United States
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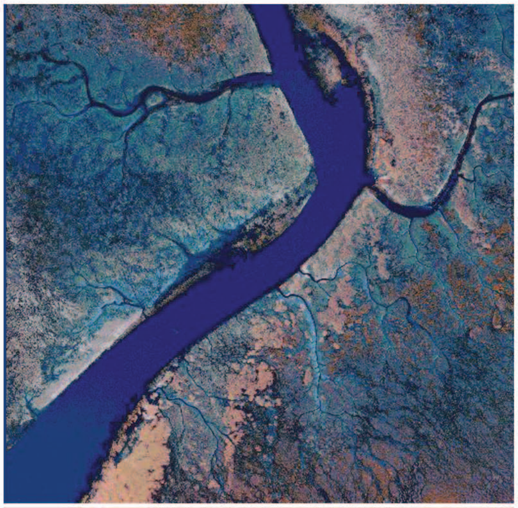
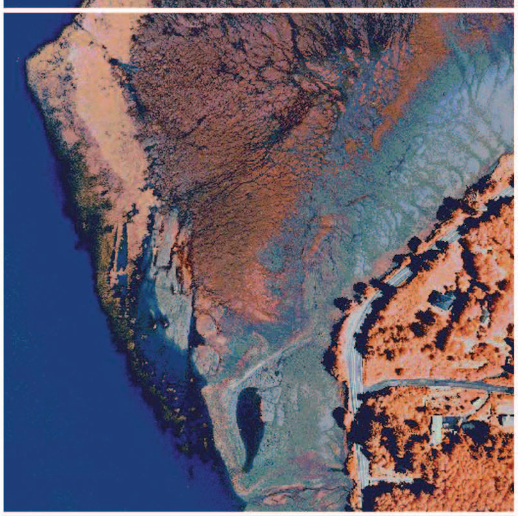
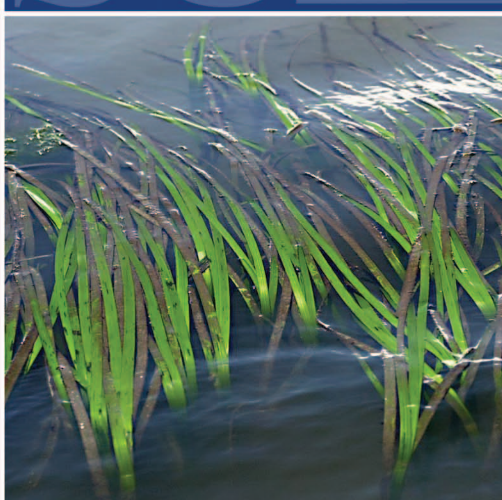




A Guide to Mapping Intertidal Eelgrass and Nonvegetated Habitats in Estuaries of the Pacific Northwest USA

SCIENCE



Office of Research and Development
National Health and
Environmental Effects
Research Laboratory,
Western Ecology Division

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A Guide to Mapping Intertidal Eelgrass and Nonvegetated Habitats in Estuaries of the Pacific Northwest USA

by

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List of Acronyms

AML	ArcInfo® Macro Language
AWAR	Area Weighted Average Resolution
CAD	Computer Aided Drawing
CD-ROM	Compact Disc Read-only Memory
CIR	Color Infrared
CMT	Corvallis MicroTechnology®
DGPS	Differentially-corrected Global Positioning System
DN	Digital Number
DPI	Dots Per Inch
DTM	Digital Terrain Model
DVD	Digital Versatile Disc
EPA	Environmental Protection Agency
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
INS	Inertial Navigation System
IR	Infrared
LCGC	Lincoln County Geodetic Control
LL	Lower Left
MLLW	Mean Lower Low Water
NAD	North American Datum
NIR	Near-infrared
NOAA	National Oceanic and Atmospheric Administration
NVDI	Normalized Vegetation Difference Index
PCEB	Pacific Coastal Ecology Branch
PNW	Pacific Northwest
RGB	Red, Green, Blue
SAVI	Soil Adjusted Vegetation Index
SAV	Submerged Aquatic Vegetation
SE	Standard Error of the Mean
SOW	Scope of Work
TC	True Color
TIFF	Tagged Image File Format
UR	Upper Right
UTM	Universal Transverse Mercator
UV	Ultraviolet
WED	Western Ecology Division

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ABSTRACT

Seagrasses are a critical habitat component of Pacific Northwest (PNW) estuaries. Scientists and managers need cost-effective methods of determining seagrass distributions in different classes of PNW estuaries. Aerial photomapping is one such technique. A protocol for conducting aerial photography surveys of nearshore habitats using true color film, based on experience from the Atlantic and Gulf of Mexico coasts, already has been developed. However, there are substantial differences between estuaries in those regions and in the Pacific Northwest. This document presents an alternate approach to obtaining aerial photomaps of seagrass and macroalgae distributions to deal with the significant intertidal habitat areas exposed by the large intertidal range typical of PNW estuaries. This condition provides an opportunity to conduct aerial photography surveys using false color, near-infrared (color infrared) film during exposed conditions, when the high absorption of near-infrared radiation by water is not a limiting factor. Classification of the resulting images of intertidal vegetation (submerged aquatic vegetation) has been found to be superior to that obtained using true color film. Issues that need to be considered in planning an aerial photography survey are discussed, and a mission planning aid is provided. Example scopes of work for acquiring commercial aerial photography, and subsequent geocoding and orthorectification of the photographs to produce digital photomaps, also are provided. In addition, approaches used to obtain corroborative information on submerged aquatic vegetation intertidal distributions from ground surveys within one PNW estuary are described.

A Guide to Mapping Intertidal Eelgrass and Nonvegetated Habitats in Estuaries of the Pacific Northwest USA

1.0 INTRODUCTION

1.1 OBJECTIVES

The objectives of this document are to provide guidance for mapping, via aerial photography, intertidal distributions of the eelgrass *Zostera marina* L. in estuaries with substantial tidal ranges, such as those found in the Pacific Northwest region (PNW) of the USA, and for assessing the accuracy of such photomap classifications.

1.2 BACKGROUND

1.2.1 Pacific Northwest Estuaries

The mean tidal range of PNW estuaries is often between 2 and 3 meters, so that a substantial proportion of the area of a given estuary is exposed when the tidal elevation is below 0.0 feet relative to Mean Lower Low Water (MLLW; in the USA, tidal height traditionally is measured in feet). These systems are characterized by extensive tideflats that support a variety of habitats, including perennial seagrass meadows and extensive beds of seasonal benthic macroalgae. Large tidal ranges and extensive intertidal flats distinguish estuaries in the PNW from those in Chesapeake Bay and other areas of the Atlantic and Gulf of Mexico coasts that have been the subject of seagrass studies for several decades (Orth 1977; Orth and Moore 1983; Valiela et al. 1992; Short and Burdick 1996; Hauxwell et al. 2003).

1.2.2 Documenting SAV Distribution

Submerged aquatic vegetation (SAV), such as the seagrasses and benthic macroalgae, constitutes a most important estuarine and shallow coastal habitat. This has stimulated efforts to develop cost-effective methods of documenting its distribution. One successful approach is the use of traditional ground surveys in combination with the production of intertidal habitat maps from aerial photographs.

2.0 APPROACH

The approach used by the US Environmental Protection Agency (US EPA) Western Ecology Division/Pacific Coastal Ecology Branch (WED/PCEB) to map intertidal SAV in the estuaries of the PNW has been through the use of false color, near-infrared (color infrared, CIR) aerial photography augmented with *in situ* surveys using global positioning systems (GPS). Other mapping methodologies are appropriate depending on the physical environment to be mapped. For example, the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center has published an excellent guide for benthic mapping that advocates the use of true color (TC) aerial photography (Finkbeiner et al. 2001). The approach described here responds to physical features of PNW estuaries that differ from those of the Atlantic or Gulf of Mexico coasts.

2.1 AERIAL PHOTOGRAPHY ACQUISITION CONSIDERATIONS

2.1.1 Introduction

In planning an aerial photography survey of SAV, decisions on a number of interrelated factors regarding equipment and mission parameters need to be made. These decisions will directly affect the resolution of the data and cost of the survey. A number of excellent publications are available that provide much greater detail on the subject of aerial photographic mapping, including Avery and Berlin (1985), Warner et al. (1996), and Finkbeiner et al. (2001). In addition, Appendix I provides useful links to internet websites dealing with remote sensing issues. Specifications for the aerial photomapping projects conducted by WED/PCEB between 1997 and 2006 are listed in Appendix II.

2.1.2 Film Type

Film type varies according to its overall range of spectral sensitivity and the number and spectral sensitivity range of emulsion layers. Panchromatic films (black and white) have a single emulsion layer with varying ranges of spectral sensitivity. Color films have three emulsion layers which also have varying ranges of spectral sensitivity. Normal black and white panchromatic film is sensitive to the light spectrum from the near-ultraviolet to the red wavelengths (~ 0.25 µm - 0.7 µm). Infrared (IR) panchromatic film has added sensitivity into the near-infrared (NIR) wavelengths (~ 0.25 µm - 0.9 µm). Natural or TC film is sensitive to visible light in blue band (0.4 µm - 0.5 µm), green band (0.5 µm - 0.6 µm) and red band (0.6 µm - 0.7 µm) wavelengths. Color infrared film (when filtered to block blue band wavelengths) is sensitive to visible light in the green and red band wavelengths, as well as the non-visible NIR photographic band wavelengths (0.7 µm - 0.9 µm) (Avery and Berlin 1985). The added discrimination between objects with different reflectance characteristics provided by the use of color films precludes the use of panchromatic films in any serious SAV mapping exercise except in the case where there is no alternative, as in mapping from historic photos.

The considerable differences in the reflectance characteristics of water and vegetation between the visible and IR bands will strongly influence the choice of film type for use in mapping SAV. Vegetation reflectance is maximized in the IR band. However, water is a strong absorber of IR radiance, with the potential to block SAV reflectance in the IR band, and thus subtidal features may not be detectable (Figure 1)**.** In contrast, while visible light in the blue band can reflect from objects down to 25 m in clear water, the greatest average percent reflectance of vegetation in the visible bands (within the green photographic band) is approximately one-third the percent average reflectance of vegetation in the IR band (Avery and Berlin 1985). This suggests that immersed SAV may be more readily imaged by TC film while exposed vegetation may be more readily imaged by CIR film.

In regions with little tidal amplitude, low turbidity and deep distributions of SAV, such as found in many southeastern estuaries, the use of TC rather than CIR film may be more appropriate for SAV mapping than CIR film (Dobson et al. 1995). However, because of the large tidal amplitudes in the PNW and the subsequent exposure of SAV during low tide events, CIR film can provide more benefits than TC film (Young et al. 1999). In a qualitative comparison of TC and CIR aerial photography nearly simultaneously acquired, taken during a low tide event within the Yaquina Bay estuary, Oregon, during the summer of 1997, PCEB researchers found little difference in the apparent subtidal distribution of inundated SAV while the detection of the intertidal distribution was more readily delineated using CIR. Turbidity may have limited the advantage of TC film in detecting SAV through the water column and thus we do not suggest that TC film is inappropriate for detecting subtidal SAV. Because significant levels of turbidity and large tidal amplitudes are common estuarine conditions in the PNW, the use of CIR film at extreme low tides is recommended for SAV photomapping in this region.

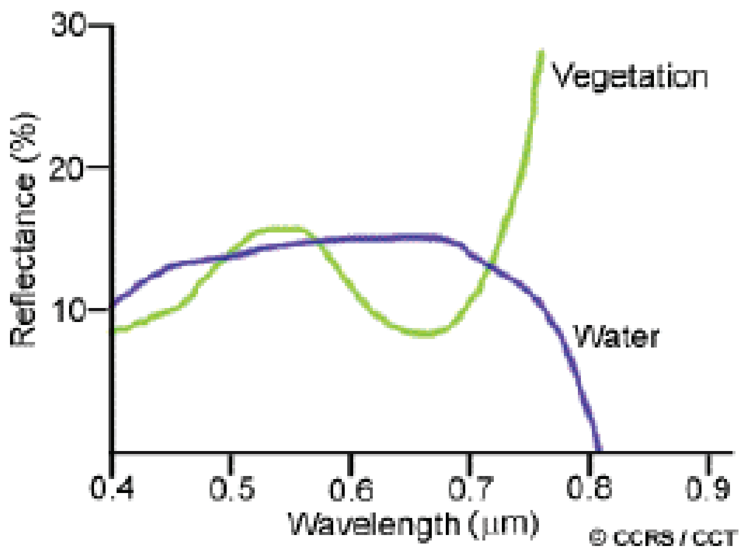


Figure 1. Typical spectral reflectance curves for vegetation and water (Canada Centre for Remote Sensing - Natural Resources Canada 2004).

2.1.3 Film Format / Camera

Another consideration is the size of the film and the associated camera, which can be divided into large format cameras (23 cm), medium format (12.5 cm to 6 cm), and small format camera (35 mm). Large format aerial cameras offer a number of advantages but are bulky and expensive to own and operate, and therefore are usually found in the hands of aerial survey firms or government agencies. Modern large format cameras are often interfaced with GPS, are computer controlled and have forward motion compensating stabilized mounts (Warner et al. 1996). Modern large format cameras are photogrammetric or metric cameras for which the geometry of the lens and film surface has been precisely calibrated. Metric cameras enable precise measurements of object scenes through the accurate reconstruction of their optical geometry (Canada Centre for Remote Sensing - Natural Resources Canada 2004). The wide field of view of large format aerial photography has made it the conventional choice for aerial photomapping. Medium and small format camera systems offer an alternative to conventional large format systems. The cameras are much less expensive, lighter and metric versions are available. A larger variety of films are available, film processing is simple and inexpensive, and a wide variety of ultralight to light aircraft can be used as aerial platforms (Warner et al. 1996). While the smaller scene capture of these films may limit their utility in mapping large areas, they may be quite appropriate for site monitoring and other large scale (small area) applications.

2.1.4 Lens Size

The choice of lens size in aerial photomapping affects the scale of the photography, the altitude of the aerial platform and the amount of radial distortion present in the photography. The scale of aerial photography is a function of the focal length, or lens size, of the camera system and the height of the focal plane of the camera. If the scale of the photography is pre-determined, the choice of camera lens will affect the altitude of the aerial platform, and vice versa. Shorter focal length lenses produce greater radial distortion in the imaged scene. This may be desirable if the purpose of the aerial photography includes the production of a Digital Terrain Model (DTM) from overlapping stereo photo pairs. Standard focal lengths for large format camera lenses are nominally 6 and 12 inches. Given the same desired photo scale, 6 inch focal length lenses have a wider angle of view which increases the possibility of introducing glint into the imagery, while 12 inch focal length lenses would be flown at twice the altitude of a 6 inch lens, introducing greater atmospheric interference into the imagery.

