PUGET SOUND INTERTIDAL HABITAT INVENTORY 1995: VEGETATION AND SHORELINE CHARACTERISTICS CLASSIFICATION METHODS

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EXECUTIVE SUMMARY

Puget Sound's intertidal areas are habitats for species of commercial, recreational, biotic, and aesthetic value. Habitat is a critical ecosystem component -- it provides living space for permanent and transitory species, and supports primary production, food webs, and other ecosystem functions. Accurate information on the quality and quantity of intertidal habitats is important to monitoring and sustaining the health of Puget Sound.

This paper summarizes methods used to survey intertidal habitat in the Puget Sound by the Nearshore Habitat Program in the Washington State Department of Natural Resources' Aquatic Resources Division. The program is part of the Puget Sound Ambient Monitoring Program (PSAMP), an ongoing project that monitors the health of the Puget Sound.

During the summer of 1995, 110 miles of shoreline were surveyed in the Whatcom County area, from Point Whitehorn southward to the Skagit County border. Paper and digital versions of inventory data and documentation are available through The Nearshore Habitat Program. The datasets are intended for use in general management and land use planning.

The inventory describes two components of intertidal habitat: vegetation types and shoreline characteristics.

<u>Vegetation Types</u>
Eight nearshore vegetation types were classified using multispectral imagery: eelgrass, brown algae, kelp, green algae, mixed algae, salt marsh, spit and berm vegetation, and red algae. The vegetation types encompass most common macroscopic vegetation found along Puget Sound's shorelines. They were selected based on aquatic resource management priorities and multispectral detection considerations.

Vegetation types were extracted from multispectral imagery using ground data to guide the classification. Aerial imagery was collected during July and August when tides were below Mean Lower Low Water in most of the study area and at sun angles which minimized sun glint. A CASI (Compact Airborne Spectrographic Imager) sensor collected 11 bands of reflectance data, ranging from 470 nanometers (nm) to 876 nm, at a resolution of approximately 13 feet (4 meters). Color infrared photography was collected simultaneously at 1:11,000 scale. The imagery was rectified using Global Positioning System (GPS) data collected in-flight

(differential corrections were applied in post-processing), and control gained from Washington State Department of Natural Resources’s digital orthographic photography. Most areas were mapped to within 40 feet (12 meters) relative to the control points.

Ground data were collected throughout the study area between June and September. The location of sites with greater than 25% vegetation cover were recorded using differentially corrected Global Positioning System (DGPS) data or aerial photograph annotation. Sites were assigned to one of eight vegetation classes, according to the type that comprised 75% or more of the vegetated cover. Sites were then divided into groups and used: (1) to guide classification of multispectral CASI imagery, or (2) to assess the accuracy of the classified image. Overall classification accuracy was 75%. The classified raster CASI data were then translated into a vector coverage and generalized.

Shoreline Characteristics

Physical attributes in intertidal areas were characterized according to *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). This system builds on the National Wetland Inventory system (Cowardin *et al*., 1979), with modifications relevant to marine and Estuarine communities. The following classification levels were delineated: System, Subsystem, Substrate, Energy, and Water Regime.

Intertidal shoreline classification was completed using ground data in conjunction with photo-interpretation of color infrared aerial photos ranging between 1:11,000 and 1:13,000 scale. The minimum mapping unit was approximately 0.2 hectares (0.5 acres). Final delineations were completed on 1:12,000 scale DNR orthophoto maps using a Zoom Transfer Scope and then digitized.

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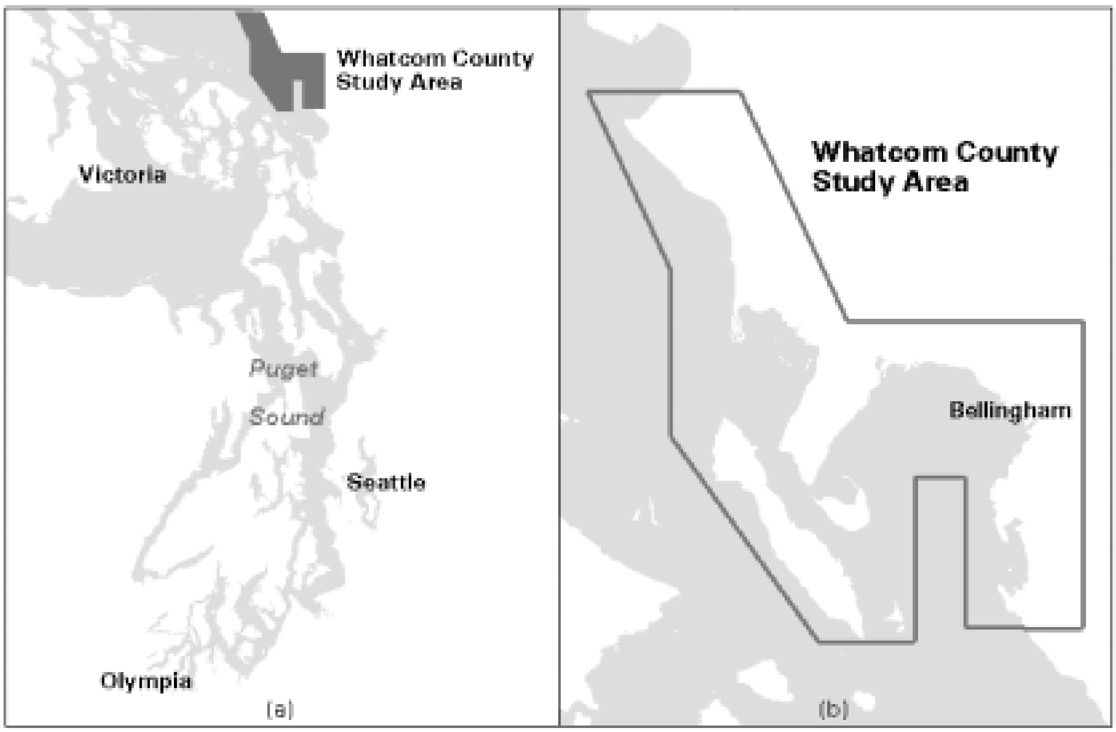
INTRODUCTION

Washington State's Puget Sound nearshore habitats have significant biological, ecological and economic value. Comprehensive management of nearshore resources requires accurate and current information about their location, abundance, and characteristics. Nearshore habitat information is being updated and improved through the Nearshore Habitat Program. This document describes methods used to inventory intertidal vegetation and shoreline characteristics in the Whatcom County area in 1995.



The 1995 Intertidal Habitat Inventory study area included approximately 110 miles of shoreline along the mainland from Point Whitehorn in the Strait of Georgia to the southern boundary of Whatcom County at Governors Point, and Portage Island, Lummi Island and Eliza Island (Figure 1). This diverse region supports a range of intertidal habitat types, including rocky and Mixed Coarse beaches with relatively high wave energy, as well as sheltered sand and mud flats. The Puget Sound Environmental Atlas (1992) documented habitat use in the area by resident and nonresident populations such as baitfish, Red Rock and Dungeness crab, salmonids, groundfish, intertidal and subtidal shellfish, seabirds, and a variety of marine mammals. Land uses found along the shoreline include the urbanized waterfront of Bellingham Bay, industrial sites, low and medium density residential housing, aquaculture, water- and shore-based recreational sites, and relatively undeveloped areas such as the Nooksack River delta.

