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Image Application for Coastal Resource Planning

Elkhorn Slough Pilot Project

FINAL REPORT

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IMAGE APPLICATIONS FOR COASTAL RESOURCE PLANNING

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Introduction

Tracking land-use change, habitat loss, and vegetation type conversion is one of the most pressing environmental problems facing national and regional resource managers, property owners, and planners. Urban sprawl, un-permitted encroachment, land-use reclassifications, invasions by exotic species, and climate change have all contributed to our fragmented and rapidly changing landscapes. Because changes in habitat and vegetation cover can profoundly influence local productivity, biotic diversity, the distribution of water resources, and even climate, they also place at risk the ability to sustain our resource base.

Remote sensing has been widely touted as the most effective and efficient means of mapping and change detection for land-use, vegetation cover, and habitat types. The advantages of being able to capture a high altitude, digital view covering literally hundreds of square miles of the country side versus conventional land-based surveys are obvious. Airborne spectral scanners combined with widely available desk top image processing capabilities can be used to accurately distinguish between many types of land-use and cover, including different species of plants and crops, plants in different stages of health or development, as well as developed and unvegetated land. Because it is relatively easy to acquire these images rapidly, several times a year, and in digital form, the potential for automated land-use mapping and change detection is enormous.

Despite the advantages and vast potential of remote sensing, this technology is not without serious limitations. Image resolution, distortion, file format, geo-location, and cartographic problems constrain the level of detail and positional accuracy currently achievable. These limitations become especially critical when attempting to apply remote sensing protocols and techniques to regions and habitats very different from those in which they were developed.

For example, NOAA's C-CAP protocol, which makes use of relatively low resolution satellite based LandSat images and is being pushed as the model for national land-cover mapping, has been developed and used successfully on the east coast of the United States. However, the wide coastal plain, rounded topography, broad river systems and estuaries, and reliably wet summers characteristic of the east produce a very different spatial habitat distribution than is found on the west coast. In the east, significant habitat patterns and change occur on the scale of thousands of meters. In the west, high topographic relief in the coastal zone combined with seasonal as well as multi-year drought cycles, produce a much finer grained and variable landscape, both in time and space. Western coastal wetlands and riparian corridors, for instance, are frequently less than 100 meters across, and are significantly impacted by incremental loss of only a few meters a year. Western agriculture and development are also constrained by the topography, and frequently occur within narrow strips of habitats bounded by high relief. Thus, protocols which classify habitats based on 100x100 meter blocks may grossly misinterpret or entirely overlook important habitat types and land-use changes occurring along the west coast of the United States.

The purpose of this project has been to evaluate the utility of digital spectral imagery at two levels of resolution for large scale, accurate, auto-classification of land cover along the Central California Coast. Although remote sensing technology offers obvious advantages over on-the-ground mapping, there are substantial trade-offs that must be made between resolving power and costs. Higher resolution images can theoretically be used to identify smaller habitat patches, but they usually require more scenes to cover a given area and processing these images is computationally intense requiring much more computer time and memory. Lower resolution images can cover much larger areas, are less costly to store, process, and manipulate, but due to their larger pixel size can lack the resolving power of the denser images. This lack of resolving power can be critical in regions such as the Central California Coast where important habitat change often occurs on a scale of 10 meters.

Our approach has been to compare vegetation and habitat classification results from two aircraft-based spectral scenes covering the same study area but at different levels of resolution with a previously produced ground-truthed land cover base map of the area. Both of the spectral images used for this project were of significantly higher resolution than the satellite-based LandSat scenes used in the C-CAP program.

The lower reaches of the Elkhorn Slough watershed was chosen as an ideal study site because it encompasses a suite of important vegetation types and habitat loss processes characteristic of the central coast region. Dramatic habitat alterations have and are occurring within the Elkhorn Slough drainage area, including erosion and sedimentation, land use conversion, wetland loss, and incremental loss due to development and encroachment by agriculture. Additionally, much attention has already been focused on the Elkhorn Slough due to its status as a National Estuarine Education and Research Reserve, and as part of the Monterey Bay National Marine Sanctuary. These designations have resulted in a rich collection of prior spatial and temporal habitat data.

Methods

Image Acquisition

Two sets of multispectral images were acquired from NASA as 8-bit data files on exabyte tape. The high-altitude multispectral image was recorded on the Thematic Mapper Simulator aboard a NASA ER-2 aircraft at an altitude of 65,000 feet on February 24, 1994, and has an approximate resolution of 25 meters. The low-altitude image was recorded on the NS001 Multispectral Scanner aboard a C-130B aircraft at an altitude of 8,100 feet on March 25, 1994, and has an approximate resolution of 6.1 meters. The spectral bands (in micrometers) acquired by each aircraft are compared below.

