In: ***Proceedings of 1997 Geospatial Conference*****, Seattle, WA, volume 3, pp. 527**

Remote Sensing of Nearshore Vegetation in Washington State's Puget Sound

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ABSTRACT

The Washington State Department of Natural Resources, in cooperation with other state and federal agencies, has developed a program to remotely sense nearshore vegetation (intertidal and shallow subtidal). The classified nearshore data are integrated into an existing geographic information system for spatial analysis to support aquatic land use planning and management decisions. In 1996, a data set for the greater Bellingham Bay area in Northern Puget Sound was completed.

Program methods incorporate advances in remote sensing technologies to overcome the constraints of the target geography, which prevent the use of more traditional inventory methods. The multispectral image data were collected by a Compact Airborne Spectrographic Imager (CASI) sensor, configured to collect 11 bands of data (from the visible to the near infrared range) with square, four meter pixels. Color infrared (CIR) photography was acquired simultaneously from the same aerial platform. Marine scientists collected field data located by a differential Global Positioning System (DGPS) or annotated aerial photographs during the same season as the image data were collected. A hybrid of supervised and unsupervised image classification techniques produced mapping of eight vegetation types. Field data were used to conduct a classification accuracy assessment. As a result of the project, two digital and two hard copy products have been defined.

INTRODUCTION

Washington State's Puget Sound nearshore habitats are a natural resource of significant biological, ecological and economic value (Puget Sound Water Quality Authority, 1992). For this project, Nearshore habitats include private and state-owned intertidal and shallow subtidal areas, and associated wetlands.

Its nearshore habitats are affected by a set of interacting influences, especially its geography. Bounded on the east by the Cascade Range and on the west by the Olympic Mountains, Puget Sound's terrain has great topographic variety (Kruckeberg, 1991). The Puget Sound region's rapidly growing population continues to strain the integrity this ecosystem to the limit (Puget Sound Water Quality Authority, 1992). Comprehensive management of this important resource requires accurate and timely information about the type, amount, and distribution of nearshore habitats.

Available nearshore habitat mapping in Washington State is incomplete, or has become inadequate to support current decision making needs. In 1988, the Washington State Department of Natural Resources cooperated with other state and federal agencies to investigate the usefulness of remote sensing technologies to inventory nearshore habitats (Mynar, 1990). Based on the study, the department initiated the Nearshore Habitat Program (NHP), which uses multispectral imagery as the primary data source for the vegetation component of the inventory.

In the summer of 1995, digital multispectral imagery and simultaneous color infrared photography were acquired over Bellingham Bay and adjacent nearshore areas (Figure 1) using a CASI (Compact Airborne Spectrographic Imager) sensor. Information on the nearshore vegetation types was then extracted from the digital imagery. The classified vegetation data have been integrated into an existing geographic information system (GIS) for spatial analysis supporting aquatic land use planning and management decisions.

