to the extent which Virginia has. Maryland's regulations have stifled the development of aquaculture in most areas. In the few areas in which Maryland may see the development of aquaculture and even greater use conflict than Virginia, Maryland has neglected to address these issues. While North Carolina permits private aquaculture, its regulations limit the large scale development of this practice. Like Maryland, it too has not fully addressed use conflict issues.

Maryland and Virginia have both partially addressed use conflict issues regarding SAV and commercial clam dredging on public bottom. Here too Virginia leads the way in pro-active policy in that Virginia not only protects existing beds but a 200 meter buffer around those beds in Chincoteague Bay. While Virginia may have written this regulation to keep watermen from accidentally straying into SAV beds, it also effectively allows for the spread of SAV beds by protecting adjacent habitat.

Many other lessons have been learned from this project with direct implications for Virginia's estuarine policy and management of subaqueous bottom lands. One of the primary findings of this process with direct management implications is that several of the key habitat requirement features are shared by both SAV and clam aquaculture. These features include a low energy (exposure) environment in shallow water 1m or less for clam tending and shallow enough for light penetration for SAV (up to about 1.5 m in Eastern Shore areas studied). It should also be noted that, while not included in these models, several studies have suggested that at least eelgrass and possibly other SAVs prefer a sandy bottom substrate over a muddy, organic rich substrate. This would of course would be the same area preferred by aquaculturists for its firmness. It is therefore reasonable to predict that conflict will continue to arise between clam aquaculture and SAV if a new pro-active management strategy is not employed.

Recommendations

The development of these models has shown that it is far better to develop an SAV management and protection strategy based upon the current distribution and potential spreading of existing SAV beds than to use water quality parameters. While water quality methods fall short in several respects including both the difficulty in obtaining the required data sets and the accuracy of predictions based upon the data, the protection model based on SAV distribution data was very promising. The above models showed that most SAV for a given year will be growing within 50 meters of SAV from the previous year. A management strategy based upon the idea of protecting existing beds and allowing for bed to spread within 50 meters of the bed perimeter would protect existing SAV and most future SAV while being fairly simple to implement.

Therefore, it is the recommendation of the author that a 50 meter buffer area be delineated around existing SAV beds on an annual basis and designated as a special management zone. Within this area aquaculturists would be either prohibited from placing aquaculture structures or permitted to plant only under special permit with understanding that should SAV spread towards or into their aquaculture site that the aquaculturists would be required to relocate their clams sites immediately. Beds placed outside of this buffer would not have to be moved, even if invaded by SAV, until the end of the clam grow out cycle. This approach would provide a means of adaptive management that would take into account any major long term changes to SAV distribution while minimizing area set aside from aquaculture operations. It would be similar to the management strategy now employed by the Army Corp of Engineers which annually evaluates and requires relocation of certain clam beds, except that this method would not require clam beds to be moved if they were placed outside of the 50 meter buffer. If such management regulations were written to include all forms and methods of aquaculture, it would not only address clam aquaculture concerns, but other concerns which might be raised by a resurgence of oyster culture or the development of aquaculture techniques for other species.

A 50 meter buffer would have an impact on clam aquaculture operations. If such a buffer were enacted today, approximately 12% of current clam operations would be affected. The models predict that about 20% of the best clam aquaculture area which is currently available for use would be affected by such a buffer around SAV. This would still leave approximately 1,940,000 square meters of the best clam aquaculture area outside of the 50 meter SAV buffer for use by clam aquaculturists in the Cherrystone and Hungars Creek systems.

Using the Conflict Model

Should a manager wish to use the developed models to assess potential conflict between hard clam aquaculture and SAV, conflict model III is the recommended model. To use this model a manager would need salinity data, shallow water bathymetry (1m at MLW), bottom hardness data, an estimate of wave exposure strength at the study site, and geographic data showing the location and extent of SAV beds. Salinity, bathymetry, and bottom hardness data would be combined to create the clam aquaculture suitability model. Any area with average salinities below 25psu (this may need to be adjusted slightly lower), soft sediments, or greater than 1 meter deep at MLW would be considered poor clam aquaculture area. Of the remaining areas, those with high wave exposure would be considered poor, while those with moderate or low wave exposure would be considered moderately or highly suitable for clam aquaculture, respectively.

An SAV suitability model would be created using a geographic polygon data set of the location and extent of SAV beds. A 50 meter buffer would be drawn around the SAV polygons with the original SAV beds being designated as highly suitable and the buffer as moderately suitable areas for SAV to grow within one year.

These two models would be combined and labeled as listed in Table 7. The resulting model will provide an estimate of bottom use conflict in the study area.

Other Issues

The purpose of this study was to look at the potential conflict between clam aquaculture operations and SAV. Several things have become obvious from this study. First, while clam aquaculture operations are fairly small at this time, they are likely to expand as there is a good deal of unexploited habitat suitable for clam aquaculture. Second, when they do expand, aquaculturists who are not currently near SAV areas will likely desire conditions which are available in many areas suitable for SAV growth. Third, anthropogenic land use may make the above concern a moot issue.

The Virginia Eastern Shore is poised on the brink of major land use changes. What has been traditionally an economically depressed agricultural area, is being discovered by retirees looking for a quiet homestead. There has been much talk about removing or reducing the toll on the bridge tunnel which separates the Virginia Eastern Shore from the cities of Norfolk and Virginia beach. Should this happen, the Virginia Eastern Shore would likely become a suburb of these two cities. Many favor this change, citing the potential for economic revitalization of the Eastern Shore. For both of these reasons, land on the Eastern Shore is being purchased by developers and subdivided for development at a rapid rate. Should this explosive development occur, the potential exists for the loss of both SAV beds and the clam aquaculture industry.

Development of the surrounding land for housing, marinas, golf courses, and other uses could bring about increased water pollution and consequently the loss of available aquaculture areas and SAV beds. Already, several parts of the study site, including parts of Hungars

Creek, Mattawoman Creek , and Kings Creek, and the entirety of The Gulf (an area designated as excellent clam habitat which already supports a clam hatchery) are closed off for clam aquaculture because of water quality concerns. Sprawl development of the shoreline areas, using septic systems which leach nutrients into sandy soil, well manicured and fertilized golf courses likely attracting resident geese, sources of nutrients and fecal coliforms, and additional marinas, a source of heavy metals, hydro carbons, and other toxins, would surely close off more areas to clam aquaculture and harm the growth of SAV beds. It is entirely possible that the greatest threats to SAV and clam aquaculture on the Eastern Shore of Virginia, are not each other, but unmanaged growth and development of the surrounding lands.

Another area of conflict not addressed by this study which will likely arise in Virginia as the population increases is that of conflict between aquaculturists and recreational users. While leases in Virginia are not supposed to exclude the public from swimming fishing, crabbing and other uses, many aquaculturists have posted their leases with "KEEP OUT" and "NO TRESPASSING" signs and actively chase people off of their shellfish areas. At least one Virginian has gone so far as to place a fence around his lease. As many of these coastal areas become popular recreational areas, and coastal properties are developed for expensive housing, it is likely that aquaculturists will come into conflict with people who wish to recreate in shallow waters or simply enjoy a waterfront view free of PVC pipes, signs, and fences. Should Maryland's current proposal to train coastal bay hydraulic clammers as aquaculturists become reality, Virginia may be able to learn from example as Maryland attempts to deal with this issue in this heavily used recreational area.

APPENDIX 1

1.0 Introduction: Examination of Policy and Regulation Concerning Aquaculture in Virginia and Neighboring States

The current quandary of the Commonwealth of Virginia in regard to the management of subaqueous bottom for both hard clams and SAV has developed in part from the inadequacies of the state bottom land leasing system to properly manage these resources. This, in fact, is of little surprise when one considers that the system was developed to manage oyster bottom and simply adapted for use with hard clams and that this system was developed many years before the protection of SAV was a concern. What follows is a summary of the leasing structure of Virginia and pertinent regulations of the Army Corp of Engineers which affects lease holders in the Commonwealth. Information about the leasing structures of the neighboring states of Maryland and North Carolina is also included for comparison.

2.0 Army Corp of Engineers

The Army Corp of Engineers regulates aquaculture placed on bottom or suspended in the water column of navigable U.S. waters. Permits are required for aquaculture activities which involve structures that may impede navigation. Traditional structures such as shell mounds are exempt. A general permit requires that aquaculture activity does not occur within beds of SAV. Should SAV encroach upon an aquaculture operation, the operation may remain but may not expand into areas colonized by SAV. Aquaculture activities also may not interfere with natural shellfish populations or other invertebrates useful to man, shorebirds, mammals, reptiles, or predatory fish. They must be marked in accordance with U.S. Coast

Guard regulation. The Army Corp of Engineers also prohibits the establishment of new leases in areas designated as a present or future navigation channel. Specific site by site permits are sometimes authorized to those who wish to plant in an SAV bed or extend existing aquaculture into SAV. These permits are authorized on a case by case level and require more scrutiny than a general permit.

3.0 Virginia

3.1 Management Agency

The Commonwealth of Virginia has created the Virginia Marine Resources Commission (VMRC) to oversee matters of concern relating to the management of marine and estuarine resources. The VMRC is comprised of a chairman and eight other members appointed by the Governor. They are to represent "all areas of interest in Virginia marine resources, including commercial, recreational, and environmental interests." The Legislature invested the VMRC with the power to write and enforce regulations involving such resources. The VMRC's power extends from the fall line of all tidal rivers and streams to, and including, the Commonwealth's territorial sea. Additionally, the VMRC's jurisdiction covers all bottom lands within the Commonwealth which may extend beyond these boundaries. The VMRC has power over all commercial fishing, marine fish, marine shellfish, marine organisms, and habitat within these areas. Prior to the creation of the VMRC, the Virginia legislature created all similar regulations as part of the Virginia State Code. The creation of the VMRC allowed a small legislative body with greater expertise than the state legislature in regards to marine resources to more quickly and efficiently respond to the ever-changing management needs of Virginia's marine waters.

3.2 Allocation of Resources

Bottom lands in Virginia are generally classified as public oyster bottom set aside by statute (Baylor Grounds), public oyster grounds set aside by regulation, public clam grounds set aside by statue and regulation, leased bottom, or undesignated bottom. Some small areas of bottom are also classified as part of a "king's grant" granted by the king of England in colonial times in which case the bottom is essentially owned by an individual and state permitting regulations do not apply. In all other cases the Constitution of Virginia applies which states that, "the natural oyster beds, rocks, and shoals in the waters of the Commonwealth shall not be leased, rented, or sold but shall be held be held in trust for the benefit of the people of the Commonwealth..." Further, other beds of the bays, rivers, and creeks, "shall remain the property of the Commonwealth and may be used as a common by all the people of the Commonwealth for the purpose of fishing, fowling, and taking and catching oysters and other shellfish." The majority of these public beds were designated in an 1892 survey and its amendments as Baylor Grounds by the state legislature. Additional public oyster grounds as well as public clam grounds and, previously, public scallop grounds have been set aside by regulation of the VMRC. A few areas outside of the Baylor ground have historically been assigned by the state to resolve conflicts to individuals as easements which act as would a "king's grant" and allow an individual to own bottom.

Virginia has no sanctuary areas nor nursery areas per se, but the VMRC regulates some public bottoms as such. Recently, the VMRC has been constructing reefs which are closed to harvest and act as both nursery and sanctuary areas. Additionally, the majority of Virginia's waters have been closed to harvest for the past several years. The remaining areas have been strictly regulated with certain areas only available for certain practices such as seed or market oyster collection.

The VMRC Commissioner has the right to lease the remaining grounds for, "planting, growing, storing, and harvesting clams, (or other shellfish)" and may "use the same application and assignment forms and procedures for leasing grounds for producing clams as provided for leasing grounds for producing oysters." Other regulations regarding the leasing of bottom for clam culture are also the same as those created for leased oyster bottom. Bottom is leased when an individual or corporation, commissions a survey by the VMRC or private contractor of a site, completes the necessary application procedure, and the lease is approved. Leases may change size and location from leaser to leaser. Currently the water column cannot be leased in Virginia, although it can be used by permit.

Riparian owners may use, without charge, up to one half acre of bottom in front of their property if they own more than 250 feet of waterfront. In North Hampton County they may use up to one fourth of their shore front but must pay rent on any acreage greater than one half acre. If all of the bottom along their riparian area has been leased, the VMRC will try to locate a parcel of bottom nearby. Riparian owners do not have to right to remove current tenants for their own benefit.

3.3 Who May Lease Ground

Any resident of the Commonwealth of Virginia or corporation owned by at least 60% Virginia residents, may lease bottom in Virginia. A resident my not "front" bottom for a resident, but under special circumstances, may employ a nonresident to tend his or her lease. A resident or corporation may employ a resident to tend a lease.

3.4 Rights of Leasers/Owners

VMRC and the state of Virginia have passed several regulations pertaining to shellfish growers. These regulations permit certain activities on leased bottom with minimal or no permitting application. Other activities not yet regulated may be permitted if a permit application is submitted and approved.

In 1989 legislation went into effect which allows shellfish growers to place structure on, and up to 12 inches above, the surface of the bottom as long as the structure is nontoxic, is not placed on existing stands of SAV, and has a minimal adverse effect on navigation. Shellfish grown on leased bottom can be harvested by any means except with a hydraulic dredge which requires an additional permit.

In 1998, legislation went into effect allowing the public to become noncommercial aquaculturists. This legislation allowed individuals to secure floating aquaculture platforms to private piers to grow shellfish for individual consumption. Permits are good for five years and may be extended. Commercial growers who wish to use floating trays must still secure a permit to do so. If the bottom beneath such an area is leased by a different individual, permission must be obtained from that person. Permits will likely be turned down if SAV might potentially be adversely affected by the racks. Additionally, no permit will be issued for waters above Baylor Grounds.

3.5 Responsibilities of Leasers/Owners

Renters of leased bottom in Virginia currently have very few responsibilities. While a "use it or loose it" clause does exist for leased bottoms, areas where oyster disease is present (nearly the entire Commonwealth) are exempt. An abbreviated report stating that the lease was used, must be submitted annually. A full production report must be submitted to the Commonwealth only upon application renewal of the lease which occurs once every 10 years. Lease renewal is determined on a case by case status with productivity of the lease and productivity of surrounding waters considered as factors for renewal. Rent is $1.50 per acre per year. Any structures placed upon the grounds must be maintained or removed.

Leased bottom must be marked when dredging equipment is to be used on the lease. It is also recommended that the lease holder constantly mark it to aid enforcement officials in the protection of private leases.

Leases do not exclude the public from using the above waters for swimming, fishing, or other uses. Crab pots are also permitted on leases except in some shallow water areas of the coastal bays.

3.6 Regulations Regarding SAV

In 1998 the VMRC passed its first regulations directly affecting the management of SAV. One of these regulations created an SAV sanctuary in Chincoteague Bay and thereby banned commercial clam and crab dredging in this area. This sanctuary includes SAV beds and a 200 meter buffer surrounding them. The second, which pertained to the use of structures on the bottom in aquaculture areas, prohibited the placement of these structures on existing beds of SAV. A third regulation, which permitted individuals to attach aquaculture floats to their piers, also stated that SAV could not be adversely impacted by the structure. These regulations, pertaining to wild shell fisheries, aquaculture fisheries, and individuals, set forth a president that the VMRC views SAV as a resource valuable enough to protect in the face of opposition from direct economic interests.

