The Integration of GIS and Remote Sensing in an Ecological Study of Queen Conch, *Strombus gigas*, Nursery Habitats

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ABSTRACT

The queen conch, *Strombus gigas*, is an important demersal resource throughout the greater Caribbean region, both commercially and culturally. Widespread declines in both juvenile and adult stocks have led to intensive studies and the need for immediate management actions. In this study Geographic Information Systems (GIS) and remote sensing were utilized in an ecological assessment of juvenile conch requirements in a near-pristine area of the Exuma Cays, Bahamas. The GIS was designed to examine trends in nursery distributions over a seven year period, and spatially associate those areas with important biological (seagrass biomass) and physical (bathymetry and tidal circulation patterns) habitat features. Image processing was integrated with the GIS to examine an historic Landsat TM image for estimation of seagrass. Results indicate that although aggregations shift from year to year, the most stable nurseries appear to be distributed about a central core. Those areas were found to be associated with a particular combination of habitat features, as well as suitable hydrographic conditions. This study showed that GIS and remote sensing can be effective tools for addressing complex ecological questions and may provide an innovative alternative for fisheries management strategies.

KEY WORDS: GIS, habitat, imagery, juvenile, nursery, *Strombus gigas*

INTRODUCTION

The queen conch, *Strombus gigas*, has been intensively studied in recent decades due to its importance as a demersal resource and the associated decimation of adult and juvenile stocks throughout the greater Caribbean region. The decline in annual harvests and the inability to sustain present demands, both for commercial export and local consumption, has led scientists to focus on

Annual Nursery Distribution

Juvenile aggregations were mapped annually, during the summers, from 1989 to 1995 (method described by Stoner and Ray, 1993), and plotted on charts (scale = 1:25,000). Aggregations contained juveniles in densities greater than 0.1 conch/m^2.

Seagrass Biomass

Seagrass biomass was determined from a previously processed earth orbiting satellite scene: 29 January 1985 (Armstrong, 1993). Armstrong's vegetation assessment used the visible bands of the Landsat Thematic Mapper (TM). The 30x30 m cell scene was band-ratioed, and algorithms were applied, producing a seventeen class image. That historic raster image was acquired for this project and further processed as necessary for transformation to a vector GIS environment. The completed digital image was grouped into six biomass classes representing seagrass densities of 0 to >79 g/m^2.

Physical Features

In addition to the remotely sensed data, physical habitat feature data were collected using conventional field survey techniques. Bathymetric data were collected by boat, and positions were determined by GPS (Magellan 5000). Measurements were collected from 6 July to 4 August 1995 at 770 stations. Determination of the location of the tidal front (at high tide) was made by observing surface temperatures, differentiating the cooler oceanic water from the warmer water of the shallow bank, during both neap and spring tides. This synoptic, temperature inferred survey was designed to generate maps depicting the extent/pattern of the tidal excursion. Two boats, equipped with bucket thermometers accurate to 0.05°C, followed a grid pattern starting at adjacent inlets and fanning out across the bank. A survey window of seventy minutes was established in which to sample the site. Two replicate surveys at both extreme tidal cycles were made (neap tides: 2,3 July 1995; spring tides: 8,9 July 1995), collecting from 81 to 110 temperature readings per survey (station positions determined by GPS).

GIS Analysis

The GIS design used in this project incorporated ERDAS 7.5 system software or digital image processing integrated with both PC (version 3.4.2B) and UNIX (version 7.0) platforms of ARC/INFO system software for vector format spatial analysis. The PC ARC/INFO system was used for the central processing of all the completed data sets. All thematic data were captured into the GIS and prepared as individual coverages prior to overlay and query.

Annual nursery distributions were digitized from charts and the resulting

ARC/INFO coverages were overlaid to indicate trends in size and location. Overlays were performed in two manners; 1) a union of all seven coverages, indicating where juveniles were located at any time in the seven years ("overall" nursery area), and 2) an intersection of the seven coverages indicating where juveniles were located in at least four of the seven years ("optimal" nursery area). The resulting overlaid coverages were then used to examine those particular geographic areas within the following habitat feature coverages.

The seagrass estimation coverage was queried to examine the distribution of seagrass within the "overall" and "optimal" nursery areas, as well as throughout the entire study site. The bathymetric point coverage was transformed to a polygon coverage and queried in the same manner. The temperature point coverages were transformed to polygon coverages and a determination of the tidal front was made from isotherm gradients. The profile of the temperature inferred tidal front, for both neap and spring tide coverages, were then examined in relation to the location of nursery areas.

RESULTS

Nursery Distributions

The mapping and overlay of nursery distribution coverages indicated that although aggregations displayed considerable inter-annual variation they remained within three distinct, isolated nursery sites. Average annual aggregation size at each nursery site was >19 ha, yet comprised less than 1% of available bank habitat. The topological overlays showed that the average "overall" nursery area covered 111 ha, while the "optimal" nursery areas were typically an order of magnitude smaller (avg. 8 ha). "Optimal" nursery areas were generally located in the center of the "overall" nursery areas, indicating that aggregations tend to be distributed about a central core. The three primary nursery areas were each located within 5 - 6 km of the closest inlet, and within or adjacent to tidal channels.

