Accessible Methodology for Monitoring Estuarine and Coastal Vegetation Cover

A Final Report Submitted to

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Submitted by

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Abstract

Estuarine and coastal vegetation, such as emergent salt marshes and submerged seagrasses, are critical and important components of estuarine and coastal ecosystems. Coastal resource managers and their staff increasingly are being called on to protect and enhance these communities and in the process expected to map the location or areal extent of those vegetative communities. However, coastal planning staff and other staff in local government, agencies, and coastal resource offices are sometimes located in small coastal locations and counties where they do not have budget or access to new remote sensing technologies nor to complex image analysis and GIS software. The overall goals of this project were to develop, test, and demonstrate an accessible methodology for mapping and monitoring estuarine vegetation cover with aerial photography, desktop computers, and ArcView 3.x (ESRI) software. A methodology was developed, tested, and demonstrated with eelgrasses in the Padilla Bay National Estuarine Research Reserve, Washington. The methodology includes procurement of aerial photographs, ground truth sampling, obtaining rectified reference photographs, scanning the aerial photos, georectifying of the aerial photos, mosaicing, photointerpretation, and on screen digitizing of vegetative cover. Various steps of the methodology are applicable or helpful to coastal resource managers in particular situations. One of the critical steps is procurement of an accurate baseline to which aerial photographs can be georeferenced. The method was demonstrated in Padilla Bay where eelgrasses were mapped for the year 2000, and historical distribution mapped in selected areas of Padilla Bay. Eelgrasses cover about 3900 hectares in Padilla Bay as a whole in 2000. Coverage decreased about 8 % around March Point from 1989 to 2000, but increased by about 120 hectares in the northeast area of Padilla Bay.

This project has demonstrated that estuarine vegetation can be mapped and monitored with technology accessible at many coastal resource offices: aerial photography, desktop computers, and ArcView 3.x.

Keywords: SAV mapping, aerial photography, ArcView, GIS, eelgrasses, Padilla Bay Washington.

Introduction

Mapping and monitoring changes in areal distribution of submerged and emergent coastal vegetation has become more important for staff in local governments, agencies, and other coastal resource offices as both the recognition of the importance of coastal vegetation has increased and as population and development pressures near the coasts have increased. Coastal vegetation is being mapped and monitored with a variety of new and sophisticated remote sensing platforms and data interpretation and classification systems. These are being developed in universities, private firms, and government agencies and offices. However, coastal planning staff and other staff in local government, agencies, and coastal resource offices are sometimes located in small coastal locations and counties where they do not have budget for or access to new remote sensing technologies nor to complex image analysis and GIS software. This project addressed this issue with the goal of developing a methodology for mapping and monitoring of coastal vegetation with the widely available desktop PC and ArcView 3.x (ESRI) and its extensions.

Estuarine and coastal vegetation such as emergent salt marshes, submerged seagrasses, and macroalgal communities are critical and important components of estuarine and coastal ecosystems. They directly or indirectly support many coastal, estuarine, and oceanic species and contribute to high biological productivity in the coastal systems in which they predominate. However, their location in the nearshore area has resulted in numerous declines in these vegetative communities (Orth and Moore 1983, Sheperd et al. 1989, Robblee et al. 1991, Short and Burdick 1996) and increasing attempts to protect these communities from further impacts and declines. These communities need to be mapped and monitored to identify areas needing protection and to assess the effectiveness of management actions taken for their protection or enhancement. Because of the inaccessibility of these communities to on-the-ground monitoring, various remote sensing methods are being used to map and monitor them, particularly satellite mounted sensors and aircraft mounted systems.

Satellite systems have been used to map emergent vegetation (Dobson et al. 1995) and for submerged vegetation (Belsher et al. 1988, Webber et al. 1987, Morton 1988, Luczkovich et al. 1993). However, because of large minimum pixel size and the need for particular local conditions (wind and sea state, no cloud cover) satellite imagery has not been favored for most submerged vegetation surveys (Ferguson and Wood 1990, Dobson et al. 1995). In the near future, 1-m resolution may be available from space and more investigators may use satellite imagery for submerged aquatic vegetation (Cracknell 1999). However, the specialized image processing technologies required for processing satellite images are usually not available to local coastal planners and investigators because of the relatively high cost of software and hardware and the requirement for specialized training or dedicated staff.