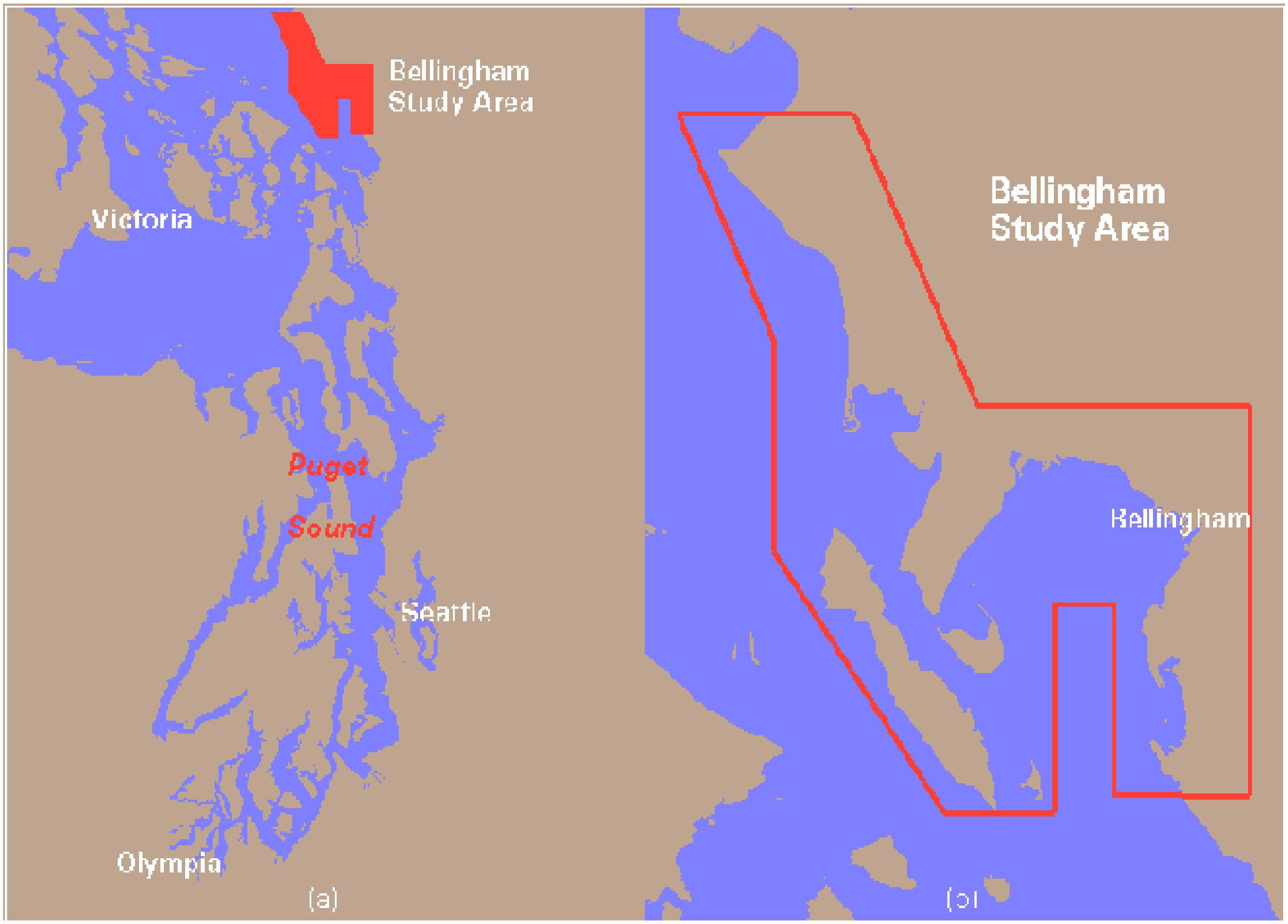

Figure 1. (a) Puget Sound estuary, (b) Bellingham Bay Study Area.

METHODS AND MATERIALS

Program Background

The unique geography of Puget Sound's nearshore environment imposes several constraints on the Nearshore Habitat Program: (1) upper intertidal areas are submerged twice daily, while lowest intertidal areas are exposed for only a few hours on limited days, (2) well defined, well distributed, stable features are lacking for use as geographic control, (3) vegetation is highly seasonal, and (4) habitat size is variable, with horizontal distances from less than one foot to 1/2 mile wide. Given these constraints, many traditional inventory methods, especially field activities, have not been feasible.

The initial stage (1991-1994) of the NHP involved an inter-agency cooperative agreement to collect and rectify multispectral data over Puget Sound's nearshore areas. Data were collected by a Daedalus DS-1260 multispectral scanner (rotating mirror) mounted in an aircraft. The delivered image data were not rectified to meet NHP specifications of +/- 40 feet, which precluded the use of DGPS-located field data in the image processing steps, and prevented us from integrating the image data into our existing GIS. Program methods were refined for the 1995 effort based on the lessons learned during the first three years of the program.

The first elements we reviewed were the sensor and the data collection parameters. To capture narrow, linear bands of vegetation, we determined the multispectral sensor needed a spatial resolutions of three to five meters and stable, consistent image geometry. Additionally, to distinguish between the required vegetation categories, the sensor had to provide a bandset that is specifically customized for detection of nearshore vegetation (exposed and slightly submerged).