Thematic Mapper Simulator	NS001 Multispectral Scanner
1: 0.42-0.45	--
2: 0.45-0.52	1: 0.458-0.519
3: 0.52-0.60	2: 0.529-0.603
4: 0.60-0.62	--
5: 0.63-0.69	3: 0.633-0.679
6: 0.69-0.75	--
7: 0.76-0.90	4: 0.767-0.910
8: 0.91-1.05	--
--	5: 1.13-1.35
9: 1.55-1.75	6: 1.57-1.71
10: 2.08-2.35	7: 2.10-2.38
11,12: 8.5-14	--
--	8: 10.9-12.3

A third image was used as a habitat base map for comparing the classification success of the two digital images. This base map was created from a mosaic of aerial photographs taken May 9, 1992. The habitats on these photographs were traced and ground-truthed, and subsequently digitized into the GIS program MapGrafix (v. 3.0 for Macintosh; ComGrafix, Inc.) (Fig. 1). The habitat types identified on this map are:

Cultivated land
Grassland
Developed land (high, medium and low density)
Dune vegetation
Oak woodland (high, medium and low density)
Non-native woodland
Mixed woodland
Riparian
Chaparral
Pickleweed marsh
High marsh
Standing water
Unvegetated
Unknown

Image Preparation

The multispectral images were provided by NASA in a flat file asci format on 8 mm tape. These files were then converted to a TIFF file format usable by DIMPLE (Digital Image Processing System v. 2.2.1 PPC, Process Software Solutions Pty. Ltd.). Once imported into DIMPLE, the high- and low-altitude images were put into separate multiband files and cropped to a square area slightly larger than the base map. The multiband files were then geo-referenced using DGPS ground control points (GCPs) obtained from a Trimble navigational system. Differential corrections were obtained from the Monterey Bay Aquarium Research Institute or a base station located near Elkhorn Slough. Six well-distributed GCPs were used to georectify each multiband file. Files were geo-referenced to Universal Transverse Mercator (UTM) Zone 10 coordinates (in meters). Once georectified, the images were further cropped to the outline of the final study area, defined as the outline of the base map with the northern extent limited to that of the low-altitude image.

Linear contrast stretching was used in an attempt to remove any atmospheric haze present in the images. However, this method appeared to remove too much data from the images (based on the poor quality of subsequent classifications) and was not further utilized.

Image Classification

DIMPLE offers two main options for image classification: supervised and unsupervised classification. Supervised classification is preferred over unsupervised classification if training sets can be acquired (i.e., if the area can be ground- or photo-truthed) (Rees, 1990). Therefore, supervised classifications were performed on these images. All spectral bands were included in the classifications.

The resulting habitat classes that were compared between classified images and the base map were as follows:

- Cultivated land
- Grassland
- Developed land (high density)
- Dune vegetation
- Total woodland, includes:
  - all oak woodland
  - eucalyptus
  - non-native woodland
  - mixed woodland
  - riparian
  - chaparral
- Total vegetated marsh, includes:
  - pickleweed marsh
  - high marsh
- Total unvegetated marsh/beach, includes:
  - mudflat
  - water
  - unvegetated land
  - sand
- Unclassified areas
- Unknown areas

Reliable classification depends partially on the quality and homogeneity of the training sets used. Because the medium- and low-density developed land classes contain more than one habitat type (buildings plus surrounding vegetation), reliable training sets could not be made for these classes. Therefore, they were omitted from the digital classifications.

Classified Image Field Verification

The resultant classified images from both flights were further verified using the FieldNotes application from Penmetrics. Both images were loaded into the program and geo-referenced on a laptop computer with a DGPS interface. Using this setup we were able to visually navigate in the field to randomly preselected habitat patches of each land cover type for each image. This approach was used to complement as well as verify the base map image.

Results

Square area (in hectares) and percent of total area of each habitat class is presented in Table 1 for the classified images (Figs. 2 and 3) and the base map (Fig. 1). Pie charts illustrating the percent frequency of broad land cover categories for the base map and multispectral images are shown in Figures 4, 5, and 6.