Aerial photography has been the preferred method for acquiring images for mapping of submerged vegetation in the United States (Simons 1987, Costa 1988, Orth et al. 1990, Bulthuis 1991), Australia (Bulthuis 1981, 1982, Larkum & West 1990), and Europe (Meulstee et al. 1986, Gilfillan et al. 1995). The NOAA Coast Watch Change Analysis Project conducted workshops around the United States soliciting input from regional scientists on the most appropriate methods for mapping of submerged vegetation. The recommendations developed from those workshops, included aerial photography as the recommended method for mapping submerged aquatic vegetation (Dobson et al. 1992, 1995), along with protocols on how such imagery should be acquired, ground truth investigations, and geographic control points. Aerial photography has been used to monitor submerged coastal vegetation in the Chesapeake Bay Program (Simons 1987, Orth and

Nowak 1990), North Carolina (Ferguson et al. 1993), Gulf of Mexico (Neckles 1994), Puget Sound (Mumford et al. 1995, Bulthuis 1995), and Oregon (Young et al. 1998).

Aerial photography as a method of acquiring images is relatively accessible for the local coastal planner or investigator. However, the protocols required to insure accurate geographic registration of aerial photographs (Dobson et al. 1995) can make the system as a whole difficult for local staff. Local staff and investigators often do not have access to sophisticated central GIS services nor to specialized training. There is a need, therefore, for a more accessible methodology that can be used by local coastal management staff, and the GIS specialists who support them, to map and monitor emergent and submerged vegetation.

Improved GPS technology combined with recent trends in desktop technology provide the setting for the development of this methodology: the power, speed, and memory of desktop computer systems continues to increase, such systems are becoming available to local coastal planners, investigators, and the GIS specialists who support them and the accuracy of GPS units has increased as the price has decreased. In addition, the GIS desktop software, ArcView 3.x, is becoming more and more powerful with some of the functions associated with ArcInfo becoming available on desktop systems via extensions for ArcView 3.x. Therefore, this project will build on these trends by testing, demonstrating, and transferring an accessible methodology to map and monitor emergent and submerged aquatic vegetation. The people most likely to use and benefit from this methodology are local planners in coastal areas who do not have access to the more sophisticated and expensive software and remote sensing platforms or who choose to use their desktop GIS with or without access to other systems, the GIS specialists who support them, and scientists in large and small coastal organizations who may lack access to more complex technologies or who may find manual methods more accurate or preferable to automated methods.

Objectives

The overall goals of this project were to develop, test, and demonstrate an accessible technology for mapping and monitoring estuarine vegetation cover with aerial photography and desktop computer software.

The specific objectives of this project were to:

- develop a methodology to map submerged and emergent vegetation with aerial photography and ArcView 3.x software;
- demonstrate the methodology by mapping eelgrasses in Padilla Bay National Estuarine Research Reserve, Washington during summer 2000;
- test the methodology on historical aerial photos of eelgrasses and salt marshes in Padilla Bay
- make the methodology available to local coastal planners, estuarine scientists, and other investigators in a methods report; and
- disseminate the methodology with presentations at meetings, informal workshops, and consultations.

Methods

The methodology developed in this project was purposefully limited to those available on desktop computers and the widely available ArcView (Versions 2.x to 3.x) in order to make the methodologies accessible to a wide variety of offices in estuarine and coastal resource management. The methodology developed in this project, along with some discussion of the options that may be available in particular circumstances is included in Shull and Bulthuis 2002. In this section of the present report, the methods that were developed in this project and then demonstrated in the mapping of estuarine vegetation in Padilla Bay NERR in 2000 are described. For further detail of the methods and some discussion of the limitations, options at various steps, and advantages of the methodology, the reader is referred to Shull and Bulthuis 2002.