We put additional emphasis on assuring better rectification. The 1995 data collection system needed to have a proven DGPS linkage to offset the lack of well distributed spatial control in the nearshore environment. Working with the Resource Mapping group within our agency, scanned orthophotographs were produced to supply the additional geographic control needed to meet our positional accuracy requirements. We had found the simultaneously acquired CIR photography to be a valuable reference set for image processing, and felt it could serve as a backup data set should the digital data be flawed.

The list of nearshore vegetation types was reviewed and refined. The original vegetation list was developed from the classification system used by the NHP, "A Marine and Estuarine Habitat Classification System for Washington State" (Dethier, 1990). The Dethier system identifies a set of physical characteristics, including diagnostic vegetation species for habitat classification. Field surveys have been the primary data collection technique for other implementations of the Dethier system (Frith et al., 1993). A separate investigation identified the detail at which the diagnostic vegetation species might be detected using multispectral data at a three to five meter spatial resolution (Aitken et al., 1995). Eight vegetation types were identified, and a recommended bandset was provided:

brown algae	eelgrass
green algae	kelp
red algae	salt Marsh
mixed algae	spit/berm vegetation

Developing field data collection conventions that could be applied consistently in the nearshore environment was critical. Additional discussions helped field staff apply the minimum mapping unit to the horizontal expanse of the landscape (the sensor's vantage point), not to the slope or the vertical expanse. To ensure a more consistent product, certain tasks, e.g., air photo annotation, were limited to select staff. Because the nearshore environment is highly seasonal, 1995 field data collection was scheduled close to imagery acquisition, so that the vegetation would be in a similar growth stage during both collection periods. Annotated vegetation information on aerial photography would continue to provide critical visual clues for relating a field site to an image site, regardless of the positional accuracy of the image data.

1995 Remote Sensing Data Acquisition

In 1995, the NHP awarded a contract to Borstad Associates Ltd. in Sidney, British Columbia to collect imagery of our study area, which consisted of Bellingham Bay, Washington and adjacent nearshore areas. Digital multispectral imagery and simultaneous color infrared photography (at 1:11,000 scale) were acquired using a CASI (Compact Airborne Spectrographic Imager) sensor and a 12" focal length Zeiss mapping camera. All flight lines were flown at 10,800' altitude, from south to north, with 50% sidelap between adjacent flight lines. The CASI was mounted in a Cessna T210 aircraft. The digital imagery was acquired using a custom 11-channel bandset as shown in Table 1 (Borstad, 1996).

CASI Band #	Wavelength/nm	Band Width
1	470-515	45
2	540-560	20
3	575-590	15
4	600-615	15
5	625-635	10
6	640-655	15
7	670-685	15
8	704-714	10
9	743-755	12
10	775-786	11
11	854-876	22

Table 1. CASI Bandset for Bellingham Bay Area.

Over a span of several years between June and September, NHP scientists collected field data to support the remote sensing effort. Field data consisted of annotated aerial photography, and differentially corrected GPS point, line and polygon features, with an accompanying data sheet for each site. Field data were assigned to one of two groups: (1) guiding the image processing classification, or (2) assessing classification accuracy.

Image Processing and Analysis

Imagery was corrected to surface radiance by applying an atmosphere correction, and corrected for roll, pitch and yaw and projected into geographic coordinates using differential GPS to yield square, four meter pixels. The resulting imagery were warped to fit existing orthophotographs and coastline vectors in Washington State Plane, south zone. Rectified and mosaicked rasters were mapped to within +/-3 pixels (12m) in most parts of the imagery (Borstad, 1996).

The NHP used Imagine 8.2 software (ERDAS, Inc., Atlanta, GA) running on a Sun workstation (Sun Microsystems, Inc., Mountain View, CA) to process the rectified, mosaicked, unsigned 16 bit image data. Classified files were produced using an iterative, hybrid approach to classification, combining unsupervised and supervised approaches. The unsupervised processes use a minimum distance, iterative clustering algorithm that examines the raster image for statistically clustered radiance values. The supervised processing relies on the field data (e.g., GPS sites and annotated photography) to develop training signature sets.