2.1.5 Filters and Exposure

Lens filters are designed to alter the properties of light entering a camera in order to enhance image quality. Anti-vignetting filters that help to compensate for darkening edges of aerial photos should be standard in any aerial photo survey. Blue haze and ultraviolet (UV) filters are desirable in TC photography. Special red or yellow filters to block the blue and UV spectrum are mandatory in CIR photography. Typical exposure settings should be increased by the filter factor of the filter used (Eastman Kodak Company 2000). CIR exposure settings for photographing SAV on exposed tideflats and in very shallow water should be increased over typical exposure settings for photographing terrestrial vegetation (Mumford and Berry 2006). We recommend consultation with the areal image acquisition provider on exposure settings appropriate to the time of day, season and target vegetation.

2.2 MISSION PLANNING

In addition to the hardware considerations discussed above, a number of operational decisions also have to be made in planning of an aerial photographic survey. The primary objectives of the survey play the critical role in mission planning decisions that ultimately determine the nature of survey product.

2.2.1 Film Scale

Photo scale is the ratio of distance on a photo to the actual distance in the scene. Photo scale equals the focal length of the camera system divided by flying height of the aerial platform. Choice of scale will affect the level of detail visible in a scene, the areal extent of the scene and the number of photos in the survey. Photo scales up to 1:20,000 are considered large scale (small area), from 1:20,000 to 1:100,000 is considered medium scale, and small scale (large area) is anything over 1:100,000 (Canada Centre for Remote Sensing - Natural Resources Canada 2004). (Note the use of 'large' versus 'small' scale in the context of mapping, with large scale referring to a small area with higher resolution and small scale referring to a large area with lower resolution.) Applications appropriate to these magnitudes of scale might be agricultural or municipal aerial surveys at a large scale, county-wide mapping at a medium scale, and state-wide surveys at the small scale. Table 1 illustrates the aerial extent of large format (23 cm) aerial photos acquired at differing scales. The choice of photo scale is crucial to any SAV photomapping project as it will directly affect other factors in the project (e.g., the resources required to digitize and orthorectify the imagery). The choice of scale should be a balance between the size of the area to be mapped and the level of detail required. The choice of photo scale also will affect the level of detail that can be achieved in digitally scanning aerial photos and therefore determines the smallest mapping unit that can be used. Although a larger mapping unit may be employed, an array of 3 x 3 pixels is required to distinguish an isolated feature represented by a single pixel. PCEB recommends a photo scale of 1:20,000 for estuary-wide mapping of SAV in the PNW. (For further discussion, see Section 2.6).

SCALE	LENGTH / WIDTH (km)	AREA (km^2)
1:10,000	2.3	5.29
1:20,000	4.6	21.16
1:40,000	9.2	84.64

Table 1. Dimensions and area captured in aerial photographs using a large format camera at differing scales.

2.2.2 Number of Photos

The number of photos in a given aerial photo survey is determined by the scale of the photography, the degree of photo overlap and the size of the study area. Photo surveys that include the purpose of stereo-compilation of a DTM typically are designed with a 60% photo overlap within each flightline and 30% photo sidelap with adjacent flightlines in order to enable stereo viewing of the entire study area. A minimum of 40% overlap and sidelap is recommended to ensure complete coverage if stereo-pairs (>50% overlapping photos) are not required. (For further discussion, see Section 2.4).

2.2.3 Photo Angle

Aerial photography can be classed as vertical or oblique, depending on the angle at which a scene is captured. PCEB's primary focus is on vertical aerial photography where the scene is captured from directly above.

2.2.4 Photo Centers

The photo center or nadir of an aerial photo is that point on the ground vertically below the camera (Warner et al. 1996). Any aerial photographic mission plan must provide the geographic location of all the photo centers in order for photography to be acquired at those locations, whether plotted on a paper map or provided as a digital list of coordinates to be loaded into a GPS. The easting and northing coordinates of a particular photo mission can be calculated and/or plotted either in-house or by a contracting aerial survey entity (see Section 2.4).

2.2.5 Timing

The timing of an aerial survey depends both upon the specific objectives of the survey as well as various practical considerations. A major consideration in the PNW is whether the objective is to capture only seagrasses, or both seagrasses and macroalgae, which will dictate the season in which the photography should be acquired. Another consideration is whether the objective is to evaluate only intertidal SAV or whether the objective is to evaluate shallow subtidal SAV as well. The practical considerations include the sun angle (enough light, too much shadow?), the weather (is it likely to be cloudy, rainy?), the tide (when do the low tides occur?), the availability of the aerial platform, etc.

Finding appropriate temporal windows at low tide with sufficient solar illumination for aerial photography in the often uncooperative maritime climate of the PNW can be challenging. The use of predictive tide height and solar angle software models can greatly aid in scheduling potential flight windows for CIR aerial photography of estuarine SAV. An example of an on-line tide prediction utility, 'WWW Tide and Current Predictor', can be found at: http://tbone.biol.sc.edu/tide/sitesel.html.

PCEB determined that the general rule-of-thumb for summer large format photography is that the tide must be below MLLW after 9:00 a.m., that the weather should be free of cloud and fog or with a uniform high altitude haze, and that surface winds should be below 12 knots.

2.3 ANCILLARY *IN SITU* SURVEY AND GLOBAL POSITIONING SYSTEMS

While aerial photography provides a cost-effective alternative to extensive ground surveys, ancillary *in situ* field surveys are usually an important component of an aerial survey. There are three primary reasons for conducting *in situ* field studies in conjunction with aerial photo surveys: 1) geographic control, 2) classification calibration, and 3) classification validation.

Ground control points (GCP) are points that fall within a photo scene whose geographic coordinates are known. GCP are used to register digitized aerial photos in real-world geographic coordinates. The establishment of geographic 'ground control' can be accomplished by the placement and precise geopositioning of aerial target 'premarks' prior to the photo mission or by establishing the precise geopositions of permanently fixed objects visible in the photo scene. Modern soft-copy photogrammetric methods combining the use of GPS and Inertial Navigation Systems (INS) have greatly reduced the need for ground control. However, while not always practical, an idealized rule-of-thumb is to establish two GCP at the ends of each flightline as well as four GCP within each flightline.

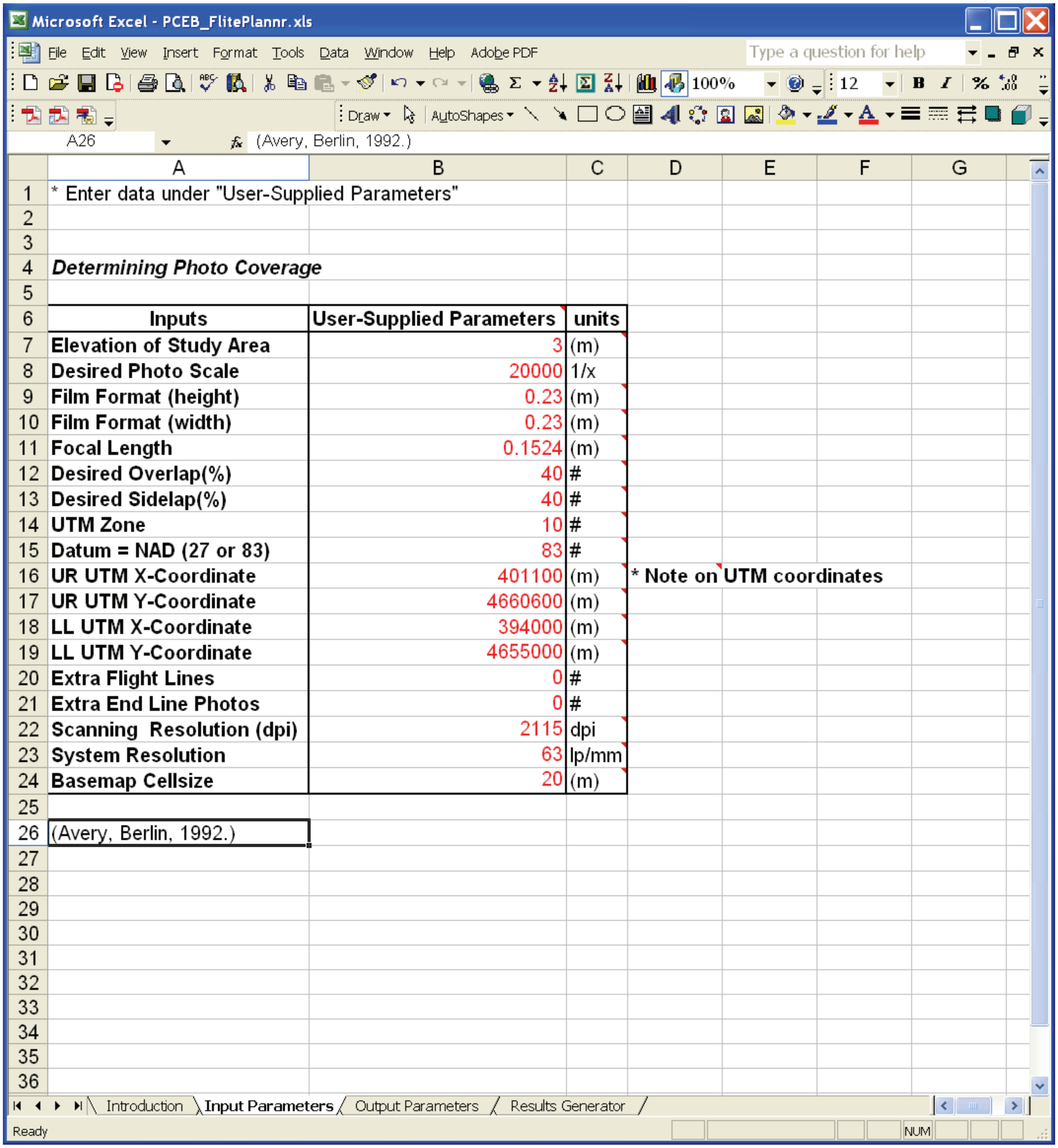
Such established geodetic control points can be used to test the spatial accuracy of orthophotography provided the description and physical context of the point location is sufficient to visually locate the point in the imagery, or the point has been premarked for visibility prior to image capture. A geographic information system (GIS) point layer is generated from the published coordinates of the geodetic points and overlaid on the orthophotography. The minimum and maximum probable distances between the overlaid point and the apparent location based on the published description of the point location are listed. Accuracy is then expressed as the mean distance between apparent and published locations with an uncertainty based on the visibility and context of the apparent location. An accuracy summary based on the aerial photography of Yaquina Bay estuary taken on July 23, 1997 is presented in Appendix III. The geodetic control points listed in the first column range in position from U.S. Highway 101 (Yaquina Bay Bridge) in the City of Newport to the City of Toledo, beyond the eastern border of most of the photo surveys of Yaquina Bay estuary made between 1998 and 2006. For the 11 photo visible control stations (without premarks) listed in Appendix III, the median difference was 0.50 m (range: 0.10 m – 1.66 m), and the average difference ($\pm$ 1 SE) was 0.67 m $\pm$ 0.14 m.

Precisely geopositioned landscape measurements are used either as calibration sites or as validation sites for image classification of ground cover. Calibration data are used to train supervised classification of imagery or to assign classes to unsupervised image classification (see Section 2.6.4). Validation or 'ground truth' data are used to assess the accuracy of classified imagery. These data should not be used interchangeably, that is, a specific photograph or location on a photograph should only be used in calibration (training) or in validation. Ideally, these classification and validation data should be collected concurrent with the photography. A delay in conducting the field survey could allow growth of seagrass extending the perimeter of the beds, which could confound the validation if a previously bare area was later covered with seagrass. A potentially greater source of error in the PNW is the seasonal bloom of macroalgae in the summer, which can cover major sections of certain intertidal areas, often commingling with seagrass. These sources of error need to be evaluated if the field survey is not concurrent with the aerial photographs. Again, ideally, at least one calibration site for each classification class should be established for each photo scene.

A robust image classification validation scheme would include the collection of 30 to 50 randomly located validation sites for each classification class (Congalton 1991; Congalton and Green 1999). Note that with three classes (e.g., eelgrass, green macroalgae, and bare substrate), this results in 90 to 150 sites to evaluate per estuary. In Yaquina Bay estuary PCEB found that,with the use of a differentially-corrected global positioning system (DGPS) in an intensive vegetation cover ground survey effort, more than 200 previously staked locations could be surveyed within one week of photo acquisition using 10 two-person teams. The DGPS used (Corvallis MicroTechnology®, CMT PC5-L) to position the numbered stake locations is rated at an average spatial accuracy of $\pm$ 0.6 m. Data logging functions of GPS units also facilitate the importation of survey data directly into a GIS, and thus decrease both the time and potential errors of transcribing data from field notes to an electronic media. A detailed procedure is presented in Appendix IV for planning, executing, and evaluating results from a typical ground survey operation.

2.4 PCEB_FLITEPLANNR.XLS

Given the number of variable inputs, planning an aerial survey can be time consuming. To assist in this effort, we have developed an interactive spreadsheet that allows the user to explore 'what if' options in aerial photographic mission planning. For example, the user can adjust the desired scale of photography and observe changes in the number of photographs the mission will require, the size of the photographic 'footprint' as well as a number of other variables (Tables 2a, 2b; Figure 2). The interactive spreadsheet also generates ArcInfo® macro language (AML) text for generating photo center points and photo footprint polygons using ArcInfo® geographic information systems.