When determining whether or not to permit use of state owned bottom land, the VMRC is directed to take a number of factors into account. One of these concerns is the impact on marine fisheries resources of the Commonwealth. Since SAV beds have been shown to be valuable habitat for the juveniles of many fisheries species, this directive gives indirect protection to SAV beds by allowing the VMRC to deny bottom lease applications for the sake of habitat protection. The VMRC tries not to grant leases in known SAV areas, although they will renew leases in an area that SAV colonizes.

4.0 North Carolina

4.1 Management Agency

North Carolina marine legislation is created by the Marine Fisheries Commission (MFC) which is analogous to the VMRC. The Division of Marine Fisheries within the Department of Environment and Natural Resources is then charged with implementing and enforcing this regulation. The MFC is responsible for drafting regulations regarding the marine and estuarine resources of North Carolina as well as advising the state with regard to issues that fall within the jurisdiction of the Atlantic States Marine Fisheries Commission, the South Atlantic

Fishery Management Council, and, "other similar organizations established to manage or regulate fishing in the Atlantic Ocean." The MFC consists of 17 members appointed by the Governor who represent the interests of commercial fishing, sport fishing, shellfishing, and marine or estuarine science. A chairman and vice-chairman are selected from the members by the governor.

One of the powers and duties of the MFC is to "adopt rules and take all steps necessary to develop and improve aquaculture, including the cultivation, harvesting, and marketing of shellfish and other marine resources, in North Carolina involving the use of public grounds and private beds." The MFC also has the power and duty to adopt rules, "regarding the leasing of public grounds for aquaculture, including oysters and clam production." These powers and duties are part of the MFC's larger power and duty to, "adopt rules to be followed in the management, protection, preservation, and enhancement of the marine and estuarine resources of the State including commercial and sport fisheries."

The Department of Agriculture regulates freshwater and land-based aquaculture, but at the present, does not regulate estuarine and marine aquaculture. The aquaculture development act does require the Department of Agriculture to promote all forms of aquaculture.

4.2 Allocation of Resources

North Carolina's bottom lands are divided into public bottoms, franchises, leases, and sanctuaries. Franchises came about in the late 1800's after a survey of state bottom grounds was performed to identify productive oyster grounds. Non productive bottom lands were "put up for grab" by the state legislature at a modest fee of 25 cents per acre to promote aquaculture and became known as an oyster grant or a franchise. Most of these franchises were never used and reverted back to state ownership. Those that still exist are regulated as leases but a franchise owner does not have to pay rent on his or her bottom.

All remaining bottom is considered public shellfish bottom. A person may lease part of this public bottom if it contains less than 10 bushels per acre of shellfish and is therefor not considered a natural shellfish bed, is not used for recreational or commercial fishing, is not part of the shellfish management program, is not closed for health concerns, does not conflict with riparian access rights (within 100ft of the shoreline), and is suitable for shellfish production. Leases must not exceed 10 acres for oyster culture or 5 acres for clam or other culture unless the applicant shows need.

The water column can be leased as well with the same permit procedure as the bottom. All water column lease areas are superjacent to shellfish bottom leases. Four oyster sanctuaries exist in North Carolina where reef habitat is being restored.

Riparian owners have the right to exclude shellfish leases 100 feet or less from their shoreline for access purposes. In North Carolina, riparian owners do not have the exclusive right to plant or lease their shoreline.

4.3 Who May Lease Bottom/Water Column

Only individual citizens may lease bottom or water column in North Carolina. No business may lease bottom, although some loose partnerships do exist between individual leasers.

4.4 Rights of Leasers/Owners

No provision is made in North Carolina for backyard shellfish growers. Individuals who wish to raise shellfish off or near their docks must follow the same permit procedure as commercial growers. Those who rent bottom or water column are granted the right to place structures such as nets and trays or floats, respectively, within that site as long as they specify the desire to do this within their management plan for the site.

Bottom renters may harvest shellfish at any time. They may use any gear they wish unless their lease is within a designated shellfish nursery area, in which case they are limited to gear which causes minimal disturbance to the bottom such as rakes and tongs. Leasers may authorize another person to work their leases with an additional permit.

The renter does not have the right to exclude the public from allowable public uses of the water column including fishing, crabbing, hunting, swimming, wading, and navigation. The applicant has the right to know of any protest filed against his/her application. The applicant may renew his/her lease each year as long as production minimums are met.

4.5 Responsibilities of Leasers, and Franchise Owners

A renter must submit a management plan to the state which outlines the following: the methods the renter will use to cultivate at least the minimum required number of shellfish, the time intervals between various phases of the production plan, the materials and techniques to be used in management, the forecasted results of management, and the productivity of any other leases or franchises held by the applicant. The applicant must also pay a processing fee of $100 and stake and mark his plot. If the applicant's application is accepted, the applicant must then commission a survey of the site. The renter must then maintain his site marking following specific standards for bottom and water column lease markers. Lease renewal requires updated management plans, a $50 filing fee, and a new survey if the earlier survey differs from the new lease. Bottom and water column leases must be continuously marked and posted.

It is the responsibility of the renter to submit annual production reports to the Division. It is the renter's responsibility to produce and/or plant at least 25 bushels of shellfish on bottom leases and franchises per year and at least 100 bushels per acre per year in water column leases. These same production requirements pertain to commercial franchises as well. It is also the responsibility of the aquaculturists to submit annual reports to the Fisheries Director concerning any resources taken from the wild as well as allow inspections by the Fisheries Director.

<u>4.6 Regulations Regarding SAV</u>

SAV is considered a "critical habitat area" in North Carolina. It is defined as, "those habitats in public trust and estuarine waters vegetated with one or more species of submerged vegetation such as eelgrass (*Zostera marina*), shoalgrass (*Halodule wrightii*) and widgeongrass (*Ruppia maritima*). These vegetation beds occur in both subtidal and intertidal zones and may occur in isolated patches or cover extensive areas. In either case, the bed is defined by the presence of above-ground leaves or the below-ground rhizomes and propagules together with the sediment on which the plants grow. In defining beds of submerged aquatic vegetation, the Marine Fisheries Commission recognizes the Aquatic (Exotic) Weed Control Act of 1991 and does not intend the submerged aquatic vegetation definition and its implementing rules to or conflict with the non-development control activities authorized by that act." This definition is most often used when deciding to open or close areas to commercial clam and oyster harvest. It is the MFC's policy to try and minimize damage by commercial fisheries to these areas.

Applications for new leases may be turned down if the lease might interfere with SAV beds. Use of current leases may not disturb SAV beds. If a site desired for lease contains SAV, the applicant must specify how he or she plans to manage the site without disturbing the SAV. Mechanical harvest equipment may not be used where there is SAV.

5.0 Maryland

5.1 Controlling Agency - MD

In Maryland the Maryland Legislature creates all laws regarding marine and estuarine resources. The Economic and Environmental Affairs Committee within the Senate and the Environmental Matters Committee within the House, draft many of the state's laws pertaining to marine resources. Laws are then subject to the full legislative review process. The laws grant the Department of Natural Resources (DNR) the right to write regulations to enact these laws and carry out their purpose. Regulations are drafted by individual divisions within DNR, go before the secretary of the department, and are put up for public comment before being enacted. DNR is also charged with the task of enforcing these laws and regulations as well as advising the Department of the Environment as to issuance of the site permits arising from these laws.

5.2 Allocation of Resources

In Maryland, certain bottom lands are designated as natural oyster bars based upon earlier surveys, the most recent of which were conducted in the late 1970's and early 1980's. These areas are considered public ground for commercial oyster harvest. All remaining bottom lands within the state are considered natural public clam bars. Citizens have the right to commission a survey by the state of a particular area of clam bar to determine if it truly contains a significant number of clams. If the site in question contains neither a significant number of clams nor oysters, does not interfere with riparian rights and is not closed for leasing, the citizen may apply to lease the bottom.

Riparian rights allow any bottom land of a creek, cove, or inlet less than 300 feet wide at the surface at mean low water may be used exclusively by the riparian owner as if it were leased bottom, regardless of the number of clams or oysters a site naturally contains. Rent is still required from the riparian owner if it is to be used as leased bottom.

In Maryland, one may harvest shellfish from most areas not under lease. Because of this, commercial harvesters have successfully lobbied to designate significant areas of bottom off-limits to leasing. Areas of the state not available for lease for shellfish cultivation include bottoms of Charles, Dorchester, Kent, Queen Anne's, Somerset, Talbot, and Charles counties except the Patuxent River. Certain areas within these counties are leased under grandfather clauses. In practice, few areas in Maryland, except in the Nanticoke River, are actually leased and cultivated. This is partially due to the threat and reality of shellfish piracy. On the Nanticoke, enough bottom is currently cultivated by different individuals to allow tenants to watch out for one another's bottom and curtail piracy.

Wharf and other structure owners may have exclusive use of the water and bottom below the wharf for growing shellfish. In Talbot and Howard Counties, this special use area extends within five feet of the wharf or structure and may be used for aquaculture baskets, trays, or other structures attached to the structure by lines or ropes of the owner. In other areas of the state, shellfish suspended beside piers, although not specifically permitted, are ignored by enforcement officials.

5.3 Who May Lease Bottom

Public high schools in tidewater Maryland are permitted to lease bottom for experimental oyster farming. Restrictive rules for planting, harvesting, and marketing shellfish are waved for schools. If the school does not use its bottom within three years of lease, it reverts back to the state.

No corporation or joint stock company may lease oyster ground. Only residents of the state may lease bottom for shellfish production, although some residents have banned together to create very loose corporations. Residents may lease only 10 acres of bottom in rivers and 30 acres in the bay. 4H clubs are allowed to lease up to 10 acres of bottom from the state and the state may match funds with them. Colleges and universities within the state may acquire bottom by assignment, gift, or bequest, submerged land bottom for education or research purposes.

5.4 Rights of Leasers/Owners

The following regulations pertain to oyster leases throughout the state with exceptions in Wicomico and Somerset Counties. Oyster lease regulations are commonly extended to apply to bottom used for clam culture as well. Lease holders have exclusive right to all oysters within a lease. Such a lease will only be used to raise oysters. Renters do not have the right to exclude state residents from fishing over leases as long as oysters are not harmed or removed. Although issues of aquaculture structures on bottoms have not yet arisen, it is likely that they would not be permitted due to potential interference with fishing. A renter may not sell the lease to another. Renters may take oysters from the bottom at any time for private use on any daylight hour except on Sunday for commercial purposes. In Wicomico and Somerset Counties a renter may authorize any state resident with a tonging license to tong oysters from his/her lease. In the Manokin River, neither the renter nor the representative of the renter need to have a tonging license. In parts of Wicomico County, a renter may use a power dredge to harvest oysters after obtaining a permit.

Issues concerning usage of the water column have not yet been resolved in Maryland. Very few commercial shellfish aquaculture operations exist in Maryland and of these virtually none utilize floating trays, racks, or other suspended devises. The Department of Natural

Resources is currently authorizing a very limited number of experimental aquaculture permits in an effort to determine and minimize areas of future aquaculture conflict. Currently, few if any of these permits are in use. Should an aquaculturist be issued such a permit, the water column may be used (for floating trays, etc.) without need to lease the bottom. "Visual pollution" from such devises is also a concern in Maryland.

5.5 Responsibilities of Leasers/Owners

The renter must keep accurate records concerning the seeding and planting of cultch and oysters on, and the harvesting and selling of oysters from his leased oyster bottom and report this information to the state. Areas to be dredged must be staked at each corner and at 100 foot intervals before dredging. Leases do not need to be marked at other times, but law enforcement officials only protect marked leases. A "use it or lose it" clause does exist for leased bottom in Maryland, but it is not enforced due to disease and logistical constraints.

5.6 Laws regarding SAV

The state of Maryland provides some protection for, "vascular or nonvascular hydrophytes, which are rooted or unrooted, that lie entirely beneath the surface of the water, except for flowering parts in some species." The general protection the state grants does not apply to, "activities involved in the harvesting of fish, shellfish, or crabs; or the construction, operation, and maintenance of agricultural drainage channels." This general protection requires any individual wishing to harvest, cut, remove, or eradicate SAV to obtain a permit before doing so. Other exceptions to this rule include owners or renters of docks, piers, marinas, and ramps who may clear a 60 foot strip to a navigation channel. Public utility companies may also clear swaths of SAV to perform maintenance and emergency work.

A new SAV law in Maryland supercedes the fore mentioned regulation in the area of fisheries and bans hydraulic clam dredging in SAV beds. The DNR is directed to delineate current SAV beds as part of this law and is also permitted to adopt additional measures to protect SAV beds.

SAV/aquaculture conflict has not become a problem in Maryland due mainly to the lack of lease space and suitable clam habitat in Maryland. Many of the areas closed to leasing are in the same locations as the largest SAV beds in the state. The lack of aquaculture due to habitat difficulties, such as salinity and disease, has also minimized conflict potential.

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VITAE

HELEN WOODS

Borne in Beltsville Maryland, Helen Woods graduated from Annandale High School in 1993, earned a B.S. in Biology and a B.S. in Marine / Environmental Science from Salisbury State University and the University of Maryland Eastern Shore in 1997, entered the masters program at the Virginia Institute of Marine Science in 1997, attained her private pilot certificate in 1999, and began instrument flight training in 2001.

