Application of Digital Imaging Technologies for Monitoring and Managing MSCP/NCCP Reserves

Douglas Stow, John O'Leary, Lloyd Coulter, Allen Hope, Janet Franklin,
Aaron Johnson, Pauline Longmire, Scott Redlin,
Alys Wall, and Elizabeth Witztum
Department of Geography, San Diego State University

Edward Almanza
Habitat Technologies Implementation Program

Subcontract to City of San Diego
Component of a California Department of Fish and Game
Natural Community Conservation Planning Program Research Grant

Executive Summary

For the Multiple Species Conservation Program (MSCP) of southwestern San Diego County, habitat monitoring, along with more intensive monitoring of populations of rare, threatened, and endangered plant and animal species and wildlife corridors, was initially prescribed in Ogden (1996). The primary approach to monitoring habitat quality, as prescribed in the report prepared for the City of San Diego (Ogden,1996), was long-term sampling of vegetation species and land cover composition at 29 sites distributed throughout the MSCP area. For each site, the report recommends three sample plots be established along a potential disturbance gradient, from an urban edge inward toward relatively pristine habitat.

The objectives of our study were to:

1. develop a better understanding of the habitat monitoring goals envisaged by the designers and implementers of the MSCP subregional plan, with a specific emphasis on the scope and definition of the construct commonly referred to as "habitat quality;"
2. assess and test the species cover sampling methodology prescribed in the Ogden (1996) report;
3. explore the potential of a specific remote sensing system for providing reserve-level information on land-cover changes that may be associated with habitat quality changes; and
4. recommend a prototypical system that exploits developments in geo-spatial technologies to monitor MSCP habitats in an effective manner.

The primary study area was Mission Trails Regional Park, with the Crestridge Habitat Reserve (CHR) established as a secondary study area.

Guidance

The MSCP Technology Advisory Committee (TAC) was established a few years prior to the start of this project and provided the impetus and guidance to conduct this study (Almanza, 1998; Stow et al., 1998). At the beginning of the project, the TAC commissioned a working group, composed of personnel from the Conservation Biology Institute, California Department of Fish & Game, the Southwest Ecoregion Monitoring Strategies Working Group, USGS Biological Research Division, SDSU Department of Biology, and members of our project team. This group identified several alternative methods for defining and measuring "habitat quality." Their investigations led to the recognition that current MSCP Monitoring Guidelines, while specific in their prescription of data collection procedures, do not clearly define the application of the data toward habitat quality assessment, nor the specific kinds of analyses to be performed on the data. In short, the nexus between data collection and monitoring for habitat management is not provided by the MSCP Guidelines. Given this situation, our team adopted an investigative approach that presents the capabilities of emerging technologies to potential users and allows them to respond according to the relative usefulness of these technologies in achieving the presumed goals of habitat monitoring. A working definition of "habitat quality" was derived in response to these conditions.

Testing MSCP Cover Sampling Scheme

An important element of the study was the testing of the habitat monitoring scheme for sampling species cover along a potential disturbance gradient, as proposed in the Ogden (1996) report. In that report, Ogden recommended stratification of "monitoring plots" into "sampling sites" along a presumed or possible future disturbance gradient extending inward from an urban edge. Stratification was proposed to include: (1) 'edge' sites (< 60 m from the preserve boundary), 'interior edge' sites (60- 180 m from a preserve boundary), and (3) 'core' sites (> 180 m from a preserve boundary). Within each "site" 40 permanent 4 x 5 m quadrats (i.e., grid of sampling point locations) were to be located permanently and sampled for plant species cover, density, and frequency. Ogden's proposed sampling design was modified in the present study to more efficiently sample plant, litter, and soil cover within each of the three stratified "sites." Locations of the three 50 m x 100 m sampling sites at MTRP and CHR were based on several field reconnaissance efforts and interpretation of remotely sensed imagery, with the goal of establishing plots that represented 'urban edge,' transition,' and 'core' (i.e., more pristine coastal sage scrub habitat types. Field sampling commenced at MTRP in early April, 2000 and concluded for the CHR in mid-May, 2000. A team of three to five SDSU faculty and students conducted the sampling, which included surveying of plot boundaries with a global positioning system. A detailed digital database containing species and land cover data was established for both study sites and has been provided to the City of San Diego.

Analysis of cover data from MTRP shows that there are not distinct differences in the cover proportions by plant growth between the three plots and if anything, the 'core' plot may have been subjected to greater disturbance than the 'transition' plot. Shrub/subshrub cover was lowest for the 'core' plot than the others, and non-native herbaceous cover was greater for the 'core' than the 'transition' plot. This result, combined with the difficulty encountered in locating suitable coastal sage scrub habitats that satisfied the disturbance gradient criteria and were adjacent to urban edge, suggests that the Ogden (1996) strategy for habitat monitoring may not be warranted and/or viable. Two other factors that have led us to this conclusion are: (1) the time cost for completing the entire sampling, surveying, and data base coding is estimated at 150 to 175 hours per sampling site, and (2) sampling plots are not likely to be representative of the rest of the reserve in which they are located and as a network of sampling sites, not representative of the entire MSCP subregion. Expanding on point (2), the 0.015 km^2 areal extent of the three sampling plots is but 0.127% of the coastal sage scrub habitat of MTRP and the 0.435 km^2 extent of all 29 proposed sampling sites combined is but 0.018% of the MSCP subregion. Other sampling schemes such as multiple belt transects running perpendicular from the urban edge may be more effective. But two questions remain: (1) Is information on changes in species or growth form and ground cover important for monitoring changes in habitat quality? and (2) Is ground-level sampling required to capture this information?