Microsoft Excel - PCEB_FlitePlannr.xls

* Enter data under "User-Supplied Parameters"

Determining Photo Coverage

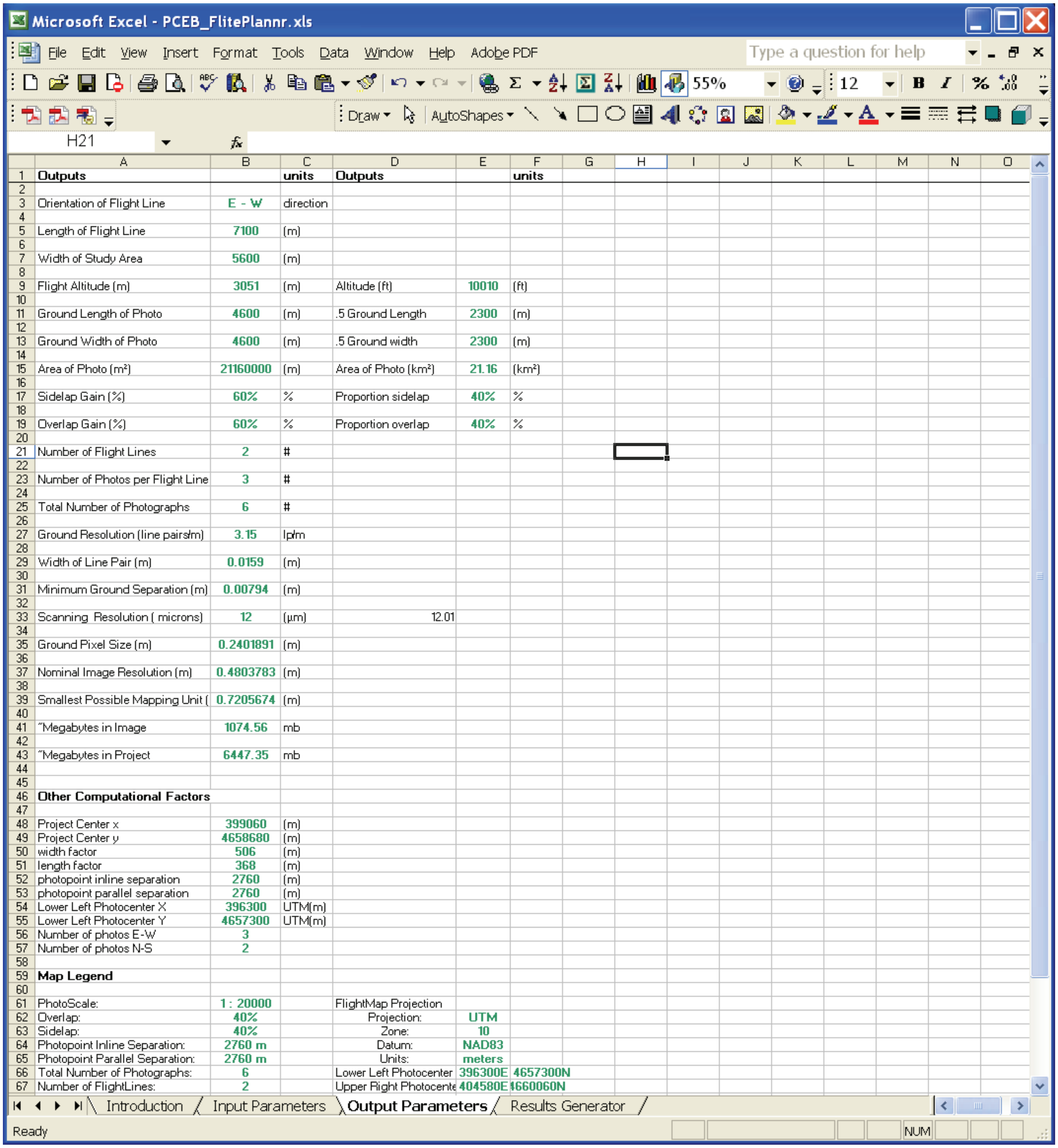
Inputs	User-Supplied Parameters	units
Elevation of Study Area	3	(m)
Desired Photo Scale	20000	1/x
Film Format (height)	0.23	(m)
Film Format (width)	0.23	(m)
Focal Length	0.1524	(m)
Desired Overlap(%)	40	#
Desired Sidelap(%)	40	#
UTM Zone	10	#
Datum = NAD (27 or 83)	83	#
UR UTM X-Coordinate	401100	(m)
UR UTM Y-Coordinate	4660600	(m)
LL UTM X-Coordinate	394000	(m)
LL UTM Y-Coordinate	4655000	(m)
Extra Flight Lines	0	#
Extra End Line Photos	0	#
Scanning Resolution (dpi)	2115	dpi
System Resolution	63	lp/mm
Basemap Cellsize	20	(m)

* Note on UTM coordinates

(Avery, Berlin, 1992.)

Introduction | Input Parameters | Output Parameters | Results Generator

Table 2a. Sample PCEB_FlitePlannr.xls Input Parameters page.



	A	B	C	D	E	F
1	**Outputs**		**units**	**Outputs**		**units**
3	Orientation of Flight Line	E - W	direction			
5	Length of Flight Line	7100	(m)			
7	Width of Study Area	5600	(m)			
9	Flight Altitude (m)	3051	(m)	Altitude (ft)	10010	(ft)
11	Ground Length of Photo	4600	(m)	.5 Ground Length	2300	(m)
13	Ground Width of Photo	4600	(m)	.5 Ground width	2300	(m)
15	Area of Photo (m²)	21160000	(m)	Area of Photo (km²)	21.16	(km²)
17	Sidelap Gain (%)	60%	%	Proportion sidelap	40%	%
19	Overlap Gain (%)	60%	%	Proportion overlap	40%	%
21	Number of Flight Lines	2	#			
23	Number of Photos per Flight Line	3	#			
25	Total Number of Photographs	6	#			
27	Ground Resolution (line pairs/m)	3.15	lp/m			
29	Width of Line Pair (m)	0.0159	(m)			
31	Minimum Ground Separation (m)	0.00794	(m)			
33	Scanning Resolution (microns)	12	(µm)	12.01		
35	Ground Pixel Size (m)	0.2401891	(m)			
37	Nominal Image Resolution (m)	0.4803783	(m)			
39	Smallest Possible Mapping Unit (	0.7205674	(m)			
41	~Megabytes in Image	1074.56	mb			
43	~Megabytes in Project	6447.35	mb			
46	**Other Computational Factors**					
48	Project Center x	399060	(m)			
49	Project Center y	4658680	(m)			
50	width factor	506	(m)			
51	length factor	368	(m)			
52	photopoint inline separation	2760	(m)			
53	photopoint parallel separation	2760	(m)			
54	Lower Left Photocenter X	396300	UTM(m)			
55	Lower Left Photocenter Y	4657300	UTM(m)			
56	Number of photos E-W	3				
57	Number of photos N-S	2				
59	**Map Legend**					
61	PhotoScale:	1 : 20000		FlightMap Projection		
62	Overlap:	40%		Projection:	UTM	
63	Sidelap:	40%		Zone:	10	
64	Photopoint Inline Separation:	2760 m		Datum:	NAD83	
65	Photopoint Parallel Separation:	2760 m		Units:	meters	
66	Total Number of Photographs:	6		Lower Left Photocenter	396300E	4657300N
67	Number of FlightLines:	2		Upper Right Photocente	404580E	4660060N

Table 2b. Sample PCEB_FlitePlannr.xls Output Parameters page.

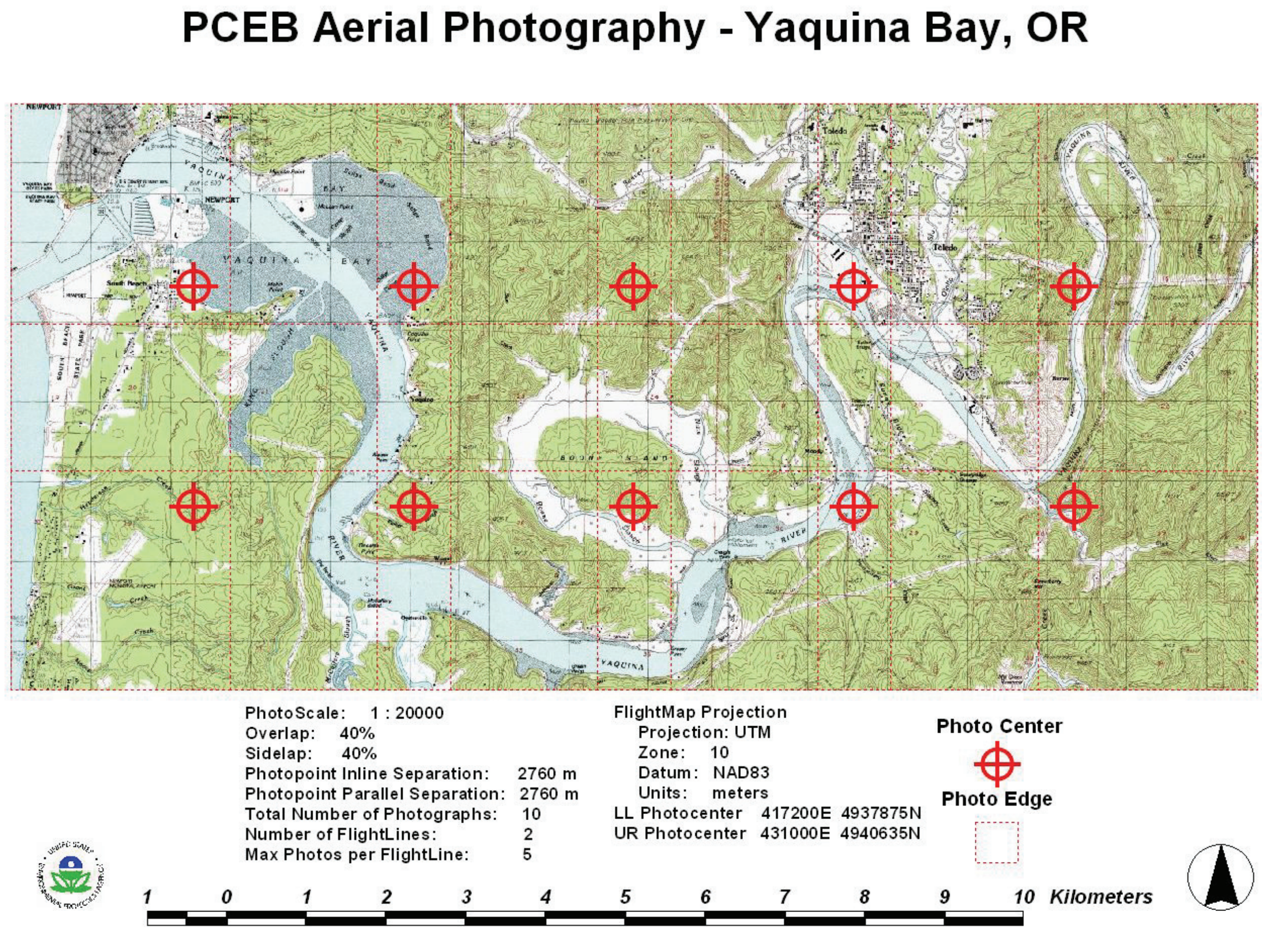


Figure 2. An example of a flight map. Flight center coordinates, center points and photo overlap areas can be generated through the use of PCEB_FlitePlannr.xls.

2.5 CONTRACTING FOR AERIAL SURVEYS

In nearly all cases, aerial surveys will be conducted either through an agreement with a federal (e.g., NOAA) or state agency or through a contract with a private firm. In either case, it is critical to clearly identify the objectives of the study and the requirements to achieve those objectives. Appendix V is an example of a scope of work (SOW) that the PCEB has used to contract for aerial surveys of Yaquina Bay estuary. This agreement can be modified to reflect specific project needs and/or contractual requirements.

2.6 AERIAL PHOTOGRAPHY ANALYSIS CONSIDERATIONS

2.6.1 Photointerpretation

The traditional method of delineating features from aerial photography involves outlining features on transparent Mylar® overlays directly from the photograph. Such manual photointerpretation relies on the photointerpreter's knowledge of the nature of the features in a photo scene, and their ability to differentiate features based on elements of photographs such as tone, color, contrast, texture, and context (Finkbeiner et al. 2001). If points with known geographic coordinates are also marked on the overlay, the delineations can be digitized and spatially referenced into a GIS using a digitizing tablet. Another method that uses the same knowledge and skill of the photointerpreter is known as 'heads-up' digitizing. In this method, features are delineated using a computer mouse on-screen, with digitally scanned aerial photos as the computer screen background, using computer aided drawing (CAD) tools. If the digital aerial photo used in this process has been georeferenced to real-world coordinates and/or orthorectified, and the delineation is done within a GIS program, the delineation automatically will be spatially referenced.

2.6.2 Digitizing Aerial Photography

Aerial photos can be scanned at varying resolutions, usually expressed in dots per inch (dpi) or in microns. Upon subsequent georectification of a photo, photo scale and scanning resolution will determine its ground resolution, the size of the area in a scene represented by a single pixel (Table 3). Aerial photography is typically digitized into the three additive color photographic bands (red, green, blue - RGB) using 256 intensity values coded on 8 bits (Kölbl et al. 1996). The color scanning process assigns digital numbers (DN) to each pixel in an image, ranging from 0 to 255, that correspond to the average intensity values of the RGB colors within that pixel. Imagery may be scanned directly from exposed film, or from diapositives or opaque prints developed from the film. We recommend that 1:20,000 scale aerial photography of PNW estuaries be scanned at 12 microns, to ensure a nominal 0.25 m ground pixel in the final orthophotography. Although it is quite possible to scan aerial photo diapositives with an in-house large format transparency scanner, we recommend that aerial photo scanning be performed with a commercial grade photogrammetric scanner directly from the exposed film to ensure the highest radiometric fidelity to the scene. The practical limit for scanning film is about 8 microns due to film granularity.

Pixel Ground Resolution (m) vs. Scanning Resolution

Scanning Resolution		Photo Scale	5000	10000	12000	24000	40000
dpi	**microns**						
300	**85**		0.42	0.85	1.02	2.03	3.39
600	**42**		0.21	0.42	0.51	1.02	1.69
800	**32**		0.16	0.32	0.38	0.76	1.27
1000	**25**		0.13	0.25	0.30	0.61	1.02
1100	**23**		0.12	0.23	0.28	0.55	0.92
1200	**21**		0.11	0.21	0.25	0.51	0.85
1300	**20**		0.10	0.20	0.23	0.47	0.78
1400	**18**		0.09	0.18	0.22	0.44	0.73
1500	**17**		0.08	0.17	0.20	0.41	0.68
2000	**13**		0.06	0.13	0.15	0.30	0.51
2500	**10**		0.05	0.10	0.12	0.24	0.41

Table 3. The ground resolution of a digitized aerial photo pixel is expressed in meters at varying scanning resolutions and photo scales.

2.6.3 Digital Image Orthorectification

A digitally orthorectified aerial photo is an aerial photo that has been digitally scanned and georeferenced to real-world coordinates in a process that compensates for the spatial distortion in the original photo caused by terrain variation and camera geometry. Distortion caused by terrain is corrected with the use of a DTM, and distortion caused by camera interior geometry is corrected with the use of parameters from a camera calibration report. Appendix VI is an example scope of work that the PCEB has used to contract for the digital orthorectification of aerial photographs of Yaquina Bay estuary. Desktop orthorectification software that corrects for camera and terrain distortion and uses pre-existing orthophotography for GCP selection can be a very cost- effective means of producing digital orthophotography in-house. Once individual photos are orthorectified, they are mosaiced together to form a complete scene.

The photographs, as provided directly from the aerial surveys, can be used to qualitatively evaluate various landscape features. However, for accurate estimates of the locations of seagrass beds or quantitative estimates of their area, we recommend working with digitally scanned, orthorectified aerial photographs.

2.6.4 Digital Image Classification

Geographic image processing software applications use a wide variety of algorithms to process DN for the purposes of image classification. Image processing algorithms can have Boolean, algebraic, spatial, and/or statistical functions. Image processing algorithms can also be unsupervised or supervised image classifiers. Unsupervised classification algorithmic groups image pixels into like classes to which a photointerpreter can later assign landscape features. In supervised classification, a photointerpreter identifies groups of pixels that are representative of features in a scene for use as input to an algorithm for interpolating the identified classes across the remainder of the image.

