Monitoring Spatial Change in Seagrass Habitat with Aerial Photography

Abstract

Photointerpretive techniques were applied to map the spatial change of seagrass habitat between 1985 and 1988 in Back Sound and southern Core Sound, North Carolina. The method constrains photography to optimize visualization of photic submerged land. It accentuates surface level training and verification of seagrass habitat observed in photographs to minimize classification errors due to variability of photographic signatures of benthic features. The method is unique in its registration of habitat data to concurrent shoreline manuscript base maps from the National Oceanic and Atmospheric Administration, National Ocean Service.

Seagrass habitat is abundant in the study area – approximately 7,000 hectares or 35 percent of the subtidal land – with a high degree of overlap in 1985 and 1988. The overall net change was a 6 percent decrease in seagrass habitat. Locations of habitat loss from 1985 to 1988 were confirmed by site visit, and two of these could be attributed to specific anthropogenic activities.

Introduction

Data on spatial change of seagrass habitat is needed to improve management of these productive habitats and the exploited and protected species that they support. Seagrasses are adversely affected by development of adjacent coastal uplands and wetlands, excessive freshwater, pollution, turbidity, and potentially by global climate change. The location and extent of seagrass habitat may be a crucial indicator of water quality and overall health of coastal ecosystems (Dennison *et al.*, 1993). A methodology to observe and display spatial change in seagrass habitat is a prerequisite to a nationwide (Thomas and Ferguson, 1990) or global change detection effort.

Seagrasses are important on a global scale (Den Hartog, 1970). Seagrass habitat is one of the most common and productive habitats in coastal marine waters worldwide (Ferguson *et al.*, 1980). Although often overlooked because submersed, seagrass habitat may equal or exceed salt marsh habitat, for example, in terms of areal extent and organic production rates in many locations. Their pivotal role in the coastal ecosystems of numerous countries and of all continents except Antarctica has been recognized (Larkum *et al.*, 1989). Organic production measurements range from 300 to 1500 g C/m^2/year (Ferguson *et al.*, 1980). Seagrasses and other submersed plants inhabit the low intertidal and subtidal depths of the photic zone of estuaries and nearshore coastal waters. These plants calm the water, stabilize and enrich sediment and provide food and refuge for a wide variety of waterfowl, sea turtles, manatees, commercially and recreationally exploited fish and shellfish, and their prey (e.g., Zieman, 1982; Phillips, 1984; Thayer *et al.*, 1984; Zieman and Zieman, 1989).

Monitoring spatial change in seagrass habitat is vital to assure viability of coastal ecosystems, but methodology for acquisition of this critical data is in the development and demonstration stage. Quantitative historical data, with few exceptions, does not exist. Monitoring spatial change in seagrass habitat requires photointerpretation of benthic features, extensive surface level observation, and accurate base maps (Ferguson and Wood, 1990; Orth *et al.*, 1991a). For example, metric quality photography must be timed not only to coincide with high seasonal biomass of the predominant seagrasses but also with low water turbidity, low surface waves, and low tide. Variable depth, water clarity, bottom sediment, epiphytes, exposed deposits of peat from eroding marshes, exposed bed rock, macroalgae, and mollusc shells can confuse identification of seagrass habitat in the photographs. Questionable features in the photographs require surface level verification. Registration of photographs to base maps by local horizontal control often relies on geographic features such as shoreline because seagrass habitat can be distant from the cultural features preferred for registration. As a consequence, accuracy of seagrass habitat data may be limited by the spatial accuracy of shorelines in the base maps. Alternatively, registration to cultural features can lead to inconsistencies between habitat data and shorelines.