TABLES

AND

FIGURES

Table 1. SAV Habitat Requirements as Defined in Technical Synthesis I (Batiuk et al. 1992)

	SAV Habitat Requirements For One Meter Restoration Habitat Requirements Which Affect Water Column/Leaf Surface Light Attenuation						SAV Habitat Requirements For Two Meter Restoration	
Salinity Regime	**Light Attenuation Coefficient (m^{-1})**	**Total Suspended Solids (mg/l)**	**Chlorophyll *a* (ug/l)**	**Dissolved Inorganic Nitrogen (mg/l)**	**Dissolved Inorganic Phosphorus (mg/l)**	**Critical Life Period**	**Light Attenuation Coefficient (m^{-1})**	**Critical Habitat Requirement For Two Meters Restoration**
Tidal Fresh	<2	<15	<15	—	<0.02	April-Oct	<0.8	April- Oct
Oligohaline	<2	<15	<15	—	<0.02	April-Oct	<0.8	April- Oct
Mesohaline	<1.5	<15	<15	<0.15	<0.01	April-Oct	<0.8	April-Oct
Polyhaline	<1.5	<15	<15	<0.15	<0.02	March-Nov	<0.8	March- Nov

Table 2. Factors Used for the Models Developed in this Study (Salinity Assumed Suitable)

	SAV	Clam Aquaculture	Conflict	Analysis Site	Validation Site
Model I	secchi depth 1 meter contour exposure (qualitative)	bottom hardness - (from photos) 1 meter contour exposure (qualitative)	SAV I Clam II	Cherrystone Hungars	Poquoson Back
Model II	SAV distribution and 50 meter buffer	bottom hardness - (ground truth) 1 meter contour exposure (quantitative)	SAV II Clam II	Cherrystone Hungars	Cherrystone Hungars
Model III		bottom hardness (ground truth) 1 meter contour exposure (qualitative)	SAV II Clam III	Cherrystone Hungars	NA

Table 3. Hard Clam HSI I (Salinity Assumed Suitable)

NW Exposure	Bottom	Depth	Suitability
Low	Hard	<1 meter	High
Moderate	Hard	<1 meter	Moderate
	All other combinations		Low

Table 4. Accuracy of Metrics Used to Identify SAV Water Quality

Method	Accuracy	Data Required
Light Attenuation	Good	K_D
TS1: 2 of 5 factors	Better	Nitrogen, Phosphorus, TSS, Chl. A, Light
TS2: Percent Light at Leaf surface (PLL)	Best*	K_D, DIN, and DIP

* Not thoroughly tested but promoted in TS2 over previous methods

Table 5. Likelihood of SAV Growing at 1 Meter or Less Under Different Light and Exposure Conditions

Light	Exposure	SAV
Good	Low	High
Good	Moderate	Moderate
Good	High	Low
Moderate	Low	Moderate
Moderate	Moderate	Moderate
Moderate	High	Low

Table 6. SAV Bed Protection One Year from Buffer Protection Assignment

Eastern Shore Protection Area (One Year)	SAV Protected from Clamming		SAV Not Protected from Clamming		Area Protected That No SAV Grows Into	
Previous Bed	2,538,844m^2	83%	497,120m^2	17%	346,719m^2	13%
Previous Bed + 50	2,832,783m^2	93%	203,181m^2	7%	1,399,449m^2	33%
Previous Bed + 100	2,901,875m^2	95%	136,247m^2	5%	2,305,994m^2	44%
Previous Bed +150	2,937,492m^2	97%	98,900m^2	3%	3,027,473m^2	51%
Previous Bed +200	2,962,881m^2	98%	73,083m^2	2%	3,659,450m^2	55%

Table 7. Calculating Potential Conflict Using Results of Clam Aquaculture and SAV Models

SAV	Clam Operations	Conflict
High	High	High
High	Med	MH
Med	High	MH
Med	Med	ML
Any Combination with Low		Low

MH = Moderately High *ML = Moderately Low*

Table 8. Regression Analysis of SAV Area in Cherrystone Creek With Clam Aquaculture Area and SAV in Similar Creeks Without Clam Aquaculture

The regression equation is

Cherrystone SAV = - 175098 + 3.81 Clams + 0.289 Other SAV

Predictor	Coef	StDev	T	P
Constant	-175098	449245	-0.39	0.71
Clams	3.809	1.655	2.30	0.06
Other SAV	0.288	0.095	3.03	0.02

R-Sq(adj) = 53.8%

Table 9: Predicted Areas of Clam Bottom, Clam Habitat Model I

	Hungars	Cherrystone	Total
Clam beds	82,169	224,049	306,218
Clam beds outside of clam habitat	55,578	0	55,578
Clam beds inside of clam habitat	26,591	224,049	250,640
Clam habitat without clam beds	2,218,100	2,712,931	4,931,031
Good clam habitat with clam beds	25,160	193,997	219,158
Good clam habitat without clam beds	1,563,969	2,435,480	3,999,449
Moderate clam habitat with clam beds	1,430	30,052	31,482
Moderate clam habitat without clam beds	654,132	277,451	931,583
Total clam habitat	2,244,691	2,936,980	5,181,671
Total good clam habitat	1,589,129	2,629,478	4,218,606
Total moderate clam habitat	655,562	307,503	963,065
% of habitat area not being used	99	92	95
% of clam beds not in clam habitat	68	0	18

Table 10. Sediment Penetration and Grain Size Analysis in Eastern Shore Creeks

Penetration (in)	Type	Clay	Silt	Sand	Gravel
0	hard	3.22	1.17	95.61	0
0.5	hard	7.99	5.9	86.08	0.03
1	hard	8.99	6.28	84.73	0
1	hard	3.24	1.33	95.43	0
1.5	hard	5.96	3.17	90.86	0.01
1.5	hard	2.13	0.7	78.43	18.74
2	hard	4.85	0.15	94.82	0.18
2	hard	4.99	2.4	92.38	0.22
2	hard	4.12	1.88	94	0
2.5	soft	11.34	16.28	72.38	0
3	soft	2.64	1.05	96.31	0
4	soft	11.98	14.19	73.82	0
4.5	soft	10.89	17.7	71.41	0
5	soft	16.6	12.41	70.99	0
5	soft	17.45	11.01	71.15	0.39
5	soft	10.99	8.8	80.22	0
5.5	soft	22.85	17.6	56.19	3.36
5.5	soft	15.57	11.47	72.8	0.16
6	soft	12.64	10.42	76.95	0
12	soft	60.94	34.17	4.64	0.25

Table 11. Predicted Areas of Clam Bottom, Clam Habitat Model II

	Hungars	Cherrystone	Total
Clam beds	81,992	224,366	306,359
Clam beds outside of clam habitat	48,461	109,743	158,204
Clam beds inside of clam habitat	33,532	114,623	148,155
Clam habitat without clam beds	2,852,041	1,785,126	4,637,167
Good clam habitat with clam beds	4,185	79,567	83,752
Good clam habitat without clam beds	2,222,808	1,261,016	3,483,824
Moderate clam habitat with clam beds	29,347	35,056	64,403
Moderate clam habitat without clam beds	629,233	524,110	1,153,343
Total clam habitat	2,885,573	1,899,749	4,785,321
Total good clam habitat	2,226,993	1,340,583	3,567,575
Total moderate clam habitat	658,580	559,166	1,217,746
% of clam habitat not being used	99	94	97
% of clam beds not in clam habitat	59	49	52

****Clam aquaculture model III**

Table 12. Predicted Areas of Clam Bottom, Clam Habitat Model III

	Hungars	Cherrystone	Total
Clam beds	82,232	224,142	306,374
Clam beds outside of clam habitat	61,020	0	61,020
Clam beds inside of clam habitat	21,211	224,142	245,353
Clam habitat without clam beds	2,710,615	2,061,135	4,771,750
Good clam habitat with clam beds	19,781	194,032	213,813
Good clam habitat without clam beds	2,085,174	1,791,756	3,876,930
Moderate clam habitat with clam beds	1,430	30,110	31,541
Moderate clam habitat without clam beds	625,441	269,379	894,820
Total clam habitat	2,731,826	2,285,277	5,017,103
Total good clam habitat	2,104,955	1,985,788	4,090,743
Total moderate clam habitat	626,871	299,489	926,361
% of clam habitat not being used	99	90	95
% of clam beds not in clam habitat	74	0	20

Table 13. Predicted Areas of SAV Bottom, SAV Habitat Model I

	Hungars	Cherrystone	Total
Good SAV Hab	1,837,337	0	1,837,337
Moderate SAV Hab	3,967,315	2,289,578	6,256,892
Total SAV Habitat	5,804,652	2,289,578	8,094,229

Table 14. Validation of Predicted Areas of SAV Bottom, SAV Habitat Model I

	Poquoson	Back River	Total
Good SAV Habitat	887,409	2,246,677	3,134,087
Moderate SAV Habitat	5,238,224	4,852,525	10,090,749
No Light Data Area	2,423,321	761,980	3,185,301
Total SAV Habitat*	6,125,633	7,099,202	13,224,835
SAV beds	3,396,716	2,925,018	6,321,735
SAV beds outside of SAV habitat (and no data area)	1,339,665	942,323	2,281,987
SAV beds inside of SAV habitat	2,042,214	1,982,696	4,024,910
SAV habitat without SAV beds (excludes no data area)	5,164,637	5,116,506	10,281,143
Good SAV habitat with SAV beds	212,334	952,328	1,164,663
Good SAV habitat without SAV beds	675,075	1,294,349	1,969,424
Moderate SAV habitat with SAV beds	1,829,880	1,030,368	2,860,247
Moderate SAV habitat without SAV beds	4,489,562	3,822,157	8,311,719
SAV located in areas with no data	14,838	0	14,838
% of best area without SAV	76	58	63
% of moderate area without SAV	86	79	82
% of SAV habitat without SAV	84	72	78
% of SAV not in SAV habitat	39	32	36

*Excluding areas without data

Table15. Predicted Areas of SAV Bottom, SAV Habitat Model II

	Hungars	Cherrystone	Total
Good SAV Hab	2,613,425	1,256,368	3,869,793
Moderate SAV Hab	962,739	585,346	1,548,086
Total SAV Habitat	3,576,164	1,841,714	5,417,878

Table 16. Validation of Predicted Areas of SAV Bottom, SAV Habitat Model II

	Poquoson	Back River	Total
SAV beds	2,788,039	2,533,254	5,321,293
SAV beds outside of SAV habitat	0	6,207	6,207
SAV beds inside of SAV habitat	2,788,039	2,527,046	5,315,085
SAV habitat without SAV beds	1,665,500	1,660,721	3,326,220
Good SAV habitat with SAV beds	2,725,710	2,420,133	5,145,843
Good SAV habitat without SAV beds	583,942	420,614	1,004,556
Moderate SAV habitat with SAV beds	62,329	106,913	169,242
Moderate SAV habitat without SAV beds	1,081,557	1,240,107	2,321,664
Total SAV habitat	4,453,539	4,187,767	8,641,306
Total best SAV habitat	3,309,652	2,840,747	6,150,399
Total moderate SAV habitat	1,143,886	1,347,020	2,490,906
% of best SAV area not being used by SAV	18	15	16
% of moderate SAV area not being used by SAV	95	92	93
% of SAV habitat without SAV	37	40	38
% of SAV not in SAV habitat	0.00	0.25	0.12

Table 17. Predicted Areas (m^2) of Bottom Conflict Model I

Original Conflict Model			
	Hungars	Cherrystone	Total
High Conflict	1,077,637	0	1,077,637
Moderately High Conflict	446,710	757,231	1,596,036
Moderately Low Conflict	652,810	783,888	955,243
Just SAV Suitability	1,382,585	748,006	4,349,679
Just Clam Suitability	67,264	1,395,908	1,437,323

Table 18. Predicted Areas (m^2) of Bottom Conflict Model II

	Hungars	Cherrystone	Total
High Conflict	867,075	505,337	1,372,411
Moderately High Conflict	766,124	510,085	1,276,210
Moderately Low Conflict	89,406	23,914	113,320
Just SAV Suitability	1,857,937	820,795	2,678,732
Just Clam Suitability	1,121,902	750,717	1,872,619

Table 19. Predicted Areas (m^2) of Bottom Conflict Model III

	Hungars	Cherrystone	Total
High Conflict	792,391	28,129	820,520
Moderately High Conflict	731,045	518,195	1,249,240
Moderately Low Conflict	83,194	5,737	88,930
Just SAV Suitability	1,973,925	500,601	2,474,526
Just Clam Suitability	1,124,738	902,723	2,027,460
Actual Clams in Potential SAV			43,397
Actual Clams Not in Potential SAV			271502
Percent of Actual Clams in Potential SAV			14
All Good Clam Area Not in SAV (Currently Usable)			2,439,391
Good Clam Area in Potential SAV			499,733
% of Currently Usable Good Clam in Potential SAV			20