NEARSHORE HABITAT PROGRAM BACKGROUND

The Nearshore Habitat Program (NHP) is in the Aquatic Resource Division of the Washington State Department of Natural Resources (DNR), and is part of the multi-agency Puget Sound Ambient Monitoring Program (PSAMP). PSAMP was established in 1988 through the Puget Sound Water Quality Management Plan to conduct long-term comprehensive monitoring of the Puget Sound environment and its resources. Monitoring is carried out by the Washington State Departments of Natural Resources, Fish and Wildlife, Health, and Ecology, and the US Fish and Wildlife Service.

The Aquatic Resources Division manages two million acres of state-owned aquatic lands, and is responsible for the nearshore habitat monitoring component of PSAMP. The Nearshore Habitat Program's goal is to map the distribution and abundance of nearshore habitats, and to monitor how these habitats are changing over time in response to human and natural factors. Results will be used to support a range of management and research activities, including aquatic land use planning, resource protection, habitat-related studies, and trend analysis.

PSAMP defines nearshore habitats to include unvegetated and vegetated habitats in intertidal, shallow subtidal, and supratidal areas (Monitoring Management Committee, 1988). The geographic extent of the Puget Sound planning area is defined to include the Hood Canal, the southern, central and northern Puget Sound and Whidbey sub-basins, the San Juan Archipelago and the southern Strait of Georgia (Puget Sound Water Quality Authority, 1986). The boundaries of the study area are Ediz Hook in the Strait of Juan de Fuca (123° 30') to the southwest and the international border between the US and Canada to the northwest and north.

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 utilized multispectral imagery through an inter-agency cooperative agreement as the primary data source for inventorying Puget Sound's nearshore areas. Data were collected by a Daedalus DS-1260 multispectral, rotating mirror, scanner mounted in an aircraft. The delivered image data were not rectified to meet NHP's positional accuracy specifications of +/- 40 feet. The imagery's low positional accuracy precluded the use of DGPS-located field data in image processing, and prevented us from integrating the image data into our existing geographic information system (GIS).

The habitat categories to be derived from the Daedalus imagery were drawn from the classification system, *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). This classification system identifies a set of physical characteristics, including diagnostic and common vegetation species. The hierarchical classification system has more than 300 possible habitat types for the Marine and Estuarine Systems. The habitat categories were too detailed to be consistently identified in the Daedalus multispectral imagery. Based on the lessons learned during the first stage of the program, habitat inventory methods were revised for the 1995 inventory. Specifications for multispectral data collection were revised to ensure better positional accuracy. The nearshore vegetation list was reviewed and simplified based on an investigation that identified the detail at which diagnostic vegetation species might be detected using multispectral data at a 96.84 square feet (9 square meters) to 269 square feet (25 square meters) spatial resolution (Aitken *et al.*, February 1995). The spectral profiles of common nearshore vegetation types in Puget Sound were used to develop a custom, multispectral bandset.

Multispectral imagery methods were limited to vegetation inventory. We concluded that multispectral imagery was not the appropriate data source for inventory of other shoreline characteristics, given the information types and level of detail required by *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). Substrate categories as defined in the classification were too detailed to be consistently distinguished by current multispectral methods. Spectral data provides little information on wave and current conditions, tidal elevation or substrate information in areas covered by vegetation or structures.

Alternative methods were adopted for inventorying shoreline characteristics as described by *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier, 1990). Since the classification system does not have an integrated mapping methodology, the inventory in the Whatcom County area was a pilot effort to produce a synoptic digital coverage. Field notes were used in conjunction with airphoto interpretation to delineate shoreline characteristics. A data format, and arc and polygon coding scheme were implemented for evaluation. Spatial resolution was determined using existing mapping tools and technology. The completed coverage will allow DNR and others to use the data and provide feedback on the utility of the inventory with respect to format, resolution, and classification parameters. Results will be used to determine future inventory methods, including minimum mapping unit, data collection methods, digital data structure, and classification system parameters.

VEGETATION INVENTORY

Vegetation Types

Eight nearshore vegetation types were classified using multispectral imagery. The vegetation types encompass most common macroscopic vegetation found along Puget Sound's shorelines. They were selected based on aquatic resource management priorities and multispectral detection considerations. Descriptions follow algal taxonomy found in Scagel *et al.* (1989):

- Brown Algae - Algae belonging to the taxonomic group Division Phaeophyta. Some common representatives in Puget Sound include rockweed (*Fucus spp.*) and *Sargassum muticum*.

- Kelp - Large brown algae belonging to the taxonomic group Order Laminariales. Some common representatives in Puget Sound include floating kelp (*Nereocystis luetkeana*) and understory kelp (*Laminaria spp.*). Because of its recognized ecological function and management importance, kelp is distinguished from other brown algae when it makes up greater than 75% of the vegetated cover.

- Eelgrass - The vascular plants *Zostera marina*, and *Zostera japonica*. Eelgrass beds are recognized as critical habitat in the life cycles of many fishes, invertebrates and birds.

- Green Algae - Algae belonging to the taxonomic group Division Chlorophyta. A common representative in Puget Sound region is sea lettuce (*Ulva spp.*).

- Red Algae - Algae belonging to the taxonomic group Division Rhodophyta. A common representative in Puget Sound region is nori (*Porphyra spp.*). Areas dominated by red algae and large enough to map at this resolution rarely occur in the summer in the intertidal zone of Puget Sound.

- Mixed Algae - Areas in which red, green, or brown algae coexist, but no single type occupies more than 75% of the vegetated cover.

- Salt Marsh - Salt-tolerant, emergent wetland plants such as pickleweed (*Salicornia virginica*), saltgrass (*Distichlis spicata*), and sedge (*Carex lyngbyei*). Freshwater marsh areas were not included in the inventory.

- Spit and Berm Communities - Areas dominantly covered with plants such as dune grass (*Elymus mollis*), gumweed (*Grindelia integrifolia*), and yarrow (*Achillea millefolium*), which generally occur above the highest tides, but still receive salt influence. The substrate is usually sand or gravel, and drift logs commonly accumulate.

The list of vegetation types to be classified was influenced primarily by spectral discrimination considerations (Aitken *et al.*, February 1995). Yet, management priorities led to the selection of some vegetation classes despite discrimination difficulties. Kelp and other brown algae have similar dominant pigments and often a similar spectral signature. However, the inventory needed to differentiate kelp because of its recognized ecological function (e.g., Foster & Shiel, 1985; Dayton, 1985; Duggins, 1988; Wheeler, 1990) and management considerations (e.g., Washington Administrative Code (WAC) 220-110-250; WAC 365-190-080; DNR POL-0300).