In digitally scanned, false color near-infrared photography, red pixel values are analogous to the reflective intensity of light in the NIR band of the spectrum; green DN are analogous to the reflective intensity of light in the red band; and blue DN are analogous to the reflective intensity of light in the green band. A common algorithm developed for use with electronically sensed spectral data, the normalized vegetation difference index (NVDI), exploits the wide difference in spectral response of vegetation between the red and NIR bands (Ray 1994) (Figure 3). The NVDI is a band ratio algorithm that can be adapted for use in classifying vegetation (including exposed SAV) from digital CIR aerial orthophotography.

NVDI = (NIR - red) / (NIR + red)

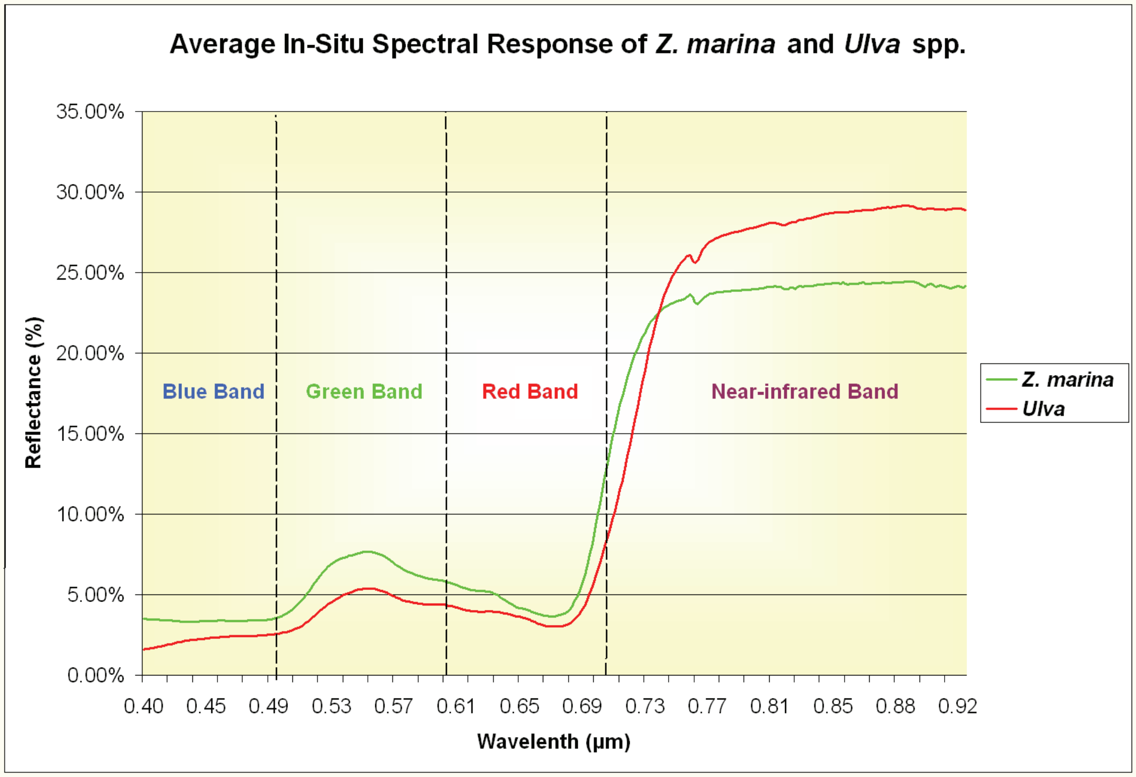


Figure 3. Spectral response curve of exposed seagrass (*Z. marina*) and macroalgae (*Ulva* spp.) measured *in situ* on intertidal flats of Yaquina Bay estuary, Oregon.

We have developed a method to digitally map the distribution of tidally exposed seagrass *Zostera marina* which combines techniques of digital image classification and traditional photo interpretation. This hybrid method enables a photo interpreter to digitally edit the results of a digital image classification. Misclassification of pixels can result from photometric variation due to a variety of causes including: intraphoto variation (vignetting), interphoto variation (mosaicing), sun angle, vegetation congruency (mixed beds), degree of exposure (bathymetry), and/or obfuscation (siltation or epiphytic cover). While a 'programmatic' solution to misclassification from such a variety of sources would be difficult at best, visual evaluation of elements of aerial photos such as pattern, texture, tone, contrast, and context can overrule error caused by simple variation in color.

The first step in the hybrid method is to digitize the upper boundary of the lower intertidal portion of the study area on-screen, using the aerial photomosaic as a background image (Figure 4). The resulting polygon is used to mask out terrestrial and emergent marsh areas from the image. In order to map the intertidal distribution of seagrass, a second mask is created using a band ratio threshold algorithm to mask out unvegetated and inundated portions of the image.

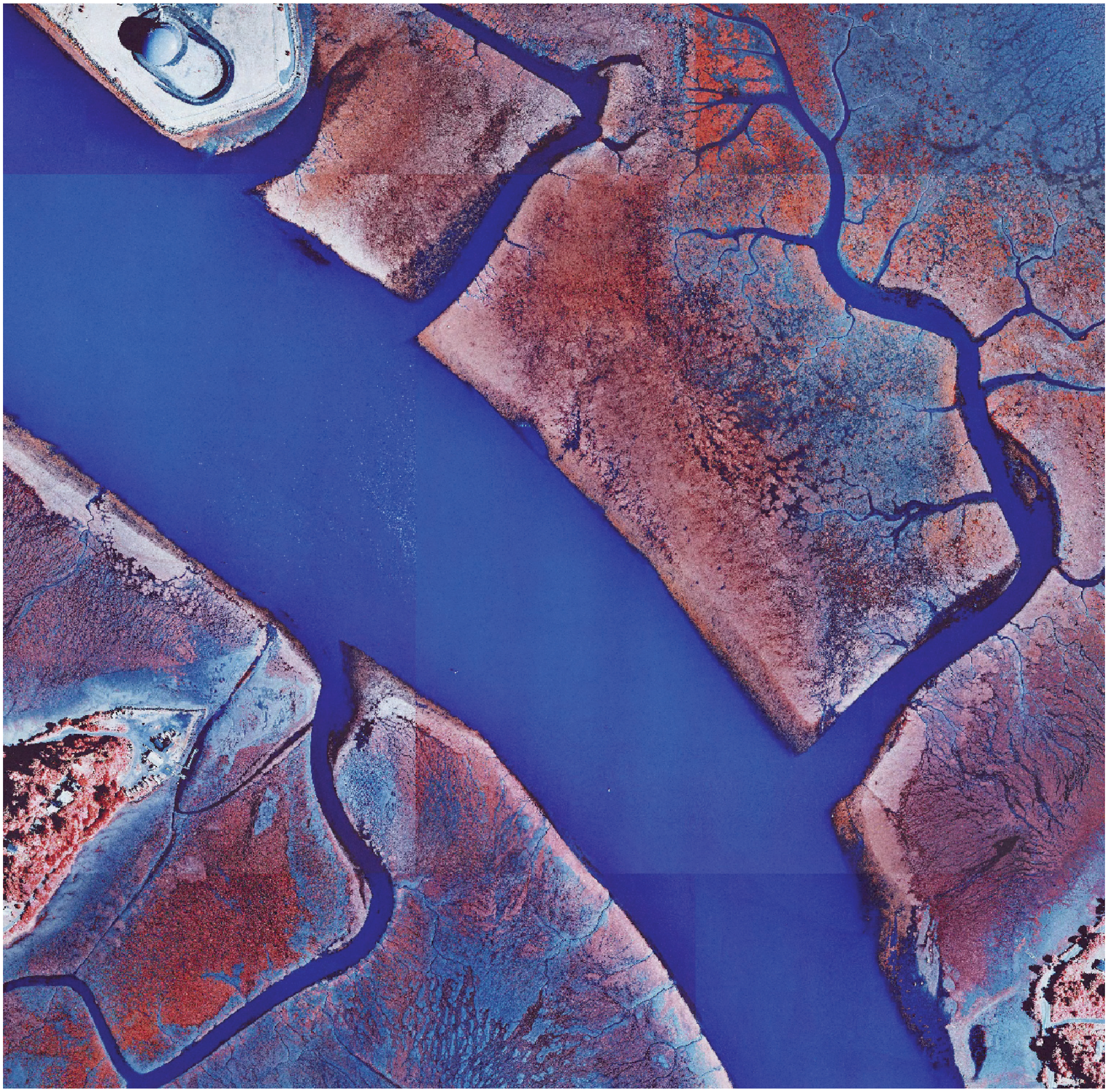


Figure 4. Aerial photomosaic detail of Yaquina Bay estuary.

The algorithm is based on the NVDI derived soil adjusted vegetation index (SAVI) (Huete 1988):

SAVI = ((NIR - red) / (NIR + red + L)) x (1 + L)

where NIR is the near-infrared band of the image, red is the red band and L is an empirically derived index of vegetation cover ranging from 0 for sparse cover to 1 for high percent cover. (Ray 1994).

The following conditional formula is applied to each band of each image in the mosaic:

if (((i1 - i2)/(i1 + i2 + (0.5)) x (1 + 0.5)) + 1) / 2 > X and inregion (r1) then i3 else null.

Here SAVI is set for moderate vegetation cover and is adjusted so that it will result in a value between 0 and 1. The variables i1 and i2 are the NIR and red bands, respectively, i3 represents the band to which the formula is applied and r1 is the lower intertidal polygon. The variable X is an interactively set variable that acts as a threshold between nominally vegetated and nonvegetated pixel classes. This is nominally set at 0.5 but can be adjusted by the photointerpreter. The resulting SAVI adjusted image (Figure 5) would ideally image only SAV but likely contains false-positive pixels. In order to eliminate false-positives and/or differentiate between SAV species or genera, further processing followed by manual editing is indicated.

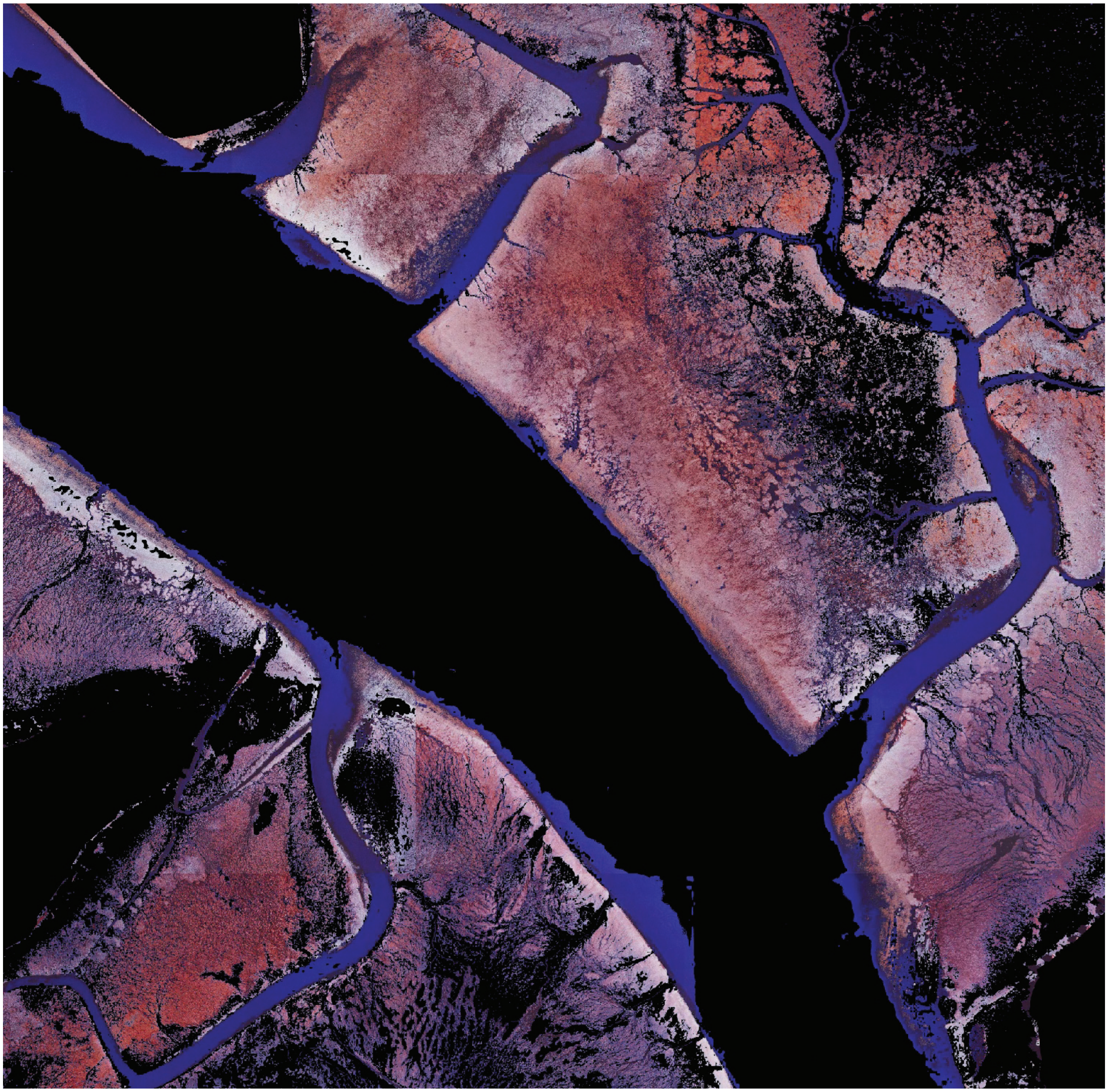


Figure 5. Detail of the SAVI and shoreline vector masked image of Yaquina Bay estuary.

The SAVI masked image is then subjected to an unsupervised isocluster classification set to a minimum of 6 to maximum of 12 classes. The resulting image will contain single values for statistically distinct clusters of pixel values (Figure 6).