Figure 1. Manual Classification Hand-digitized Aerial Photo

- oak woodland-high density
- oak woodland-medium
- oak woodland-low density
- cultivated land
- pickleweed
- grassland
- non-native woodland
- mixed woodland
- riparian
- chaparral
- dunes
- high marsh
- standing water
- developed land- high density
- developed land-medium density
- developed land- low density
- unvegetated
- unknown

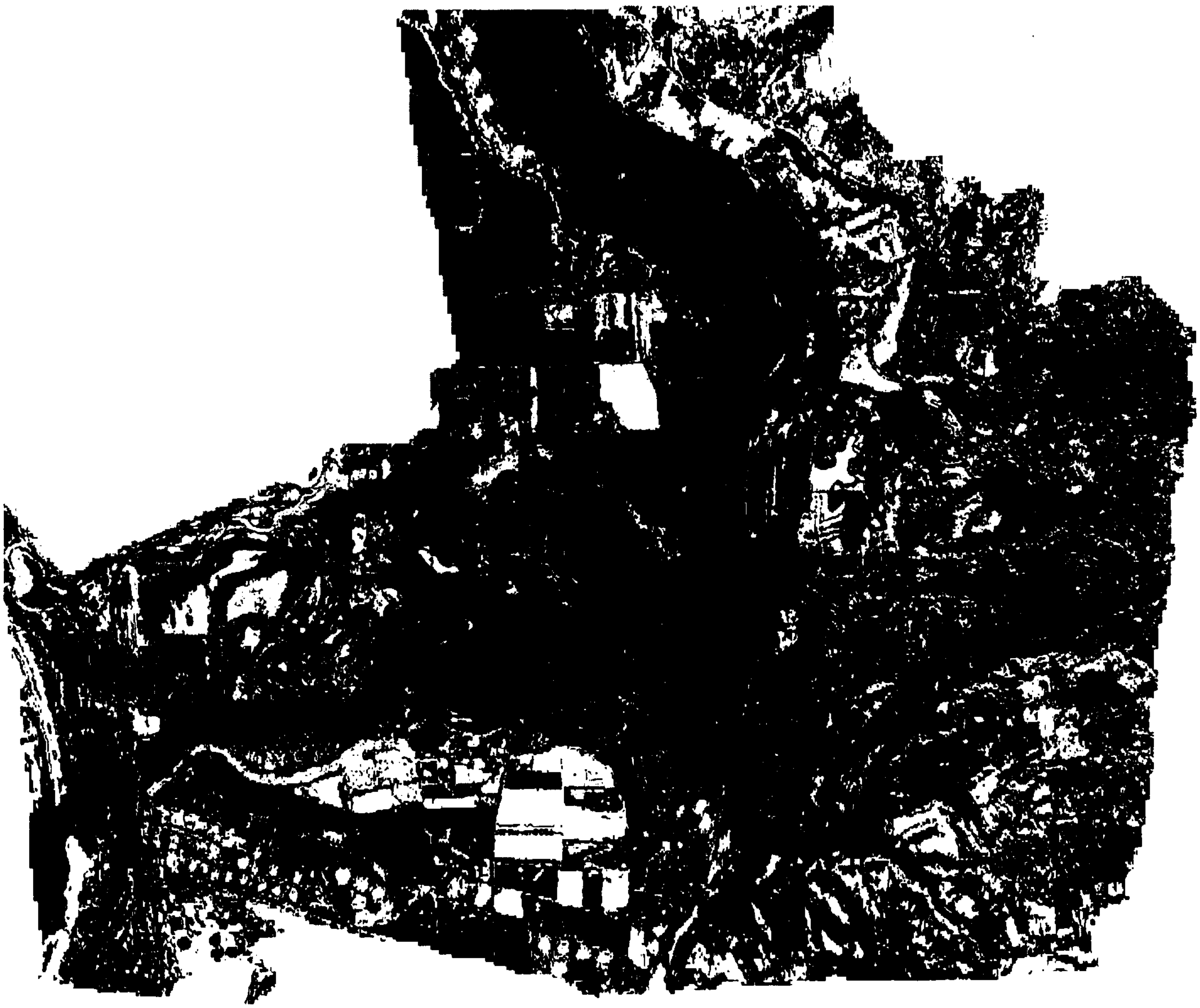
Date: May 9, 1992
Resolution: 2 meters

Figure 2. Supervised Classification High-altitude Digital Image

□ unclassified	■ developed	■ oak
■ cultivated 1	■ dune	■ pickleweed
■ cultivated 2	□ eucalyptus	□ sand
■ cultivated 3	■ grassland	■ water
■ cultivated 4	■ mudflat	

