MAPPING SPATIAL/TEMPORAL DISTRIBUTIONS OF GREEN MACROALGAE IN A PACIFIC NORTHWEST COASTAL ESTUARY VIA SMALL FORMAT COLOR INFRARED AERIAL PHOTOGRAPHY*

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ABSTRACT

A small format 35 mm hand-held camera with color infrared slide film was used to map blooms of benthic green macroalgae upon mudflats of Yaquina Bay estuary on the central Oregon coast, U.S.A. Oblique photographs were taken during a series of low tide events, when the intertidal mudflats along the drowned-river were exposed. The resulting images were digitally scanned and georeferenced to commercially produced digital orthophotographs. Benthic surveys of two transects (~ 3500 m^2) oriented perpendicular to the estuary's channel were conducted within about two weeks of each aerial survey. Distributions of the perennial seagrass *Zostera marina* along the upper edge of the channel were delineated from the aerial photographs taken in late spring before extensive development of the green macroalgae beds. Summer expansion and fall contraction of these algal beds (comprised principally of *Ulva* spp. and *Enteromorpha* spp.) was documented via a series of four aerial and ground surveys conducted between May and December. The study demonstrated the usefulness of this approach in mapping blooms of green macroalgae in Pacific Northwest estuaries.

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INTRODUCTION

The steady growth in human habitation of the Pacific Northwest (PNW) has led to increased concern regarding eutrophication of coastal estuaries in this region of the U.S.A. Nutrients released by anthropogenic sources in coastal watersheds can stimulate growth of algae in freshwater and estuarine receiving waters (Cerco and Seitzinger, 1997; Raffaelli *et al.*, 1998). Such eutrophication can affect natural populations of ecologically important organisms (Isaksson and Pihl, 1992). The rapid development of benthic macroalgae on estuarine mudflats during the summer growing season makes difficult the accurate documentation of spatial and temporal distributions of such algae from ground surveys alone. This paper describes progress made in developing a relatively inexpensive method of mapping estuarine intertidal vegetation throughout the year using small format (35 mm) color infrared (CIR) aerial photography. This approach is well suited for the dynamic and demanding conditions encountered in the coastal environment of Oregon. The timing of monthly low tide cycles requires the capability to acquire quality photos under variable light and weather conditions. CIR film was selected because the resultant false color images can be used to delineate water, soil, and classes of actively growing vegetation (Young *et al.*, 1998; 1999). However, for consistent results CIR film requires meeting special handling needs and working within a narrow exposure latitude (ca 0.5 f stop).

BACKGROUND

Digital orthophotographs had been obtained from large-format CIR aerial surveys conducted on July 23, 1997 (photoscale 1:7200) and August 10, 1998 (1:6000). Comparison of the 1997 images with results of associated ground surveys (Young *et al.*, 1998; 1999) showed that, during that summer of relatively low algae densities, major beds of native eelgrass (*Zostera marina*) generally were distinguishable from those of green macroalgae (mainly *Ulva* spp. and *Enteromorpha* spp.). Distributions of the introduced eelgrass species *Zostera japonica* near the upper edge of the mudflats also were discernable in the 1997 and 1998 CIR aerial photographs (Specht *et al.*, 2000). From these images there appeared to be a distinct increase in the 1998 distribution of green macroalgae over that mapped in 1997. The temporal disparity of these surveys (two and one-half weeks) may explain the increased macroalgae in 1998. To address this question, as well as concerns that high densities of green macroalgae among the seagrass can mask its CIR signature, we initiated a small format aerial photography time series program in concert with associated ground surveys at selected sites within the estuary.