Image-based Monitoring Approaches

Analyses of very-high resolution digital imaging technologies for habitat monitoring focussed on the utility of the Airborne Data Acquisition and Registration (ADAR) System 5500 (Stow et al., 1997; Stow et al., 1998). SDSU owns and operates an ADAR system, which for this project, was utilized to capture digital multispectral camera images in visible and near infrared wavelengths from fixed-wing and helicopter platforms. Image data with 1 m spatial resolution were acquired from fixed-wing aircraft in May, 1999 and 2000 for the MTRP and CHR study areas. Experimental image data were captured from a helicopter in May/June 2001 to achieve sub-meter spatial resolution imagery. Building on results from a companion NASA-funded study, radiometric and geometric pre-processing routines were applied to several of these ADAR data sets to generate image mosaics for an extensive portion of MTRP (1998,1999 and 2000) and the entirety of CHR (1999). The CHR mosaic was provided to the Conservation Biology Institute, who in conjunction with the County of San Diego, have generated a baseline vegetation community type map for the reserve.

Based on image data sets for MTRP, three types of image-derived products have been assessed: (1) change detection images for identifying "hot spots" of land cover change, (2) maps of proportion of bare ground cover and shrub/subshrub cover, and (3) maps of trails, predominantly associated with recreational activity. The most effective and efficiently created change detection images were generated by incorporating multitemporal difference images from red and near infrared wavebands and the normalized difference vegetation index into an unsupervised image classification routine. Land cover changes associated with fires, landscaping, shrub extraction, vegetation removal from recreational disturbances, and exotic plant invasions were detected, some on order of 1 – 2 meters in extent. False change artifacts were commonly associated with misregistration between multitemporal ADAR images, but in most cases, are easy to visually distinguish from actual land cover changes. Up to 70 % of the variation in bare ground cover and 45% shrub/subshrub cover can be predicted using simple image-derived indices. This finding is based on comparison of ADAR-derived metrics with ground-level cover data sampled from 3 m x 3 m plots within the MTRP study area. These results suggest that at a minimum, reliable maps of cover fraction interval classes (e.g., 0-5%, 6-10%…) can be generated over time, to monitor changes in growth form cover, but not changes in (most) species composition. After applying simple digital image enhancement routines, a majority of the length of recreation trails having widths that are at least 50% of the spatial resolution of the imagery (e.g., $\leq$ 0.5 m width for 1 m resolution imagery) can be visually detected and mapped.

Prototype Monitoring System

Based on our findings to date, we propose a prototypical monitoring system for the MSCP, with the caveats that our research into the role of geo-spatial technologies will be continuing for at least the next few years and that there are many uncertainties pertaining to the future of public and private sector developments of these technologies. For long-term monitoring of individual habitat reserves we recommend a top-down monitoring strategy based on very-high resolution, digital, multitemporal CIR image data, from a direct digital imaging system such as ADAR. A temporal sampling interval of three to five years would likely be warranted. An optimal strategy for monitoring the entire MSCP subregion (i.e., system of reserves) is more difficult to recommend, particularly because it is unclear whether or not there will be management activities and therefore, the information needs pertaining to habitat conditions at this level of the NCCP hierarchy are unclear. Requirements for ground sampling and reconnaissance will likely be reduced by adoption of geo-spatial technologies, but will remain an important component of the prototype habitat monitoring system. However, changes in the sampling schemes for long-term monitoring plots and/or transects are warranted. Low-level imaging from ADAR-like sensors mounted on helicopters, provide a very efficient means for quantifying cover fractions of growth form types and some shrub and subshrub species within randomly or systematically located frames across a reserve.

Introduction and Project Objectives

An important determinant of the long-term success of the Natural Community Conservation Planning (NCCP) program will be effective monitoring of habitats that support rare, threatened, and endangered species endemic to southern California. With the exception of potentially improving scientific understanding of southern California ecosystems, monitoring will only be effective if it supports management actions for maintaining or improving the quality of habitat. Managers of habitat reserves and systems of reserves are likely to: (1) desire spatially comprehensive monitoring information about the quality and condition of habitat within the lands that they manage, and (2) be substantially limited in personnel and financial resources available to fulfill monitoring and management tasks. Remote sensing and related geo-spatial technologies such as geographic information systems (GIS), global positioning systems (GPS), and internet mapping have the potential to enable comprehensive and affordable habitat monitoring by focussing ground-based observations and actions.

For the Multiple Species Conservation Program (MSCP) of southwestern San Diego County, habitat monitoring, along with more intensive monitoring of populations of rare, threatened, and endangered plant and animal species and wildlife corridors , was initially prescribed in Ogden (1996). The primary approach to monitoring habitat quality, as prescribed in the report prepared for the City of San Diego (Ogden,1996), was long-term sampling of vegetation species and land cover composition at 29 sites distributed throughout the MSCP area. For each site, the report recommends three sample plots be established along a potential disturbance gradient, from an urban edge inward toward relatively pristine habitat.

The objectives of our study were to:

1. develop a better understanding of the habitat monitoring goals envisaged by the designers and implementers of the MSCP subregional plan, with a specific emphasis on the scope and definition of the construct commonly referred to as "habitat quality,"
2. assess and test the species cover sampling methodology prescribed in the Ogden (1996) report;
3. explore the potential of a specific remote sensing system for providing reserve-level information on land-cover changes that may be associated with habitat quality changes; and
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The primary study area was Mission Trails Regional Park, with the Crestridge Habitat Reserve (CHR) established as a secondary study area.