Image acquisition

True color vertical aerial photographs were taken on July 30, 2000 at scales of 1:12,000 and 1:36,000 during a one-hour period around a predicted low tide of -0.85m below MLLW. A single flight line of five images with 60% overlap at 1:36,000 included all of Padilla Bay. More than 60 images with 60% overlap and 30% sidelap at 1:12,000 were needed to cover Padilla Bay. Contact prints (nine inches by nine inches) of all photos were developed and provided by the contractor.

Ground control points and ground truthing

Before the aerial photos were taken twelve ground control markers were placed in various parts of Padilla Bay to aid in georectification. The geographic coordinates of these markers were determined with a Trimble Geo Explorer II both at the time of deployment (June 27 and 28, 2000) and as soon as possible after the aerial photographs were taken on July 30.

At more than 250 ground truth points, the vegetative cover and geographic coordinates were determined on July 18, 19, 26, 27, 28 and 31, 2000 (See Fig 01.jpg). Geographic coordinates were marked with Garmin 12 or Garmin 12XL Global Positioning System receivers. (Because selective availability was turned off at that time by the Department of Defense, the precision of these inexpensive GPS units had improved to about <5m with averaging (without differential correction). Each ground truth site was visited during low tide by walking to the site; estimating percent cover of macrophytes in three cover class categories (<10% cover, 10-50% cover, 51-100% cover) over an area of about 10m by 10m; determining the species of eelgrass (Zostera marina or Z. japonica) or the presence of macroalgae; estimating the relative contribution of each (Z. marina, Z. japonica, macroalgae) to the total macrophyte cover; and indicating whether the site is within a relatively homogeneous macrophyte cover or whether it is on a transition between species or percent cover classes. The data collected at each ground truth site were entered in a spreadsheet and the GPS location transformed to a GIS shapefile and displayed in a standard projection in ArcView.

Image processing

The contact print aerial photographs were scanned at a resolution of 200 dpi (1:12,000 scale photos) or 600 dpi (1:36,000 scale photos) for a five foot pixel resolution. The scanning was done on a large format Epson 836XL scanner.

A simple rubbersheeting method was used to georectify the scanned images. The rectification method was a process that was refined from the start of the project to the final product after several iterations. The rubbersheeting was done using Image Warp, a free shareware extension, written by Kenneth McVay. In this method there are two factors over which the user has control, one is the number of ground control points selected, (ground control points are designated in the image and on a reference dataset with a real world coordinate system) and the other is the order of the transformation (polynomial equation) used to rubbersheet the image to the real world coordinate system.

Reference datasets were selected and used as they became available. In the first step a purchased set of Washington State Department of Natural Resources orthophotographs taken in 1998 was used. Statewide shorelines delineated and distributed by the Washington State Department of Natural Resources (WA DNR) were tested as possible reference for georectifying. Neither the orthophotographs produced by WA DNR nor the georectified color aerial photographs aligned with the shoreline (See Fig 02.jpg). On the otherhand, a shoreline marked by a Trimble Geo Explorer II, aligned very well with the WA DNR 1998 orthophotos and with the georectified color aerial photos (Figure 2). Three of the 1:36,000 scale year 2000 aerial photographs were georectified to the reference image with a second order polynomial and nearest neighbor resampling method and then mosaiced to make a single coverage of Padilla Bay. Next, about 50 of the 1:12,000 scale aerial photographs were georectified to the 1:36,000 mosaic and the ground control markers using a first order rectification, keeping the RMS under two pixels. The images were displayed individually with the central area of each photograph used for delineation and the unwanted edges cropped off.

Delineation

Delineation was done on screen using the (free) habitat digitizer tool. The delineation and identification of vegetative communities (photointerpretation) utilized the on-screen scanned aerial photos, contact prints, knowledge of vegetation in previous years, and the 250 plus ground truth sites in 2000.