Sensor: Thematic Mapper Simulator
Date: February 24, 1994
Altitude: 19817 meters
Resolution: 25 meters

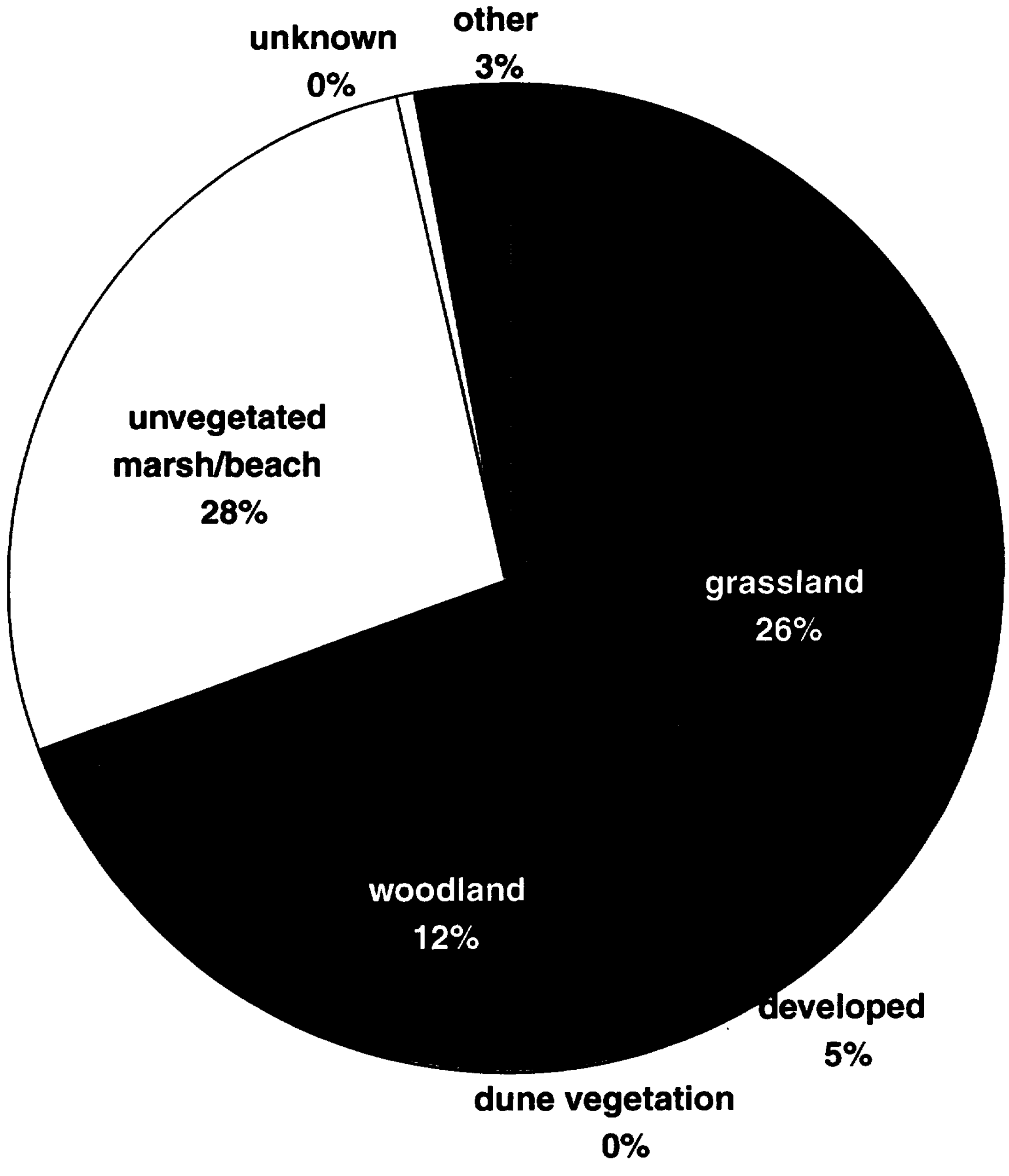
Figure 3. Supervised Classification Low-altitude Digital Image



□ unclassified	■ developed	■ oak
■ cultivated 1	■ dune	■ pickleweed
■ cultivated 2	□ eucalyptus	□ sand
■ cultivated 3	■ grassland	■ water
■ cultivated 4	■ mudflat	