Monitoring Strategies

Development of technologies to serve MSCP monitoring is inextricably related to the goals and overarching design of an MSCP monitoring strategy. To date, no such monitoring strategy has been established. Development of a monitoring strategy necessitates a clear statement of monitoring objectives, including definitions for such constructs as "habitat quality." Steps toward formulating a monitoring strategy might include the following:

(1) Identify the features and variables that characterize the landscape (i.e., develop a vocabulary of variables and organize them in a meaningful hierarchy).

(2) Identify which of those features/variables can be monitored cost-effectively using either in situ or remote sensing methods.

(3) Develop supporting models that tell managers about important relationships between these variables and "habitat quality" as defined by a variety of management objectives.

The sequential steps listed above represent a bottom-up approach to developing a monitoring strategy. Theoretically, these same steps could be performed in reverse order to reflect a top-down approach. In the latter approach, theory precedes the identification of variables and dictates which variables will be monitored, while the bottom-up sequence begins by identifying those changes that are readily evident in the landscape.

The question of whether a top-down or bottom-up approach is followed is central to defining how geo-spatial monitoring tools are to be applied to the MSCP and NCCP programs. A great deal of effort has been expended in recent years by working groups to derive a top-down strategy. The NCCP Monitoring Strategy Work Group established by Peter Stine (USGS/BRD) in 1997, which later morphed into the Southwest Ecoregion Monitoring Strategy Work Group (coordinated by Cameron Barrows of CNLM), did not successfully yield a monitoring strategy that met consensus (for any of the three monitoring scales). Similarly, efforts to implement a bottom-up approach, either by convening a team of experts in the field to develop a catalogue of habitat quality variables, or by conducting a systematic investigation to identify the range of possible actions available to preserve managers (and thus, their information needs), have also been unsuccessful.

The reasons for these failures are several-fold. A principal difficulty is the lack of organization and consensus within the NCCP/MSCP community. Because of the multiple agencies, jurisdictions and interests involved in the NCCP/MSCP, and the absence of leadership among the participants, it is difficult to garner support for coordinated efforts to develop monitoring methodologies. This certainly seems to be the case for efforts to define how broad NCCP/MSCP policies will be implemented at the local levels. But the task of defining appropriate monitoring strategies is compounded by the need to monitor the NCCP preserve system at all three scales – individual preserve, subregion and region. The absence of active monitoring at the subregional and regional levels is also a major obstacle to defining the information needs, and therefore the technologies, that might support monitoring at those levels.

Efforts to develop monitoring strategies using a top-down approach are additionally hampered by gaps in relevant data and in the science necessary to model ecosystem processes. While several different high-order models of ecosystem interactions have been proffered by the strategy work groups, it has not been demonstrated how use of these models will identify feasible methods for measuring variables that will in turn lead to specific management decisions.

An Iterative Approach

In the absence of an established monitoring strategy, our team adopted an iterative approach to the development of monitoring technologies, whereby the capabilities of emerging technologies are presented to potential users. The users are asked to respond according to the relative usefulness of those technologies in achieving the presumed goals of habitat monitoring. This interactive process enables future users to shape the use and application of technologies, and to forge the beginnings of a monitoring strategy based on practical capabilities.

On October 13, 2000, preliminary findings of this research were presented to the TAC (Technical Advisory Committee) of the NCCP Technologies Implementation Program. The meeting was also attended by the Southwest Ecoregion Monitoring Work Group. Since its inception in 1996, presentation to the TAC has been the principal means for researchers of the Technologies Implementation Program to solicit review and comment from potential users within the NCCP/MSCP community. This joint meeting was an effective way of conveying recent results to several potential user groups, including preserve managers, researcher ecologists, regulators, and staff persons who already manage geo-spatial data for their own jurisdictions. The Southwest Ecoregion Monitoring Work Group represented an additional set of researchers interested in developing monitoring strategies.

Among the actions taken at the meeting was the decision to initiate a small breakout group tasked with developing a long-term, programmatic strategy for further development of geo-spatial technologies for monitoring. The breakout group was commissioned to develop a framework for a program that employs remote sensing and other geo-spatial technologies to monitor MSCP preserves. The group would define the specific categories and quality of data obtained using remote sensing and identify precise methods for data collection. The framework would describe the potential utility of remote sensing data in meeting the MSCP monitoring and management goals. The group's charge is to return to the TAC with recommendations for a monitoring strategy that exploits the capabilities of geo-spatial technologies, to achieve (at least partially) the monitoring objectives of the MSCP. These recommendations will be based on methods that have been pilot-tested at MSCP sites and found to be technically sound and feasible. In addition, the breakout group will make further recommendations to facilitate the appropriate use of geo-spatial technologies for MSCP and NCCP preserves. These recommendations may include additional research tasks, development of specific technical capabilities, methods of coordination, cost-sharing among users, etc.

The breakout group (comprised of members of the technical research team and the Conservation Biology Institute) has met several times to discuss monitoring methods and protocols[1]. To date, these discussions have led to the tentative recommendation that remote sensing be used to monitor percent changes in (*a*) vegetative cover and (*b*) native versus non-native plant species. These two parameters were targeted because they are believed to be useful indicators of relative disturbance and general habitat condition, and they are known to be detectable and measurable using remote sensing systems and methodologies tested as part of this research.