During delineation each polygon was assigned to one of the following classes. For a few polygons, the species of eelgrass could not be determined, and the polygon was designated Zostera sp. For many of the polygons the species and percent cover class was clear. In a few parts of Padilla Bay there are extensive areas of mixture of Zostera marina and Z. japonica or a mixture of Z. marina and green macroalgae. Vegetative boundaries were delineated near the approximate center of the intermixed areas. The resulting "map" of area of each vegetative type thus includes intermixed areas as well as areas that are relatively mono specific.

Zostera marina subtidal
Z. marina intertidal 51-100% cover
Z. marina intertidal 10-50% cover
Z. japonica 51-100% cover
Z. japonica 10-50% cover
macroalgae (Ulvaceae) 51-100% cover
macroalgae (Ulvaceae) 10-50% cover
native salt marsh
subtidal with macrophyte cover 0-10%
intertidal with macrophyte cover 0-10%

The minimum mapping unit used during delineation was 0.05 hectares. Units smaller than 0.05 hectare usually were not mapped and were included in the surrounding apparent vegetative unit.

Areal estimates of each polygon and cover class were generated by ArcView.

Historical comparisons of vegetative cover

The above methods were applied to aerial photos in three areas of Padilla Bay to test the usefulness of the methodology for monitoring changes in the vegetative cover. At March Point and in the northeast corner of Padilla Bay, aerial photos of each of the three areas taken in 1989, 1992, and 1996 were georectified to the 1:36,000 photomosaic of Padilla Bay from the year 2000 using first order rectification. At a third area, Sullivan Minor salt marsh, aerial photos from 1989, 1992, 1996, and 2000 were georectified to the 1998 DNR orthophotos with the addition of several ground control points determined with a Trimble GPS ProXR system. Comparisons of vegetative cover between years were made with ArcView measuring tool (for distance comparisons) and with tools for merging and intersecting polygons and tools for calculating perimeter, length, and area, and polygons (for area comparisons).

Results

The primary objective of this project was the development of an accessible methodology to map and monitor estuarine vegetation cover with aerial photography and desktop computer hardware and ArcView 3.x extensions. This objective has been met with the methods described in the previous section. As with any multi-step methodology, the methodology developed in this project is not a single method, but an overall approach, along with various options at each step. Users may select different options depending both on the application of the method in their situation and the software or hardware available to the them. Some of the optional steps were tested at Padilla Bay and advantages or disadvantages are indicated when possible. For other steps the user will want to do some testing in their estuarine or coastal area in order to determine which option will be best for their application.

A report of the method has been published in the Padilla Bay National Estuarine Research Reserve Technical Report Series and is available for distribution (a project deliverable):

Shull, S. and D.A. Bulthuis. 2002. *A methodology for mapping current and historical coverage of estuarine vegetation with aerial photography and ArcView*. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve: mount Vernon, Washington. Padilla Bay National Estuarine Research Reserve Technical Report No. 26.

The emphasis of this project has been on development of methods. The methods were tested in many applications in Padilla Bay in the course of the development of the methodology. The results that are presented are illustrative and demonstrate the use of the method on vegetative communities in Padilla Bay. An extensive analysis of vegetative communities in Padilla Bay was not the objective of this project, nor this report.

Eelgrasses, macroalgae, and salt marshes were distributed throughout Padilla Bay in July 2000 (See Fig 03.jpg). Within any habitat polygon designated as a particular vegetative cover, there were sometimes patches up to the size of the minimum mapping unit (0.05 hectares) that were of another vegetation or bare. In addition, some polygons included patchy areas where there was a mixture of bare area and vegetative cover. The designated vegetative cover classification was applicable to the polygon as a whole, not equally to all parts of the polygon. However, distinguishable patches that were the size of the minimum mapping unit or larger were mapped separately and sometimes patches slightly smaller than the minimum mapping unit were also delineated. This was particularly true of channels, which are narrow and do not cover much area, but provide an important habitat feature.