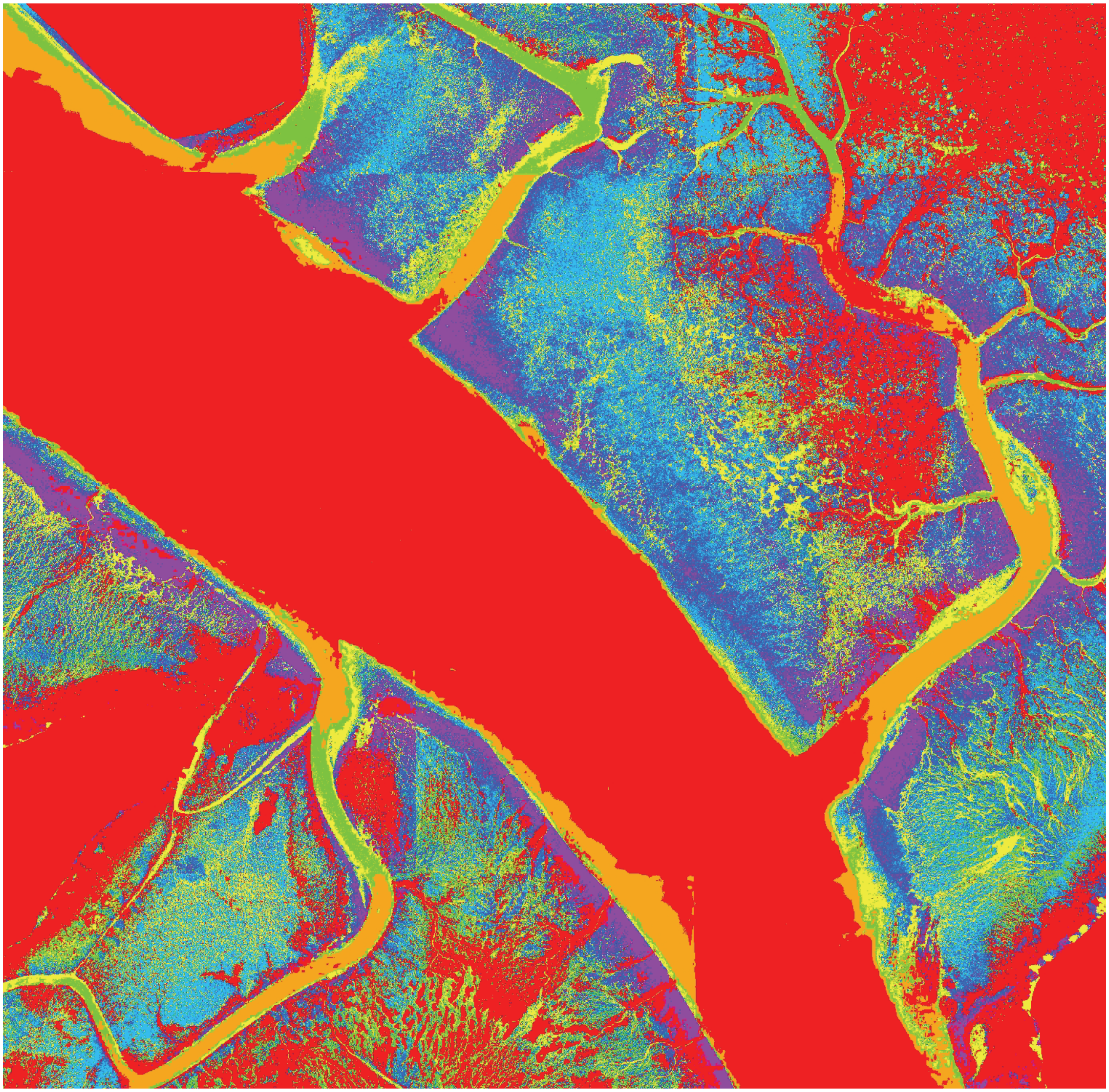


Figure 6. Detail of an unsupervised seven-class isocluster classification of a SAVI masked image of Yaquina Bay estuary.

The image classification steps above were developed using ERMapper® v.6.1 geographical image processing software, but may be adapted to other such software. The following steps were developed in ESRI ArcMap® desktop and ArcInfo® workstation GIS software.

The isocluster image was converted to an ArcInfo® grid with cell values representing the isoclusters. A new binary (0 or 1) grid was created for each value using conditional statements in ArcInfo® GRID®. The unsupervised classification value of 1 usually represents null values in the SAVI masked image. Initial analysis may eliminate other values from further analysis as primary contributors of noise to the signal.

Each remaining grid is then interactively edited while overlaid on the orthorectified imagery using the ArcScan suite of tools in ArcMap. These tools enable the replacement of binary grid cell values with 0 or 1, through the on-screen selection using polygons, rectangles or circles. In this case, the tools are used to erase false-positive eelgrass pixels by assigning a value of 0.

Once all the grids are edited, they are merged and the training data are overlaid to provide an initial assessment of the results. Further editing is performed on the constituent grids and they are reassembled using map algebra for final editing and accuracy assessment. Figure 7 illustrates the work flow.

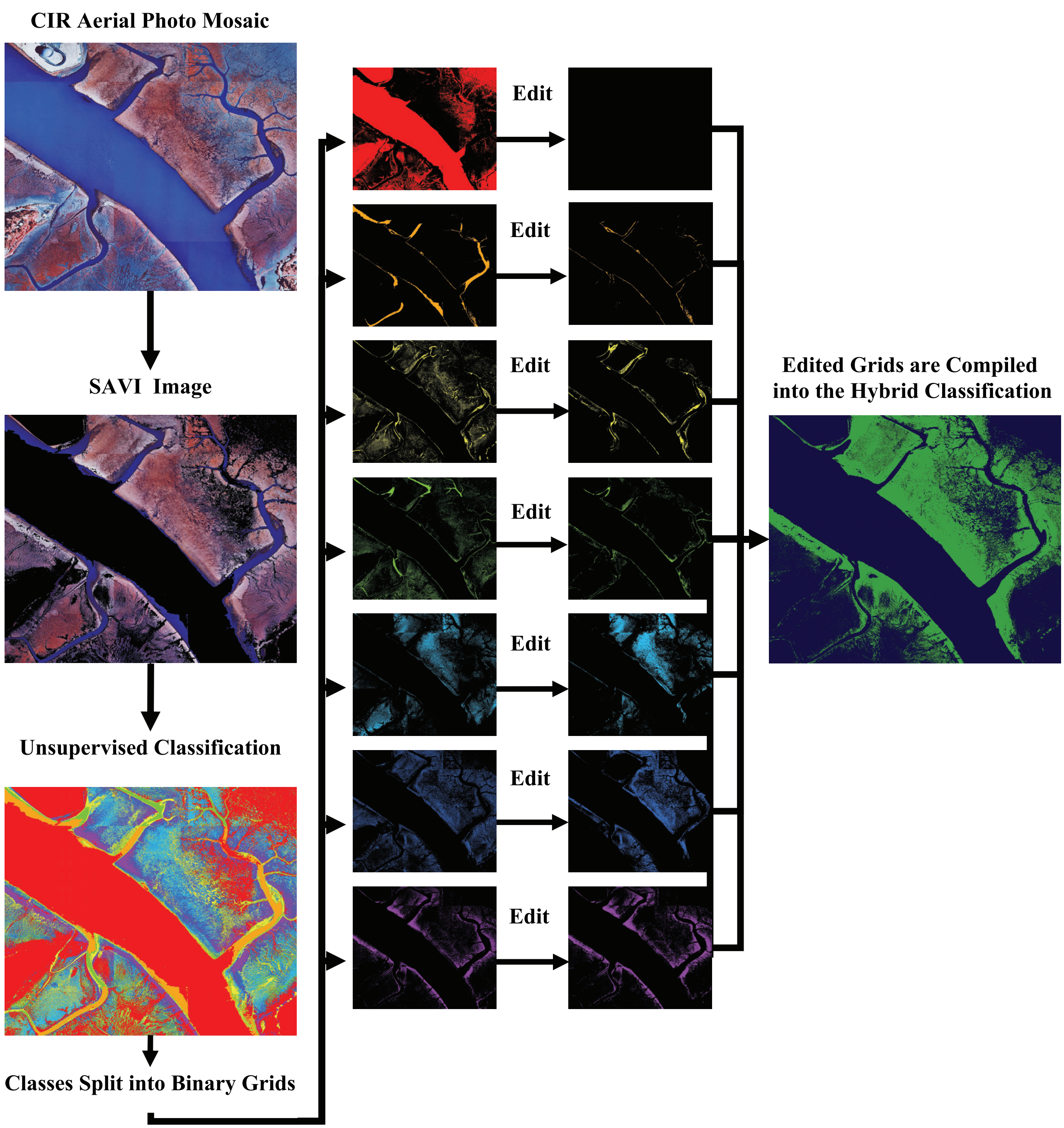


Figure 7. Hybrid classification work flowchart.

2.7 CLASSIFICATION ACCURACY

2.7.1 Theory of Classification Accuracy

A key component of any classification effort is an assessment of its accuracy. Efforts to develop methods for obtaining quantitative assessments of photo interpretation began in the 1950's, but the importance of this issue was not generally recognized for several decades. A comprehensive discussion of this subject has been provided by Congalton and Green (1999), including their description of the utility of the error matrix (Table 4 replaces Figure 2-1 below) in assessing the accuracy of digital maps, as follows:

> *"An error matrix compares information from reference sites to information on the map for a number of sample areas. The matrix is a square array of numbers set out in rows and columns that express the labels of samples assigned to a particular category in one classification relative to the labels of samples assigned to a particular category in another classification (Figure 2-1). One of the classifications, usually the columns, is assumed to be correct and is termed the reference data. The rows usually are used to display the map labels or classified data generated from the remotely sensed data. Thus, two labels from each sample are compared to one another:*
>
> - *Reference data labels: the class label of the accuracy assessment site derived from data collected that is assumed to be correct; and*
> - *Classified data or map labels: the class label of the accuracy assessment site derived from the map.*
>
> *Error matrices are very effective representations of map accuracy, because the individual accuracies of each map category are plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. A commission error occurs when an area is included in an incorrect category. An omission error occurs when an area is excluded from the category to which it belongs.*
>
> *In addition to clearly showing errors of omission and commission, the error matrix can be used to compute overall accuracy, producer's accuracy, and user's accuracy (Story and Congalton 1986). Overall accuracy is simply the sum of the major diagonal (i.e., the correctly classified pixels or samples) divided by the total number of pixels or samples in the error matrix. This value is the most commonly reported accuracy assessment statistic. Producer's and user's accuracies are ways of representing individual category accuracies instead of just the overall classification accuracy".*

Reference Data

Classified Data / Land Cover	A	B	C	D	Row Total
A	**60**	7	2	15	84
B	4	**75**	11	9	99
C	1	21	**80**	14	116
D	5	13	0	**83**	101
Column Total	70	116	93	121	**400**

Overall Accuracy

(60+75+80+83)/400 = 74.5%

Land Cover	Producer's Accuracy	
A	60/70 =	85.7%
B	75/116 =	64.7%
C	80/93 =	86.0%
D	83/121 =	68.6%

Land Cover	User's Accuracy	
A	60/84 =	71.4%
B	75/99 =	75.8%
C	80/116 =	69.0%
D	83/101 =	82.2%

Table 4. Example error matrix for four hypothetical land cover categories (A – D).

2.7.2 Accuracy Assessment

In order to compare the final seagrass and bare substrate classifications with the ground survey percent cover data, the ArcInfo® Grid Blocksum function with a 10 x 10 pixel kernel is used to count the number of 0.25 m pixels classified as seagrass in a 2.5 m array around each pixel. The results are then binned using a Grid® conditional statement into classes 'greater than' and 'less than or equal to' 10% of the total. Percent cover values of the ground survey station areas are similarly binned into classes greater than and less than or equal to 10% cover. The classification grid and validation point cover are overlaid in ArcView® v3.3 (Figure 8), and the Spatial Analyst® Kappa

Analysis® v.1.2 extension is used to generate an error matrix, user's and producer's accuracy statistic, and the Kappa statistic for the accuracy analysis (Jenness and Wynne 2004).

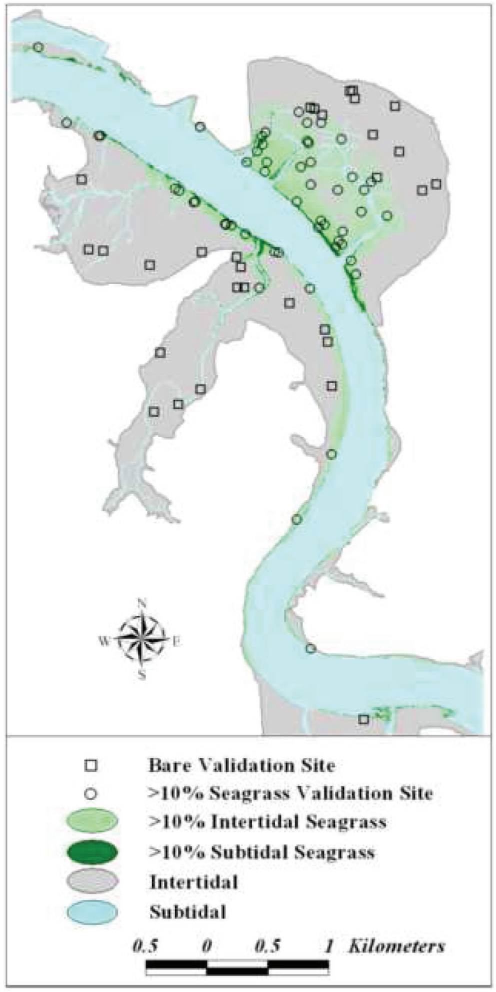


Figure 8. Seagrass classification grid and validation point cover.

3.0 SUMMARY

Aerial photography is a powerful tool to survey the distribution (extent and cover density) of seagrasses in intertidal estuarine habitats. A number of decisions have to be made in planning an aerial survey, ranging from the size of the camera to the elevation of the imaging platform (i.e., height of the plane). Each of the key considerations in planning an aerial survey is briefly discussed in terms of mission planning. To assist in planning, a spreadsheet tool has been developed that calculates the number of photographs required, resolution, computer storage requirements for the digitized photographs, etc. Based on these user inputs, the spreadsheet outputs an ArcInfo® AML to generate photo centers and photo boundaries as GIS datasets. This planning tool allows users to easily evaluate different strategies based on their objectives and resources. Because many aerial surveys will be conducted by contracting with a private contractor, example scopes of work for acquiring commercial aerial photography, and for subsequent geocoding and orthorectification of the photographs to produce digital photomaps, also are provided.

During the PCEB aerial surveys of Yaquina Bay estuary, Oregon, it became apparent that the estuaries in the PNW differ in a number of fundamental characteristics from those on the Atlantic and Gulf of Mexico coasts, such as the much larger tidal amplitude in PNW estuaries. In turn, these differences require modifications to the procedures that have been used in other regions. It was found that the use of CIR film during surveys conducted at low tides provided superior classification of the SAV than from TC film.

An important component of any aerial photography mapping program is an accuracy assessment of the classification process, that is, the assignment of each pixel to a specific habitat class (e.g., eelgrass vs. bare sediment). Ideally, the accuracy assessment consists of a field survey of the photographed site close to the time when the photographs were taken. A statistically rigorous accuracy assessment usually takes a considerable field effort, but is required to estimate uncertainty in the classification of the images in the orthorectified photographs. The approaches used to date to obtain corroborative information on SAV intertidal distributions from ground surveys within one PNW estuary have been described in this guide.