Testing MSCP Cover Sampling Scheme

An important element of the study was exploration of a habitat monitoring scheme for sampling species cover along a potential disturbance gradient. The sampling scheme that we tested differed in approach from that proposed by Ogden Environmental and Energy Services (1996) who recommended stratification of "monitoring plots" into "sampling sites" along a presumed or possible future disturbance gradient extending inward from an urban edge. Stratification was proposed to include: (1) 'edge' sites (< 60 m from the preserve boundary), 'interior edge' sites (60- 180 m from a preserve boundary), and (3) 'core' sites (> 180 m from a preserve boundary). Within each "site" 40 permanent 4 m x 5 m quadrats (i.e., grid of sampling point locations) were to be located permanently and sampled for plant species cover, density, and frequency.

We modified Ogden's proposed sampling design to sample more efficiently plant, litter, and soil cover within each of the three stratified "sites." Locations of the three 50 m x 100 m sampling sites at MTRP and CHR were based on several field reconnaissance efforts and interpretation of remotely sensed imagery, with the goal of establishing plots that represented 'urban edge,' transition,' and 'core' (i.e., more pristine coastal sage scrub habitat types. Within each plot, canopy cover of individuals of all plant species, as well as various types of ground cover (i.e., litter, soil, and rock cover) were measured along 16 50-m line transects placed parallel to each other in a stratified-random manner from the plot's 100-m long baseline. Plot baselines were placed parallel to contour on either the top or base of a plot, depending on approach to the plot. Sixteen line transects for each plot were placed randomly using a random number table within each of 16 intervals along the 100 m long baseline (e.g., 0-7 m, 7-14 m, 17-24 m, etc.). The 16 intervals were chosen to ensure adequate spatial representation/generalization of the entire sampling plot.

Data were collected using a point-intercept method (Bonham, 1989) and recorded onto data sheets as illustrated in Appendix A. Fifty points were sampled along each of the 16 line transects beginning at the 0.5 m point and continuing at 1.0 m intervals to the 49.5 m point of each of the 16 transects. Using the measuring tape as a guide, a rod measuring 1 m in length and 3/16" in diameter was positioned vertically over each point and lowered to the ground. All vascular plant species and ground-cover types intercepted by the vertical line were recorded. If more than one species was intercepted, the top-most one

[1]Development of recommendations to refine MSCP Biological Monitoring Protocols is a task commissioned to CBI through an NCCP Urgent Implementation Grant.

was noted as such. Doing so later allowed computation of two types of ground cover. The first is termed 'top down' cover and represents plant and ground cover viewed from an aerial vantage. The second is termed 'total ground cover' and, unlike 'top-down' cover, may exceed 100% due to two or more species overtopping individual sample points.

Field sampling commenced at MTRP in early April, 2001 and concluded for the CHR in mid-May, 2001. A team of three to five SDSU faculty and students conducted the sampling, which included surveying of plot boundaries with a global positioning system.

A detailed digital database containing species and land cover data was established for both study sites and has been provided to the City of San Diego. Plant nomenclature throughout this report follows Hickman (1993). Table 1 presents selected physical characteristics of plots sampled at the MTRP site.

Table 1. Selected physical characteristics of plots sampled at the MTRP and Crestridge sites. Individual plots may exhibit more than one aspect and/or slope angle due to their large sizes. Geographic coordinates are of each plot's four corners.

Site/ Plot	Geographic Coordinates		Plot Characteristics: Elevation	Substrate	Aspect(s) degrees
MTRP					
1	32° 48’ 52.33” N 32° 48’ 52.85” N 32° 48’ 50.29” N 32° 48’ 49.86” N	117° 02’ 34.02” W 117° 02’ 32.25” W 117° 02’ 29.93” W 117° 02’ 31.58” W	192 m	granite	240°, 258°
2	32° 48’ 53.24” N 32° 48’ 52.98” N 32° 48’ 49.91” N 32° 48’ 50.15” N	117° 02’ 29.68” W 117° 02’ 27.81” W 117° 02’ 27.42” W 117° 02’ 29.11” W	216 m	granite	305°, 300°
3	32° 48’ 49.17” N 32° 48’ 49.53” N 32° 48’ 46.43” N 32° 48’ 46.02” N	117° 02’ 24.75” W 117° 02’ 22.74” W 117° 02’ 21.64” W 117° 02’ 23.50” W	238 m	granite	222°, 258°
Crestridge					
1	32° 50’ 30.24” N 32° 50’ 31.31” N 32° 50’ 28.72” N 32° 50’ 27.74” N	116° 52’ 22.00” W 116° 52’ 20.60” W 116° 52’ 18.11” W 116° 52’ 19.55” W	250 m	gabbro	230°, 255°
2	32° 50’ 32.31” N 32° 50’ 32.85” N 32° 50’ 29.66” N 32° 50’ 29.42” N	116° 52’ 19.36” W 116° 52’ 17.55” W 116° 52’ 15.95” W 116° 52’ 17.76” W	305 m	gabbro	198°, 243°, 270°
3	32° 50’ 34.88” N 32° 50’ 36.36” N 32° 50’ 35.25” N 32° 50’ 34.28” N	116° 52’ 14.29” W 116° 52’ 13.74” W 116° 52’ 10.25” W 116° 52’ 11.60” W	372 m	gabbro	225°

Appendix B contains coverage values of individual species arranged in rank order within growth forms for all plots. Analysis of cover data from MTRP (Figure 1a-c) shows that there are not distinct differences in the cover proportions by plant growth forms, litter, and bare ground between plot 1 (the ‘edge site’) and plot 2 (the ‘interior edge site’). However, it appears that the ‘core’ plot may have been subjected to greater past disturbance than the other plots. The ‘core plot’ supported substantially lower shrub/subshrub cover, and substantially higher non-native herbaceous cover (particularly forbs, see Figure 2) and bare ground than the other plots. Cover data from the Crestridge plots (Figure 3a-c) exhibits a trend more indicative of decreased disturbance with distance from the urban edge. Subshrub cover increased substantially from plots one through three while herbaceous cover, especially that contributed by non-native grasses,