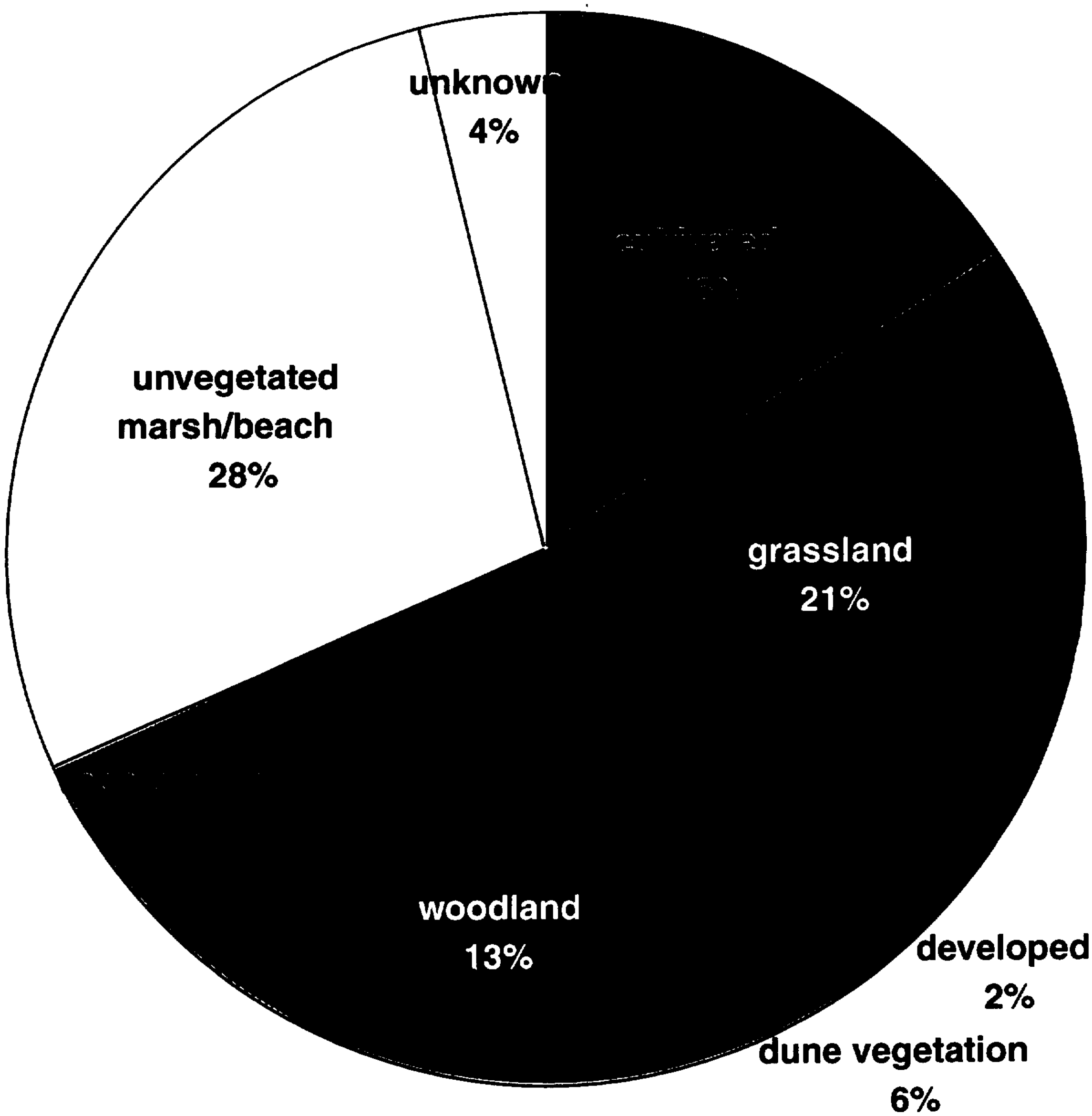
Sensor: NS001 Multispectral Scanner
Date: March 25, 1994
Altitude: 2468 meters
Resolution: 6.1 meters