Both green algae and eelgrass contain chlorophyll *a* and *b* pigments and have a similar spectral profile. Yet, management considerations required that they be differentiated. Eelgrass beds have recognized ecological function (e.g., Phillips, 1984) and management considerations (e.g., WAC 220-110-250; WAC 365-190-080; DNR Policy 0300, 1991; Wyllie-Echeverria et al., 1994). Green algae can be an indicator of other processes such as eutrophication.

The spectral signature for mixed algae varies with species composition, yet the mixed category was required in order to identify the presence of vegetation of varying composition.

Salt marsh and spit/berm communities are often narrow and obscured by overhanging vegetation, making discrimination difficult using current methods. Despite spectral and spatial discrimination challenges, the salt marsh and spit/berm categories were included due to the recognized functional importance of wetlands, and because habitats at the land-water interface tend to be impacted highly by development. Additionally, salt marshes have recognized ecological functions (e.g., Seliskar & Gallager, 1983) and management considerations (e.g., WAC 220-110-250; WAC 365-190-080; DNR POL-0300).

<u>Vegetation Inventory Field Data Collection</u>

Field data were collected by Nearshore Habitat Program (NHP) scientists in the Whatcom County study area when tides were below +1.0 mean lower low water (MLLW), between June and September in 1993, 1994 and 1995. The minimum mapping unit (MMU) was approximately 13 feet (4 meters). Information on vegetated sites were located by either differentially corrected Global Position System, annotated multispectral image plots, or annotated aerial photographs with transparent overlays. Additionally, 35 mm slides were taken of vegetation features at regular intervals along the shoreline and at all DGPS-located sites. Field data was collected by boat or on foot. Areas to be surveyed were identified in advance by apportioning the available field days over the study area as a whole, and considering access to the shoreline. During the field season, a tally of the number of sites for each vegetation class was maintained to ensure that field data representing each of the vegetation classes were collected throughout the study area.

Field sites that had a total vegetation cover greater than 25 percent were recorded as vegetated sites. Field assignments were based on the dominant vegetation category at a site, i.e., the vegetation class making up 75 percent or more of the vegetated area. A crucial factor in selecting field sites was to consider the appearance of vegetation patches from a planimetric perspective. Discussions between field, GIS, and remote sensing staff led to refining field data collection conventions, e.g., applying the minimum mapping unit to the horizontal expanse of the landscape (the sensor's vantage point), and recording percent cover of vegetation and cover class of vegetation as viewed from above. To ensure consistency, certain tasks, particularly, aerial photography annotation, were limited to select staff.

Annotated photography data describing field sites included a polygon or line representing the feature accompanied by notes stating vegetation type, and, when possible, primary species composition and substrate. GPS-located site data were collected as line, point or polygon features, depending on patch shape and location. At GPS-located sites, information on vegetation, fauna, and other physical parameters were recorded. After collection, GPS data were differentially corrected based on local base station data and converted to ArcInfo coverages.

In 1995, most field sites were annotated on photography rather than located using DGPS. Photo annotation was a more rapid data collection method. Additionally, with the MMU at 13 feet and the positional accuracy of the multispectral imagery at +/- 40 feet, small DGPS-located sites could be difficult to position in the image data precisely. The annotated photography method provided critical visual clues for relating a field site to an image site. When positional discrepancy was in question with a DGPS-located site, we found that 35-mm slides taken of each site and its surrounding features were the best tools for determining site location within the imagery.

In the office, field data were assigned to one of two groups: (1) to guide the image classification process, or (2) to assess classification accuracy. Field sites were divided between the two groups so that data were distributed throughout the study area, and so that sites within each vegetation type were apportioned equally. When assigning sites, the staff confirmed that proximate field data did not contradict or overlap, and that the effects of spatial autocorrelation on the accuracy assessment methodology were kept to a minimum.

Imagery Acquisition
In 1995, the NHP contracted with Borstad Associates Ltd. in Sidney, British Columbia to collect, rectify, and mosaic imagery 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. Imagery was acquired at an approximately 169 square feet (16 square meters) spatial resolution on July 12, and August 13, 1995 during low tides.

The CASI is a passive, electro-optical imaging spectrometer. The 'push-broom' imager operates by looking down in a fixed direction, building up a two-dimensional image as the aircraft moves forward. The instrument's spectral range is 400 nm to 1000 nm, and it has a 37.8 degree field of view. For the Bellingham Bay project, the instrument was operating in spatial mode, programmed with a custom, 11-channel bandset as shown in Table 1 (Borstad, 1996).

Table 1. CASI Sensor Bandset for Whatcom County Study Area (from Borstad, 1996).

Band No.	**Wavelengths (nm)**	**Purpose**

1	470-515	Chlorophyll *b* absorption at 480 nm Carotenoid reflectance peak at 500 nm Penetration of clear water
2	540-560	Green vegetation reflectance peak (eelgrass and green algae) Penetration of turbid water
3	575-590	Brown algae absorption well
4	600-615	First reflectance peak for brown algae
5	625-635	Well between reflectance peaks for brown algae
6	640-655	Second reflectance peak for brown algae, chlorophyll *b* absorption at 650 nm (eelgrass)
7	670-690	Absorption well for chlorophyll *a* (all vegetation)
8	704-714	Red rise, near infrared reflectance for shallow submerged and floating vegetation, but in avoiding 720 nm water vapor feature
9	743-755	Near infrared reflectance for submerged and floating vegetation, but in avoiding 762 nm water vapor feature
10	775-786	Near infrared reflectance for emerged and marsh vegetation, substrate delineation
11	854-876	Near infrared reflectance for emerged and marsh vegetation, substrate delineation

The CASI imagery collection system was composed of various components in addition to the sensor (Aitken *et al.*, June 1995). A low wattage 486 computer recorded roll and pitch from a two-axis gyroscope. The analog signal from the gyroscope was converted to digital form, and recorded on the computer's hard drive. Yaw was measured using a flux-gate compass. GPS recorded horizontal and vertical movement information (drift, ground speed, and altitude changes) of the aircraft. GPS base station data were used to differentially correct the aircraft's rover GPS data in post-processing. The raw image data were acquired with 12 bit precision and written in unsigned 16 bit format onto 8mm tape.

The CASI system was mounted in a Cessna T210 aircraft. All flight lines were flown at a 10,800' altitude, from south to north, with 50% sidelap between adjacent flight lines. Flying in a consistent direction reduced radiometric discrepancies due to sun angle and sensor viewing angle. Target dates for image acquisition were selected based on maximum intertidal exposure (minus 1.0 foot mean lower low water or below), and times when sun angle would reduce sun-glint. Actual date, tidal levels, and time of day that each flight line was collected are listed in Table 2.

Table 2. Imagery Collection Date, Time and Tidal Elevation for Whatcom County Study Area.