Eelgrasses are the dominant vegetative community in Padilla Bay and cover extensive intertidal flats. Eelgrasses also occur subtidally in channels and along the western side of the Padilla Bay intertidal flats. The areas characterized as intertidal eelgrass cover include both Zostera japonica and Z. marina. Z. japonica occurs higher in the intertidal while Z. marina occurs in the mid to lower intertidal flats (Figure 3). In many places distinct bands or beds of Z. japonica occurred close to shore and the species of eelgrass could be mapped from the aerial photographs based on its location. In other areas, there was either a mixture of Z. marina and Z. japonica, or the two species could not be distinguished on the aerial photographs. In such cases the areas were characterized as "eelgrass" rather than either species. Three percent-cover categories were distinguished in the ground truth investigations and for habitat polygons mapped from the aerial photos: 51-100% cover, 10-50% cover, <10% cover. The last category was designated as "intertidal bare" flats. The other two categories were distinguishable in most of the aerial photographs. In some places, however, the percent cover category was not clear. A judgement was made to place them in one category or the other, but the data on percent cover should be interpreted with caution. In addition to the patchiness that might occur within a habitat polygon, macroalgae were intermixed with the eelgrasses. The most common algae were in the genera Ulva and Enteromorpha,. Because of the uncertainties associated with mixed beds of Z. marina and Z. japonica and the variations in percent cover categories, the vegetative classes were also grouped in Padilla Bay into eelgrasses (Zostera sp.), macroalgae (Ulvaceae), and native salt marsh (See Fig 04.jpg).

Macroalgae, predominately chlorophyta of the Ulvaceae family, also were distributed in beds where they were the predominate cover vegetation. This was particularly true in the southern part of Padilla Bay. The ground truth investigations indicated a mixture of eelgrasses and algae with sometimes Enteromorpha sp. or Ulva sp. greater than 50% cover and adjoining areas had greater than 50% cover of Zostera marina. The differences among these two types of vegetative cover were not always clear on the aerial photos. However, in most places where ground truth indicated a predominance of algae, there was a distinct hue of green that was visible on the aerial photographs.

Native salt marsh communities occur in patches or linear features along the shoreline of Padilla Bay. The main plants in these salt marshes included Distichlis spicatum and Salicornia virginica. Spartina alterniflora was not present in large clones nor visible on the color aerial photographs.

The total area covered by seagrasses in Padilla Bay in 2000 was 3867 hectares with Z. marina accounting for 3029 hectares and Z. japonica 838 hectares, (See Tables.doc-Table 1).

Near March Point, the distribution of eelgrasses (mainly Z. marina) declined from 1992 to 2000 (See Fig 05.jpg, Fig 06.jpg, Fig 07.jpg, and Fig 08.jpg). This decline was visible first as openings in the once relatively continuous eelgrass bed, to patches of eelgrass, to a decline in the area covered by patches (See Fig 07.jpg and Fig 08.jpg). This set of aerial photos illustrates how the methodology can be used for retrospective historical analysis. The total area covered by eelgrasses in the March Point designated project area (see outline in Fig 05.jpg) declined from 121 hectares in 1992 to 112 hectares in 2000 (See Tables.doc-Table 2).

In the northeast corner of Padilla Bay eelgrasses covered only a small portion of the intertidal flats in 1989 (See Fig 09.jpg). Mapping the distribution of eelgrasses in 1992, 1996, and 2000 indicated fluctuations in the area covered (See Fig 10.jpg, Fig 11.jpg, and Fig 12.jpg). In the historical aerial photographs, two general types of eelgrass coverage could be identified: continuous cover and sparse cover. In the four years (1989, 1992, 1996, 2000) for which eelgrass cover was mapped, there were wide fluctuations in the area of sparse cover, as little as 8 hectares in 1989 and as much as 61 hectares in 2000 (See Tables.doc-Table 3). Continuous and total eelgrass cover also fluctuated during these years (See Tables.doc-Table 3).