FIGURE 1. Study Sites

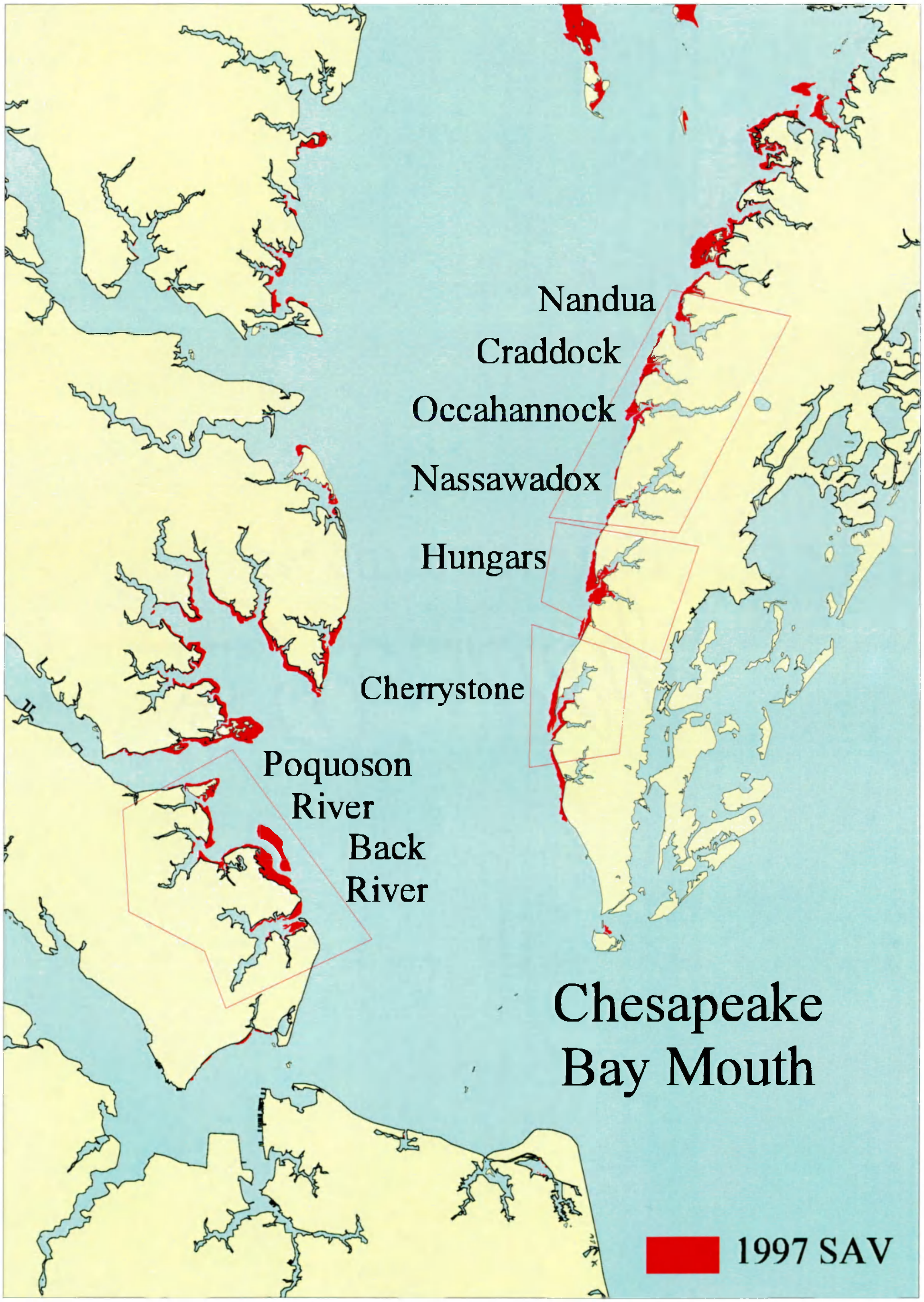


FIGURE 2. Hugars and Cherryston Creek Systems

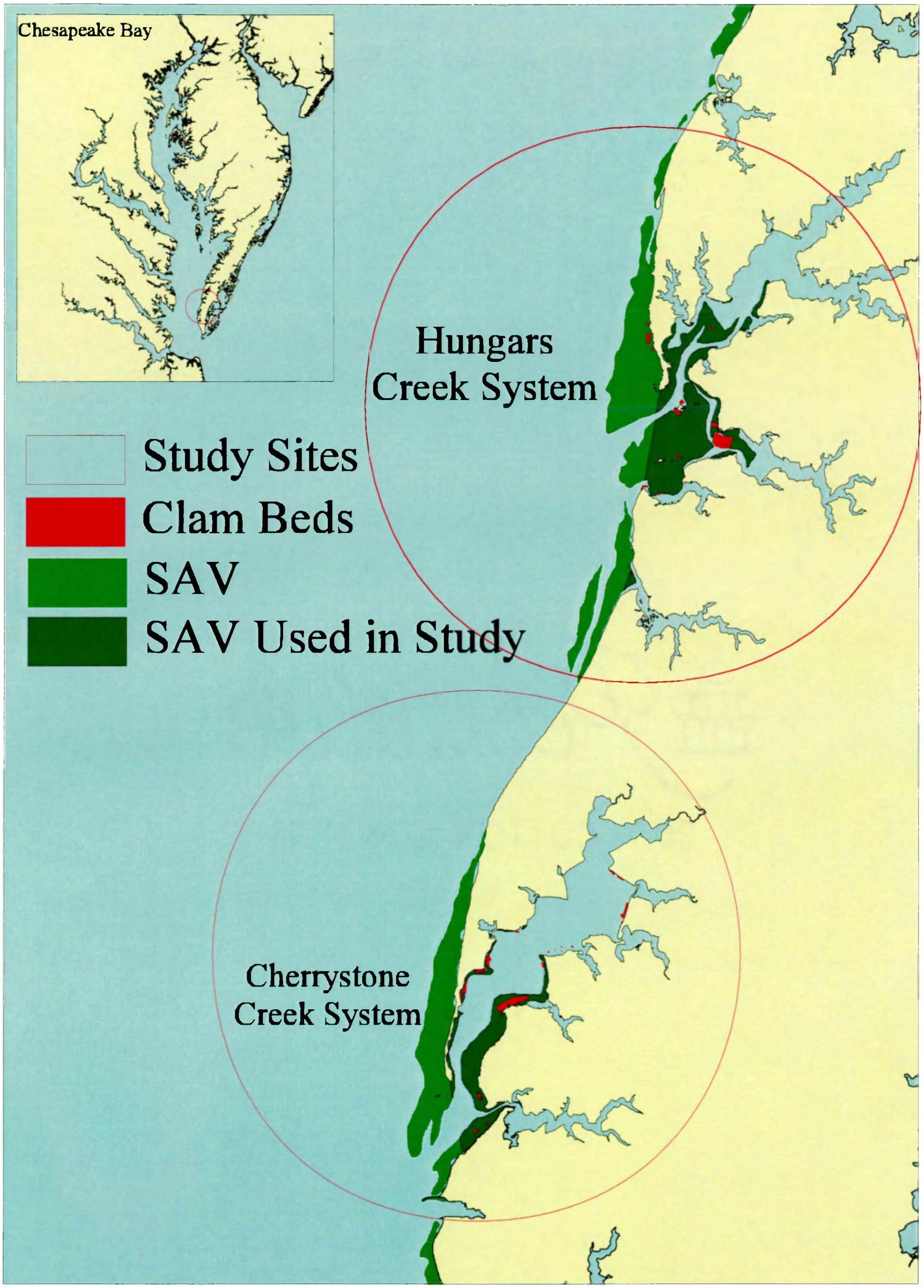


Figure 3. Quantitative Exposure Method

Area was gridded into 0.1km cells, each with a central point. For any given point, 1 km NW vector was drawn with 4 11.25° vectors on either side. Coded each vector based upon features it intersected:

1 = Land Exposure

2 = Sand Bar Exposure

3 = Open Bay Exposure

Added values of all vectors for each point.

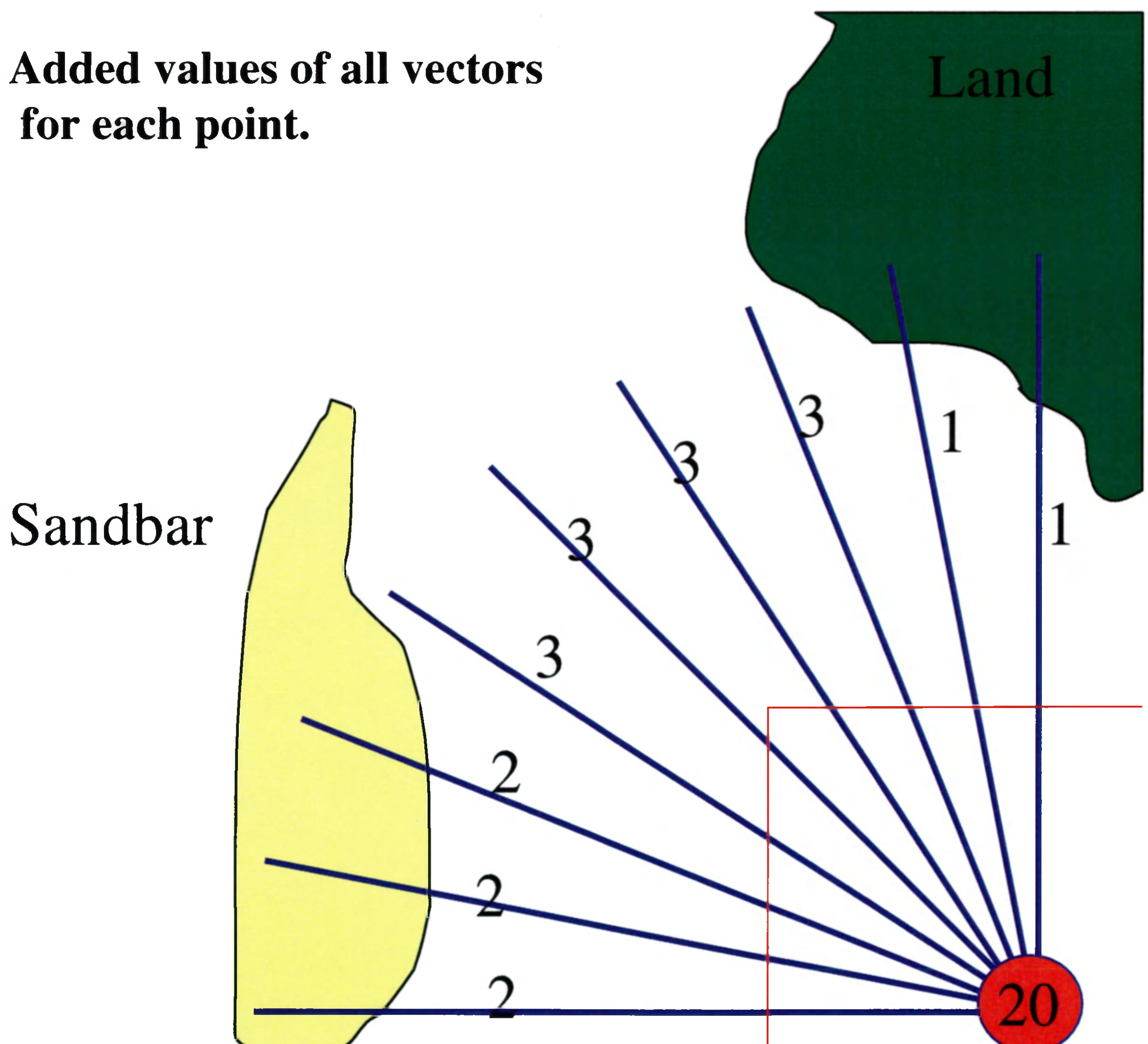
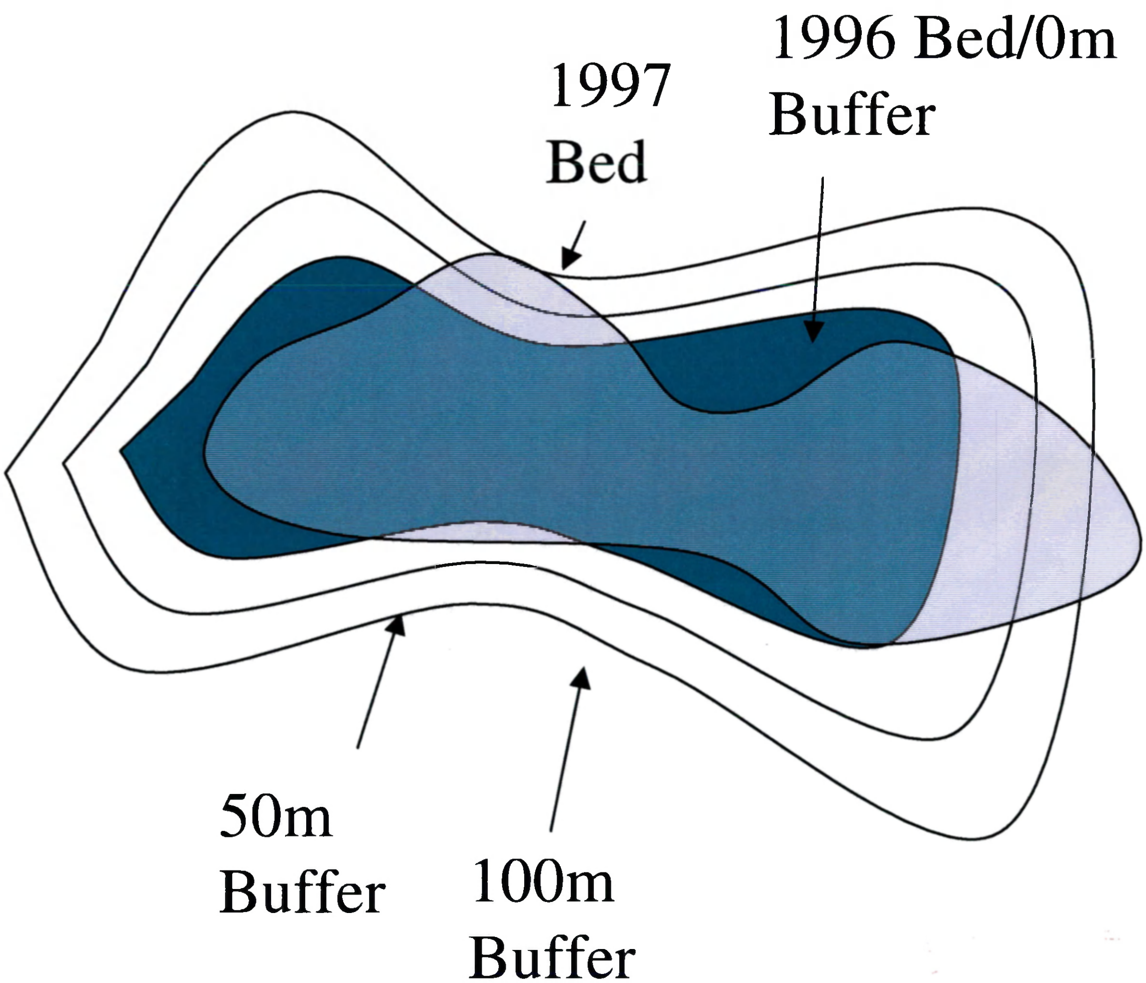


FIGURE 4. SAV Buffer Experiment



Increased buffer size affords additional protection for SAV beds. However, the amount of SAV protected compared to buffer size decreases as buffer distance is increased beyond the core area.