The National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS) produces highly accurate data of shorelines and other coastal features (Ellis, 1978; Crowell *et al.*, 1991). Shoreline and coastal data, in graphic and digital form, are products of the NOAA Coastal Mapping Program. Copies of these data are available from NOAA, NOS. Shoreline data are produced from tide-coordinated photographic data and ground level survey data by the Photogrammetry Branch of NOAA, NOS and meet or exceed National Map Accuracy Standards (Slama, 1980; NOAA Photogrammetry Branch, 1989; Swanson, 1949). Horizontal ground control meets or exceeds third-order, class I specifications found in the geodetic control standards (Federal Geodetic Control Committee, 1984). Coastal mapping projects provide data that depict the delineation of the mean high water line, the limit of emergent vegetation (apparent shoreline) and/or cultural shoreline, and, for the present study area, the approximate mean lower low water line.

This report details an approach to graphically display spatial change in seagrass habitat based on interpretations of aerial photographs registered to contemporary NOAA, NOS

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shoreline base maps in eastern North Carolina. The research is a prototype for change detection of coastal submersed habitat in the CoastWatch Change Analysis Project (C-CAP) of NOAA's Coastal Ocean Program (Dobson and Bright, 1991; Ferguson and Wood, 1990; Thomas and Ferguson, 1990; Thomas *et al.*, 1991).

Methods

Study Area

Separated from the Atlantic Ocean by Shackleford Banks and Core Banks, the study area comprises about 19,000 hectares of submerged land between Cape Lookout and Drum Inlet, North Carolina (Plate 1). Included are southern Core Sound, between Core Banks and the mainland, Back Sound, between Shackleford Banks and Harkers Island, and The Straits, between Harkers Island and the mainland. The mainland and Harkers Island are rural and relatively undeveloped. Core Banks and Shackleford Banks are within the Cape Lookout National Seashore and are virtually undeveloped. Most bottoms in the study area are in the photic zone. Broad shallows, less than 2 metres deep at mean lower low water, are punctuated by relatively few deeper basins and channels. Shallow draft recreational and commercial fishing vessels frequent the area. Freshwater is from drainage of adjacent wetlands, low-lying forests, farmland, scattered homesteads, and a few small towns. Exchange of seawater with the Atlantic Ocean occurs through Drum Inlet on the northern extreme, Barden Inlet adjacent to Cape Lookout, and Beaufort Inlet, about 7 km west of the study area.

Seagrass habitats are major features of the study area (Ferguson *et al.*, 1989b; 1992). The most widespread and abundant species is *Zostera marina* (eelgrass) but *Halodule wrightii* (shoalgrass)(Ferguson *et al.*, 1993) and *Ruppia maritima* (widgeon grass) are often found with eelgrass and can be locally dominant. Seasonal maximum standing crop and flowering of eelgrass in North Carolina is late winter to early spring (Thayer *et al.*, 1984).

Aerial Photography

Seagrass habitat was captured in vertical metric quality aerial photographs by NOAA, NOS, Photogrammetry Branch using standard flight and photographic procedures (NOAA, Photogrammetry Branch, 1980). The aircraft and flight crew staged to the area based on the phenology of eelgrass, east coast weather forecasts, and local tide data. Aerochrome MS Film 2448 color-reversal film was exposed in March, 1985 (1:20,000 and 1:12,000 scale). (Reference to manufacturer or trade name does not imply endorsement by the Federal Government.) Color-reversal film and false-color-reversal infrared film (Aerochrome Infrared Film 2443) were exposed in tandem cameras at a nominal scale of 1:24,000 in April, 1988. The endlap of sequential exposures was 60 percent in 1985 and 80 percent in 1988.

Photography was coordinated with low tide and sun angle and conducted with minimal haze, no clouds below the aircraft, and no visible shadows of high clouds. Water was essentially free of white caps and clear enough for visualization of vegetated and shallow unvegetated bottoms. Episodic wind, haze, local turbidity, and airborne pollen often precluded photography for one or more days. Sun angle during photography ranged from 15 to 30 degrees. This sun angle localized sun glare to one edge of the photographs while presenting illumination below the water surface. Optimum sun angle for photobathymetry is 20 to 25 degrees (Keller, 1978).