Date	Flight Line	Start Time (PDT)	Tidal Height (MLLW)
July 12	24	09:47 am	-2.8
July 12	23	10:04 am	-2.8
July 12	22	10:21 am	-2.8
July 12	21	10:37 am	-2.8
July 12	20	10:49 am	-2.6
July 12	12	11:01 am	-2.5
July 12	13	11:19 am	-2.2
July 12	14	11:36 am	-1.9
July 12	15	11:53 am	-1.5
July 12	16	12:11 pm	-1
July 12	17	12:29 pm	-0.5
July 12	18	12:42 pm	-0.3
July 12	19	12:51 pm	-0.1
August 13	11	11:50 am	0.6
August 13	10	12:03 pm	0.5
August 13	9	12:17 pm	0.5
August 13	8	12:38 pm	0.6
August 13	7	12:52 pm	0.7
August 13	6	01:08 pm	0.8
August 13	5	01:28 pm	1.1
August 13	4	01:30 pm	1.3
August 13	3	01:44 pm	1.6
August 13	2	02:16 pm	2.1
August 13	1	02:25 pm	2.3

Imagery was adjusted to surface radiance by applying an atmosphere correction, corrected for roll, pitch and yaw and projected into geographic coordinates using DGPS data to yield 169 square feet (16 square meters) pixels (Borstad, 1996). The resulting imagery was warped to fit DNR's orthographic aerial photographs and coastline vectors in Washington State Plane, south zone, unit of measurement is feet, North American Datum of 1927 (NAD '27). The flight lines were rectified to within +/-3 pixels (approximately 40 feet) in most parts of the imagery. The rectified flight lines were mosaicked into five, non-overlapping blocks, requiring a total of nearly 732.8 MB of disk space. Figure 2 shows the CASI sensor flight lines and mosaic boundaries for Whatcom County Study Area.

Image Processing and Analysis

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 relied on the field data (e.g., DGPS-located sites and annotated photography) to develop training signature sets.

The nearshore vegetation layer was produced by running a series of iterative Imagine software routines that identify vegetated areas of interest, and eliminate areas of non-interest. In summary, the following steps were used:

- On-screen digitizing was used to eliminate areas of non-interest, e.g., uplands and deep water.
- A minimum distance classification with an unsupervised signature set was run on the masked multi-channel raster.
- Coarse editing on the minimum distance classifier file was used to reduce further areas of non-interest, e.g., deep water and substrate. Classes of non-interest were recoded to zero.
- Used pixel values assigned to nearshore vegetation types in the editing the classified file to masked pixels in the original multi-channel raster, producing a masked, multi-channel raster used in subsequent classification processes.
- Developed a supervised signature set from the original multi-channel raster.
- The masked, multi-channel raster and supervised signature set were used to produce a maximum likelihood classified file.
- Areas that accurately represented a nearshore vegetation classes were selected interactively and recoded to the target class values for each land cover type.
- Again, masked specific areas from the original multi-channel raster based on user selected digital values in the edited maximum likelihood classified file to produce a masked, multi-channel raster.
- The remaining pixels in the masked, multi-channel raster 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, interactively edited and recoded. In the final iteration all pixels that represent a nearshore vegetation type were identified.
- Wrote a program to copy selected portions of the classified files into a composite classified file based on conditional statements.
- The plot used in classification accuracy assessment consisted of the composite classified file over a single-channel, gray-scale backdrop at 1:12,000 scale.

Classification of multispectral imagery depends on isolating a unique spectral signature for each category in the classification scheme. Vegetation has distinct reflectance differences in the visible and near infrared portions of the electromagnetic spectrum. When the pigmentation among the exposed vegetation types varies, e.g., green, red, and brown algae, the visible wavelengths (400 nm - 700 nm) provide good spectral discrimination (Swain and Davis, 1978). In the near infrared wavelengths (700 - 1300 nm), reflectance response is determined largely by intra-cellular structure and canopy structure (Swain and Davis, 1978). In cases where spectral discrimination was not sufficient to differentiate classes, alternative methods were used for discrimination.

Kelp and other brown algae have similar dominant pigments and often a similar spectral signature. Contextual cues were used to separate kelp from other brown algae. In the case of *Fucus* spp., habitat context was used. While kelp is found mainly in the subtidal zone, *Fucus* is common to rocky beaches. The different viewing backgrounds of kelp and *Fucus* facilitate spectral discrimination. *Sargassum muticum* also forms canopies in the shallow subtidal. To differentiate *Sargassum muticum* from kelp we used pattern and context cues provided by the simultaneously acquired color infrared photography (CIR) photography.

Both green algae and eelgrass contain chlorophyll *a* and *b* pigments and have a similar spectral profile. At times, environmental context can be used to distinguish eelgrass and green algae. When green algae are on a tidal flat and eelgrass is located in the subtidal zone, the two can be identified by relying on the different spatial location and different substrate/water background cues. However, when these environmental cues are lacking, spectral separation is difficult. Green algae also commonly grows intermixed with eelgrass, in these cases the areas were classified as eelgrass because eelgrass is the more persistent vegetation and more politically important.

The spectral signature for mixed algae varies with species composition, and the layering of the different species. Mixed algae can be confused spectrally with any of the algal categories. However, the mixed algae category allows us to summarize species composition in a manner that keeps tractable the number of classification categories.

Salt marsh and spit and berm vegetation communities are separable from the macroalgae and eelgrass mainly because they contain emergent vegetation and the spectral signatures more closely resemble terrestrial vegetation (Aitken *et al.*, June 1995). Intertidal zonation is another important spatial cue, since these vegetation types occur in the upper intertidal and supratidal zones. To differentiate salt marsh and spit and berm communities from other terrestrial vegetation, the upland areas were masked.

Detecting submerged vegetation was difficult. Spectral discrimination of submerged vegetation is influenced by water depth, surface roughness, water clarity and bottom type. 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.

In addition to the spectral characteristics of the features themselves, environmental factors influence the energy levels ultimately recorded by the sensor. For vegetation, its type, vigor, density, moisture content, degree of exposure, and amount of coverage by epibenthos will all affect spectral response. Vegetative response is affected also by the amount and type of its background, e.g., substrate or water. Atmospheric particles also influence the signal recorded by the sensor by absorbing and scattering radiant energy. These variations have strong implications for image classification. Signature extension relies on applying the training data for a particular feature to all other sites in the imagery that represent that feature.

Classification Accuracy Assessment

Understanding the accuracy and reliability of a classification is important to applying its results appropriately. Accuracy assessment methods need to consider both statistical validity and practical implementation issues. Field data served as the reference data set against which the classified data were evaluated. When the field reference data were in hard copy form, NHP marine scientists used plots to evaluate the classification derived from the imagery; digital field sites were overlaid onto the composite classified file and evaluated on-screen. For each assessment site, the vegetation class or classes present in the classified imagery was recorded. Because assessment sites included line and polygon features, establishing 'correctness' was not always a binary decision. We assigned points as follows:

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

The points assigned during the classification accuracy assessment work for the Whatcom County study area were compiled into an error matrix (Table 3). The number of assessment sites classified as a particular category is 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.

Table 3. Nearshore Vegetation Classification Accuracy Assessment Results for the Whatcom County Study Area.