Figure 4. Manual Classification Hand-digitized Aerial Photo



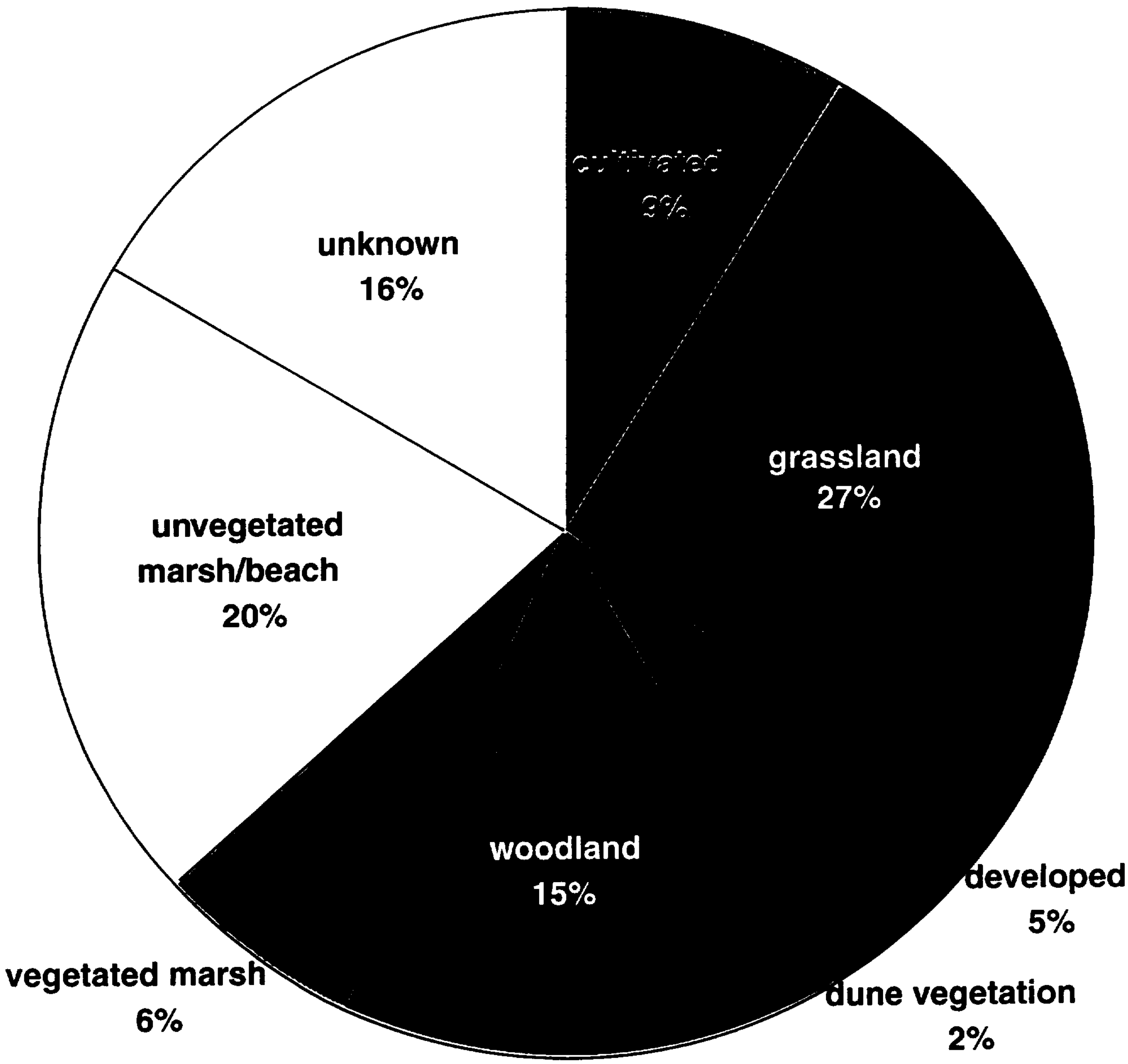
Date: May 9, 1992
Resolution: 2 meters

Figure 5. Supervised Classification High-altitude Digital Image



Sensor: Thematic Mapper Simulator
Date: February 24, 1994
Altitude: 19817 meters
Resolution: 25 meters

Figure 6. Supervised Classification Low-altitude Digital Image



Sensor: NS001 Multispectral Scanner
Date: March 25, 1994
Altitude: 2468 meters
Resolution: 6.1 meters

Percent differences were calculated between the classified images and the base image, and are also presented in Table 1. Classification ambiguities and the accuracy of aerial estimates are summarized in Table 2, and are discussed below.

Cultivated Land

Both high-and low-altitude classifications faired marginally for assessments of cultivated land. However, they were more or less visually correct. A large tract of land was clearly omitted on the low-altitude image that would probably account for the -40% difference from the base map. Other differences are likely due to the high variation in soil moisture and plant cover with season, as well as the different types of crops grown in the area, more than due to the inadequacies of the classification. The high-altitude classification of cultivated land was aerially more accurate, but was sometimes interpreted as grassland or dune vegetation. Better training sets are needed for cultivated land, to include crop-specific and condition-specific ground-truthing.