FIGURE 5. SAV and Clam Coverage in Cherrystone Creek System

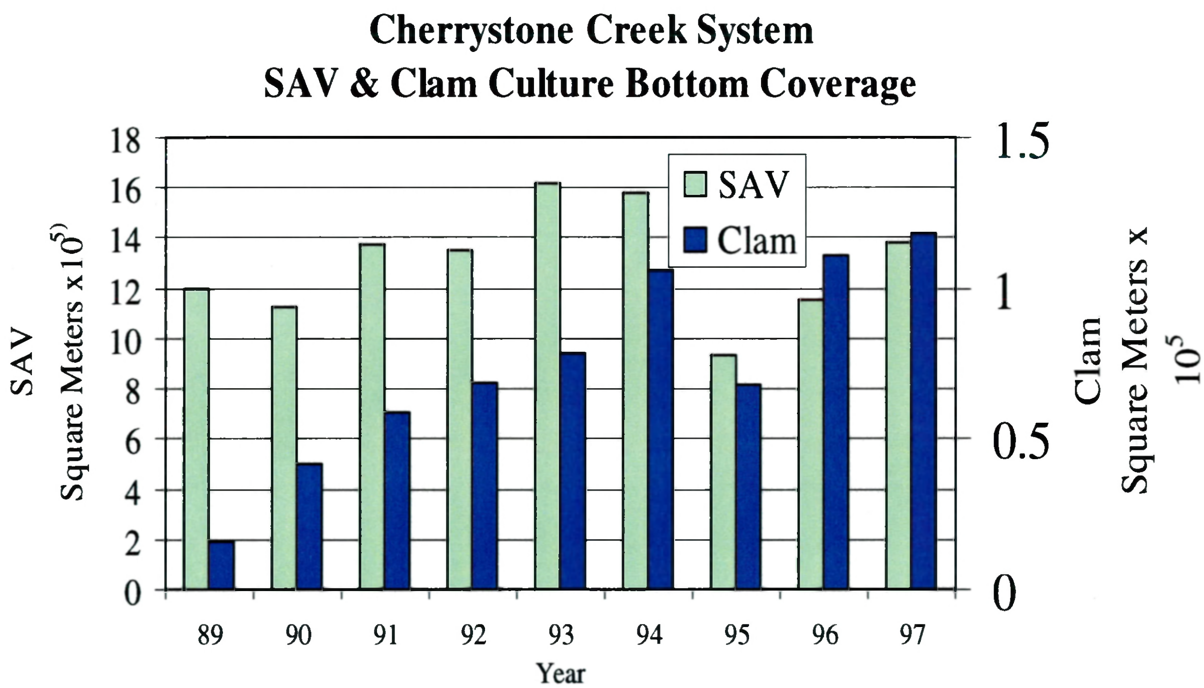


FIGURE 6. Change in SAV in Creeks with and without Clam Aquaculture

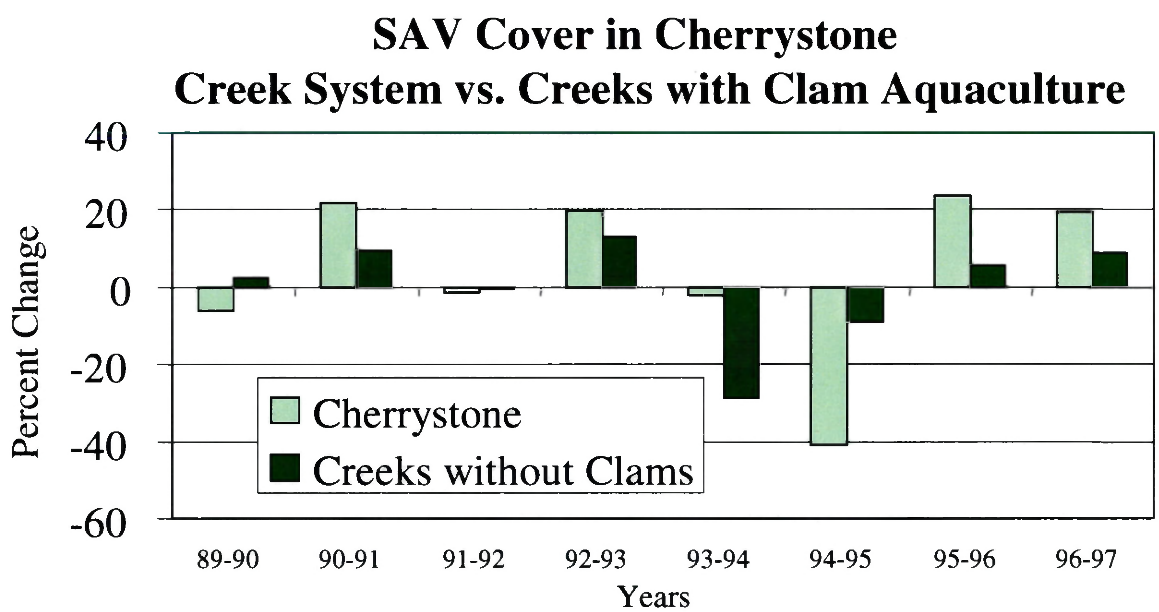


FIGURE 7. Change in SAV and Clam Coverage in Cherrystone Creek System

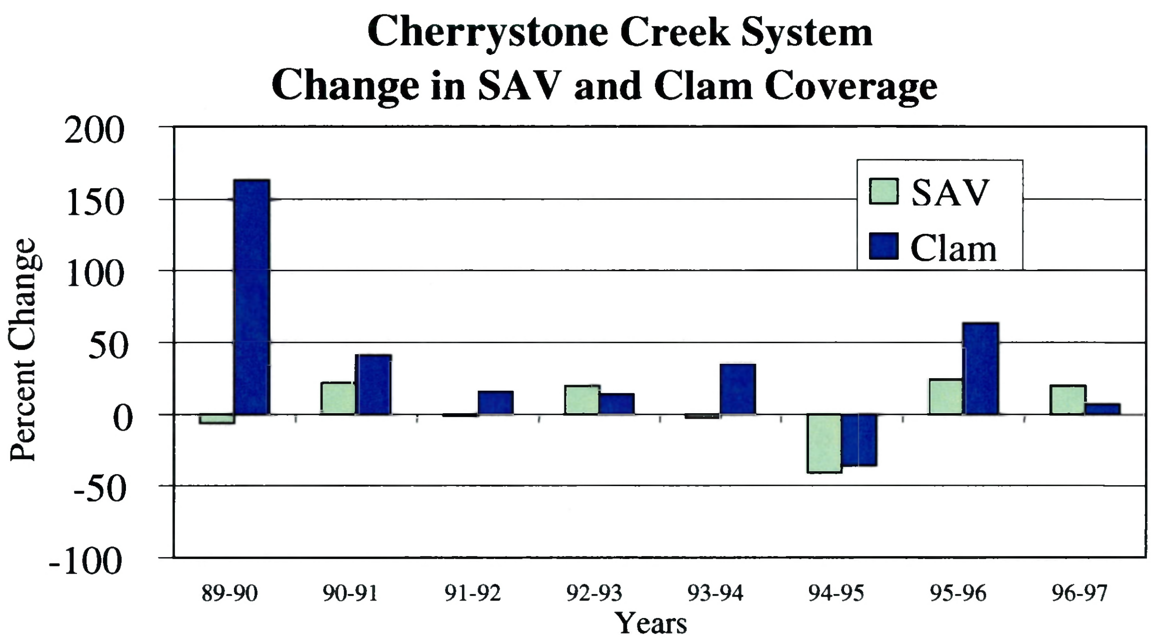
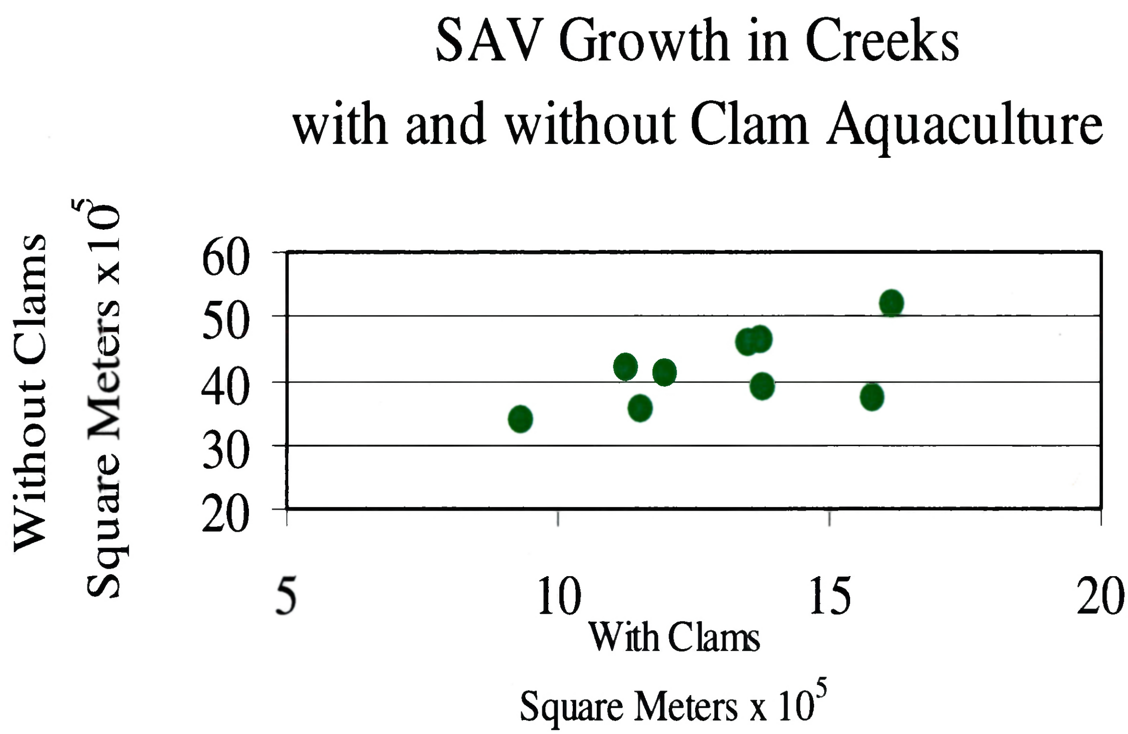