Imagery Classified Data	**Field/Reference Data**							
	brown algae	green algae	kelp	mixed algae	eelgrass	salt marsh	spit/ berm	total no. classified
brown algae	10.5			1.0				11.5
green algae		15.5		1.0	1.0			18.0
kelp	1.5		19.0	1.0	1.0			22.5
mixed algae		4.5	1.0	8.0				13.5
eelgrass		3.5			33.5			37.0
salt marsh		0.5				26.0		26.5
spit/ berm							5.5	5.5
none	3.0	14.0	2.0		5.5	4.0	2.5	30.5
total reference sites	15.0	38.0	22.0	11.0	41.0	30.0	8.0	165.0

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 classified in that category. Table 4 shows Producer's and User's classification accuracy by land cover type.

Table 4. Producer's and User's Classification Accuracy Percentages by Land Cover Type for the Whatcom County Study Area.

Classification Accuracy		
Land Cover	**Producer's %**	**User's %**
brown algae	70.0	91.3
green algae	40.8	86.1
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

Overall, the vegetation accuracy rates are encouraging with respect to prospective data set uses. Eelgrass, kelp and salt marsh vegetation, which are important to land-use related decision making, had generally high accuracy rates. Most often, the User's accuracy level was higher than the Producer's accuracy level, pointing to a trend of lower commission error and higher omission error. For example, a person using a classified plot in the field would be likely to find that a site called salt marsh on the plot was actually salt marsh on the ground (lower commission error), but may find sites on the ground that were not classified on the plot (higher omission error).

Omission error was the most significant error type in most categories, e.g., 14 green algae reference sites were not included in the classified file. Multiple factors could have contributed to this result. Training signatures used by the statistically-based classifier to assign pixels to classes may not have represented the population. The percent cover threshold for a vegetated site (25 percent or greater) may have been too low for consistent detection. Temporal changes in vegetation could have occurred between the time at which the field data was collected and the time at which the multispectral imagery was collected, common short term changes include green algae blooms and changes in the composition of beds. While collecting field data on the same date as imagery acquisition would be ideal, study area size and resource limitations required a seasonal approach to field data collection.

The basic assumption of this approach to accuracy assessment is that the error matrix accurately represents the entire classification effort. Congalton (1991) points to the importance of a number of factors, including the classification scheme and sampling design, in generating a proper analysis. The classes of any classification scheme should be mutually exclusive and totally exhaustive. If the classes of a system are exhaustive, a site will fall into one and only one class. However, management priorities led to separate classes for kelp and brown algae, although kelp are brown algae. Further, the present eight classes do not exhaust the possible vegetation community compositions in the nearshore environment. For example, field staff have reported sites where green algae and eelgrass are intermixed at the 13.123 feet (four meters) minimum mapping threshold. These sites were classified as eelgrass, because eelgrass is more persistent vegetation and more functionally recognized constituent.

Welch (1981) has suggested that spatial resolution should be less than half the size of the target feature measured in its smallest dimension. Therefore, the minimum mapping unit for the vegetation inventory should not be equal to spatial resolution of the sensor. Assuming that the sensor's pixels will align precisely with the ground feature is unrealistic. However, altering either of these variables has strong implications for the program. For example, increasing the minimum mapping unit to a value twice the sensor's spatial resolution would result in a higher degree of generalization and many narrowly-banded vegetation features that are biologically important in the nearshore would not be considered because they fall below the MMU. Selecting a finer sensor spatial resolution would result in much larger datasets, increased processing time, and increased data management costs.

Generalization & Conversion

Based on the assessment/review work of the marine scientists, modifications were made to the classified file. After final adjustments, the classified raster was converted to vector format for subsequent use and analysis in DNR's GIS. Vector data formats are a DNR standard for analysis and cartographic production. In addition, the generalized coverage provides users of systems with limited raster capabilities with a vector data set of a manageable size for common computer configurations.

As part of the data conversion, generalization was required to reduce the number of features and arcs in the coverage to a manageable number for common computer system configurations. The objective was to simplify the coverage while maintaining the salient characteristics of vegetation features at an appropriate scale. The following evaluation criteria were used to select the best data conversion methods:

- Significant reduction of the number of features and arcs in the polygon coverage.

- Less than 10 percent variation in total acreage per vegetation class between the ungeneralized raster data and the final vector coverage.

- Similar visual appearance of ungeneralized and generalized features, when viewed at 1:12,000 scale.

- Minimization of required feature-by-feature editing, to achieve consistent results throughout the study area and to increase time efficiency.

After initial testing of generalization and conversion in small areas, the following steps were applied:

- Mosaic blocks were joined into a single grid file for the study area, and then separated by vegetation type for generalization.

- An ArcInfo GRID (ESRI, Redlands, California) focal filter function was used to smooth feature boundaries. Smoothed grids for each vegetation type were then recombined according to a hierarchy, so that in cases where a pixel was assigned multiple vegetation values, the higher priority vegetation type was retained. The assignment hierarchy was based on the relative significance of vegetation types in management and environmental decision making: eelgrass (highest), kelp, salt marsh, spit berm, mixed algae, brown algae, green algae (lowest). The recombined grid was then converted into a polygon coverage.

- Features with an area equal to four or fewer pixels (approximately 690 square feet) were eliminated. The elimination decreased the total number of features by two-thirds, while changing the total acreage by less than 5 percent. In determining the size of features to eliminate, the effect of elimination on visual appearance turned out to be more important than the effect on total vegetation acreage because the size distribution of vegetation features was skewed. As a result, the visual appearance of the coverage could change markedly without a corresponding change in acreage. The narrow, linear vegetation features areas were most affected by area elimination thresholds. They were evaluated at 1:12,000 scale to decide which elimination threshold best maintained feature representation.

While the generalization did not significantly affect the areal extent of vegetation, it changed the frequency distribution of size classes. Two-thirds of the total number of vegetation features were eliminated. This effect of generalization should be considered when using the vector data set.

SHORELINE CHARACTERISTICS INVENTORY

Classification System

A Marine and Estuarine Habitat Classification System for Washington State (Dethier, 1990) is a hierarchical system that is based on the widely used U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) classification (Cowardin *et al.*, 1979). Major adaptions in the Washington State system include an additional level describing Energy (waves and currents), description of substrate in all habitats, and description of aquatic vegetation as diagnostic and common species. Table 5 summarizes the classification system.

The shoreline characteristics inventory delineated the following levels: System, Subsystem, Class, Subclass, Energy, Water Regime. Classification was implemented according to Bailey *et al.* (1993). Water Chemistry was not photo-interpreted due to a lack of visual cues that reliably indicate salinity regime. Diagnostic and common aquatic vegetation species were not included because they are provided in a separate vegetation inventory.

There are inconsistencies in how the Class and Subclass categories are defined in the classification system and how they are used in common implementations. The system describes substrate at the Class and Subclass levels (e.g., Unconsolidated, Sand). However, the habitat descriptions in the classification use Subclass rather than Class level categories (e.g., Sand). One exception is the Artificial Class, where no Subclasses are used. Most implementations and reviews also use Subclass for every category except Artificial, including the state's Compensation Schedule for Marine and Estuarine Waters (WAC 173-183-400), Puget Sound Estuary Program (Simenstad *et al.*, 1991), and implementations and reviews in British Columbia (Harper & Morris 1994 and Frith *et al.*, 1993). The shoreline characteristics inventory adopted this approach, but changed the name of the attribute to Substrate to avoid mixing the Class and Subclass values. The Substrate category includes descriptions at the Subclass level of detail for consolidated and unconsolidated substrates and at the Class level of detail for Artificial substrates. Code tables are provided to translate to Class and Subclass categories.