The final nearshore vegetation layer was produced by running a series of iterative routines that identify vegetated areas of interest, and eliminate areas of non-interest. First, on-screen digitizing was used to eliminate areas of non-interest, e.g., uplands and open water. Next, a minimum distance classification with an unsupervised signature set was run on all bands of the original data. Coarse editing on the classified file was used to reduce further areas of non-interest, e.g., open water and substrates. The remaining areas were input to a maximum likelihood classification with a supervised signature set. Areas that accurately represented a nearshore vegetation classes were interactively selected and recoded to the final class values for each land cover type. The remaining pixels were sent through one or two more iterations of reclassification using a minimum distance classifier with an unsupervised signature set. Each time the classified file was reviewed, and interactively edited. In the final iteration all pixels that represent a nearshore vegetation type were identified. A model was used to copy selected portions of the classified files into a composite classified file based on conditional statements.

Classification Accuracy Assessment

NHP marine scientists used plots to conduct classification accuracy assessment of the field data in hard copy form, and evaluated digital assessment sites on-screen by overlaying the field features onto the composite classified file. Based on the field data, the vegetation class or classes present for each assessment site was recorded. Because assessment sites included line and polygon features, establishing 'correctness' was not always a binary decision. We assigned points as follows:

% Feature Correctly Classified	Points Awarded
<33%	0
34% - 66%	0.5
>66%	1

The points assigned during the classification accuracy assessment work for the Bellingham Bay area were compiled into an error matrix (Table 2). The number of assessment sites classified as a particular category are shown relative to the actual category as recorded in the field. In matrix form, commission and omission errors present in the classified data are identified readily.

Classified Data	Reference Data							
	brown algae	green algae	kelp	mixed algae	eelgrass	salt marsh	spit/ berm	total no. classified
brown algae	10.5	0.0	0.0	1.0	0.0	0.0	0.0	11.5
green algae	0.0	16.5	0.0	1.0	1.0	0.0	0.0	18.5
kelp	1.5	0.0	19.0	1.0	1.0	0.0	0.0	22.5
mixed algae	0.0	4.5	1.0	8.0	0.0	0.0	0.0	13.5
eelgrass	0.0	3.5	0.0	0.0	33.5	0.0	0.0	37.0
salt marsh	0.0	0.5	0.0	0.0	0.0	26.0	0.0	26.5
spit/ berm	0.0	0.0	0.0	0.0	0.0	0.0	5.5	5.5
none	3.0	12.0	2.0	0.0	5.5	4.0	2.5	29.0

total reference sites	15.0	37.0	22.0	11.0	41.0	30.0	8.0	164.0

Table 2. Nearshore Vegetation Classification Accuracy Assessment Results for the Bellingham Bay Area.

Congalton (1991) discusses two descriptive techniques for analyzing an error matrix, i.e., "producer's accuracy" and "user's accuracy". Producer's accuracy is the probability of a reference site being correctly classified, i.e., a measure of omission error. It is the number of sites correctly classified as a land cover divided by the total number of reference sites for that land cover. User's accuracy indicates reliability, or the probability that a site classified on the image is really that land cover type on the ground. It is the number of sites correctly classified as a land cover divided by the total number of sites that were classified in that category. Table 3 shows Producer's and User's classification accuracy by land cover type.

Classification Accuracy		
Land Cover	**Producer's %**	**User's %**
brown algae	70.0	91.3
green algae	44.6	89.2
kelp	86.4	84.4
mixed algae	72.7	59.3
eelgrass	81.7	90.5
salt marsh	86.7	98.1
spit/berm	68.8	100.0

Table 3. Producer's and User's Classification Accuracy Percentages by Land Cover Type for the Bellingham Bay Area.

We are in the process of analyzing the classification accuracy assessment results. Most often, the User's accuracy level is higher than the Producer's accuracy level, pointing to a trend of lower commission error and higher omission error. Omission errors are significant in most categories, e.g., 12 green algae reference sites were not detected in the classified file. Possible explanations for the errors include: poor training signatures, inter-annual changes, seasonal changes, land cover types that are not mutually exclusive, (e.g., kelp are brown algae), differing atmospheric conditions during data acquisition periods, and whether a feature was submerged or exposed.