Seagrass Distribution

Analysis of the completed coverage estimating seagrass showed that seagrass meadows were distributed over 86% of the study area. Seagrass biomass densities within the "overall" and "optimal" nursery areas ranged from 9 – 75 g/m^2 and 18 – 75 g/m^2, respectively. The most persistent juvenile aggregations were located in or adjacent to seagrassbeds of 32 – 75 g/m^2. Expansive areas of uninhabited seagrass beds within these density ranges were indicated throughout the study area.

Bathymetry

Over 70% of the study area was found to be within a depth range of 1 - 3 m.

Greatest depths (4 – 5 m) occurred in tidal channels. Depths within the "overall" and "optimal"nursery areas ranged from 1 – 4 m and 2 – 4 m, respectively. Two of the three nursery sites were associated with moderate topographic gradients. "Optimal" depths (2 – 4 m) were found over 62% of the available bank area.

Tidal Excursion Patterns

The tidal excursion maps generated showed a pronounced temperature gradient, indicating the location of the tidal front. Both neap and spring tide coverages indicated a well defined tidal plume extending from 5 to 8 km, respectively, beyond inlets onto the bank. In each case, nurseries laid within the tidal excursion of oceanic water moving onto the bank from Exuma Sound. This condition of oceanic flushing was found across nearly 50% of the study area.

DISCUSSION

Increased human pressures on the marine environment have prompted resource managers to step up efforts in acquiring and analyzing ecological data. Monitoring of fishery resources using traditional management techniques will find resource managers ill prepared to meet present demands (Chagarlamudi and Plunkett, 1993). Current needs require precise and timely information, and the ability to store, manage, and process that information (Friel and Haddad, 1992; Welch *et al.*, 1992).

Two technological tools; remote sensing and Geographic Information Systems (GIS), have emerged in recent years to fill those needs, particularly in applications to coastal environments (Chagarlamudi and Plunkett, 1993). The potential for these tools in assisting in marine habitat assessment has only recently been exploited. In this study GIS and remote sensing were utilized for the first time in the investigation of conch distributions, to both obtain large-scale data and perform integrative spatial analyses using a multi-feature database.

Although queen conch populations have been intensively studied throughout the greater Caribbean region scientists have had limited success in explaining ecological requirements (Stoner *et al.*, 1994; Stoner *et al.*, 1996). By using GIS in this study it was possible to incorporate multi-feature habitat data in an easily managed database, synthesize multiple year distributional data for juvenile distributions, and spatially associate those data to define optimal habitat conditions. Similar designs have recently been implemented in the assessment of resources in marine reserves (Rogers, 1992), but few studies have integrated the assessment of habitat features with the spatial distribution of important fishery species (Sluka *et al.*, in press).

In addition to the data processing environment afforded by GIS, the satellite imagery provided a detailed seagrass (*Thalassia testudinum*) biomass assessment, essential due to the habitat association of demersal fishery species (Greenway and Fry, 1988; Kirkman *et al.*, 1988). Remote sensing for biomass of monospecific stands of seagrass has been conducted in few studies and results have not always been accurate or complete (Virnstein and Cairns, 1986; White, 1986). However, the historical image utilized for this study was previously determined to be highly accurate and provided a cost effective means for obtaining density data over a large area (Armstrong, 1993). Analyses showed that optimal nursery habitat occurred in areas of medium density seagrass, particularly along a seagrass gradient.

Variation in size and location of conch aggregations throughout the seven years surveyed indicated varying levels of stability between the primary nursery sites. More permanent nurseries were found to be strongly associated with tidal flow fields (at depths of 2 – 4 m), supporting earlier theories (Stoner *et al.*, 1996). In addition, the tidal excursion data show that all three nurseries were flushed with clear, oceanic water on every tidal cycle. These findings suggest that particular tidal circulation patterns are critical to juvenile distributions, and that seagrass biomass alone may not be as important as previously believed. This association of tidal fronts with faunal distributions has been well established for estuarine systems (Wolanski, 1988; Largier, 1993), but is novel to the study of coastal/island systems. It now appears likely that juvenile conch require not only a combination of suitable habitat features, but particular hydrographic conditions as well.

These findings have important implications for fishery management as well as conservation efforts. An improved understanding of ecological requirements should increase our chances of success in outplanting conch and enhancing nursery areas. However, our increasing realization of the restrictive ecological requirements for juveniles now suggests that preserving existing stocks may be more effective than attempting to re-establish decimated populations. The analyses provided by GIS and remote sensing may enable scientists to identify critical habitats, thus indicating appropriate areas for protection and assisting in marine reserve design (Friel and Haddad, 1992; Katz, 1994). As marine ecologists and fisheries managers work together to solve problems of overfishing and changes in population structures, these tools and their innovative use will become increasingly important.

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