Delineation Methods

Intertidal shoreline characteristics were delineated on mylar overlaid on diazo prints of DNR's 1:12,000 scale orthophoto maps. The mylar overlays had reference information plotted on them, including geographic control marks, the NWI extreme low water line and the DNR water level line. A Bausch and Lomb Zoom Transfer Scope was used to superimpose annotated aerial photographs, maps, and National Oceanic and Atmospheric Administration (NOAA) charts onto the mylars. Lines and polygons were traced directly onto the mylar overlay and coded using either a 0.5 mm pencil or a colored pencil.

Table 5. Overview of *A Marine and Estuarine Habitat Classification System for Washington State*

System	Subsystem	Class	Subclass	Energy	Water Regime
Marine	Intertidal	Consolidated	Bedrock		
			Boulder		
			Hardpan	Exposed	
		Unconsolidated	Cobble		Eulittoral
			Mixed Coarse	Partially Exposed	
			Gravel		
			Sand		
			Mixed Fine		Backshore
			Mud	Semi-Protected	
			Organic		
		Reef		Protected	
		Artificial			
	Subtidal	Consolidated	Bedrock		
			Boulder		
			Hardpan	High	
		Unconsolidated	Cobble		Shallow
			Mixed Coarse	Moderate	
			Gravel		Deep
			Sand		
			Mixed Fine	Low	
			Mud		
			Organic		
		Reef			
		Artificial			
Estuarine	Intertidal	Consolidated	Bedrock		
			Boulder		
			Hardpan		
		Unconsolidated	Cobble	Open	Eulittoral
			Mixed Coarse		
			Gravel		
			Sand		Backshore
			Mixed Fine	Partly Enclosed	
			Mud		
			Organic		
		Reef		Lagoon	
		Artificial			
	Subtidal	Consolidated	Bedrock	Channel/Slough	
			Boulder		Shallow
			Hardpan		
		Unconsolidated	Cobble		Deep
			Mixed Coarse		
			Gravel		
			Sand		
			Mixed Fine		
			Mud		
			Organic		
		Reef			
		Artificial			

Data sources used to delineate shoreline characteristics include:

- Color infrared aerial photography collected by DNR Nearshore Habitat Program in 1989 (1:12,000 scale), 1992 (1:13,000 scale), and 1995 (1:11,000 scale).

- Field notes annotated on aerial photography and multispectral imagery collected throughout the study area from 1989 through 1995. Many sites also include 35 mm slides.

- NOAA NOS (National Ocean Service) nautical charts 18421 and 18424.

- U.S. Geological Survey 7.5 Minute Series (Topographic) maps.

- The Washington Coastal Zone Atlas (Department of Ecology, 1978).

- Intertidal transect information measuring percent cover of surface substrates and organisms collected by DNR Nearshore Habitat Program during 1995.

- U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) wetlands classification of the Puget Sound in paper and digital format.

The minimum mapping unit was determined to be approximately 20,000 square feet (1,800 square meters) on the ground, approximately 0.5 acre. The threshold was set by experimenting with the size of features that could be reliably delineated and digitized at base map scale using current methods. In areas where the intertidal zone was created by estimating planimetric intertidal width and buffering anthropogenic features such as dikes and jetties, some features smaller than the minimum mapping unit were delineated.

The entire study area lies within the geographic boundaries of the Estuarine System, as defined by the Habitat Classification System for Washington State (Dethier, 1990). Within the study area, the Intertidal Subsystem was delineated to show Substrate, Energy, and Water Regime (Table 5). The following features were delineated:

- Extreme Low Water Line (ELW) - The ELW line divides the Intertidal and Subtidal areas at the Subsystem level, and is the seaward extent of classification in the pilot study. NOAA estimates ELW in the study area to range from -4.0 to -4.5 feet. The location of ELW was estimated by superimposing low-tide aerial photographs of known tidal height onto the orthophotos. This line was then extrapolated seaward based on comparison to superimposed bathymetric lines from USGS topographic maps or NOAA charts. Our estimate was compared to the National Wetlands Inventory ELW line, and in portions where the two estimates did not differ significantly, NWI's ELW line was used.

- Extreme High Water Line (EHW) - The EHW defines the upland extent of classification. The location of EHW was estimated using visual cues such as vegetation changes, cliffs, bluffs, and seawalls. The digital line was created by altering the plotted DNR Water Level Line as necessary based on comparison to aerial photographs and topographic maps. On wide beaches, EHW is significantly farther inland than the Water Level Line. On narrow beaches, at the spatial resolution of this mapping project, EHW is in the same location as the Water Level Line.

- Substrate Polygons - Areas of homogenous substrate types, as defined by the Substrate categories (Table 5 and Dethier 1990). Since the inventory was limited to the Intertidal zone, the seaward and landward boundaries of substrate polygons were the EHW and ELW lines. In delineating Substrate, field data describing substrate size were transferred onto mylar. In areas between field data, pattern, color, texture and morphological cues were used to delineate boundaries between categories.

- Energy Polygons - Areas of homogenous energy, classified by comparison to Dethier (1990). The Energy level classes are broad enough to be applied to a whole section of shoreline (Bailey *et al.*, 1993). A single Energy value was assigned to the upper and lower intertidal portions of a segment of shoreline with the exception of Backshore areas in Open Energy regimes, which were assigned Partly Enclosed Energy value.

- Water Regime Polygons - The classification defines regularly inundated areas between ELW and mean higher high water (MHHW) as Eulittoral, and rarely inundated areas between MHHW and EHW as Backshore (Dethier, 1990). Backshore areas along the shoreline rarely met the minimum mapping unit threshold. As a result, few Backshore polygons were delineated.

In practice, the EHW and ELW lines were delineated first. Then, within the Eulittoral zone defined by these lines, separate polygons were delineated and coded whenever any of the attribute values changed. Since substrate values changed most frequently, substrate polygons were delineated. Then, Energy and Water Regime values were delineated by outlining and labeling one or more substrate polygons and adding polygons as required.

Each orthophoto was annotated with complete polygons. When polygons spanned onto adjacent orthophotos, complete polygons were drawn on each orthophoto so that the boundary lines overlapped. Overlapping lines were later dissolved during GIS processing.

Digital Data Structure

A single polygon theme of integrated terrain units was created (Dangermond *et al.*, 1982). The integrated theme simplified production since the boundaries of different levels were often coincident, and obviated potential spatial inconsistencies between layers of information. Attributes for each Shoreline Characterization parameter were associated with each polygon. A series of 3-letter codes were used to code polygon attributes (Table 6).