Photointerpretation

Seagrass habitat was observed in the photographs with high quality viewing optics (Wild, AVIOPRET, APT2, photo-stereoscope). Polygons of habitat were traced on overlays affixed to each photograph. We did not differentiate continuous from discontinuous coverage, sparse from dense coverage, or species of seagrass from the photographs for biological and methodological reasons. The occurrence of small patches of sparse seagrass can increase abundances of animals dramatically over that of unvegetated bottom in North Carolina (M. Fonseca, unpublished data). Quantification of percent cover and plant density within seagrass habitat from aerial photographs has been problematic (Lo and Ries, 1992). Monitoring change in percent cover within habitat based on photographs at different scales was not recommended (Orth *et al.*, 1991a) and, in North Carolina, species of seagrasses often are closely associated in mixed communities.

The identification of seagrass habitat in the photographs required visual evaluation of spectral reflectance, tone, texture, contrast, context, and hue information which was supported by extensive field training and signature verification at surface level. Delineation of seagrass habitat was a function of minimum detection unit and minimum mapping unit. At a photographic scale of 1:24,000, and ideal conditions (i.e., abundant seagrass growing on light-colored sediment in shallow, clear, calm water) a minimum detection unit of 1-metre diameter was possible. The minimum mapping unit in this study was 0.03 hectare. An area with a diameter of about 20 metres was circumscribed by a drawing pen with a 0.25-mm diameter tip at the compilation scale of 1:24,000. Discontinuous distributions of seagrass were mapped according to objective and subjective criteria: (1) the total area exceeded 0.03 hectare; (2) the local context, hue, tone, and texture of benthic features indicated continuity or smooth gradients within the distribution; and (3) intervening areas of unvegetated bottom were not large relative to the minimum mapping unit.

Accurate location, shape, and size of polygons of seagrass habitats was obtained with a zoom transfer scope. Delineated polygons, still affixed to the photograph, were referenced and edge matched onto transparent stable base overlays of direct copies of NOAA, NOS, shoreline manuscript maps on stable base medium. The base maps were NOAA, NOS shoreline manuscripts, TP #'s 1516, 1517 and 1518, Project Number CM-8710, reduced from a scale of 1:20,000 to 1:24,000. These manuscripts had been compiled from photographs taken in 1988.

Seagrass habitat for both 1985 and 1988 was interpreted and transferred by one individual onto separate overlays of the base maps. There was no side-by-side comparison of photographs, interpretations, or compiled habitat data between the two years until all of the interpretations and transfers were finished. Interpretation and transfer of the 1988 data was completed before work was started on the 1985 photographs. The habitat data and the base maps were consolidated and reduced to 1:36,000 scale. The 1985 and 1988 polygons were reproduced onto peelcoats to create open windows for the color screening process (Robinson *et al.*, 1978). The type on the shoreline manuscripts was edited to eliminate non-essential information and to reflect the reduced scale, and the final product was published in two colors (Ferguson *et al.*, 1992). The spatial data from the published chart were photographically reduced and the shorelines were redrawn at the reduced scale to prepare Plate 1.

Polygons of seagrass habitat were measured at the compilation scale with a personal computer-based video image