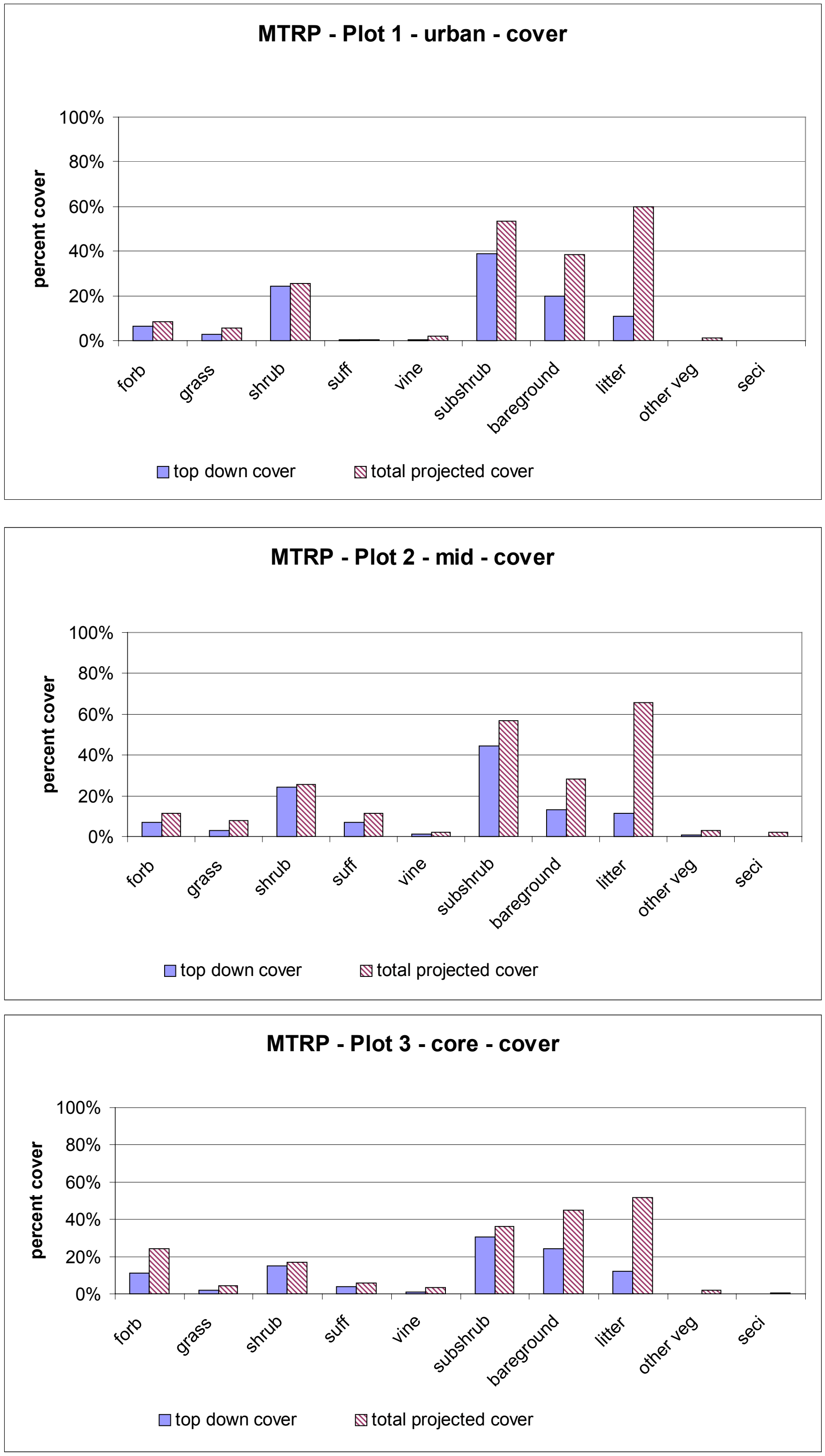

Figure 1a-c. Percent cover ("topdown" and total projected) of major plant growth forms and ground cover types. The abbreviation "seci" refers to Selaginella cineraseus (ashy spike moss), which has a prostrate, mat-like ground cover. The abbreviation "suff" refers to suffrutescent (a plant that is obscurely shrubby, with very little woody material). 'Other veg' refers to unidentifiable species of herbaceous cover.