Grassland

The low-altitude image was much better at classifying grassland on an basis than was the high-altitude image. The high-altitude image classified some grassland as cultivated land, which could be responsible for some of these differences. Both classifications appeared generally visually correct.

Dune Vegetation

The high-altitude classification included the known dune areas but also included some cultivated land. The low-altitude dune classification appears to be correct, and the error in the estimates is likely due to the omission of small pockets of dune on the base map that greatly affect the small total area of dune vegetation.

Developed Land

The high-altitude classification located most developed areas, but interpreted some sand or breakers as developed. The low-altitude classification picked up more of the developed land, but also included some unvegetated areas and a small swath of cultivated land. In both classifications, the tops of large storage tanks were often unclassified, which probably contributes to the low measurements.

Total Woodland

The high-altitude classification was aerially and visually correct for total woodland habitats, marsh and beach areas. The low-altitude classification generally placed the woodland correctly, but also placed some of it in the pickleweed marsh and cultivated land.

Vegetated Marsh, Unvegetated Habitats

The high-altitude classification was aerially and visually correct for vegetated and unvegetated areas. The low estimates of unvegetated and vegetated marsh in low-altitude classification are likely due to one large unvegetated area and some vegetated marsh areas being classified as developed land/oak woodland/unclassified. The pickleweed high-altitude classification seems to include the high marsh areas as well, but the low-altitude classification does not. Again, better training sets can probably tease apart these inconsistencies. Also, some of the pickleweed areas on the base map are known to be sparsely vegetated and would likely appear in the classification as mudflat.

Other Habitat Classes

There were several digital classes that were not compared with the base map or not lumped into a final category. Oaks generally appeared where they should, and eucalyptus appeared among the oak woodlands and in at least one known monoculture stand. In general, better training sets are needed to delineate tree classes. Mudflat and water were generally visually accurate, but differed between altitudes due to the number of tidal creeks classified (more in the low-altitude classification) and the large tract of unvegetated marsh that appeared as mudflat in the high-altitude classification but as developed/unclassified in the low-altitude. Sand varied some between altitudes (about 10%), probably due to a small tract of cultivated land that was labeled sand in the high-altitude classification.

Approximately 4% of the high-altitude image remained unclassified, whereas approximately 16% of the low-altitude image remained unclassified. Some of these areas are the same on both classifications, indicating that some habitat or variation of a habitat was not accounted for in the training sets. Large areas of grassland were unclassified in the high-altitude classification, as were large areas of unvegetated marsh and cultivated land in the low-altitude classification.

Conclusions

The supervised classification of both the high and low images generally worked well, with each having its own strengths and weaknesses. Deviations from the base map values were typically due to misclassification of a few large areas. A summary of cover estimate accuracy and classification ambiguities are given in Table 2. The pros and cons of each digital method are summarized in Table 3. Better ground-truthing of training sets will likely improve classification, especially of low-altitude image.

When ever possible, ground-truthing should take place as close as possible to the flight time. This simultaneity is especially important for cultivated lands which can change from vegetated to unvegetated or plastic covered in < 24 hours. Wetlands and grasslands can also change dramatically over short time periods, such as at the beginning of the rainy season.

Perhaps the most important result is the ability of the higher resolution spectral image (Fig. 3) to illustrate the fine grain nature of habitat and vegetation diversity in the Elkhorn Slough watershed. Intricate fine scale patterning of narrow corridors and sinuous vegetation zones clearly seen in the low altitude image (Fig. 3) are much less obvious in the lower resolution, high altitude image (Fig. 2). This fine grain patterning represents the biotic diversity associated with the numerous ecotomes and buffer zones characteristic of high topographic relief habitats with complex drainage patterns.

Indeed, it is this divers surface morphology that is responsible for the existence and maintenance of the high biotic diversity within the Elkhorn Slough watershed. (The Elkhorn Slough consistently ranks as first or second in the annual nation-wide Audubon New Years Bird Count). As a result, remote sensing survey images that do not resolve this fine grain habitat diversity will not be able to detect fine scale but important land cover change and habitat loss. Consequently, land use policy and planning decisions based on low resolution images may not match the true nature of the landscape and will therefore overlook many of the most important processes responsible for land cover change and habitat loss.