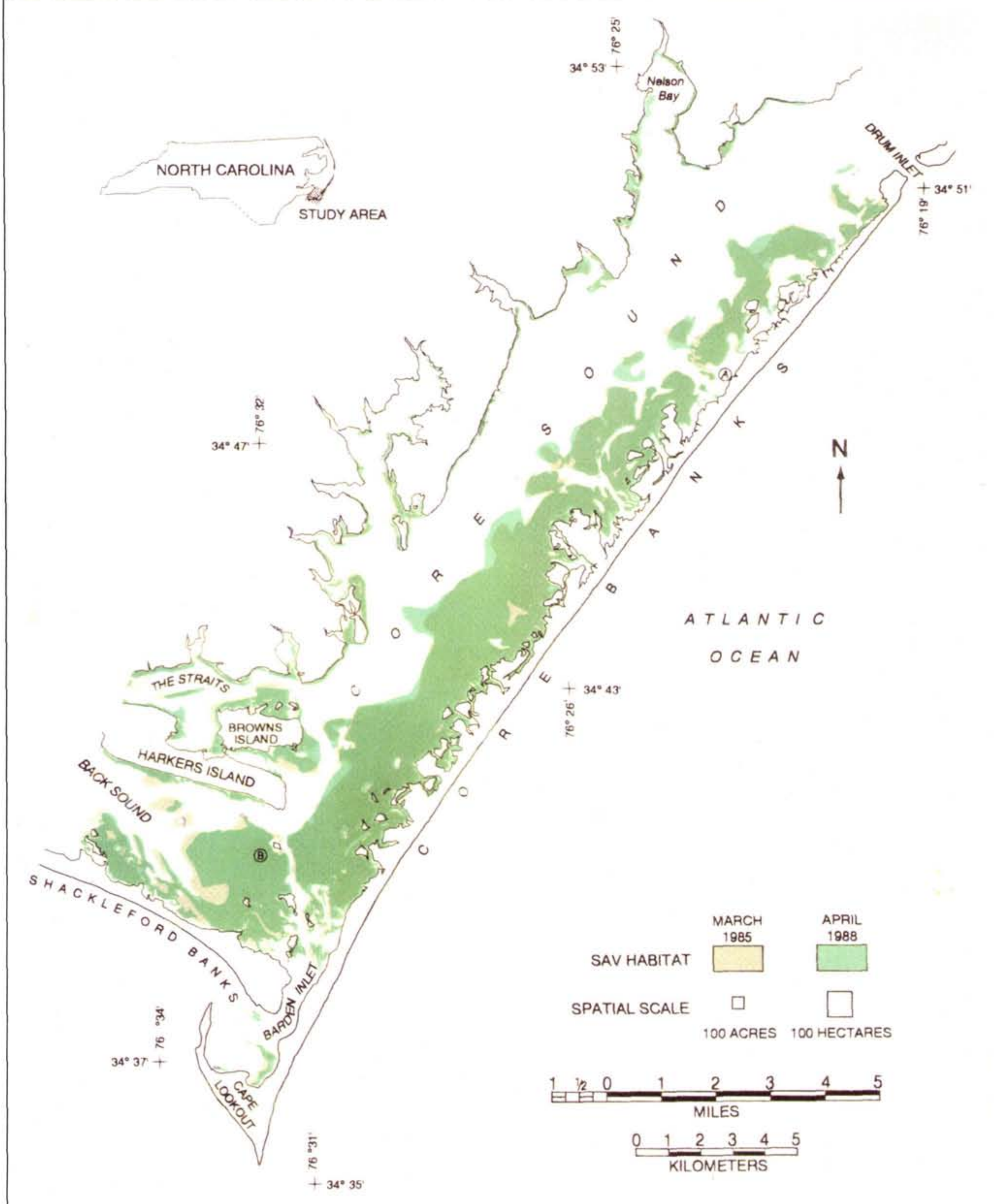

Plate 1. Occurrence of seagrass habitat in Back Sound and southern Core Sound in 1985, gray, and in 1988, green. Pure gray indicates habitat present in 1985 but not in 1988. Light green indicates habitat in 1988 but not in 1985. The overlap of gray and green indicates the presence of habitat in both 1985 and 1988. (A) Head of The Hole, an area where seagrass habitat was decreased as a result of mechanical harvesting of clams. (B) Spoil deposition island from which uncontained spoil was released into the water and buried seagrass habitat.

analysis system (Southern Micro Instruments, MICROCOMP). The minimum measurement unit in the video imagery was 4 pixels, or about 0.01 hectares.

Surface Level Surveys

Small boat surveys were conducted during March, 1988, to familiarize the photointerpreter with the study area, to determine the distribution of species of seagrasses, and to collect environmental data. Stations were examined by wading, snorkeling, or SCUBA diving, depending on water depth and clarity. For March, 1988, 42 stations were chosen by overlaying a rectangular grid (stations 1.3 scaled nautical miles apart) on NOAA Nautical Charts (#'s 11544 and 11545). Stations were limited to water depths shallower than the 10-foot contour (mean lower low water), deeper than the maximum depth that supports seagrasses in North Carolina (Ferguson *et al.*, 1989b), and were located in the field by LORAN C instrumentation. The spatial extent of a station included a radius of about 0.2 nautical miles. Species of seagrass were identified, and sediment, Secchi depth, water depth, and salinity were sampled or measured.