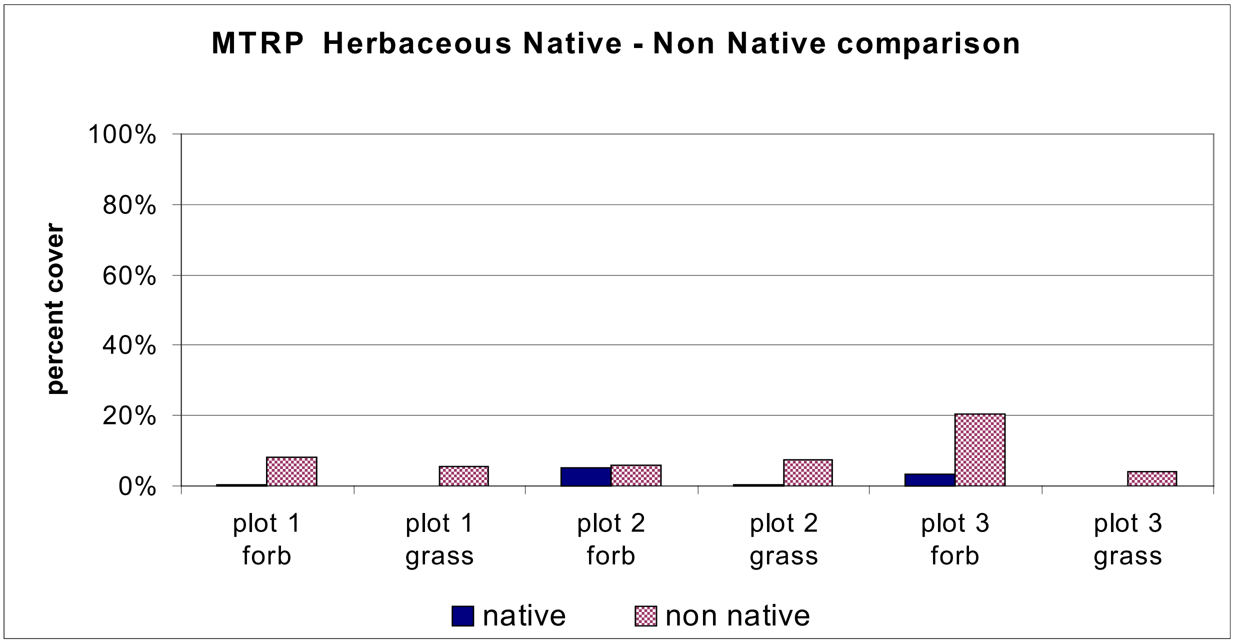

Figure 2. Herbaceous cover differentiated by forb and grass cover (native and non-native) at the MTRP plots.

decreased substantially (Figure 4). The MTRP result, combined with the difficulty encountered in locating suitable coastal sage scrub habitats that satisfied the disturbance gradient criteria and were adjacent to urban edge, suggests that the Ogden (1996) strategy for habitat monitoring may not be warranted and/or viable. Two other factors that have led us to this conclusion are: (1) the time cost for completing the entire sampling, surveying, and data base coding is estimated at 150 to 175 hours per sampling site, and (2) sampling plots are not likely to be representative of the rest of the reserve in which they are located and as a network of sampling sites, not representative of the entire MSCP subregion. Expanding on point (2), the 0.015 km^2 areal extent of the three sampling sampling sites combined is but 0.127% of the MSCP subregion. Another sampling scheme that might be utilized is intermediate in scale to the sampling scheme described in this report and that proposed by Ogden. An intermediate sampling strategy might entail random placement of eight 25 m X 25 m monitoring plots in each of the three zones described above. Such a sampling scheme might provide greater but not necessarily full representation of the full spatial heterogeneity characteristic of coastal sage scrub within a given reserve's entire extent. But two questions remain: (1) Is information on changes in species or growth form and ground cover important for monitoring changes in habitat quality? and (2) Is ground-level sampling required to capture this information?