Table 6. Polygon Attributes		
Attribute	**Code**	**Description**
System	mar	Marine
	est	Estuarine
Subsystem	int	Intertidal
	sub	Subtidal
Substrate	bed	Bedrock
	bou	Boulder
	har	Hardpan
	cob	Cobble
	mco	Mixed Coarse
	gra	Gravel
	san	Sand
	mfi	Mixed Fine
	mud	Mud
	org	Organic
	art	Artificial
Energy	opn	Open
	pen	Partly Enclosed
	lag	Lagoon
	csl	Channel/Slough
Water Regime	bks	Backshore
	eul	Eulittoral

Each arc was coded to describe the type of boundary it delineated (Table 7). Because a single arc was often associated with changes in the values of multiple parameters, we prioritized the boundary value to be selected based on data display and analysis goals. Elevation lines defining the upper and lower limit of the Intertidal Subsystem were prioritized highest, followed by System boundaries, Backshore boundaries, Energy boundaries and Substrate boundaries.

Table 7. Line Attribute Codes

Significant Boundary Code (Sigbnd_cd)	Description
11	Boundary between upland and Marine/Estuarine areas. Approximate Extreme High Water Spring (EHWS).
12	The boundary between Subtidal and Intertidal areas. Approximate Extreme Low Water (ELW).
13	Boundary between Marine and Estuarine Systems.
14	Boundary between Backshore areas and Eulittoral areas. Approximate mean higher high water.
15	Boundary between areas with different Energy values.
16	Boundary between areas with different substrate values.
99	Boundary at the edge of the study area or at the edge of digitized sections.

Digitizing and Review

Line data were manually digitized from each 1:12,000 map manuscript into a tile registered to DNR's 5000-foot grid GIS registration tics. After tiles were digitized and checked, coverage tolerances were set as follows:

Tolerance	Units (feet)
Fuzzy	1
Dangle	0
Edit	40
Node Snap	40
Weed	10
Grain	10
Snap	10

Thirteen individual, topologically correct coverages were created. Attribute values for polygon and line features were then added. Next, check plots of the tiles were reviewed for attribute and line work accuracy. Coverage edge matching was performed from north to south. Where corrections were necessary, the southern edge was edited to match the tile to the south and the eastern edge was edited to match the tile to the east. Coverage tiles were joined into a single geodataset for the entire study area and then checked for proper arc and polygon topology. Finally, tile boundaries were eliminated to create a seamless data set. A final set of check plots were generated and reviewed for line work and attribute coding accuracy.

Accuracy Assessment

In order to assess the accuracy of the final classification, the completed GIS coverage was compared to field survey reference sites classified during in 1994 and 1995 that had been located using a Trimble Pathfinder GPS. Differential corrections were applied in post-processing. The reference sites were compared to the final classification by overlaying the two digital coverages in ArcView. Classified values for Subsystem, Substrate, Energy and Water Regime were compared at 168 reference sites.

Data were analyzed using an error matrix that compared the reference field information to the photo interpreted classification, using the methods described previously in the vegetation accuracy assessment section of this document. As in the vegetation accuracy assessment, when a reference site corresponded to more than one classified value, up to two classification values were recorded and partial credit attributed as appropriate.

While the accuracy assessment provides a general guideline as to the quality of the classification, several methodological and technical factors limit its interpretation. The field data used to guide and evaluate the shoreline characteristics inventory were originally collected for use with multispectral imagery classification. With the exception of one site, all of the DGPS-located sites were smaller than the minimum mapping unit for shoreline characteristics mapping. As a result, discrepancies between the values of the reference sites and the classified data could be due to the greater generalization of information needed to conform to the coarser minimum mapping standards of the inventory. Positional error in the DGPS data, the basemap, or the coverage was another source of uncertainty, and could lead to comparison of areas that are not actually in the same location. In cases where positional accuracy was uncertain, we referenced 35 mm slides of the sites to visually assess location.

Due to the limitations of the accuracy assessment, only overall accuracy statistics are discussed. Overall accuracy was 86% for Subsystem classification. This suggests that our ability to delineate intertidal and shallow Subtidal areas using photo interpretation of aerial photography with known tidal heights in conjunction with bathymetric data is generally good. Delineation of EHW had slightly lower accuracy, showing greater confusion between upland areas and the Intertidal zone.

Overall accuracy was 37% for substrate classification. Some sites were not classified with substrate values because they had been incorrectly identified as upland during Subsystem classification. If these sites are excluded, accuracy increased to 43%. Most frequently, incorrect classifications were assigned to a proximate size class (e.g., a Cobble reference site was classified as Gravel), or were assigned to a mixed size class (e.g., a Gravel reference site was classified as Mixed Fine). Confusion between single classes and mixed classes could be due in part to the size of accuracy assessment sites; substrate types commonly vary over areas smaller than the minimum mapping unit. The low overall accuracy suggests a need to refine methods for determining substrate type. The weakest component of the methods was believed to be the field data for Substrate, which was collected for different purposes and below the level of the shoreline characteristics inventory minimum mapping unit. Also, the classification categories may be too detailed for these photo interpretation methods.

Overall accuracy was 68% for Energy classification, or 78% when adjusted for sites that were not classified due to previous classification of the area as upland. The errors in Energy classification could be attributed to differing individual interpretations of the threshold between Energy categories. Previous field implementations cite Energy as the least consistently applied category in the habitat classification system (Bailey *et al.*, 1993). While both Marine and Estuarine Energy levels have been difficult to apply, the Estuarine categories of Open, partially enclosed, and Lagoon and Channel/Slough have caused the most confusion. Improving the definitions for the Energy level's categories, and better defining the thresholds between the Energy categories in the Dethier system should be investigated.

Overall accuracy was 82% for Water Regime classification, or 96% when adjusted for sites that were not classified due to previous classification of areas as upland. The greatest confusion was between Intertidal and upland classes.

DATA USAGE CONSIDERATIONS

Introduction

The Nearshore Habitat Program goal is to provide information that is sufficiently detailed and accurate for decision making and that is available Puget Sound-wide. This purpose impacts the intended uses of the data. Data were created for general planning purposes, and should not be used for site-specific analysis or to replace site-specific surveys. We will use the data set for assessing resources for scientific and management purposes across areas of Puget Sound.

To meet multiple user needs, vegetation types and shoreline characteristics data are available digitally and in paper format. A paper map series showing the vegetation and habitat data at 1:24,000 scale has been designed for use by nearshore habitat and aquatic resource managers, and will have limited production and distribution. Digital data, metadata, and methods documentation are available on CD-ROM through the Nearshore Habitat Program.

Ultimately, it is the user who must assess the appropriateness of a data set for a particular use. Usage is constrained by how the data were defined, collected, processed, and the accuracy of the resulting data set. Key usage considerations for the vegetation and shoreline characteristics data are discussed below.

Vegetation Type Usage Considerations

The methods employed for inventorying vegetation determine the limitations of the final classification. The following factors impact useability of results:

- The inventory reflects vegetative conditions at a single period in time (July or August 1995). The data do not provide information on peak conditions, seasonal variation or interannual variation.

- Vegetation type classification was based on the dominant vegetation type present. Other types of vegetation may be present in abundances of less than 30%.