METHODS

AERIAL SURVEYS

Low oblique, 35 mm color infrared photographs were acquired over ground transects on six mudflats of Yaquina Bay estuary near low tide during each of four survey dates between May and December, 1999. The general study area, including Site 2 (Idaho Point) and Site 3 (Coquille Point) discussed here, is illustrated in Figure 1 of our companion paper (Specht *et al.*, 2000). Using CIR 35 mm slide film (Kodak Ektachrome infrared [EIR], 36 exposures), photographs were taken from an open window of a Cessna 170 airplane using a hand-held Nikon N90 camera equipped with an MF-26 programmable back. Two different Nikon AF Nikkor lenses were used: a 50 mm 1:1.4 D and a 24 mm 1:2.8 D, both equipped with Tiffen filters (Sky 1-A and #12 [yellow]). Usual altitudes averaged 400 m, resulting in photoscales of 1:8,000 to 1:16,666, respectively, for 50 and 24 mm lens. Photos were framed to include permanent landmarks around each site. Typical camera settings for a photo survey on a cloudy day were: auto-exposure with matrix metering, manual focus infinity (lens taped), shutter priority, shutter speed 1/500 s, 3.6 fps auto-film advance, ISO 200 (for E-6 processing), exposure compensation -0.5 stop, and 3-frame exposure bracketing of +/- 0.7 stop. During a typical 30 minute flight, one 36-exposure roll was used. Each site was photographed twice, once with each lens, resulting in 6 frames of mixed scales and exposures from which to select one or more for continued analysis.

Following development by E-6 processing, the uncut film frames were scanned digitally using an Epson 836xl transparency scanner at a resolution of 6400 dpi, and the digital photographs were georeferenced using ground control points from the digital orthophotos obtained from the 1997 and/or 1998 large-format CIR survey. Due to variation in photoscale, resulting ground pixel sizes of the georeferenced imagery varied between 15 and 25 cm. Geographical Image Processing software (ERMapper v. 6.0) was used to classify SAV reflectance in the georeferenced imagery in an iterative process based on band ratio algorithims of image pixel intensity values (Clinton *et al.*,2000). Due to photometric variation between images, a standard algorithim for use with all images was not achieved. In some cases, more than one algorithm would be used in order to classify both submersed and emmersed SAV's, or to distinguish between SAV taxa. Photointerpretation training was derived from previous SAV photointerpretation projects, and ground survey data from these two sites was reserved for an independent comparison with the results obtained from the digital classification (Figure 1).

GROUND SURVEYS

Ground survey zones were established at the six study sites whose range incorporated most of the intertidal range of native eelgrass in Yaquina Bay estuary. A "permanent" transect 100 meters in length was established by placing 11 -12 wooden stakes along a line perpendicular to the river channel, generally at 10 meter intervals (in narrow eelgrass beds a 5 m line was added). Each transect was situated so that the first three or four stakes (labeled 0 m, 10 m, 20 m, ...) were within the upper section of the eelgrass bed, with the next stake (30 m or 40 m) just outside (upslope) of the dense section of the bed. These transect stakes were geopositioned using a backpack Differential Global Positioning System (DGPS) (CMT Model PC5-L) with a ~ $\pm$ 0.6 m horizontal accuracy (Young *et al.*, 1998). From each transect stake a lateral line ~ 35 m long (station) was established perpendicular to the transect line , and three randomly selected distances along this line (approximating a bathymetric contour) were marked by numbered sample stakes. This established a fixed ground survey zone of ~ 3500 m^2 at each of the six sites, with the lowest three to four of the 11 -12 stations situated within the dense upper portion of the native eelgrass bed. Between early June and mid-August, 1999, during each ground survey three randomly-selected distances from the transect stake were preselected for each station (excluding a two meter interval around a fixed station stakes where the vegetation may have been altered by the stake's presence). Beginning in late August, at Sites 2 and 3 only stations 0 m, 10 m, 20 m, 50 m, and 90 m were sampled. Percent cover values for native eelgrass, green macroalgae, and bare substrate were obtained from each of these samples (and usually a fourth sample collected near the transect stake, outside the range of apparent disturbance). These samples were taken during low tide when the stations were exposed, using a 0.5 m square quadrant containing two perpendicular sets of 5 equally-spaced taut wires. The values were obtained by measuring the frequency of occurrence under the 25 intercept points and/or by visual estimation. Results from the two approaches have been found to be highly correlated ($r^2 = 0.97$; Young *et al.*, 1998).