FIGURE 8. SAV Growth in Creeks with and without Aquaculture



P = 0.23

FIGURE 9. Bottom Type Component I

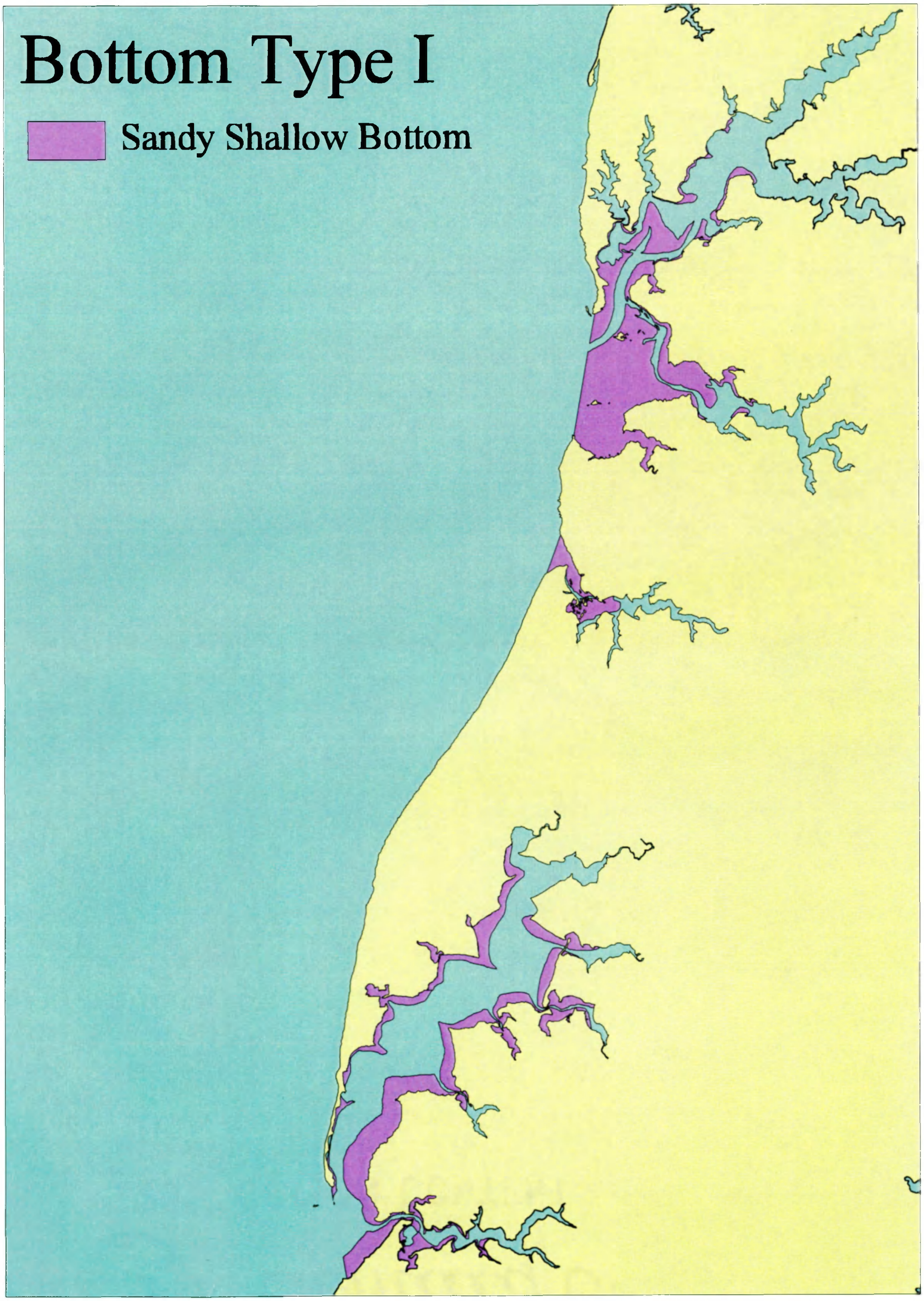


FIGURE 10. Exposure Component I

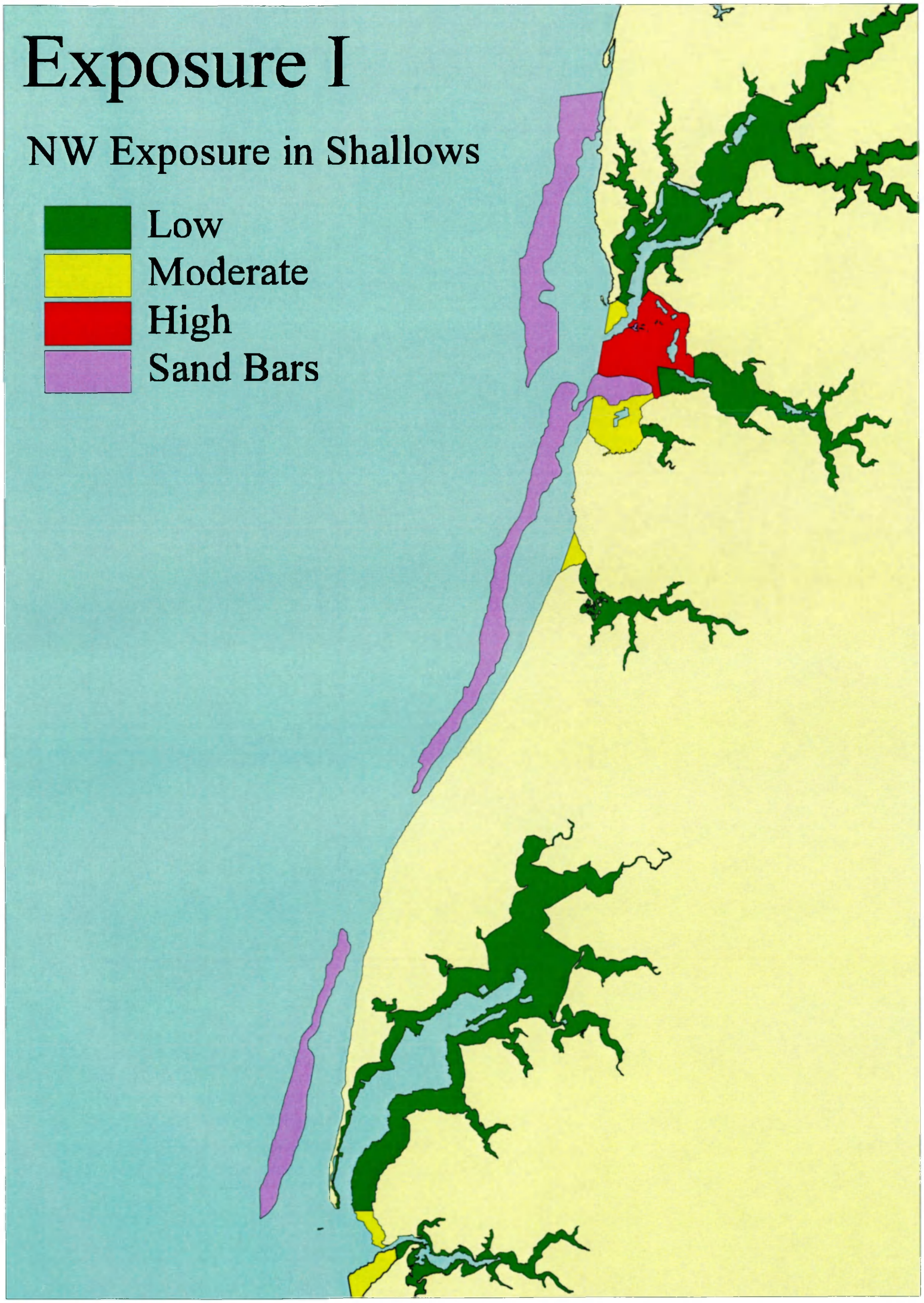


FIGURE 11. Clam Model I

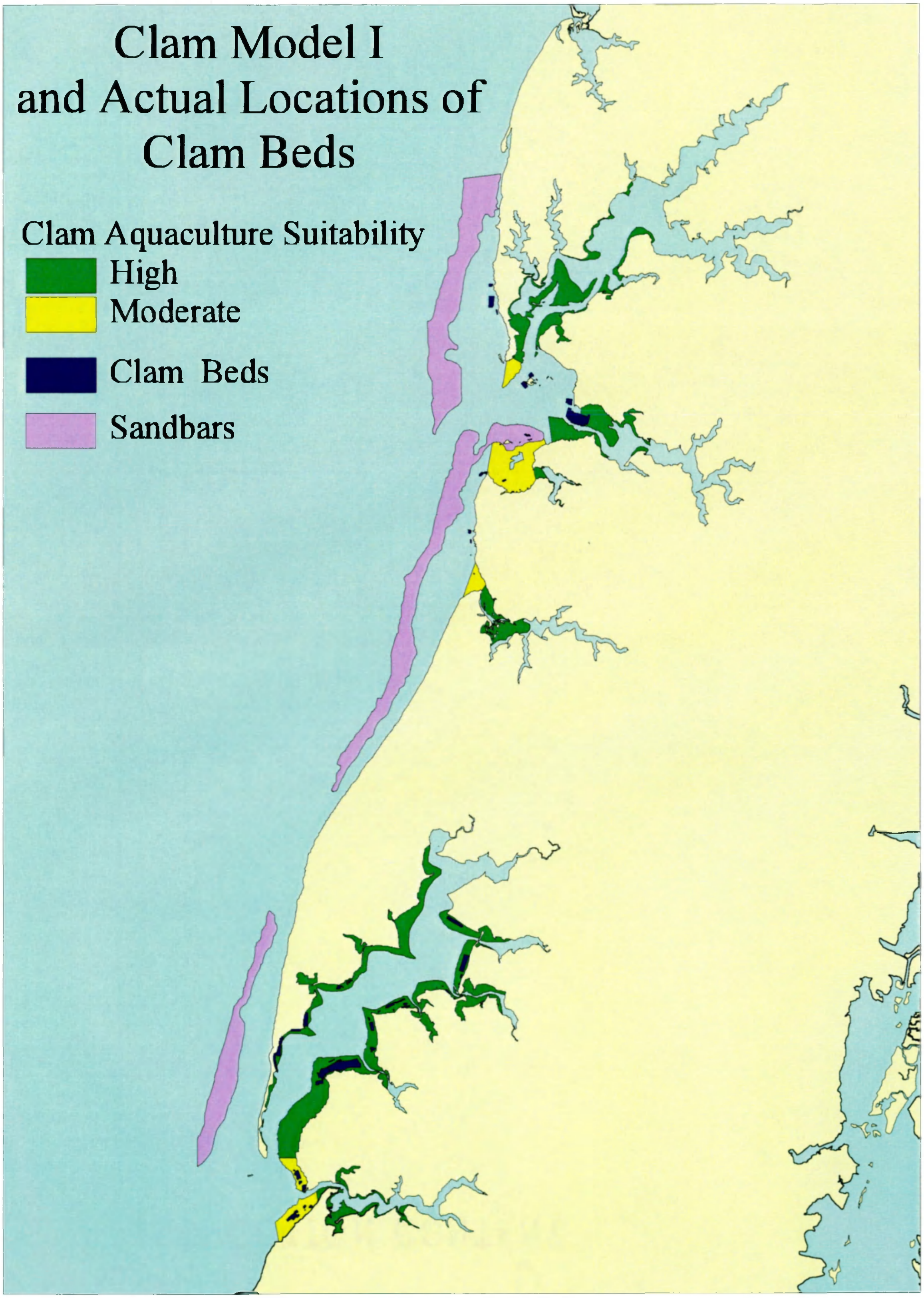


FIGURE 12. Bottom Type Component II