4.0 ACKNOWLEDGEMENTS

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APPENDIX I: USEFUL LINKS

DRAFT Standards for Aerial Photography **-** American Society for Photogrammetry & Remote Sensing

http://www.asprs.org/resources/standards/photography.htm

Fundamentals of Remote Sensing Tutorial - Canada Centre for Remote Sensing

http://ccrs.nrcan.gc.ca/resource/tutor/fundam/pdf/fundamentals_e.pdf

Guidance for Benthic Habitat Mapping - NOAA Coastal Services Center

http://www.csc.noaa.gov/benthic/mapping/pdf/bhmguide.pdf

Downloadable Digital Orthophotography, Digital Raster Graphics (USGS Quads), and Digital Elevation Models – Natural Resources Conservation Services

http://www.ncgc.nrcs.usda.gov/products/datasets/index.html

US EPA Remote Sensing Example Applications

http://oaspub.epa.gov/eims/eimsapi.dispdetail?deid=15997
http://www.epa.gov/esd/land-sci/epic/pdf/fs-epic.pdf
http://www.epa.gov/GED/crc/epa620r-01-001h.pdf
http://www.epa.gov/esd/land-sci/epic/aerial-photos.htm

Tide and Current Prediction

http://tbone.biol.sc.edu/tide/sitesel.html
http://www.wxtide32.com/

GeoTiff Links

http://www.remotesensing.org/geotiff/geotiff.html

APPENDIX II: SPECIFICATIONS FOR AERIAL PHOTOGRAPHY USED BY WED/PCEB FOR AERIAL PHOTOMAP/CLASSIFATION PROJECTS BETWEEN 1997 AND 2006

Estuary	Year	Day-Month	Photoscale	Format	Digitized	OrthoRectified	Ground Pixel	Classified
Yaquina	1997	7/23	7200	CIR	Photogrammetric/Diapositive	SoftCopy	0.20m	Yes
Yaquina	1997	7/23	7200	RGB	Photogrammetric/Diapositive	SoftCopy	0.20m	No
Yaquina	1998	8/10	6000	CIR	Photogrammetric/Diapositive	SoftCopy	0.15m	Yes
Yaquina	1999	7/15	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	Yes
Yaquina	1999	9/10	7200	CIR	No	No		
Yaquina	1999	10/24	7200	CIR	No	No		
Yaquina	2000	6/17	14400	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2000	6/17	14400	RGB	No	No		
Yaquina	2000	6/20	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2000	8/2	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	Yes
Yaquina	2000	10/24	3600	CIR	Non-Photogrammetric/Diapositive	No		
Yaquina	2001	5/9	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2001	7/25	7200	CIR	No	No		
Yaquina	2001	10/15	7200	CIR	No	No		
Yaquina	2002	1/11	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2002	8/11	7200	CIR	Non-Photogrammetric/Diapositive	No		
Yaquina	2002	9/23	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2002	5/15	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Yaquina	2003	5/19	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	Partial
Yaquina	2003	8/1	10000	CIR	No	No		
Yaquina	2003	10/21	7200	CIR	No	No		
Yaquina	2004	4/9	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.25m	Yes
Yaquina	2005	7/21	20000	CIR	Photogrammetric/Film	Desktop	0.25m	No
Yaquina	2006	5/16	20000	CIR	Photogrammetric/Film	Desktop	0.25m	No
Alsea	1999	9/10	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	Yes
Alsea	2004	4/9	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.25m	Yes
Siletz	1999	9/10	7200	CIR	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Salmon	2000	6/20	7200	CIR/RGB	Non-Photogrammetric/Diapositive	Desktop	0.20m	No
Salmon	2004	4/9	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.25m	Yes
Nestucca	2004	4/9	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.25m	Yes
Tillamook	2004	4/9	10000	CIR	Non-Photogrammetric/Diapositive	Desktop	0.25m	Yes
Tillamook	2005	6/9	20000	CIR	Photogrammetric/Film	Desktop	0.25m	No
Coos	2005	5/26	20000	CIR	Photogrammetric/Film	Desktop	0.25m	Yes
Umpqua	2005	7/24	20000	CIR	Photogrammetric/Film	Desktop	0.25m	Yes
Suislaw	2005	7/24	20000	CIR	Photogrammetric/Film	No		
Cocquille	2005	7/26	20000	CIR	Photogrammetric/Film	No		

APPENDIX III: SPATIAL ACCURACY OF ORTHOPHOTOGRAPHY

Lincon County Geodetic Control

Control	Order	Database	Premark?	Visibility	Context	Described	Min Dist.	Max Dist.	Mean Dist.	Accuracy	+/-
SB10	1O	LCGC	Yes	High	High	Recovered	0.10	0.30	0.20	0.20	0.10
YB32	1O	LCGC	No	Low	High	Description	0.10	0.45	0.28	0.28	0.45
SEC7	2C1	LCGC	No	Low	Med	Description	0.20	1.66	0.93	0.93	1.66
8927	2C1	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
9021	2C1	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
9026	2C1	LCGC	No	Low	High	Description	0.10	0.51	0.31	0.31	0.51
9029	2C1	LCGC	No	Low	Med	Description	0.35	0.50	0.43	0.43	0.50
90103	2C1	LCGC	No	Low	Med	Description	0.20	0.50	0.35	0.35	0.50
9136	2C1	LCGC	Yes	low	High	Recovered	0.10	0.30	0.20	0.20	0.10
5161	2C1	LCGC	No	Low	Med	Description	0.10	0.30	0.20	0.20	0.30
8932	2C1	LCGC	No	Low	Med	Description	0.35	0.50	0.43	0.43	0.50
9019	2C1	LCGC	No	None	Med	Description	N/A	N/A	N/A	N/A	N/A
9024	2C1	LCGC	No	None	Med	Description	N/A	N/A	N/A	N/A	N/A
9053	2C1	LCGC	No	None	Med	Description	N/A	N/A	N/A	N/A	N/A
9122	2C1	LCGC	No	None	Med	Description	1.00	1.30	1.15	1.15	1.30
AZ9021	3O	LCGC	No	None	Low	Description	0.40	1.15	0.78	0.78	1.15
AZ9026	3O	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
AZ9029	3O	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
COR90103	3O	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
COR9136	3O	LCGC	No	Low	Med	Description	0.20	0.40	0.30	0.30	0.40
AZ9024	3O	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
COR9025	3O	LCGC	No	None	Poor	Description	N/A	N/A	N/A	N/A	N/A
AZ9053	3O	LCGC	No	None	Med	Description	N/A	N/A	N/A	N/A	N/A
AZ9122	3O	LCGC	No	None	Med	Description	N/A	N/A	N/A	N/A	N/A
VENTS	1O	NOAA	No	High	High	Recovered	0.10	0.30	0.20	0.20	0.10
Mean										0.44	0.58
Mean no premark										0.49	0.67
Standard Deviation										0.31	0.49
Standard Deviation no premark										0.32	0.48

Table III-1. Worksheet showing spatial accuracy of orthophotography based on the published location of geodetic survey points between U.S. 101 (Yaquina Bay Bridge) in the City of Newport and the City of Toledo, Oregon, compared to locations obtained from orthorectified photographs for the aerial photosurvey of Yaquina Bay estuary on July 23, 1997.

APPENDIX IV: PROCEDURES FOR CONDUCTING GROUND SURVEYS OF INTERTIDAL VEGETATION PERCENT COVER IN SUPPORT OF AERIAL PHOTOGRAPHY HABITAT MAPPING

1.0 INTRODUCTION

The Pacific Coastal Ecology Branch (PCEB) of the US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Western Ecology Division (EPA/ORD/NHEERL/WED) conducts aerial photography surveys of Pacific Northwest (PNW) estuaries using false color, near-infrared (color infrared, CIR) film. The project includes a 'ground truthing' component needed both for training the image analyst and (using separate, independent data) assessing the accuracy of the final habitat classification (map) of the target habitats. A primary guide to the present procedure is the text *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices* (Congalton and Green 1999). This guide emphasizes the necessity of using randomly located stations, which may be stratified according to target habitat classes if such information is available. The procedure described here relies upon previously obtained aerial photomaps, or upon survey reports such as *The Oregon Estuary Plan Book* (Cortright et al. 1987) to provide polygons for target habitats such as eelgrass meadow (*Zostera marina* L.) or nonvegetated substrate in the intertidal zone of estuaries under investigation (which generally become covered by green macroalgae in summer). Locations of randomly positioned stations are provided by a geographic information system (GIS) specialist for entry as 'way points' into a global positioning system (GPS) used to navigate to these randomly positioned stations in the field.

1.1 PLANNING

A. Locate the most reliable map of the target habitat classes, such as intertidal eelgrass *Zostera marina* (*Zm*) and nonvegetated substrate (N) in the study site (e.g., a PNW estuary). Transfer it into a GIS.

B. Using the GIS, create polygons for each target habitat class within the intertidal zone. Using a random position program, create 100 randomly positioned stations within each habitat stratum, with the percentage in a given polygon being proportional to the area of that polygon relative to the total stratum area. Overlay the polygon layer on a layer illustrating the areas covered by the individual photographs from the aerial survey; insure that there are at least two stations for each stratum in each photo area. For each stratum, number the stations from 1 to 100 as they appeared in the random sequence.

C. Print out color maps of each stratum on a base map of the study area, showing the locations of the numbered stations. Protect these in waterproof plastic sleeves for use in the field.

1.2 POSITIONING

A. Use a differentially-corrected global positioning system (DGPS) instrument with sub-meter accuracy.

B. Document the accuracy and precision of this DGPS by taking three 30-second positionings at a survey marker with as high an horizontal accuracy rating as possible, within the study area or as close to it as possible. At least ten sets should be taken on different days.

C. In the data logger of the DGPS, create a feature list of numbered stations for each stratum in the study.

1.3 GROUND STATION SURVEYING

A. Using the DGPS, navigate to the first station in a given habitat stratum. (PCEB has found that the use of a reliable hovercraft vessel is of inestimable value in efficiently reaching randomly located positions during exposed conditions on an estuarine intertidal mud flat). Place a marker 'blindly' by throwing it over a shoulder. This is the center position of the 2.5 m x 2.5 m survey area. If any part of this area (oriented with two opposing sides pointing toward true north) lies within 2.5 m of the edge of the habitat (e.g., an eelgrass meadow margin or a 'hole' whose minimum diameter exceeds 2.5 m), move the marker 'inward' (perpendicular to the habitat local margin) just enough so that no part of the survey area is within 2.5 m of the habitat margin. This minimizes the probability that, owing to the approximately 2.5 m uncertainty in positioning via the orthorectified digital photomap, the area of the image which the analyst classifies lies just across the actual margin and outside the habitat surveyed on the ground. Replace the station marker. On the field data sheet, record how far, and in which direction, the station marker was moved.

B. Place a quad (outer dimensions 1.25 m by 1.25 m, strung with two orthogonal sets of five equally spaced taut strings) in the southeast sector of the zone around the marker (Sector 1), with the northwest corner of the quad just touching the marker. Use a compass to orient the quad so that two opposing sides point toward true north.

C. Without walking into the sectors (and thus disturbing their survey areas), survey the 25 intersections (points) of the orthogonal strings in Sector 1. Assign a single habitat as most representative of the ground cover directly beneath each point. Determine the count (of a total of 25 points in the quad area) for each target habitat, leaving bare substrate as the default count (remainder). Thus, the count for Sector 1 might be 10 *Z. marina*, 5 benthic green macroalgae and 2 *Z. japonica,* leaving 8 points represented by bare substrate to constitute the total of 25 points. Enter the cover counts for *Z. marina*, benthic green macroalgae, and *Z. japonica* in the three fields provided in appropriate data field of the data logger. Also record the entries in appropriate fields for that station on a waterproof field data sheet (Table IV-1), along with information for that day's survey. Describe the types and counts of any miscellaneous material (that should be subtracted from the bare substrate default count) in the 'Notes' column or on the following row of the field data sheet. Then take a (numbered) photograph of the quad, positioning the camera as near as possible over the center of the quad to obtain a vertical photograph of the survey area. Avoid shadows in the photo.

Aerial Photomapping Ground Survey

Estuary:	**Date:**
Low Tide Level (ft):	**Time:**
Crew Initials:	**Vessel:**

			Quad1			Quad2			Quad 3			Quad 4			GPS Position		
Way Point No.	Time	Photo Nos.	*Zm*	GM	*Zj*	*Zm*	GM	*Zj*	*Zm*	GM	*Zj*	*Zm*	GM	*Zj*	Northing	Easting	Notes:

Table IV-1. Example field data sheet for aerial photomapping ground surveys.

D. Flip the quad over to the west and repeat the procedure outlined in Section 1.3(C) for Sector 2 (southwest sector).

E. Flip the quad over to the north and repeat the procedure, for Sector 3 (northwest sector).

F. Flip the quad over to the east and repeat the procedure for Sector 4 (northeast sector).

G. Determine the position of the station marker by placing the DGPS antenna directly over it, and obtain one 30-second position reading at one-second intervals. Also record the position reading (northing and easting) on the data sheet.

H. Proceed to the second station of the stratum and repeat the survey procedure. Note: If it is very likely that a specific number of the stratum's stations will be sampled (e.g., 65), for efficiency the stations may be sampled out of order (grouping adjacent stations) if it is very likely that no gaps (or only a small number) will be left in the station sequence (1 - 65) at the end of the ground survey.

I. Proceed with this sampling as described above.

1.4 MOVING A STATION INTO A TARGET HABITAT

Owing to insufficient information in planning the ground survey, a station may be found to lie outside the target habitat. If the target habitat lies within an estimated 100 m of that point (a rough limit of the distance that can be ranged visually), the station may be moved into the habitat if this is done in a manner that maintains the randomness of the positioning. There are two realistic scenarios:

1. **Case I**: If only one 'front' of the target habitat lies within this (arbitrary) 100 m range, proceed along a track perpendicular to that front until reaching the habitat edge. Proceed 2.5 m into the habitat. Then estimate the width of the habitat along a projection of this track, within the candidate sampling area bounded by the 2.5 m wide 'buffer zone' but not more than 100 m (except in special circumstances, noted on the field sheet). Using a table of random numbers, enter it blindly and select the first number that is less that this net width of the sampling area. Proceed that distance from the 2.5 m buffer zone along the track to the new sampling location. Record the direction and distance moved to the new station location (so that any user may decide whether or not to accept the moving of this station).

2. **Case II**: If more than one front lies within 100 m, using a compass determine the radial range that encompasses the candidate habitat positions (e.g, from 90 degrees - due East - to 270 degrees - due West). Since a random number table typically has 2-digit numbers, select the first number encounter between 9 and 27, multiply it by 10, and select that as the compass heading to a candidate habitat. Then continue following the procedure specified in Case I. Again, record the direction and distance moved to the new station location.