Small boat surveys were conducted in October, 1989, and May to August, 1990 after initial interpretation of the 1988 photographs. These surveys verified the range of seagrass signatures and identified questionable features in the photographs.

Results and Discussion

Surface Level Surveys

In March, 1988, seagrasses occurred at water depths of 0.2 to 1.7 m and at 32 of the 42 stations: eelgrass at all 32 stations, shoalgrass at 20 of the stations, and widgeon grass at 6 of the stations. Secchi depth, a measure of light penetration into the water, ranged from 0.3 to 1.5 m for the 11 observations in water deep enough to take a measurement. Mean Secchi depth, 0.8 m, exceeded the mean water depth, 0.6 m (range of 0.2 to 1.7 m). Mean salinity was 32.9 ppt (range of 26 to 38 ppt). The sediment was predominantly sand (mean of 76 percent, range of 37 to 89 percent) with the remainder primarily silt-clay. Gravel was absent from most of the samples. A mean of 1 percent gravel was due to a few samples having up to 21 percent gravel. Organic matter in the sediment was low (mean of 1.57 percent dry weight, range of 0.42 to 4.31 percent dry weight). For analytical methods, frequency of species occurrence, and ancillary data for 1985, refer to previous publications (Ferguson *et al.*, 1989a; 1989b).

The surveys in 1989 and 1990, were conducted to limit false positive delineations of seagrass. For example, small circular features observed near the mainland in Core Sound seemed to be out of context. The features were identified as automobile tires covered with macroalgae. These surveys also verified the range of signatures of seagrass habitat and confirmed apparent losses of habitat between 1985 and 1988.

Aerial Photographic Study

Seagrass habitat is a major resource in the study area, comprising about 35 percent of the subtidal land (Plate 1). Total extent, location, and size distribution of polygons of seagrass habitat was similar in 1985 and 1988. Total area of habitat changed less than 6 percent from 7030 hectares in 1985 to 6637 hectares in 1988. Polygons along the mainland and Harkers Island tended to be linear and close to shore. Large broad areas of seagrass habitat occurred in the subtidal shallows east of Browns Island, north of Shackleford Banks, and west of Core Banks. The total number of habitat polygons was similar in the two years, 151 in 1985 and 149 in 1988. Polygons tended to occur in the same approximate sizes, shapes, and locations. Five percent of the polygons exceeded 48 hectares and 61 hectares in 1985 and 1988, respectively. The largest in 1985 was 4187 hectares but most were much smaller (mean of 1.6 hectares and median of 1.4 hectares). The largest in 1988 was 3189 hectares but most were much smaller (mean of 1.9 hectares and median of 1.6 hectares). The smallest unvegetated area mapped within seagrass habitat was 0.06 hectares.

Locations of apparent gain or loss of habitat between the two years were re-examined to categorize these apparent changes: confirmed change with known cause, confirmed change with unknown cause, and unconfirmed change. Four locations of habitat loss were confirmed. Two of these were attributed to their causes. Mechanical harvest of clams, in North Carolina by a process called clam kicking, eroded bottom sediments with propeller wash to bring clams to the surface. This fishery (N.C. division of Marine Fisheries, 1988) eroded seagrass habitat near Head of the Hole, in Core Sound (A in Plate 1), and left characteristic scars. These scars were visible in the photographs and were confirmed by site visit. In early 1988, a dredging operation (Wilmington District Corps of Engineers, 1987) buried seagrass habitat when uncontained spoil was deposited on a spoil island (B in Plate 1). The northward expansion of the spoil island, shallowing of open water and burial of seagrass was observed by M. Fonseca (personal communication). Losses of seagrass habitat in Back Sound and in The Straits (Plate 1) were confirmed by site visit, but these losses were due to unknown causes.