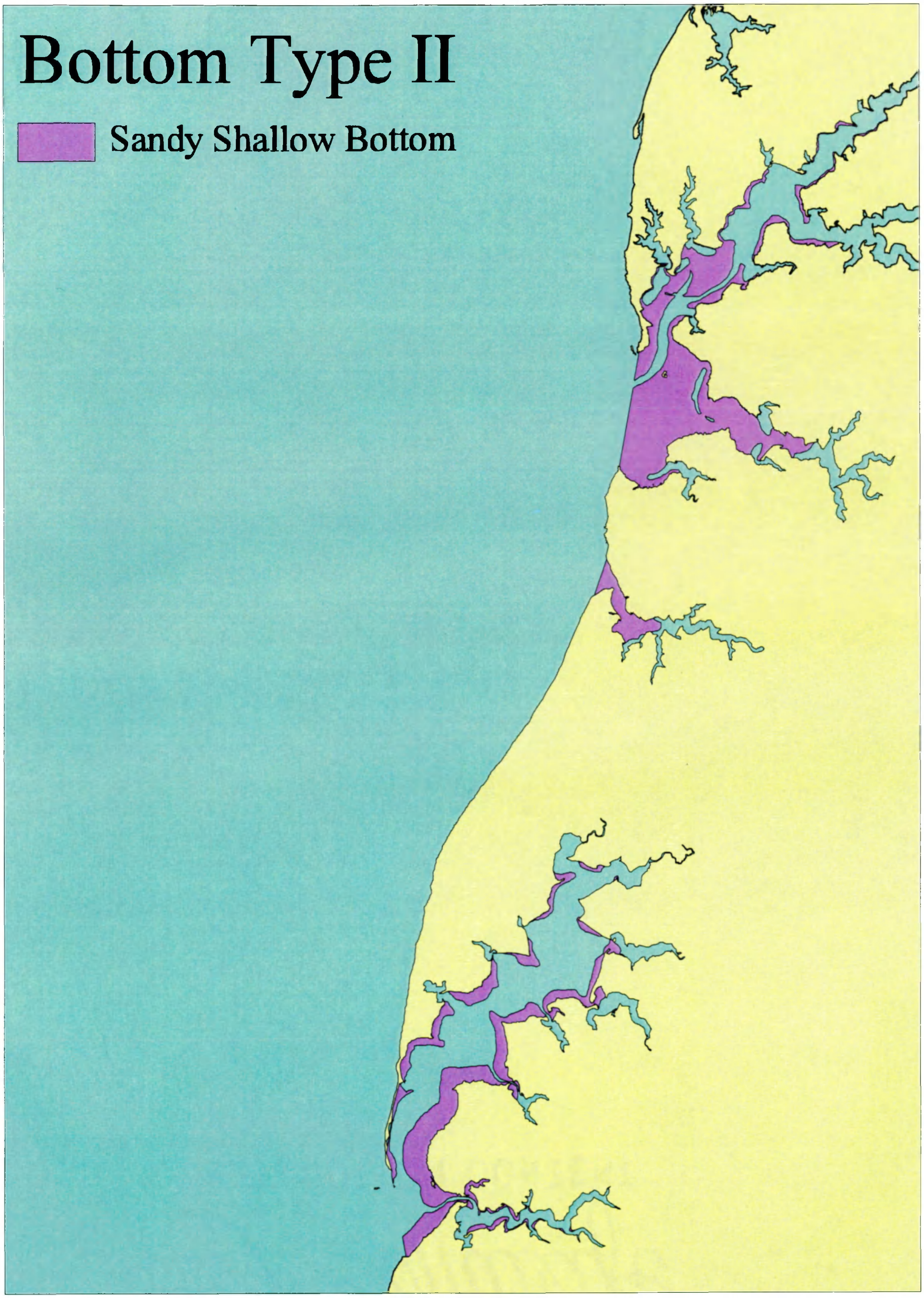


FIGURE13. Exposure Component II

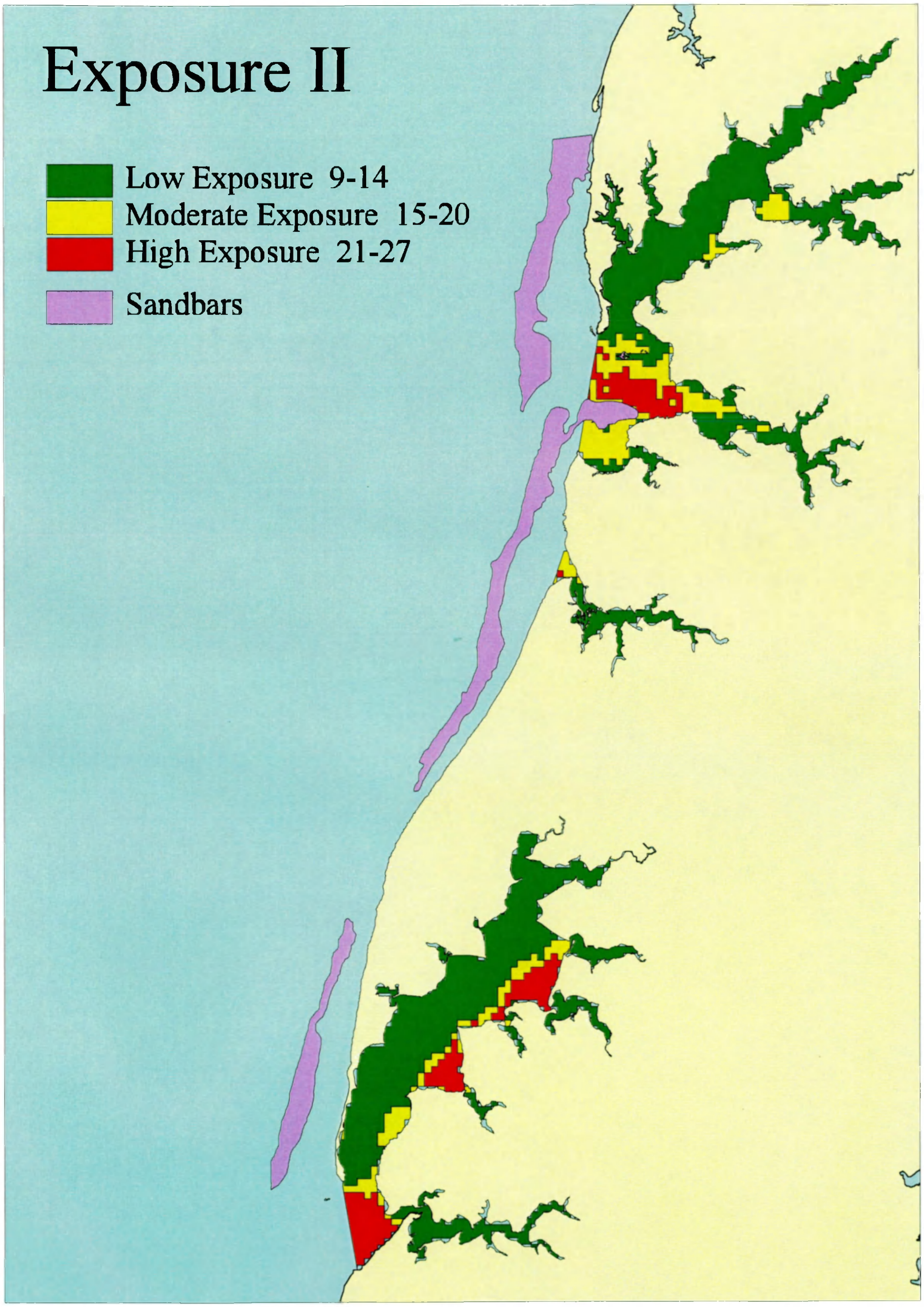


FIGURE 14. Clam Model II

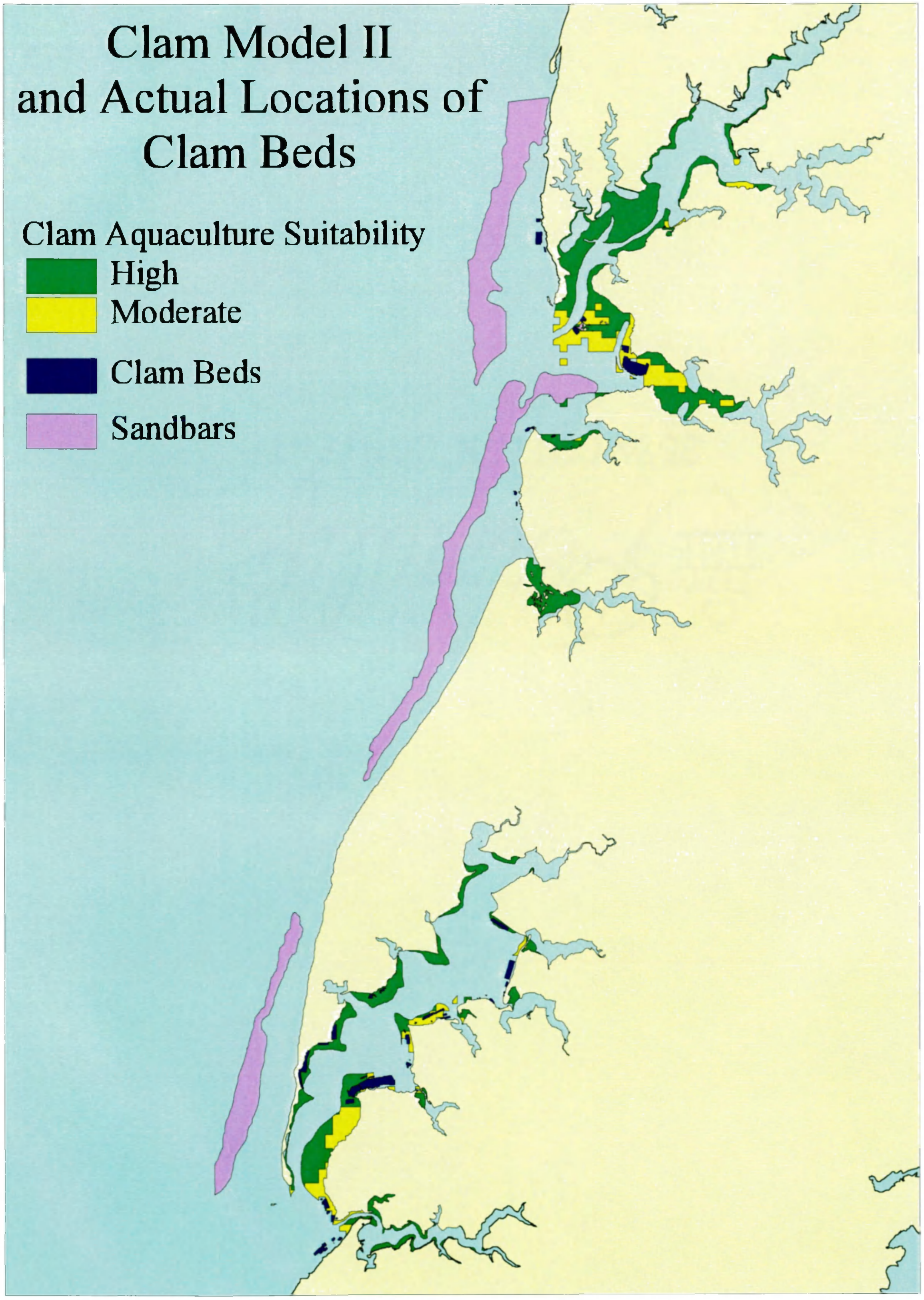


FIGURE 15 - Clam Model III

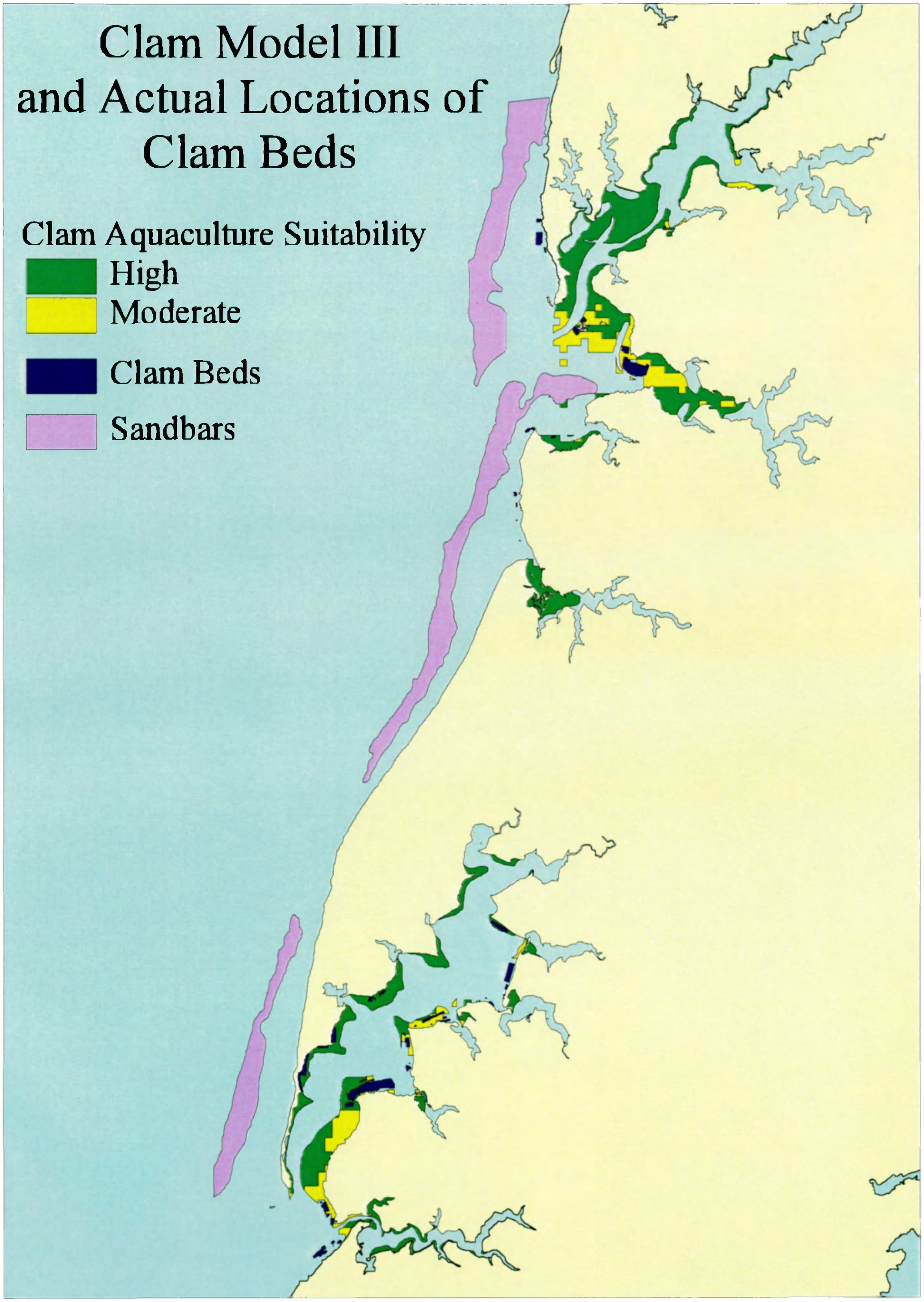
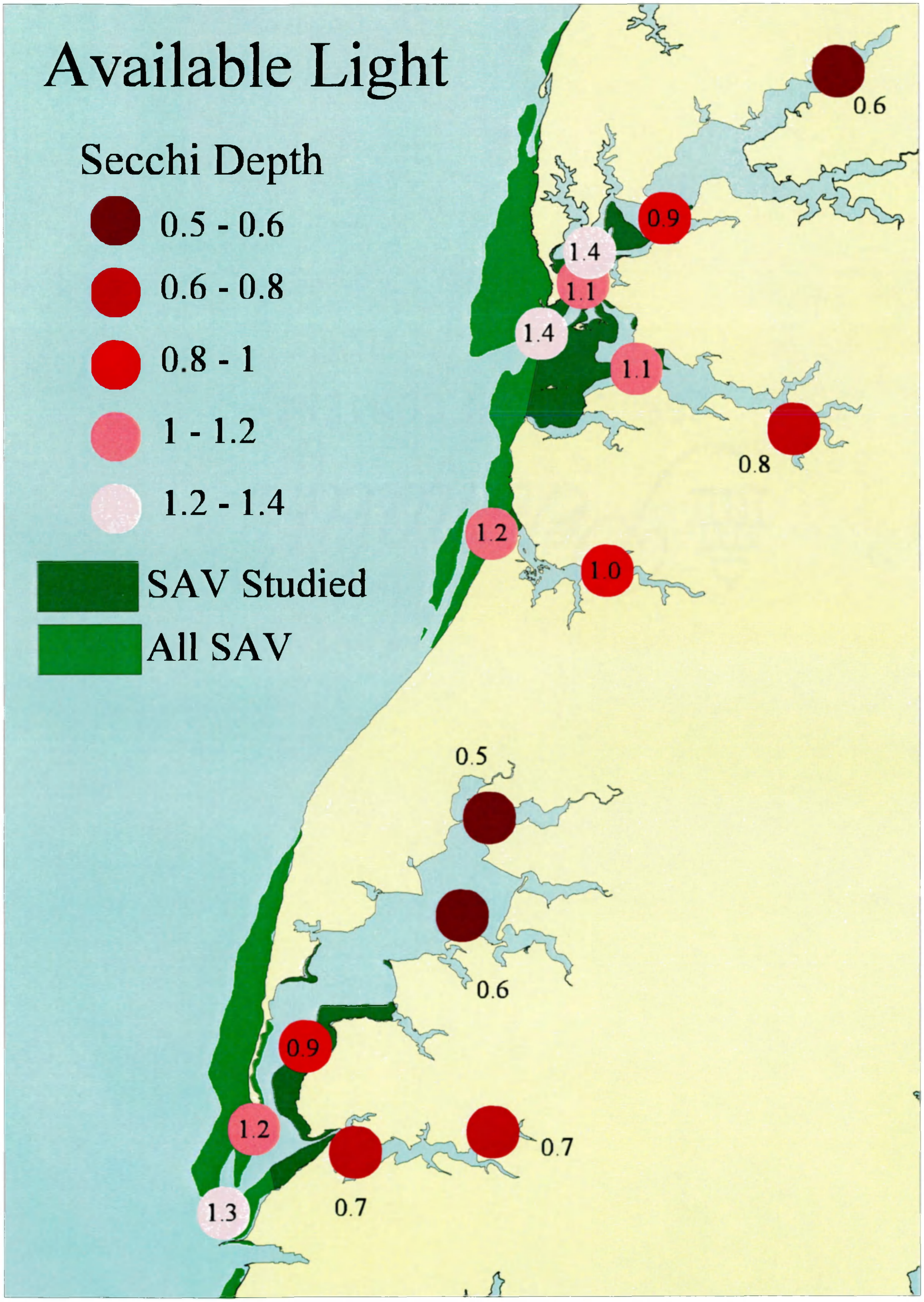
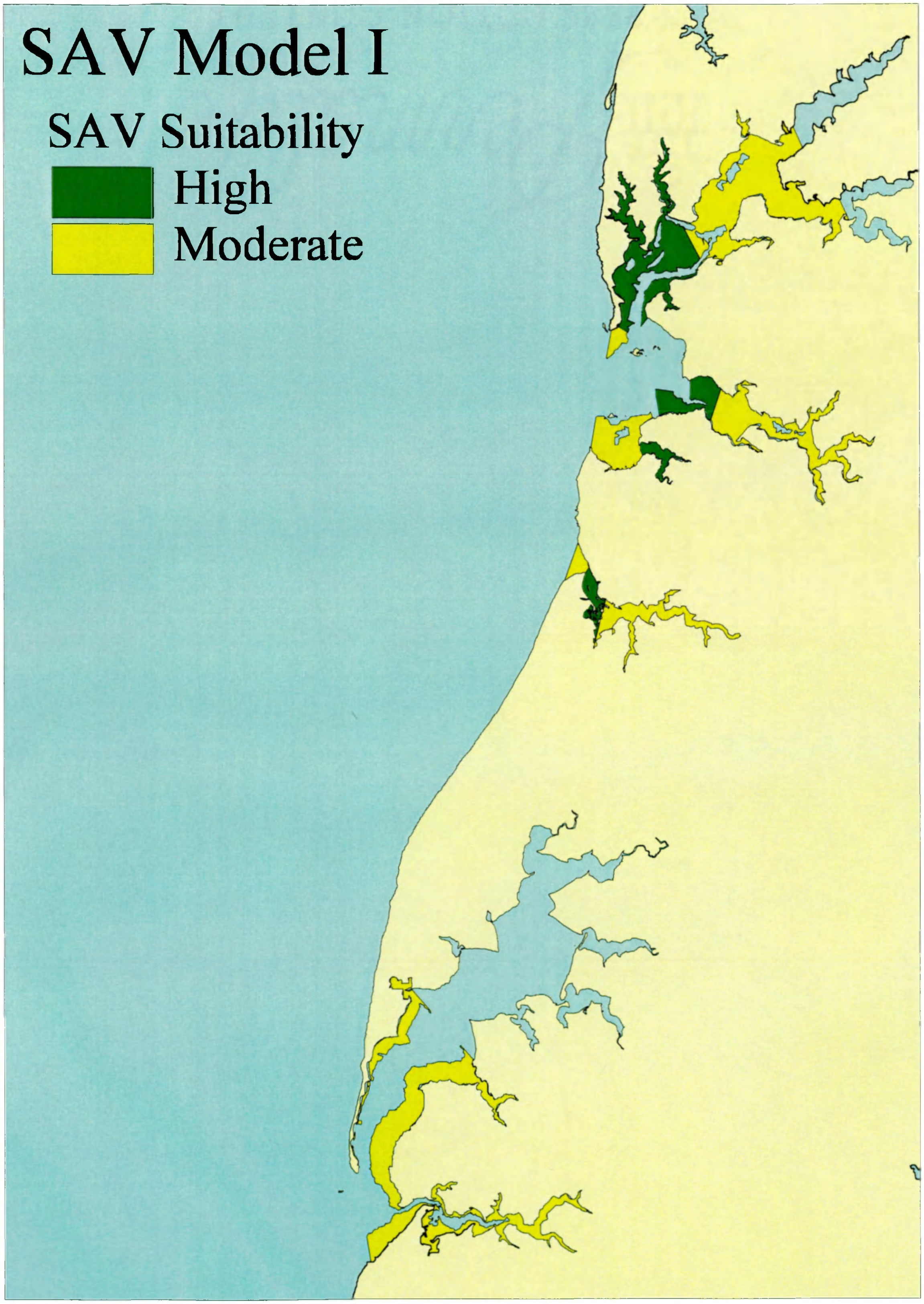