PERCENT COVER CALCULATIONS

To obtain percent cover values from the digital classification, rectangular grids 10 m wide and 35 meters long centered around the ground station lines were established in the EPA Geographical Information System (GIS) and overlayed on the SAV classifications. The percent area within a given rectangle classified as SAV then was determined. Average percent cover values for native eelgrass, green macroalgae, and their sum (grouped as SAV) also were determined from the values for the three to four quadrat samples obtained at each station during a given ground survey. Because the aerial survey conducted in early November fell midway between the dates of the ground surveys conducted in late October and late November (a period of rapid change in the SAV distributions), the percent cover measurements made during those two months were combined to obtain the November average (n = 8) for each station.

RESULTS

For each site and survey period, the average percent cover values for SAV in a 10 m x 35 m grid, determined via the digital classification and the ground survey methods, are compared (Figure 1). We note that a relatively sharp spatial gradient in the percent cover values for native eelgrass was observed during the first ground survey in early June, before the development of dense green macroalgae cover that could mask this eelgrass boundary zone. Specifically, at Site 2 the average ($\pm$ 1 std. error) values for percent cover by eelgrass at the 20 m and 30 m stations were 48 $\pm$ 11 and 0 $\pm$ 0 percent, respectively. At Site 3 the corresponding values for the 30 m and 50 m statons were 81 $\pm$ 4 and 0 $\pm$ 0 percent. These upper boundary zones for the dense sector of the native eelgrass bed at Site 2 and at Site 3 are indicated by the vertical dashed lines (Figure 1).

The late October and late November ground survey averages for the 50 m station at Site 2 were 96 $\pm$ 1 and 51 $\pm$ 11 percent, respectively. Corresponding values for the 90 m station were 88 $\pm$ 5 and 19 $\pm$ 3 percent. For Site 3, the October and November 50 m station values were 95 $\pm$ 3 and 12 $\pm$ 6 percent, respectively. Corresponding values for the 90 m station were 86 $\pm$ 4 and 1 $\pm$ 1 percent. For each of these stations, the two-month average and 95 % confidence interval is illustrated in Figure 1.

DISCUSSION AND CONCLUSIONS

The two methods of measuring SAV percent cover were compared; in general, they agreed within about 20 percentage points. However, somewhat greater discrepancies were observed for the lower stations at Site 3 during August, and at Sites 2 and 3 during December. In both cases, the percent cover values obtained from the digital classification were lower than those obtained from the ground survey. The differences in the December values may reflect the fact that the ground survey was conducted early in the month, while the aerial survey was conducted two weeks later. Thus, the lower digital classification values may indicate a measurable loss of algal coverage over that period. November's digital classification values for station 50 m at Site 2, and 50 m and 90 m at Site 3, also were lower than those obtained from the ground surveys (although only the first difference was significant). A review of the November aerial photographs after this comparison revealed inundation of the stations up to and including the 80 m station. This suggests that, at the lower stations, the high percent cover values from the digital classification could have been caused by floating eelgrass blades; upslope of these beds, the CIR signal from the benthic green macroalgae could have been diminished by absorption of light in these spectra via passage through the overlying water.

In any case, the large drop in percent cover of green macroalgae (which constituted the entire SAV signal at the 50 m and 90 m stations) between the late October and late November ground surveys illustrates the need for a practical method of frequently monitoring intertidal SAV coverage in PNW estuaries. As noted in the previous section, at each site a relatively sharp boundary was measured along the upper edge of the native eelgrass bed during early June, when there was insignificant coverage by green macroalgae. Results of various eelgrass distribution surveys conducted in the estuary indicate that this boundary does not undergo a major shift up-slope during the summer growing season. This suggests the strategy of accurately mapping the upper edge of the native eelgrass beds between late fall and early spring, and then masking out these areas in the GIS analysis. This would allow temporal changes in the exposed intertidal distributions of SAV, obtained from frequent surveys using small-format CIR aerial photography, to be interpreted with confidence as representing temporal changes in green macroalgae coverage outside the relatively fixed upper boundary of the native eelgrass beds.

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