- Due to water conditions, subtidal vegetation that does not form a canopy may not be distinguished. Therefore, conclusions regarding the presence or absence of subtidal vegetation should not be drawn based on this data set.

- Vegetation patches smaller than one pixel in size are not likely to be detected. At a spatial resolution of approximately 169 square feet (16 square meters), many small patches of nearshore vegetation are below the horizontally measured threshold. Examples of features that are regularly smaller than the minimum threshold include spit and berm vegetation and intertidal vegetation along narrow shorelines. Furthermore, the detection of vegetation patches the same size or slightly larger than one pixel will be affected by how the sensor's pixel grid overlays the vegetation feature. If a feature is divided between multiple pixels, each individual pixel may not contain sufficient vegetative cover to be classified as having vegetation. Therefore, analysis of the raster data set should consider that vegetated sites less than 2 pixels in size may not be represented in the data set. Analysis of the vector data should be based on a larger minimum mapping unit (see below).

- Low density vegetative cover is likely to escape detection. We assumed that areas with surface cover less than 25% would be omitted. However, this estimate was not formally evaluated.

- The data set has known accuracy limitations. We estimated overall accuracy, and producer's and user's accuracy for each vegetation class (see Vegetation Inventory, Classification Accuracy Assessment section). These statistics should be considered when using the vegetation data. Additionally, the influence of the sampling method design on subsequent uses of the data must be considered. Accuracy assessment sites were not selected randomly; site accessibility was a major consideration in selection, and sites were stratified by vegetation type to assure that examples from each type were included. The vegetation type for subtidal accuracy assessment sites were not verified by diving surveys. These methodological considerations limit how closely the accuracy assessment results represent the population surveyed. Finally, the accuracy assessment relates only to the raster data set, not the generalized vector data set.

- The vegetation data set was rectified using GPS data collected in-flight (differential corrections were applied in post-processing), and control gained from Washington State Department of Natural Resources's digital orthographic photography. Most areas were mapped to within approximately 40 feet (12 meters) relative to the control points. Positional accuracy is poorest in areas surrounded by water where there are few available ground control points, such as portions of Lummi Island. Positional agreement between the vegetation data set and datasets developed from other sources may vary. The grayscale CASI image from the original data set is available. When using the grayscale imagery as a backdrop for the vegetation data set, positional agreement is complete.

- Life cycle characteristics of different vegetation types affect how they might have been detected. For ephemeral vegetation, such as green algae, the time of data collection will have a major impact on the classified abundance and distribution. Subtidal species are likely to be under-represented. Features that are characteristically covered or obscured by overhang, such as salt marsh or algae on steep rocky shores, are likely to be under-represented.

Raster and generalized vector versions of the vegetation data are available. The raster imagery contains the original classification results and was not generalized. Accuracy assessment was completed on the raster data set. DNR will use the raster data set for detailed data analysis and areal estimates.

The vector format was created for use on systems with limited raster capabilities. To decrease file size, features smaller than 4 pixels in area were deleted, making the minimum mapping unit for the vector vegetation data approximately 850 square feet. Additionally, spit and berm vegetation features were buffered to make them viewable at smaller scales. The accuracy assessment results do not apply to the generalized vector data set. Large scale or detailed usage of the vector data is not recommended, and acreage calculation based on the vector data set are not recommended. DNR will use the vector data set for general-purpose information display and cartographic production.

<u>Shoreline Characteristics Usage Considerations</u>

The shoreline characteristics data can be analyzed using line attributes and multiple polygon attributes. Some habitat assessment policies and protocols that employ this classification and can be applied directly in analysis include EPA Puget Sound Estuary Program's Estuarine Habitat Assessment Protocol, WAC 220-110, and WAC 173-183.

The methods employed for inventorying shoreline characteristics determine the detection limitations of the final classification. The following factors should be considered when using the data set:

- Intertidal elevation boundaries were estimated visually, not surveyed. Uncertainty associated with this method should be taken into account when applying the data set.

- Given a minimum mapping unit of approximately 0.2 hectares (0.5 acres), many intertidal zones fall below the minimum threshold. Analysis of this data should take into consideration that many narrow, linear habitats related to tidal elevation were below the mapping resolution. Examples include, bands of substrate found at characteristic tidal elevations, and Backshore areas.

- The substrate classification received relatively low accuracy assessment results. This may be due in part to the accuracy assessment methods (Shoreline Characteristics, Accuracy Assessment). Most frequently, incorrect classifications were assigned to proximate substrate types or proximate mixed types, i.e., a Gravel reference site was classified as Cobble or Mixed Fine. Analysis of this data should consider a likelihood of confusion between proximate classes.

- The influence of the accuracy assessment's sampling method design on subsequent uses of the data must be considered. Accuracy assessment sites were not selected randomly; site accessibility was a major consideration in selection, and sites were stratified by substrate type to assure that examples from each type were included. These methodological considerations limit how closely the accuracy assessment results represent the population surveyed.

- Energy classification was applied broadly to correspond with the degree of detail provided by the Energy classes (Bailey *et al*., 1993). Classification was applied to sections of shoreline rather than individual polygons, with the exception of Backshore areas, which were never assigned a value of Open. Given these methods, the minimum mapping unit for Energy values was significantly larger than for other attributes, with the exception of Backshore areas behind Open Intertidal areas, these were automatically classified as Partly Enclosed. As a result, Energy values should be assessed over larger areas than other classification categories.

- A grayscale CASI image is available for use as a backdrop for the shoreline characteristics data set. Since the shoreline characteristics data set was delineated on orthophoto base maps, positional agreement with the image varies. The image was rectified using GPS data collected in-flight (differential corrections were applied in post-processing), and control gained from orthophoto base maps. Most areas were mapped to within approximately 40 feet (12 meters) relative to the control points. Positional accuracy is poorest in areas surrounded by water where there are few available ground control points, such as portions of Lummi Island. Digital orthophotography, available through DNR, has the best positional agreement with the shoreline characteristics coverage.

IN CLOSING

The Nearshore Habitat Program balances the need to provide information for decision making that is sufficiently detailed and accurate, against the reality of covering approximately 2,300 shoreline miles in Puget Sound with limited resources. Since the inception of the program, we have learned that the technical and environmental complexity of our task makes coordination among the marine scientists, remote sensing, and GIS staff critical.

Continuing to refine our methods for vegetation and shoreline characteristics inventory is critical to improving information quality and usefulness. A major vegetation inventory issue to consider is whether multispectral-based image classification is the best approach. Future program investigations should compare the cost, results and rapidity of different alternatives, against tradeoffs in spatial detail and classification category detail.

Issues facing the shoreline characteristics inventory component include determining the appropriate spatial and classification resolution given user needs, basemaps, and available funding. We are currently comparing shoreline characteristics classification systems used in the region to improve the capability to translate between systems and the applicability of the system to management.

Future inventory methods will incorporate feedback from users about the usefulness of the 1995 Intertidal Habitat Inventory data set. We urge input from users on how the datasets were used and how they were useful.

NOTICE

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