FIGURE 16. Light Component I



FiIGURE 17. SAV Model I



FIIGURE 18. SAV Suitability Model Validation I

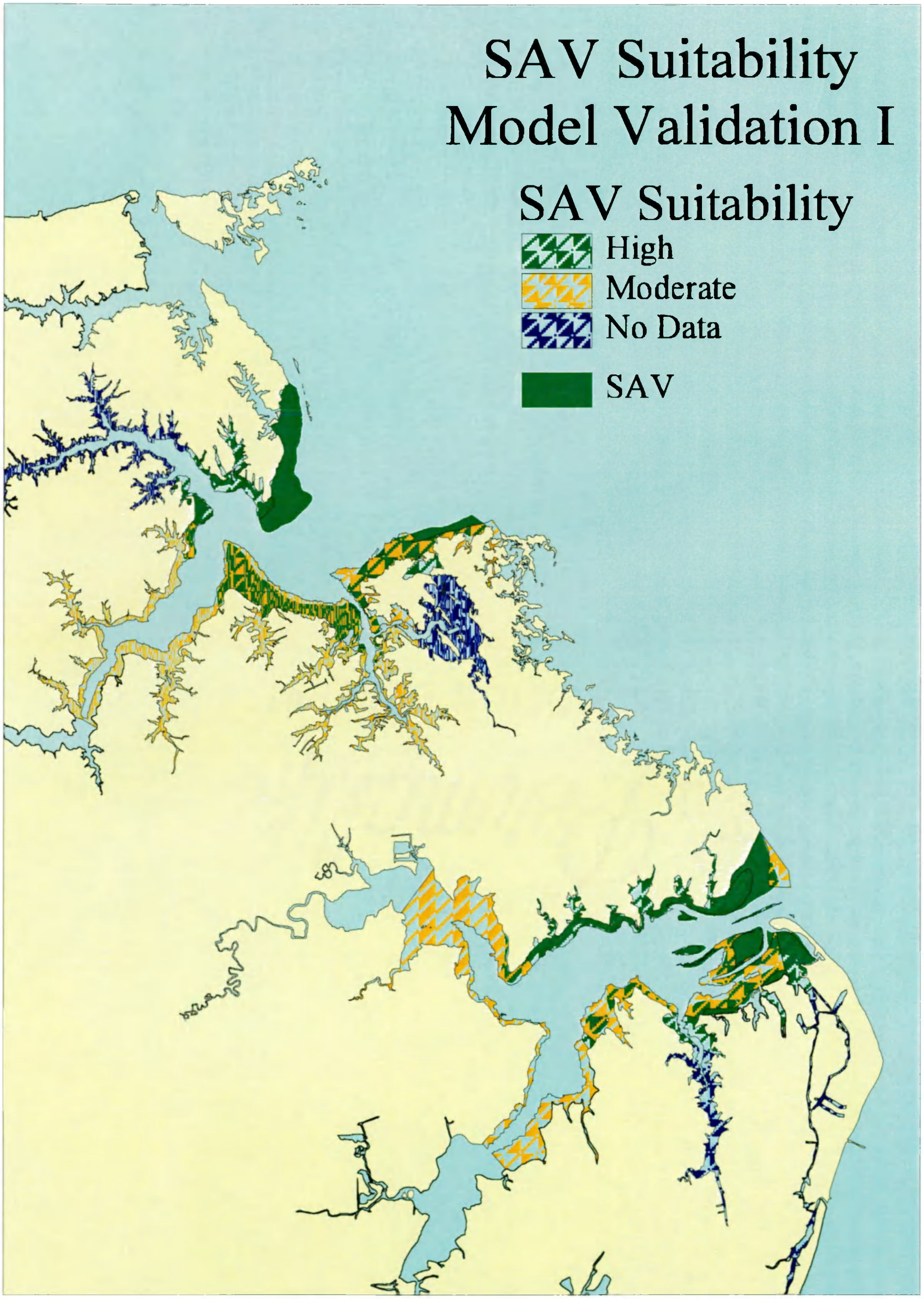


FIGURE 19 - SAV Model II

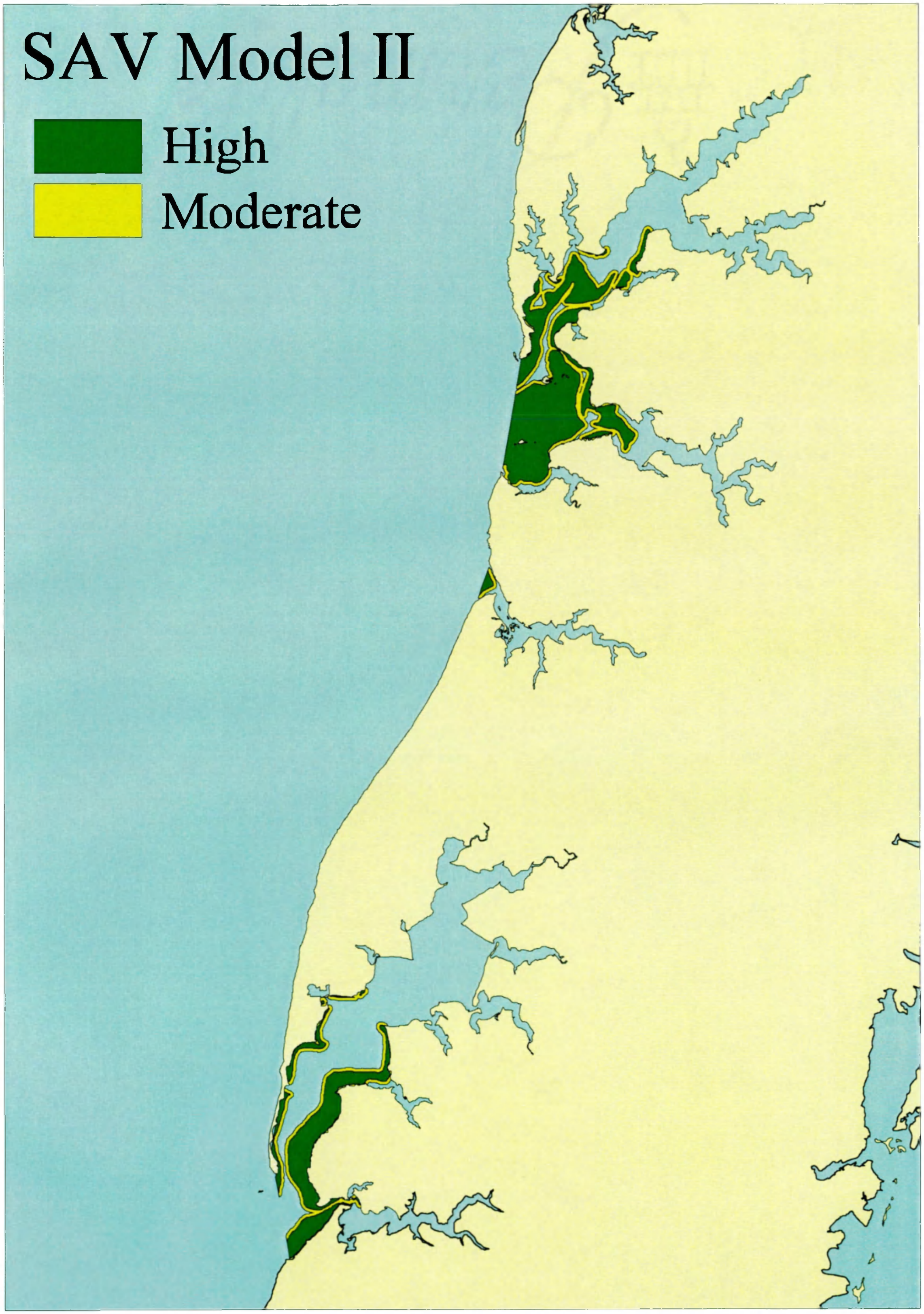


FIGURE 20. SAV Suitability and Validation II

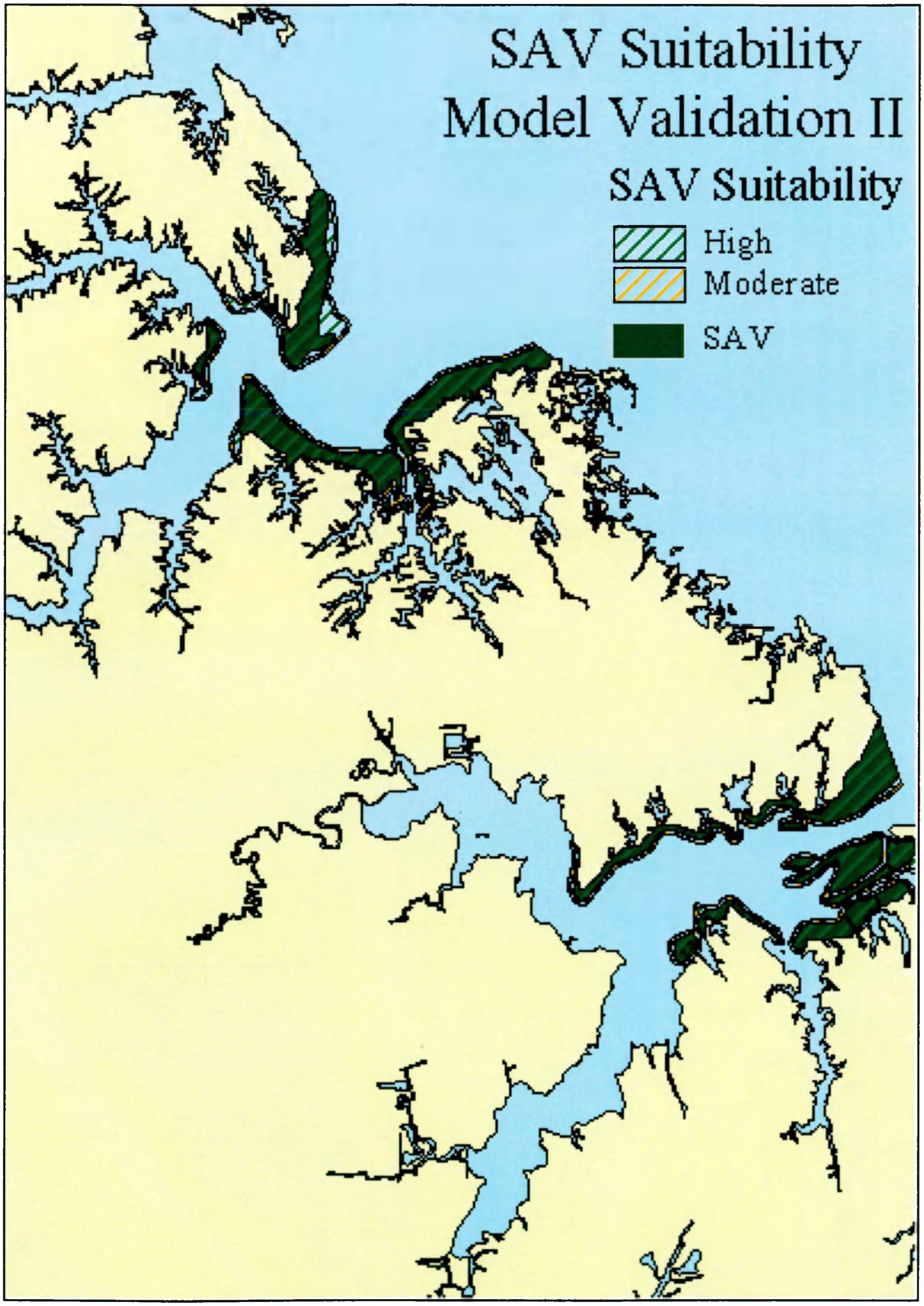


FIGURE 21. Conflict Model I

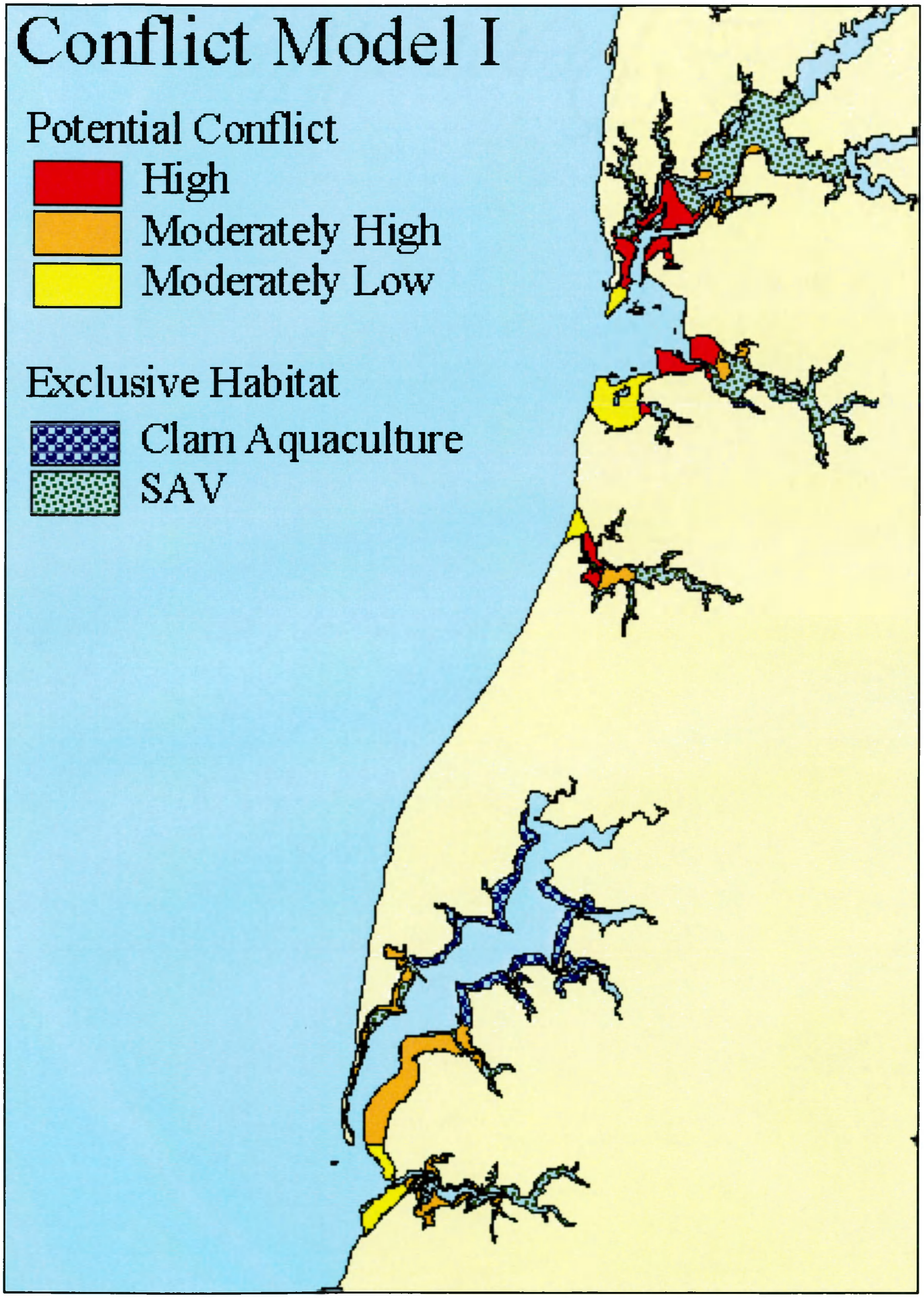


FIGURE 22. Conflict Model II

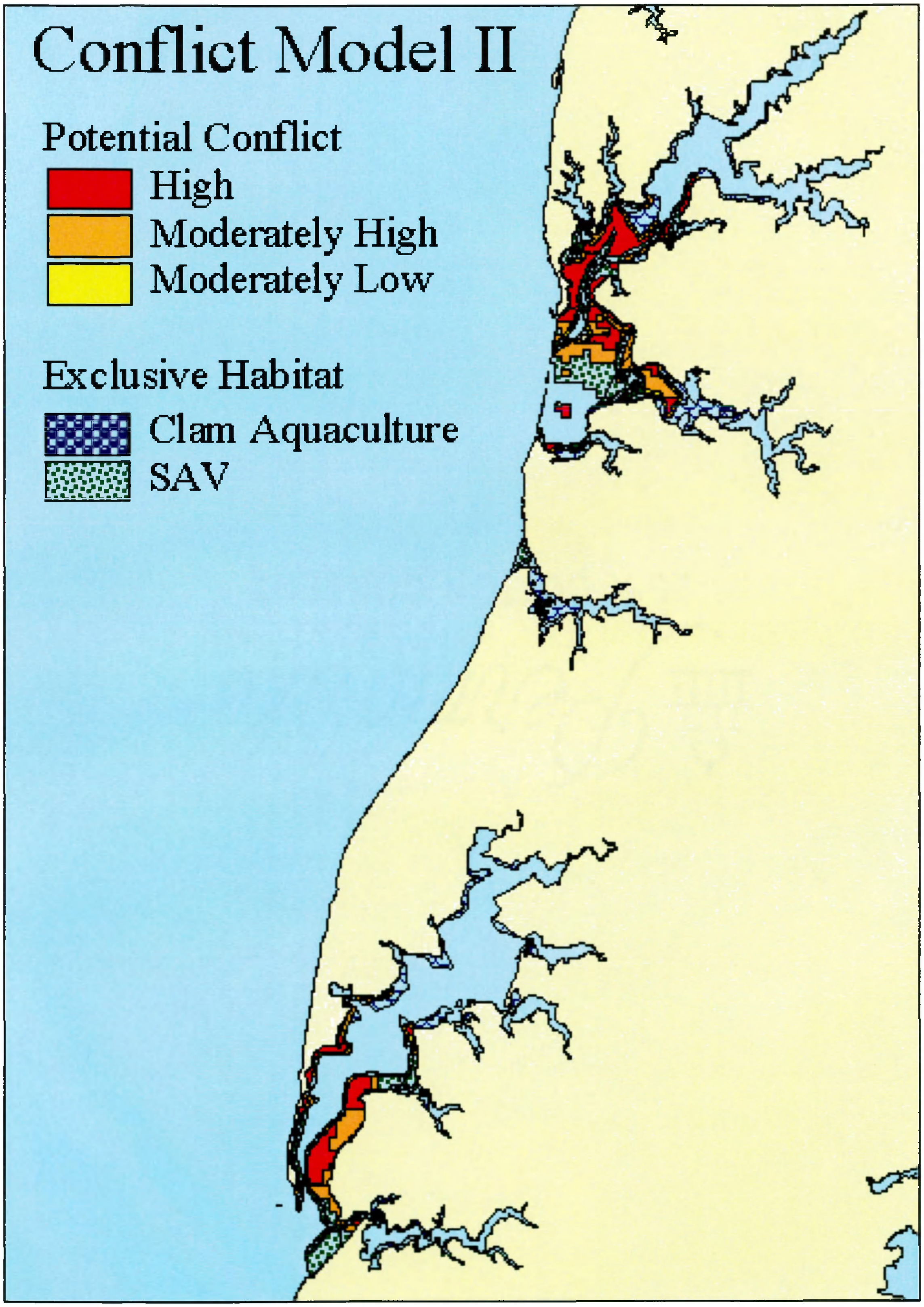


FIGURE 23. Conflict Model III