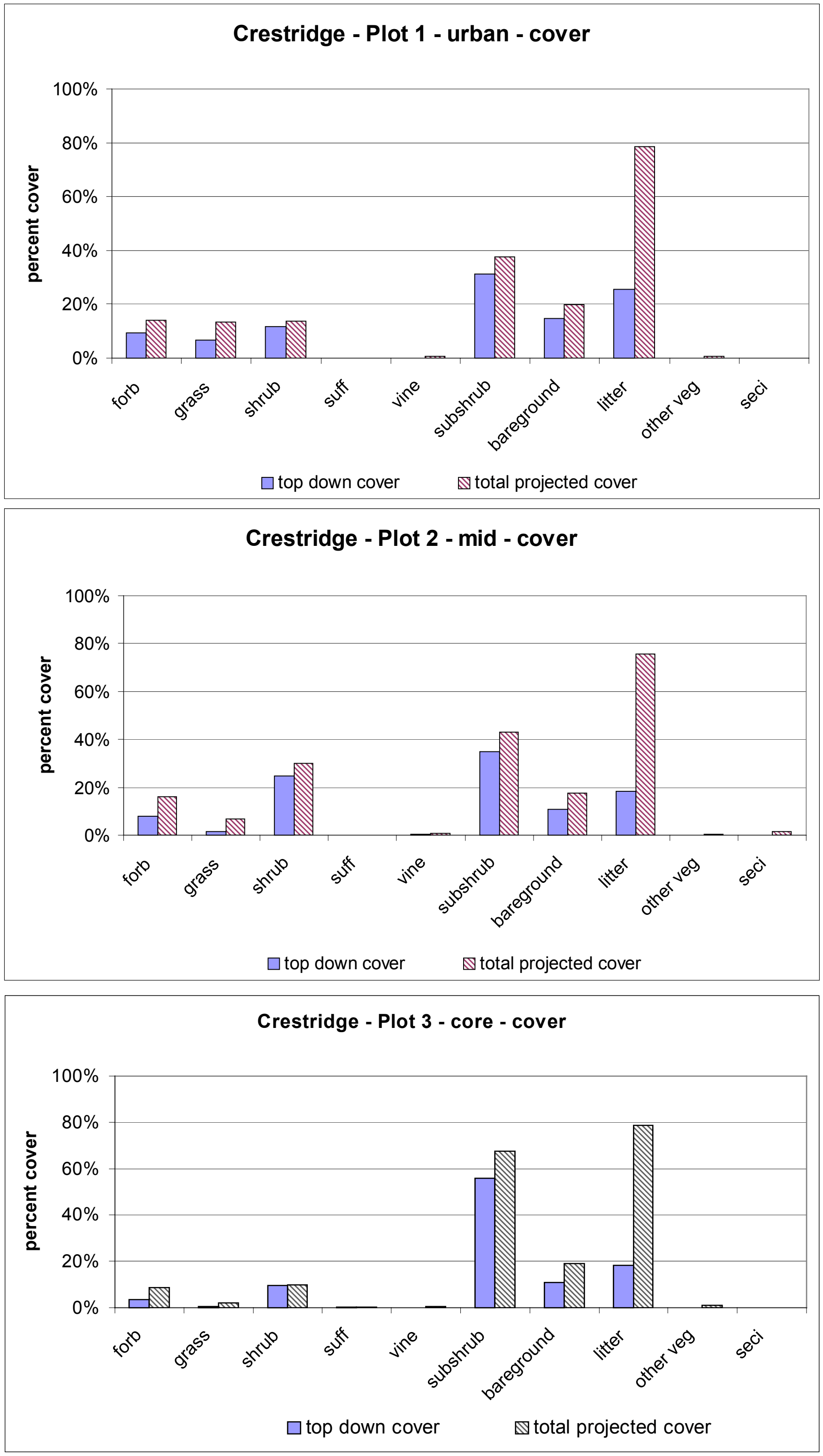

Figure 3a-c. Percent cover ("topdown" and total projected) of major plant growth forms and ground cover types. The abbreviation "seci" refers *to Selaginella cineraseus* (ashy spike moss), which has a prostrate, mat-like ground cover. The abbreviation "suff" refers to suffrutescent (a plant that is obscurely shrubby, with very little woody material). 'Other veg' refers to unidentifiable species of herbaceous cover .

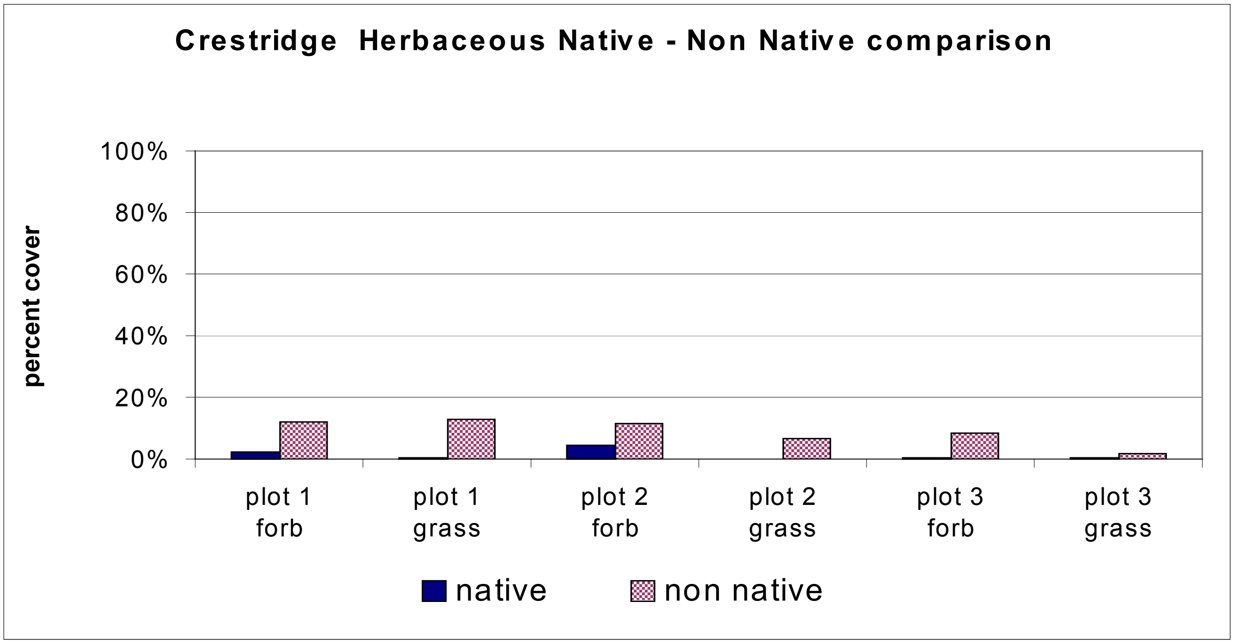

Figure 4. Herbaceous cover differentiated by forb and grass cover (native and non-native) at the Crestridge plots.

Cover vs. Spectral Data Relationships

In order to investigate the relationship between ADAR digital multispectral image data and percentage bare ground and shrub/subshrub cover, image-derived measures were compared to ground data from vegetation cover sampling. Throughout the duration of vegetation plot sampling, the corners of each 3 m x 3 m plot were logged using a GPS unit.

Sample sites were selected to incorporate areas within the park that have varying degrees of recreation activity and bare cover fraction. Seven study sites with at least four ground sampling plots at each site were sampled. Four of the sites were in areas with designated recreational uses in the park, including two areas designated for hiking only, one area for BMX biking and a multi-use area. The other three sites were located with the larger species sampling sites. This included a plot near the urban fringe, a second plot at least 150 m from the urban fringe (very low recreation intensity), and third plot located in the transition zone between the urban fringe and greater than 150 m distance from the fringe.