Some instances of apparent habitat increase between 1985 and 1988 remained unconfirmed because of limitations in the 1985 photographs and absence of surface level surveys in 1985. The presence of visual clues in photographs that were consistent with unvegetated bottom was sufficient to delineate with certainty, in most cases, edges of seagrass habitat. Unfortunately, photographic coverage in 1985 was not complete for parts of central Core Sound due to the limited foot print of the 1:20,000-scale photographs and apparent increases there could not be confirmed. In addition, benthic features were partially or totally obscured by turbidity in a few locations in 1985. In 1988, the photographic scale was reduced to 1:24,000 which improved coverage, and photography was delayed until after the end of the season for mechanical harvest of clams (N.C. Division of Marine Fisheries, 1988), a major source of turbidity. An apparent increase in seagrass habitat which could not be confirmed was in Nelson Bay (Plate 1). Local turbidity plumes from small creeks were visible in the 1985 photographs and these may have obscured habitat.

Findings

Photography

Panchromatic, natural color, and false-color infrared are three film emulsions that may be used to record submersed coastal habitat. Panchromatic is the least expensive and has a relatively fast effective aerial film speed but does not provide color dependent visual clues. In side-by-side comparisons in this study, color-reversal photographs were superior to false-color-reversal infrared photographs for visualization of seagrasses in moderately turbid water. Natural color film has superior water penetration, near 75 feet in clear water, making it the most desirable of the three for general photointerpretation of benthic details (Johnson and Munday, 1983). Color negative diapositives (Aerocolor Negative Film 2445) have demonstrated greater contrast compared to color reversal film (2448) (NOAA Photogrammetry Branch, unpublished data).

Three recommendations in obtaining photographs for use in measuring seagrass habitats are to (1) make the final decision to photograph while in the air, based on direct observation of prevailing conditions by the flight crew and surface level observers; (2) use color negative diapositives for superior water penetration and sharpness of image; and (3) quality review the photographic negatives (shadows, white caps, wind rows, turbidity, endlap, and sidelap) for an expedient evaluation of the mission's objectives, while the aircraft and crew are still in the vicinity.

Accuracy

Qualitative accuracy of habitat delineations is critical to effective change detection. Seagrasses and other benthic features present a variety of signatures in aerial photographs due in part to variability in coverage, species present, sediment type, water depth, water clarity, and surface conditions. The accuracy of submersed habitat data, therefore, is particularly dependent upon the conditions at the time of photography, and the quality and quantity of surface level information.

Positional accuracy in submersed habitat data is highly dependent on the accuracy of base maps. Most of a photograph, ideally about two thirds of each frame, is over water. This restricts the potential number of horizontal control points, particularly in areas with a paucity of cultural features. The habitat data for 1985 originally had been referenced to United States Geological Survey (USGS) 7.5-minute topographic maps on stable base medium (Ferguson *et al.*, 1989a). The dearth of cultural features and frequent inconsistencies between geographic features in the photographs and the topographic base maps made referencing the photographs problematic. Overlap of seagrass habitat and dry land in the base map occurred, as with previous applications with this type of base map (e.g., see Orth *et al.* (1991b)). The seven USGS topographic maps comprising southern Core Sound incorporated data from photographs taken in 1946; four of these maps had been revised, based on 1980 photographs, for cultural features and man-made alterations of shoreline, but not for other changes in shorelines.

NOAA, NOS shoreline manuscripts are ideal base maps for the subject method but may not exist for all areas and in some cases may be out of date. The USGS 7.5-minute topographic map series is virtually comprehensive in coverage of the coastal U.S.A. but the maps generally are out of date, particularly for shorelines. The USGS 7.5-minute orthophotoquad map series is a problematic alternative, particularly in areas with few cultural features because orthophotoquads do not delineate geographic features such as shoreline.