1.5 MARGIN MAPPING

The Principal Investigator will decide if positioning of the margin (edge) of a habitat, such as an eelgrass meadow or patch, is to be part of a ground survey, and if so, the maximum length of the sectors (e.g., 100 m) and whether their starting positions are to be selected randomly, or arbitrarily in the field. If the mapping is to be done by foot, the field survey pair makes a best effort to walk along the edge of the habitat in the selected area with the DGPS unit. For seagrass, this edge is defined according to the National Oceanic and Atmospheric Administration Coastal Change Analysis Program (C-CAP) protocol (Dobson et al. 1995) as the 10% cover contour. The upper margin usually is quite sharp. For a shallow meadow, at a good low tide it may be possible to wrap an entire sector by foot. Otherwise, only the upper part of the meadow is mapped by foot; the lower margin then may be mapped by transporting the DGPS along it from a slow moving boat or hovercraft.

1.6 DATA ARCHIVING

Upon return to the laboratory, the positions for the day's surveys are post-processed to yield the most accurate differentially-corrected positions. These corrected positions are entered into a file that includes the percent cover values for the stations surveyed. The directory or file names should include the site (estuary) and date sampled, and indicate whether the data are habitat margin positions or percent cover values for positioned stations. The digital photographs also should be transferred to a corresponding computer file.

1.7 APPLICATION OF GROUND SURVEY DATA

A. In the simplest case, the 'margin mapping' data (DGPS positions from the 'line' mode) are provided to the image analyst for training purposes (these locations may be selected arbitrarily). In more advanced studies, sectors approximately 100 m in length are randomly selected; 20% are provided to the image analyst for training (with a minimum of two sectors per image). The remaining line sectors are retained by the Principal Investigator, for comparison with (e.g., determining the average deviation from) the margin of the habitat classification following completion of the digital photomap.

B. In the simplest case, for each target habitat class specific locations are determined by the image analyst or by the survey team in the field, and surveyed for percent ground cover and station position as training data for the analyst. Alternatively, the training data are incorporated into the field survey as follows. The ground stations surveyed are randomly subsampled, so that both positioning and percent cover data from approximately 20% of the stations (again, with some minimum number - e.g., two per image) are provided to the image analyst for training. Following completion of the classification, only the positions (but not the percent cover data) of the remaining 80% of the ground survey stations are provided to the image analyst, who then samples the classifications at these positions. In this case, using a pixel ground dimension of 0.25 m, an array of 10 x 10 pixels (equivalent to a ground sampling area of 2.5 m x 2.5 m) is centered around a given station's position. The number of pixels (out of the 100 total pixels) classified as belong to a given habitat class (e.g., eelgrass) then is the percent cover of that vegetation class determined at that station via the classification. This step is repeated to yield percent cover values for all the target habitats (e.g., native eelgrass *Z. marina*, green macroalgae, non-indigenous 'dwarf' eelgrass *Z. japonica*, bare substrate) at that station. It is noted that this procedure results in the same shape, orientation, and total area of the station surveyed from the ground and from the photomap classification (2.5 m x 2.5 m, with sides oriented toward true north). The two classes of percent cover data (from the ground and the image samplings) then are compared via an error matrix for predetermined percent cover classes, taking the ground results as the reference data (Congalton and Green 1999). In the simplest case, the C-CAP protocol is accepted: any station with greater than 10 percent seagrass cover is to be classified as a seagrass station. The results for the two classes targeted in this procedure - intertidal eelgrass and bare substrate - via the error matrix then are determined. In all cases, the error matrix results are to be assessed for accidental agreement via the Kappa correction (Congalton and Green 1999; Jenness and Wynne 2004). It is to be noted that, since a rim 2.5 m wide around each habitat is excluded from the survey (to avoid misinterpreting photo positioning error as image classification error), the accuracy assessment results do not apply to these unsampled areas. This fact places more importance on including a margin mapping component in the ground survey.

1.8 LITERATURE CITED

Congalton, R. G., and K. Green. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Lewis Publishers, CRC Press, Inc., Boca Raton, FL, 137 p.

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Dobson, J. E., E. A. Bright, R. L. Ferguson, D. W. Field, L. L. Wood, K. D. Haddad, H. Iredale III, J. R. Jensen, V. V. Klemas, R. J. Orth and J. P. Thomas. 1995. NOAA Coastal Change Analysis Program (C-CAP). Guidance for Regional Implementation. NOAA Technical Report NMFS 123. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Charleston, SC, 129 p.

Jenness, J. and J. J. Wynne. 2004. Kappa analysis (kappa_stats.avx) extension for ArcView 3.x. Jenness Enterprises. Available at: http://www.jennessent.com/arcview/kappa_stats.htm

APPENDIX V: EXAMPLE SCOPE OF WORK – AERIAL PHOTOGRAPHY

SCOPE OF WORK

TITLE: **Aerial Photography Survey of Yaquina Bay Estuary, Oregon during 2006.**

The United States Environmental Protection Agency (US EPA) National Health and Environmental Effects Laboratory - Western Ecology Division/Pacific Coastal Ecology Branch (NHEERL-WED/PCEB) is engaging in a study of Oregon coastal estuaries, in order to characterize intertidal biological communities and determine potential impacts of multiple stressors. This will include color infrared (CIR) aerial photography of Yaquina Bay estuary, illustrated in Attachment I. The goal is to obtain the photography in the spring before the mid-summer macroalgal blooms. The original photography must be accomplished during the days and hours of lowest tide between April 29 and August 12, 2006 when the tidal flats are most exposed during daylight hours. Any reflight photography required by WED/PCEB must be accomplished within the period specified above. The Contractor must have the ability and commitment to utilize the date/time windows necessary to obtain all photographs under the conditions specified in the contract.

SPECIFICATIONS

1.1 LOCATION OF WORK

The area for data collection shall include those portions of Yaquina Bay estuary illustrated in Attachment I. This figure delineates the study area, including the approximate intertidal/subtidal areas to be covered by image acquisition and specific flight lines over these areas with photography intervals, and precise locations of corresponding photo centers. A digital file containing the locations of the photo centers will be provided by WED/PCEB to the Contractor upon request.

1.2 DEFINITIONS

Camera System: The combination of lens, cone, magazine(s), and camera filter(s) which have been calibrated as an integral unit.

Original Photography: All aerial photography, as secured by the Contractor, prior to its inspection by EPA/PCEB, including any reflights made at the discretion of the Contractor.

Reflight Photography: Photography reflown at the request of WED/PCEB, to replace rejected original photography. Any replacements shall be provided at no additional cost to the Government.

1.3 AERIAL PHOTOGRAPHY REQUIREMENTS

A. For optimum photographic coverage of the intertidal flats, the aerial photography shall occur only during the time periods and on the dates (flight windows) specified in Attachment II. The following criteria shall be met:

1. Nominal Photographic Scale: 1:20,000. The flight lines shall be oriented in the west-east direction, numbered from north-to-south (e.g., 1-, 2-), and corresponding photo centers from west to east (e.g., -1, -2, -3, -4, -5).

2. Flight Schedule: Flight windows are scheduled based on tidal exposure windows. These flight windows (in Pacific Daylight Saving Time) are provided in Attachment II.

3. Photographic conditions: Photography shall be undertaken when skies are free from smoke and excessive haze, and clouds are above the flight altitude without casting shadows that obscure sectors of the estuary. High overcast skies are acceptable.

4. Aircraft: The design of the aircraft shall be such that when the camera is mounted with all its parts within the outer structure, an unobstructed vertical field of view is obtained. The field of view shall be shielded from the exhaust gases, oil, effluence and air turbulence. Four fiducial marks shall be visible on each frame of the film.

5. Aerial Camera:

   (a) Forward motion compensating and GPS-triggered camera is required.

   (b) Nominal lens focal length: (six) 6 inches or 153 mm

   (c) Filter(s): Kodak Wratten filter #12 or equivalent.

   (d) AWAR rating of approximately 90 or higher

6. Aerial Film:

   (a) Film characteristics: Kodak Aerochrome® Infrared 2443 film, or equal*, as specified by the Contractor, in 23 cm x 23 cm (9 in. x 9 in.) format. Color infrared film shall be sensitive to the visible and near infrared spectrum from 400 to 900 nanometers.
   *NOTE: “equal” must be specified in response and acceptable to WED/PCEB.

   (b) Film storage and handling: Color infrared film shall be kept refrigerated in a waterproof container until one day before being exposed and returned to cold storage after exposure until processed. All rolls of aerial film shall be contained in Contractor-furnished sturdy, cylindrical plastic cans.

(c) Film processing:

(1) The film shall be processed in a continuous roller transport processor to achieve consistent and uniform development throughout the roll.

(2) Film shall be processed within 48 hours of exposure to avoid undesirable changes in the latent image.

(d) Physical quality:

(1) All aerial film shall be free from chemicals, stains, tears, scratches, abrasions, watermarks, finger marks, lint, dirt and other physical defects. The imagery shall be clear and sharp in detail and uniform in density. It shall be free from light streaks, static marks, and other defects that would interfere with the intended purpose.

(2) All film shall be thoroughly fixed and washed to ensure freedom from chemicals and shall be of archival quality.

(3) Film found to contain an excess of residual chemicals, by testing in accordance with manufacturer's procedures, shall be rejected or returned to the Contractor for refixing and rewashing at no cost to the government.

(e) Composition of Film Roll: A roll of aerial film shall consist only of exposures made with the same camera system. All film on any roll shall have the same roll number.

(f) Film labeling:

(1) Placed on each exposure shall be the sponsor identifier "EPA/WED/PCEB", the flight date, time, nominal scale, flight line number (e.g., 1- or 2-, north to south - see Section 1.3.A.1) and exposure number (e.g, -1 to -5, west to east - see Sector 1.3.A.1) corresponding to the flight map.

(g) Digital Scans:

(1) Prior to completion of the survey flights, WED/PCEB shall submit to the Contractor sets of test diapositives from previous aerial photography surveys of Pacific Northwest estuaries, with the choice made by WED/PCEB for the

preferred color balance for each set. Based upon this information, the Contractor shall select the color balance that best reflects previous selections by WED/PCEB, and, using a roll-feed photogrammetric-grade scanner capable of scanning original color infrared negatives at 12 micron resolution, produce digital scans at a resolution of 12 microns corresponding as close as possible to the sample diapositives provided by WED/PCEB. A pilot area shall be scanned and approved for color balance by WED/PCEB before scanning all images. The film first shall be cleaned of surface dust. Scans shall include all fiducial marks complete to the edge of the image. WED/PCEB reserves the right to reject any imagery that does not match pre-approved color samples. The output format shall be uncompressed TIFF image format. The delivery media shall be DVD or portable hard drive, which shall be delivered to WED/PCEB within 20 working days of completion of the final aerial photography survey. Following satisfactory transfer of the digital images to the WED/PCEB computer system, the DVDs or hard drive(s) will be returned to the Contractor.

(h) Flight Log: A copy of the pilot's flight log shall be provided upon delivery of the digital scans of the film from the aerial photography surveys.

1.4 FLIGHT PLAN DATA

A. Areas to be Photographed:

1. The area of the estuary to be photographed using CIR film is specified on the study area map presented in Attachment I, along with a map of required flight lines and photo centers.

B. Photographic Scale: The project flight plan has been designed to achieve a nominal photographic scale of 1:20,000, using a lens with a nominal focal length of 6 inches or 153 mm.

C. Coverage:

1. Coverage shall be obtained to the terminal points of each flight line, as indicated by the terminal marks on the flight line map(s).

2. All flights and reflights shall be made in accordance with the following requirements:

(a) Rejection of any exposures shall be cause for rejecting some or all of the remaining exposures in that flight line and/or area.

(b) Photography shall be undertaken only during the hours when acceptable imagery can be produced in accordance with the photographic conditions as specified in 1.3.A.3.and Attachment II.

D. Horizontal Deviation:

1. Compass bearing of each flight line should be within 5 degrees of the charted flight line direction.

E. Tilt shall not exceed 4 degrees for each exposure. Tilt shall not average more that 2 degrees for the entire project.

2.1 BUSINESS ARRANGEMENTS

A. Invoicing:

1. One invoice shall be submitted for the aerial color infrared photography, film processing and scanning, and delivery of digital scans.

B. Schedule for Deliverables:

1. All aerial photography, including reflights, shall be completed by August 12, 2006. Prior to completion of the flight(s), WED/PCEB shall submit to the Contractor sets of test diapositive from previous aerial photography surveys of Pacific Northwest estuaries, with the choice made by WED/PCEB for the preferred color balance for each set. Based upon this information, the Contractor shall select the color balance that best reflects the previous selections by WED/PCEB, and produce the digital scans for the six estuaries surveyed. This digital scan information shall be delivered to WED/PCEB within 20 working days of completion of the aerial photography survey.

C. Schedule of Payments

1. Final billing shall be submitted on or before August 31, 2006.

The Contractor shall certify to the following:

3.1 MINIMUM QUALIFICATION REQUIREMENTS

A. Offeror must certify that they meet the following minimum qualification requirements. The Contractor shall have:

1. General aerial photography experience.

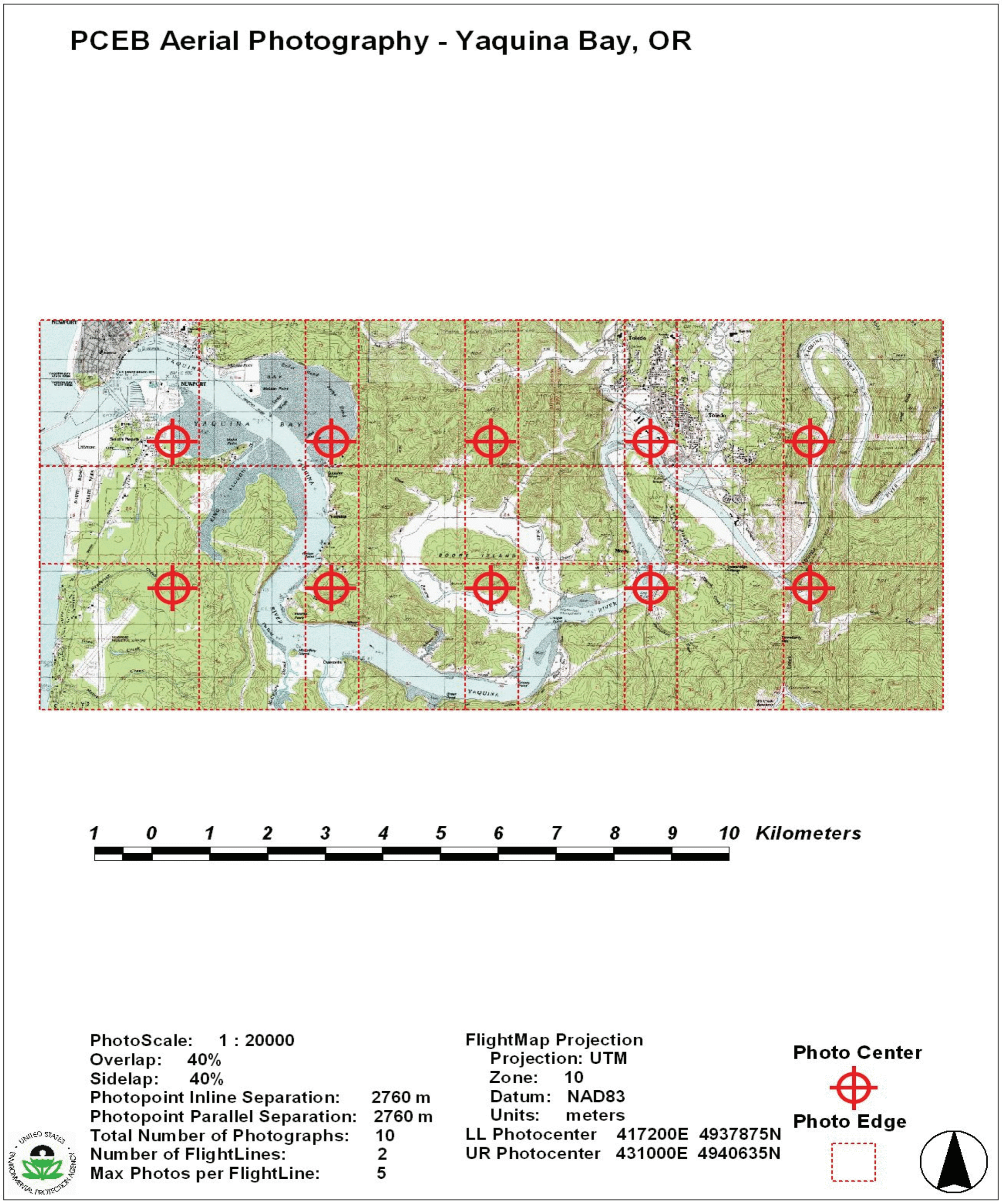
2. Coastal/estuarine aerial photography experience.
3. Experience with color infrared film photographing, processing and printing.
4. Global positioning (GPS) capability on the aircraft, with GPS-triggered camera.
5. In-house lab facility or cooperation with outside photo laboratory.
6. Flexibility of flight schedule to conduct flights during the times specified in Attachment II.
7. Ability to deliver products within time frames specified in Section 2.1.B.
8. The Contractor shall provide documentation that the minimum qualification requirements 1 through 7 are met. This documentation will be evaluated by EPA based on its previous experience with contracting coastal/estuarine aerial photography projects.
9. Aerial camera calibration: Tested and calibrated precision aerial cameras for taking aerial photographs are required. One copy of the Report of Calibration from the US Geological Survey, for any camera (including lenses) to be used, is required to be submitted with the proposal. A camera report shall not be acceptable if more than three years old at the time of the scheduled date for receipt of offers. The three year period may be waived if written evidence is furnished of a firm scheduled date the camera is to be tested at the US Geological Survey Optical Science Testing Laboratory. The fees for such tests are the responsibility of the Contractor.

Contact for Calibration Tests

US Geological Survey
National Mapping Division
Attention: Chief, Optical Science Section
526 National Center
Reston, VA 22092
Telephone: (703) 648-4682

10. Capability for film processing or digital scanning. If the Contractor uses the services of an outside lab for film processing or digital scanning, the Contractor shall submit a certification as to that laboratory's qualifications for proper film processing and/or digital scanning.

Attachment I: Required flight lines and precise locations of photo centers for Year 2006 color infrared aerial photography of Yaquina Bay estuary, Oregon.



Attachment II: Time/tidal elevation (ft) windows for allowable photography of Yaquina Bay estuary, Oregon, April 29 – August 12, 2006 (initial page only).

Tide Windows 2006		Day						
Date	Time	Sun	Mon	Tue	Wed	Thu	Fri	Sat
4/29/2006	900							-1.65
	915							-1.4
	930							-1.09
	945							-0.73
4/30/2006	900	-1.76						
	915	-1.71						
	930	-1.6						
	945	-1.43						
	1000	-1.19						
	1015	-0.91						
	1030	-0.58						
5/1/2006	900		-0.99					
	915		-1.15					
	930		-1.24					
	945		-1.27					
	1000		-1.23					
	1015		-1.14					
	1030		-0.99					
	1045		-0.79					
	1100		-0.54					
5/15/2006	900		-1.5					
	915		-1.37					
	930		-1.18					
	945		-0.94					
	1000		-0.66					
5/16/2006	900			-1.51				
	915			-1.56				
	930			-1.56				
	945			-1.49				
	1000			-1.36				
	1015			-1.17				
	1030			-0.94				
	1045			-0.66				

APPENDIX VI: EXAMPLE SCOPE OF WORK – DIGITAL ORTHORECTIFICATION OF AERIAL PHOTOGRAPHS

SCOPE OF WORK

BACKGROUND

The United States Environmental Protection Agency (US EPA) National Health and Environmental Effects Laboratory - Western Ecology Division/Pacific Coastal Ecosystems Branch (NHEERL-WED/PCEB) is engaging in a study of Yaquina Bay estuary on the Oregon central coast, in order to characterize intertidal biological communities and determine potential impacts of multiple stressors. This includes color infrared (CIR) aerial photography of a portion of the estuary, approximately from river mile 0.5 to river mile 12.5. The original photography is to be accomplished by August 31, 1998 at a scale of 1:6000 using a 6 inch lens in 23 cm aerial film format during morning when the tidal flats are most exposed. Nine east-west flightlines are to be flown with varying numbers of photos per flightline with a standard 60% overlap and 30% sidelap totaling 120 exposures. Approximately 105 exposures include aquatic portions of the Yaquina Bay estuary. A cross line flightline of 20 exposures also is to be flown at an angle to the main flightlines to aid aerotriangulation calculations.

BID SPECIFICATIONS

1.1 DEFINITIONS

A. **WED/PCEB**

US Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Western Ecology Division, Pacific Coastal Ecology Branch located at the Hatfield Marine Science Center in Newport, Oregon, 97365-5260.

B. **WED/PCEB GIS system**:

The Geographic Information System in use at the WED/PCEB facility using Arc/Info® v.7.1.1; ArcView® 3.0; and ER Mapper® v.5.0 software running on a Windows NT Intel platform. Other software used includes Excel® v.5.0, PCGPS® v.3.2, FieldNotes®, and Image Alchemy PS®.

C. GeoTIFF

"GeoTIFF" refers to Tagged Image File Format (TIFF) files which have geographic (or cartographic) data embedded as tags within the TIFF file. The geographic data can then be used to position the image in the correct location and geometry on the screen of a geographic information display. GeoTIFF is a metadata format, which provides geographic information to associate with the image data. But the TIFF file structure allows both the metadata and the image data to be encoded into the same file. The most current version of the GeoTIFF specification is maintained on a WWW site at:

http://www.remotesensing.org/geotiff/spec/geotiffhome.html

D. TIFF

TIFF is a raster data format for storage, transfer, display, and printing of raster images. The TIFF imagery file format can be used to store and transfer digital satellite imagery, scanned aerial photos, elevation models, scanned maps or the results of many types of geographic analysis.

E. TIFF World File

The world file is an ASCII text file that is associated with an image by the following naming convention at ARC/INFO® 7.x and ArcView® (all versions). If the image file name has a 3-character extension (e.g., image1.tif), the world file has the same name followed by an extension containing the first and last letters of the image's extension and ending with a "w" (e.g., image1.tfw). The following summarizes the contents of the world file:

1. line 1: x-dimension of a pixel in map units
2. line 2: rotation parameter
3. line 3: rotation parameter
4. line 4: negative of y-dimension of a pixel in map units
5. line 5: x-coordinate of center of upper left pixel
6. line 6: y-coordinate of center of upper left pixel

1.2 PHOTOGRAPHIC HARD COPY

A. Diapositive transparencies of 1998 color infrared aerial photography of Yaquina Bay estuary (a total of 140 exposures) will be provided to the Contractor by WED/PCEB. The diapositives will be produced by WED/PCEB according to color-model specifications developed in consultation with the Contractor.

B. The diapositive transparencies must be handled in such a manner to keep them clean and free from stains, blemishes, uneven spots, fog, and finger marks.

2.1 PHOTOGRAPHIC DIAPOSITIVE DIGITIZATION

The Contractor shall digitize the color infrared diapositive photographic transparencies required for digital orthorectification of the aquatic portion of Yaquina Bay estuary. Scanning shall be accomplished with a high resolution photogrammetric color scanner at a scanning resolution of 25 microns or higher in 24 bit color. Scanning shall be conducted in a consistent manner that will ensure the highest fidelity to the colors present in the photographic diapositive transparencies. The make, model, and calibration settings of the scanner used by the Contractor in the production of the above data files shall be provided to WED/PCEB by the Contractor prior to product delivery.

2.2 IMAGE RECTIFICATION

A. Color Infrared Image Rectification

1. Aerial Triangulation

   Using diapositives of 1998 color infrared aerial photography of Yaquina Bay estuary provided by WED/PCEB; coordinates and elevations of photo centers of 1998 color infrared aerial photography of Yaquina Bay estuary provided by WED/PCEB; ground control points provided by WED/PCEB; and any Contractor-provided additional post-flight ground control points; the Contractor shall perform and aerial triangulation process that shall include the following:

   a. Project preparation
   b. Control and image point selection and coding
   c. Image point marking and cross-marking
   d. Control and image point mensuration
   e. Block adjustment
   f. Results analysis

2. Digital Elevation Modeling

   Upon request, WED/PCEB shall provide the Contractor spot elevations, break line point elevations, and digital orthophotography with a spot accuracy of +/- 0.3 meter compiled from July 23, 1997 color infrared imagery sufficient to model the aquatic portions of the 1998 CIR imagery.

3. Orthorectification

   The Contractor shall orthorectify the aquatic portions of the color infrared digital imagery (described in Section 2.1 above) to remove displacement effects due to radial distortion and aircraft motion (roll, pitch, true heading, altitude, and variations in speed); and georeferencing the Roth-rectified digital imagery in a Universal Transverse Mercator projection based upon NAD83(91) datum in meter units. The orthorectified images shall have a pixel size of approximately 0.15 meters in ground units with a horizontal accuracy expressed with a nominal horizontal accuracy of +/- 0.5 meter or better. The orthorectified images shall be georeferenced, tiled and edgematched. Image tiling shall be performed so as to produce square images representing uniform ground dimensions. Image tiles shall be oriented so that true north (in the UTM projection) is at the top of the image. Image tile data files shall not exceed 300 megabytes in size. The preferred nominal file size for tiled images is 240 to 300 megabytes with the exception of image tiles at the edge of the orthocoverage which may be of a smaller file size. The resultant 24 bit color data files are to be provided to WED/PCEB on CD- ROM disks in uncompressed GeoTIFF format. The GeoTIFF files shall be accompanied with TIFF World Files (.tfw) compatible with the WED/PCEB GIS system containing georeferencing data for each image.

B. **Ground Control Point Location**

The Contractor shall coordinate the location of any post-flight ground control point location with WED/PCEB. WED/PCEB has located (in addition to four premarked ground control points) several well-defined photo visible first to third order horizontal and/or vertical ground control points documented by the National Geodetic Survey and/or the Lincoln County Survey Department. The Contractor shall provide WED/PCEB with the location, description, and documentation of any additional ground control points used for orthorectification described in Sections 2.2.A and 2.2.B.

3.1 DIGITAL FILE NAMING CONVENTION

All digital files shall be provided to WED/PCEB using the following file naming convention:

1. Orthotile image names shall reflect:
    a. column number beginning with the westernmost tile and proceeding east
    b. row number beginning with the southernmost tile and proceeding north.

2. The system developed by the Contractor for the above naming conventions shall be supplied as part of the metadata delivered with the above products.

3.2 DOCUMENTATION OF IMAGE RECTIFICATION

The Contractor shall provide WED/PCEB with written documentation on the processing of the digital data, including description of all geometric corrections. The report shall be delivered with the rectified digital data. The report shall include information on:

1. Procedures used to rectify the data;
2. The source, location and description of control used for data rectification;
3. Root mean square error for each file;
4. The residuals for each control point;
5. The resampling algorithm and transformation used;
6. The number of times the data were resampled.

3.3. QUALITY ASSESSMENT - IMAGE RECTIFICATION

It is the intent of WED/PCEB to incorporate information derived from the color infrared digital data into its geographic information system. The quality of the rectification shall be judged by:

1. Registration to existing WED/PCEB geographic information system data;
2. Root mean square error for each file;
3. The residuals for each control point;
4. The order of the rectification algorithm used;
5. Positional accuracy of a feature's local geometry.

4.1 BUSINESS ARRANGEMENTS

A. Schedule for Deliverables:

The Contractor shall establish specifications described in Section 1.2 in consultation with WED/PCEB within 15 working days of the award of Contract. The Contractor shall arrange to take delivery of all CIR diapositives within ten working days of the establishment of the specifications described in Section 1.2 and provide WED/PCEB in writing with an accurate estimate of the total number of ortho-image tiles that are expected to be produced.

1. The following products:

    a. Aerial triangulation results analysis described in Section 2.2.A.1;
    b. All orthorectified color infrared digital images in 24 bit color GeoTIFF format described in Section 2.2.A.3;
    c. All TIFF World Files for each GeoTIFF file above;
    d. All color infrared diapositives supplied by WED/PCEB;
    e. All documentation and metadata required above.

2. Shall be delivered according to the following schedule:

a. The initial delivery (Phase I) shall take place within 40 working days of the Contractor's receipt of the color infrared diapositives and consist of the aerial triangulation results analysis described in Section 2.2.A.1;
b. The second phase delivery (Phase II) shall take place within 50 working days of the delivery of Phase I and consist of the CIR ortho-tiles in GeoTIFF format along with their associated TIFF World files on CD-ROM disks as described in Section 2.2.A.3;
c. All color infrared diapositives shall be returned to WED/PCEB upon completion of Section 4.1.A.1 above;
d. All documentation and metadata required above shall be delivered upon completion of Section 4.1.A.1 above or before as required.

B. Point of Delivery

All deliverables shall be shipped to the following address:

NOTE: Insert address for Deliverables here

(Address in italics)

C. Schedule of Payments

NOTE: Insert Payment Schedule here

5.1 TECHNICAL EVALUATION CRITERIA

The Government will award a Purchase Order resulting from this Request for Quote to the responsible offeror whose quote will be the most advantageous to the Government, price and other factors considered. Offerors shall provide the following information to allow for technical evaluation of their quote:

1. A brief description of their proposed technical approach to complete the requirements of the statement of work. Include a discussion of personnel, equipment and facilities available to perform the work.

2. Provide up to three references for whom work of similar scope and size was performed within the past year. Include the company or agency name and addresses, project title and/or contract number, project officer, contracting officer and phone number and time frame in which work was performed. This information is used to assess past performance history.

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