A linear native salt marsh along the eastern shore of Padilla Bay, called Sullivan-Minor marsh has had its seaward edge eroded shoreward from 1989 to 2000 (See Fig 13.jpg, Fig 14.jpg, Fig 15.jpg, Fig 16.jpg, and Fig 17.jpg). The marsh width decreased 11m from 108 m to 97 m near the area of maximum erosion. An estimated 1410 m^2 of Sullivan-Minor marsh was lost in the eleven years from 1989 to 2000, although there was also some gain in areas as Salicornia viriginica and Distichlis spicatum became established in areas that had been predominately log cover (See Fig 13.jpg, Fig 14.jpg, Fig 15.jpg, and Fig 16.jpg).

Discussion

This project developed a methodology for mapping and monitoring current and historical distribution of estuarine submerged and emergent vegetation using a desktop computer, ArcView 3.x, and aerial photography. This methodology provides an option for coastal planners, estuarine scientists, and their respective GIS support staff who lack assess to the more complex and expensive software, hardware, and remote sensing platforms for mapping of coastal vegetation. The methodology offers a practical alternative that can provide meaningful and useful data on the current and historical distribution of estuarine vegetative communities as has been illustrated for Padilla Bay.

One of the important issues that arose in the development of the methodology was the precision and accuracy of the georectification of the scanned aerial photographs. Numerous factors can help make the georectification more accurate. One is access to good quality orthorectified photos. In this project we purchased orthophotos covering the Padilla Bay area from the Washington State Department of Natural Resources. The stated accuracy for the orthophotos is "national map accuracy standard." However, national map accuracy standard is ±40 feet. Checking of the orthophotos with high grade GPS on shore features and roads indicated much higher accuracies than ±40 feet, within the three foot pixel resolution (See Fig 02.jpg). However, the high tide black and white orthophotography was not as high a grade base photo as desired for georectifying other aerial photos.

Another factor in the accuracy of georectification is the number and distribution of stable recognizable features on the base (orthophotograph) and the photograph to be georectified. When the vegetative area to be mapped is near the coastline and there are good features visible, the georectification will be more accurate. Similarly, a good distribution of points throughout the photograph increases the accuracy of georectification. In this project, accuracy of georectification was hampered because of the extent of intertidal flats without distinguishing features in Padilla Bay. More than sixty aerial photos were required at a scale of 1:12,000 to cover the areas of intertidal and submerged vegetation in Padilla Bay. Many of the photos had no land features in them at all. And for those that did include some upland, most of the upland was confined to one side of the photo. In applications where coastal vegetation is in small areas and close to the shoreline and upland features, a greater accuracy of georectification may be achieved using this methodology than was done in the Padilla Bay demonstrations.

The concerns about accuracy (and precision) of georectification are particularly important in attempting to monitor vegetative changes over time or mapping of historical vegetative cover.

The uncertainties are amplified when one georectified photograph is compared with another. Any apparent changes in cover should be carefully assessed before being attributed to changes in vegetation and not due to differences in georectification of the aerial photos. In spite of these concerns both in Padilla Bay and for historical comparisons at March Point and in the northeast of Padilla Bay, the methodology was used to clearly document a loss of the eelgrass Zostera marina of about 9 hectares from 1992 to 2000 at March Point and a gain of about 120 hectares in northeastern Padilla Bay (See Tables.doc-Table 2 and Table 3).

This project developed a methodology for mapping and monitoring current and historical distribution of estuarine submerged and emergent vegetation using aerial photography, a desktop computer, and ArcView 3.x. This methodology is readily accessible by coastal resource managers, is ready to be used now, and is being used by resources managers in a variety of settings (for specifics see Technology Transfer and Management Application section).