Further study is needed to determine the positional accuracy of mapped seagrass habitat. Ongoing research in North Carolina is assessing positional accuracy of the habitat data with a Global Positioning System (GPS). Seagrass habitats mapped at surface level with portable GPS equipment in 1992 will be compared to those habitats to be mapped from photographs acquired in spring, 1992. The GPS data have been post processed for differential correction to a circular error probable of < 5 m. These data, and digitized versions of the 1985 and 1988 habitat data described here, will be compared in a geographic information system (see Lo and Ries, 1992).

Management

Timely and reliable monitoring is a prerequisite to effective management of seagrass habitats and the exploited and protected species that they support. Evaluation of environmental policies and regulations designed to maintain seagrass habitat at current levels and to restore lost habitats will require monitoring and feedback to managers at temporal and spatial scales consistent with survival of that habitat. This report demonstrates that it is possible to monitor spatial change in seagrass habitats by special application of aerial photographic and photointerpretive techniques to photic submerged land.

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References

Crowell, M., S. P. Leatherman, and M. K. Buckley, 1991. Historical Shoreline Change: Error Analysis and Mapping Accuracy, *Journal of Coastal Research* 7(3):839–852.

Den Hartog, C., 1970. *The Seagrasses of the World, North Holland*, Amsterdam, 275 p.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk, 1993. Assessing Water Quality with Submersed Aquatic Vegetation: Habitat Requirements as Barometers of Chesapeake Bay Health, *Bio Science* 43(2):86–94.

Dobson, J. E., and E. A. Bright, 1991. CoastWatch—Detecting Change in Coastal Wetlands. *Geo Info Systems* 1(1):36–40.

Ellis, M.Y., 1978. *Coastal Mapping Handbook*. United States Government Printing Office, Washington, D.C. 200p.

Federal Geodetic Control Committee, 1984. *Standards and Specifications for Geodetic Control Networks*, Section 2 page 1, National Geodetic Information Branch, N/CG17X2, NOAA, Rockville, Maryland.

Ferguson, R. L., B. T. Pawlak, and L. L. Wood, 1993. Flowering of the Seagrass *Halodule wrightii* in North Carolina, USA. *Aquatic Botany* (in press).

Ferguson, R. L., J. A. Rivera, and L. L. Wood, 1989a. *Seagrasses in Southern Core Sound, North Carolina*. NOAA-Fisheries Submerged Aquatic Vegetation Study, Beaufort Laboratory, SEFSC, 101 Pivers Island Road, Beaufort, NC 28516. 3' by 4' chart, with text and illustrations.

Ferguson, R. L., J. A. Rivera and L. L. Wood, 1989b. *Submerged aquatic vegetation in the Albemarle-Pamlico estuarine system*. Albemarle-Pamlico Estuarine Program, Project No. 88-10, N.C. Department of Natural Resources and Community Development, Raleigh, N. C., and U. S. EPA, National Estuary Program. 68 p.

Ferguson, R. L., G. W. Thayer, and T. R. Rice, 1980. Marine Primary Producers, Functional Adaptation of Marine Organisms. F. J. Vernberg and W. Vernberg editors. Academic Press, New York, pp. 9–69.

Ferguson, R. L., and L. L. Wood, 1990. Mapping Submerged Aquatic Vegetation in North Carolina With Conventional Aerial Photography, *Federal Coastal Wetland Mapping Programs* (S. J. Kiraly, F. A. Cross, and J. D. Buffington, editors), U.S. Fish and Wildlife Service Biological Report 90(18):125–133.

Ferguson, R. L., L. L. Wood, and B. T. Pawlak, 1992. *SAV Habitat in*

1985 and 1988: Cape Lookout to Drum Inlet, N.C., NOAA, Coastal Ocean Program, Submerged Aquatic Vegetation Study, Beaufort Laboratory, SEFSC, 101 Pivers island Road, Beaufort, NC 28516. 3′ by 4′ chart with text, and illustrations.

Johnson, R. W., and J. C. Munday, Jr., 1983. The Marine Environment, *Manual of Remote Sensing* (J. E. Estes and G. A. Thorley, editors), Second Edition, Volume II, American Society of Photogrammetry, pp. 1371–1496.