Products of this NASA study are already being used in the following projects:

Estuarine wetland and watershed inventory using NOAA Coastwatch change analysis project (C-CAP) protocol in California's Central Coast. NOAA and California Coastal Commission joint grant;
Site characterization for the Monterey National Marine Sanctuary; Tideland restoration in the Elkhorn Slough National Estuarine Research Reserve; Rates of tidal scour, erosion and loss of salt marsh in the Elkhorn Slough, all these are NOAA Sanctuaries and Reserves Program grants;
Fort Ord Watershed Demonstration project, Department of Defense grant;
GeoSar: A radar based terrain mapping project. ARPA, California Department of Conservation, JPL, Calgis project.

Results of NASA study have been presented to the following organizations:

Elkhorn Slough Foundation Annual Meeting
Watsonville Rotary Club
Elkhorn Slough Docent Annual meeting
Point Lobos State Reserve Docent Seminar Series

Bibliography

Rees, W.G. 1990. Physical Principles of Remote Sensing. Cambridge: Cambridge University Press.

Table 1. Estimates of landcover (hectares and percent cover) in the Elkhorn Slough study area from the basemap, high altitude, and low altitude images.

habitat class	base map ("B")	% of total B	high-altitude image ("HA")	% of total HA	% diff. B%-HA%	low-altitude image ("LA")	% of total LA	% diff. B%-LA%	% diff. HA%-LA%
cultivated	422	15%	455	16%	-1%	252	9%	6%	7%
grassland	734	26%	610	21%	4%	759	27%	-1%	-5%
developed (high dens.)	150	5%	51	2%	3%	131	5%	1%	-3%
dune vegetation	12	0%	178	6%	-6%	49	2%	-1%	4%
				0%	0%			0%	0%
oak woodland (total)	254	9%	324	11%	-2%	367	13%	-4%	-2%
eucalyptus/non-native wdlnd.	24	1%	41	1%	-1%	74	3%	-2%	-1%
mixed woodland	53	2%	--	--	--	--	--	--	--
riparian	13	0%	--	--	--	--	--	--	--
chaparral	14	0%	--	--	--	--	--	--	--
total woodland	358	12%	365	13%	0%	441	15%	-3%	-3%
								0%	0%
pickleweed	268	9%	295	10%	-1%	182	6%	3%	4%
high marsh	42	1%	--	--	--	--	--	--	--
total vegetated marsh	310	11%	295	10%	1%	182	6%	4%	4%
								0%	0%
mudflat	--	--	320	11%	--	171	6%	--	5%
water	298	10%	454	16%	-5%	391	14%	-3%	2%
unvegetated	478	17%	--	--	--	--	--	--	--
sand	--	--	19	1%	--	21	1%	--	0%
total unveg. marsh/beach	776	27%	793	28%	-1%	582	20%	7%	7%
								0%	0%
unclassified/unknown†	14	0%	114	4%	-4%	465	16%	-16%	-12%
areas not used	86	3%	--	--	--	--	--	--	--
total area††	2861		2861			2861			

† calculated for HA and LA as (total area - total classified area)

††estimated for HA and LA based on base map

Table 2. Summary of Accuracy and Classification Ambiguities

	Accuracy of estimate relative to base map*	Misclassified as other habitats**
High-altitude classification		
Cultivated land	fair	grassland, dune vegetation
Grassland	fair	cultivated land
Developed land	poor	unclassified
Dune vegetation	poor	none noted
Woodland	good	none noted
Vegetated Marsh	good	none noted
Unvegetated Marsh/ Dune/Water	good	developed land
Low-altitude classification		
Cultivated land	poor	unclassified, probably grassland
Grassland	good	probably cultivated
Developed land	fair	unvegetated, cultivated, unclassified
Dune vegetation	poor	none noted
Woodland	fair	vegetated marsh, cultivated
Vegetated Marsh	poor	oak woodland
Unvegetated Marsh/ Dune/Water	poor	unclassified, developed

*Good = <5% difference from base map
Fair = 5%-25% difference from base map
Poor = >25% difference from base map

Table 3. Pros and Cons of Using High-altitude and Low-altitude Digital Imagery for Habitat Classification

	Pros	Cons
High-altitude image	Requires fewer training sets	Less resolution of small objects or habitat patches
	Requires less computer memory	Difficult to identify ground control points
Low-altitude image	Better resolution of small objects or habitat patches	Requires more training sets or classes to resolve habitat types
	Easy to identify ground control points	Requires more computer memory
Both methods	Once good training sets (including seasonal variation) are established, you can apply them to any digital image, provided an irradiance reference point has been established marsh habitats	Cannot estimate presence of understory features May be difficult to identify riparian, chaparral and high