Technology Transfer and Management Application

The potential users of the methodology developed in this project are local government coastal planners, coastal resource managers, scientists, and their GIS support staff who do not have access or budget for more sophisticated remote sensing platforms or more expensive image analysis software and full-scale GIS software, but do have access to desktop computers and Arc View (versions 2.0 to 3.x). These staff also have some responsibility to protect or monitor estuarine vegetation, to map estuarine vegetation when considering potential impacts of proposed actions or have historical aerial photos they wish to georectify for background image or area assessment. The methodology developed in this project is not a single method, but a series of steps and processes with various options at each step. While the methodology may be adopted and used in total in some offices, the primary value of the methodology is 1) to demonstrate that estuarine vegetation can be mapped by offices with limited budget and software/hardware capabilities and thus encourage staff in such offices to do so; 2) to provide an overall framework to conduct historical analyses or current monitoring of submerged or emergent vegetation; and 3) to provide specific guidance regarding particular steps in the process, e.g. georeferencing.

During the course of the project the methodology was made available through the following methods. Presentations were made at various conferences and workshops, a local western Washington state workshop was organized at Padilla Bay, advice and ideas were provided to a variety of local and regional GIS user groups, and one on one consultation was provided to staff in offices that were applying all or individual steps in the methodology. In addition, a report documenting the methodology was written.

The following presentations were made at various meetings during the course of the project (plus one presentation 'committed' for January 2003):

Bulthuis, Douglas A. 2000. Accessible methodology for monitoring estuarine and coastal vegetation. Paper presented in session titled "Application of new environmental technologies for improved coastal management" at The Coastal Society 17th International Conference, 'Coasts at the Millennium', July 9-12, 2000, Portland, Oregon.

Bulthuis, Douglas A. and Suzanne Shull. 2000. Accessible methodology for monitoring estuarine and coastal vegetation. Poster presented at 14th Annual Workshop of the

National Estuarine Research Reserve System and the National Estuarine Research Reserve Association, October 15-19, 2000, Williamsburg, Virginia.

Shull, Suzanne and Douglas A. Bulthuis. 2001. Accessible methodology for monitoring estuarine and coastal vegetation. Paper presented at Coastal GeoTools '01 Conference, January 8-11, 2001, Charleston, South Carolina.

Shull, Suzanne and Douglas A. Bulthuis. 2001. Accessible methodology for monitoring estuarine and coastal vegetation cover. Paper presented at Pacific Estuarine Research Society, May 17-19, 2001, Tacoma, Washington.

Shull, Suzanne and Douglas A. Bulthuis. 2002. GIS projects at Padilla Bay NERR. Presentations to the NERRS Stewardship Coordinators, January 8-10, 2002, LaConnor, Washington.

Shull, Suzanne and Douglas A. Bulthuis. 2003. Delineation of salt marsh and eelgrass habitat to detect interannual changes in Padilla Bay, Washington. Paper to be presented at Coastal GeoTools 2003 Conference, January 6-10, 2003, Charleston, South Carolina.

An informal seagrass mapping workshop for interested staff in western Washington was organized at Padilla Bay in January 2002. Attendees included staff from tribes, from Washington State agencies, from county planning staff, and scientists from companies that map seagrasses for counties, ports and harbors in western Washington. A variety of methods for mapping seagrasses were presented and discussed at the meeting, with particular emphasis on the methodology developed in the present project.

During the three years of this project, Suzanne Shull regularly participated and provided advice where appropriate at the quarterly meetings of the northwest Washington GIS Users Group that includes county, city, and tribal staff, who work on estuarine and other mapping, and planning issues. Participants include counties (Island, San Juan, Snohomish, Skagit, and Whatcom); tribes (Lummi, Swinomish, Tulalip, and Skagit); cities (Bellingham, Mount Vernon, Anacortes); state agencies (Ecology, Natural Resources), and Western Washington University. Ms. Shull also provided assistance where needed at the monthly GIS Users' meeting in Bellingham that included a similar, but somewhat smaller spectrum of staff from local governments with Shoreline Master Programs under Washington's Coastal Zone Management law.

A technical report outlining the methodology developed in this project has been written and will be distributed as a Padilla Bay National Estuarine Research Reserve Technical Report. Copies can be obtained by contacting:

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and requesting a copy of Padilla Bay National Estuarine Research Reserve Technical Report No. 26.