Keller, M., 1978. A Study of Applied Photogrammetric Bathymetry in the National Oceanic and Atmospheric Administration. *Proceedings: Coastal Mapping Symposium*. American Society of Photogrammetry. Falls Church, Virginia, pp. 45–54.

Larkum, A. W. D., A. J. McComb, and S. A. Shepard, 1989. *Biology of Seagrasses*, Elsevier, Amsterdam, 841 p.

Lo, T. H. C., and T. F. Ries, 1992. Change Detection of Seagrass in Tampa Bay, Florida, Using GIS Technology. *ASPRS/ASCM/RT92, Technical Papers*, Washington, D.C., Volume 3, GIS and Cartography, pp. 240–253.

N.C. Division of Marine Fisheries, 1988. *Proclamation re: mechanical harvest of clams*. N. C. Department of Natural Resources and Community Development, SF-3-87/88. 3 p.

NOAA Photogrammetry Branch, 1980. *Standard Operating Procedures for Flight Operations Group of the Photographic Operations Section*, In-house publication, NOAA, Rockville, MD 20852.

———, 1989. *Coastal Mapping Program Operations Manual*, Section 3, Quality Program, In house publication, NOAA, Rockville, MD 20852.

Orth, R. J., R. L. Ferguson, and K. D. Haddad, 1991a. Monitoring Seagrass Distribution and Abundance Patterns, *Coastal Wetlands Coastal Zone '91 Conference-ASCE*, Long Beach, California, July, pp. 281–300.

Orth, R. J., J. F. Nowak, A. A. Frisch, K. P. Kiley, and J. R. Whiting, 1991b. *Distribution of Submerged Aquatic Vegetation in Chesapeake Bay and Tributaries and Chincoteague Bay - 1990*. Virginia Institute of Marine Science, Gloucester Point, Virginia, Final Report to U.S. Environmental Protection Agency, 261 p.

Phillips, R.C., 1984. *The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile*. U.S. Fish and Wildlife Service FWS/OBS-84/24. 85 p.

Robinson, A., R. Sale, and J. Morrison, 1978. *Elements of Cartography*, Fourth Edition, John Wiley and Sons.

Slama, C. C (editor), 1980. *Manual of Photogrammetry*, Fourth Edition, American Society of Photogrammetry. 1056 p.

Swanson, L. W., 1949. *Topographic Manual, Part 2, Photogrammetry*. U.S. Department of Commerce, Special Publication No. 249.

Thayer G. W., W. J. Kenworthy, and M. S. Fonseca, 1984. *The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile*. U. S. Fish and Wildlife Service FWS/OBS-84/02, 147 p.

Thomas, J. T., and R. L. Ferguson, 1990. National Oceanic and Atmospheric Administration's Habitat Mapping Under the Coastal Ocean Program, *Federal Coastal Wetland Mapping Programs* (S. J. Kiraly, F. A. Cross, and J. D. Buffington, editors), U.S. Fish and Wildlife Service Biol. Rep. 90(18):27–37.

Thomas, J. P., R. L. Ferguson, J. E. Dobson, and F. A. Cross, 1991. NOAA's CoastWatch: Change Analysis Program, *Coastal Wetlands, Coastal Zone '91 Conference ASCE*, Long Beach, California, July, pp. 259–267.

Wilmington District Corps of Engineers, 1987. *Public Notice: Maintenance Dredging in Channel from Back Sound to Lookout Bight Carteret County, North Carolina*. U. S. Department of the Army, SAWCO-ND-88-28-0009. 5 p.

Zieman, J. C., 1982. *The Ecology of the Seagrasses of South Florida: A Community Profile*. U.S. Fish and Wildlife Service, FWS/OBS-82/25. 185 p.

Zieman, J. C., and R. T. Zieman, 1989. *The Ecology of the Seagrass Meadows of the West Coast of Florida: A Community Profile*. U.S. Fish and Wildlife Service Biological Report 85(7.25). 185 p.

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