Detecting submerged features has been especially difficult. Water attenuates the spectral response of submerged features. The longer wavelengths, e.g., near infrared, are absorbed in a few tenths of a meter of water (Lillesand and Kiefer, 1994). The water clarity of Puget Sound further hampers identification. Although the submerged feature is apparently vegetation, the vegetation type is not evident. Further, vegetation in the nearshore environment is highly seasonal, a site that is a green alga in early June can be a brown alga site by the end of July.

Based on the assessment/review work, the marine scientists compiled a list of modifications to be made to the composite file. The final adjustments were made, and the final raster data has been made available to support aquatic land use decision making activities through the use of ARC/INFO GRID analysis tools (ESRI, Redlands, California). The raster information will be converted into vector format for ease of use and cartographic production purposes within the existing GIS. Routines for translating the raster vegetation features to vector equivalents are being completed. They involve generalizing the raster version of each vegetation class separately, and then layering them back together according to the relative importance of the vegetation. Once in vector format, small polygons (less than or equal to the area of nine pixels) can be eliminated, and the boundaries of the remaining features smoothed to reduce the "stair-step" effect of the original raster data.

RESULTS AND DISCUSSION

The Nearshore Habitat Program balances providing information for decision making that is sufficiently detailed and accurate, against the reality of covering 2,300 shoreline miles on a limited budget. The program has combined airborne acquired multispectral imagery with field-based data to produce a mapping of eight nearshore vegetation types in the Bellingham Bay area. Classification accuracy assessment has given users an indication of the reliability of the digital classification. The raster vegetation data set is being integrated into Washington State's Department of Natural Resources' GIS for subsequent spatial analyses.

As the program matured, the complexity of our task becomes more apparent. Coordination among the marine scientists, remote sensing, and GIS staff is critical. We strive to balance the approaches of the different disciplines. For example, increasing the minimum mapping unit to a value two to three times greater than the spatial resolution of the sensor could improve classification accuracy assessment results and provide more manageable GIS data sets, but at the cost of not detecting many narrowly-banded vegetation features that biologically important in the nearshore. We continue to examine ways to improve the information content and the efficiency of the remote sensing program, including: (1) automating the process of identifying nearshore vegetation types, (2) improving detection of submerged features, and (3) reducing between class confusion.

Products and Data Use

Two digital and two hard copy products have been defined. The original, classified raster vegetation data are complete for the Bellingham Bay area. The vector translation should be forthcoming in the second quarter of 1997. While the vegetation data itself is a high priority information set, the NHP intends to combine the vegetation layer with data sets of other nearshore habitat components.

Substrate and energy layers are being developed, and will be integrated into the GIS to create a data set of fully classified habitat. A 1:24,000-scale hard copy map set showing vegetation, substrate and energy information, will be produced in limited numbers for distribution to and use by aquatic land use planners with jurisdiction in the area. A second map series at 1:12,000 showing only vegetation is being designed for use by nearshore habitat and aquatic resource managers and also will have limited production and distribution. The digital data and graphics files of both map series could be made available via the Internet, but this is unlikely to happen quickly, given limited resources.

Within the Department of Natural Resources, the vegetation and data on other habitat components are being used via ArcView (ESRI, Redlands, California) to assist in contaminated sediment management planning and harbor area relocation planning. The enthusiastic feedback received thus far indicate the data are meeting the agency's business requirements.

NOTICE

The information presented in this paper does not necessarily reflect the views of the Washington State Department of Natural Resources, and no official endorsements should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ACKNOWLEDGMENTS

None of this would have been possible without the hard work of the Bellingham Bay Project team: Tom Mumford, Allison Bailey, Helen Berry, Betty Bookheim, Bruce Dahlman, and Paul Salop. Funding was provided by the Washington State Department of Natural Resources. We have been fortunate to work with many talented and hard working professionals. Special thanks to the staff at Borstad Associates Ltd., and Washington State's Department of Natural Resources' Mapping Resources group.

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