Application and use of this methodology to coastal resource management has been ongoing throughout the project period. Because the emphasis is on an accessible methodology, and because there are many steps in the methodology (some of which will be applicable in a local situation and other steps that will not be applicable), tracking and quantifying the applications is not possible. However, the following examples of people involved in some aspect of coastal resource management and to whom direct assistance was provided (either concerning the methodology as a whole or some step in the process) indicate the breadth of application that has already occured. Further application to local coastal resource management is expected when the Padilla Bay National Estuarine Research Reserve Technical Report is distributed.

Examples include Dr. Greg Hood of the tribal Skagit Systems Cooperative who is mapping Sweet Gale in the Skagit River salt marshes, Dr. Natalie Cosentino - Manning of National Marine Fisheries Service in San Francisco who is developing habitat (eelgrass and salt marsh) restoration in San Francisco Bay, Jeff Robinson of the Humboldt Bay Harbor District, Dr. Don Young and Patrick Clinton of U.S.E.P.A. labs in Newport, Oregon in mapping eelgrasses, Douglas Couvelier of the (tribal) Skagit Systems Cooperative in determining historical changes in stream channel morphology of salmon bearing streams, and staff in the nonprofit organization Nahkeetah NW in mapping greenbelt and salmon habitat in urban areas.

Technology Commercialization

The goals of this project were to test and demonstrate an accessible technology for mapping and montioring estuarine vegetation cover with aerial photography and widely available commercial software—ArcView 3.x. Thus, no intellectual property rights, patents, copyrights, or licensing products were expected nor have resulted from this project. We have not had any private sector partnerships; nor is there potential for commercial production of the methodology developed in this project.

Scientific and Academic Achievement

No manuscripts were published or submitted to refereed journals as of November 2002.

No graduate students worked on this project as part of their thesis work. However, Dan Hahn, Ph.D. Candidate in the Zoology Department, University of Washington assisted with ground truth invistigations in this project in work that was ancillary to his Ph.D. thesis on *Competition between, and biodiversity associated with, an introduced seagrass (Zostera japonica) and its native congener (Z. marina)*.

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Table 1. Area (hectares) of estuarine vegetation in Padilla Bay, Washington and the area of intertidal flats and subtidal channels without macrophytes (cover less than 10%) in the Padilla Bay study area in July 2000. (See Figure 03 for distribution of these categories in Padilla Bay.)

Submerged or emergent vegetation and percent cover category	**Area (hectares)**
Zostera marina intertidal 51-100%	2779
Zostera marina intertidal 10-50%	33
Zostera marina subtidal	217
Total Zostera marina	**3029**
Zostera japonica intertidal 51-100%	723
Zostera japonica intertidal 10-50%	114
Total *Zostera japonica*	**838**
Total *Zostera sp*.	**3867**
Macroalgae 51-100%	124
Macroalgae 10-50%	80
Total macroalgae	**204**
Saltmarsh	47
Total vegetation	**4117**
Intertidal bare	1144
Subtidal bare	944

Table 2. Area of eelgrasses (*Zostera sp*.) in the March Point study area in Padilla Bay, Washington in 1989, 1992, 1996, and 2000. The eelgrass covered areas were divided into those with an apparent continuous cover or those with a sparse cover.

Year	**Continuous eelgrass (hectares)**	**Sparse eelgrass cover (hectares)**	**Total eelgrass cover (hectares)**
1989	115.8	5.2	121.0
1992	118.9	3.6	122.5
1996	107.9	8.6	116.4
2000	92.3	19.6	111.9

Table 3. Area of eelgrasses (Zostera sp.) in the northeast study area in Padilla Bay, Washington in 1989, 1992, 1996, and 2000. The eelgrass covered areas were divided into those with an apparent continuous cover or those with a sparse cover.

Year	Continuous eelgrass (hectares)	Sparse eelgrass cover (hectares)	Total eelgrass cover (hectares)
1989	40.6	7.9	48.5
1992	107.3	27.4	134.6
1996	91.9	8.6	100.5
2000	107.3	61.1	168.3