Study sites in the areas with higher recreation intensity were located in areas designated for recreation and near the urban fringe. Half of these sites were randomly selected at lower elevations from the control site where edge effects are an issue. To help define areas associated with different recreation activities, MTRP rangers made recommendations regarding recreation locations of activities in various parts of the park. Their expert advice enabled recreation sites to be selected to include mountain biking, hiking, rock climbing and BMX areas. Sampling plots locations were based on a visual assessment of bare ground to ensure evenly distributed samples of percent bare cover (0 – 100% bare cover.)

At each of the sites, ground cover presence was sampled with a series of 3 m x 3 m plots. Within each 3 m x 3 m plot, 50 points of data were collected, 10 points along each transect. Transects were placed every 0.5 m, and cover data (bare ground, vegetated, rock or litter) at point intercepts collected every 0.3 m along each transect (Figure 5). Percent bare ground and shrub/subshrub cover was calculated based on the number of points in the plot that have bare cover (shrub/subshrub canopy), divided by the total number of total in the plot.

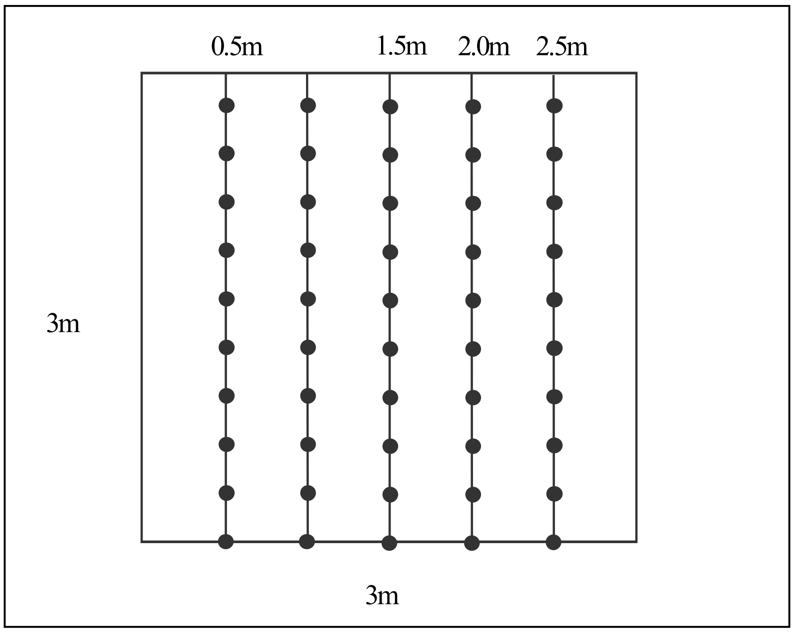

Figure 5. Sampling strategy within 3 m x 3 m plots.

Image brightness values for each band (blue, green, red, and NIR) were extracted and band values were used to compute spectral vegetation indices (SVI). Linear regression techniques were applied to identify the image-derived variable that best explains the variation in percentage cover of bare ground and shrub/subshrub growth forms.

Approximately 50% of the variation in bare ground cover fraction and 40% of shrub/subshrub cover was explained using simple spectral indices derived from the May 2000 ADAR image data (1 m resolution) (Figures 6-9). When some of the sample points were eliminated because of their greater uncertainty in co-locating field plots and specific pixels representing those plots, the regression coefficient (r^2) for band 3 (red wavelength) digital numbers was as high as 0.7. The normalized difference vegetation index yielded r2 values that were about 0.05 (5%) lower than the red band alone. A multiple regression model using all ADAR bands as input explained 50% of the shrub/subshrub variation of sample plots, and increase of about 10% for single band/index regressions.

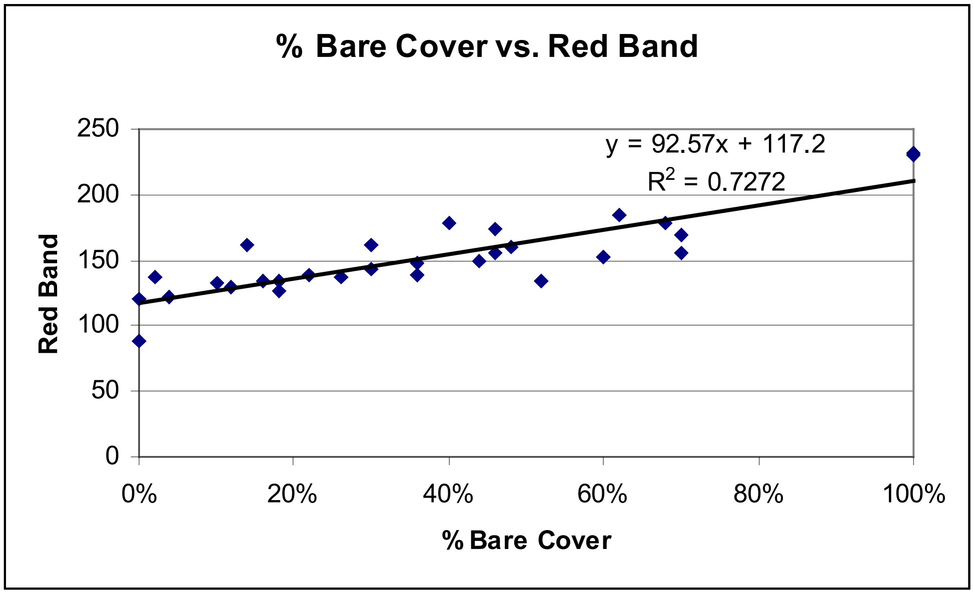

Figure 6. Relationship between percent bare cover and red waveband digital numbers.

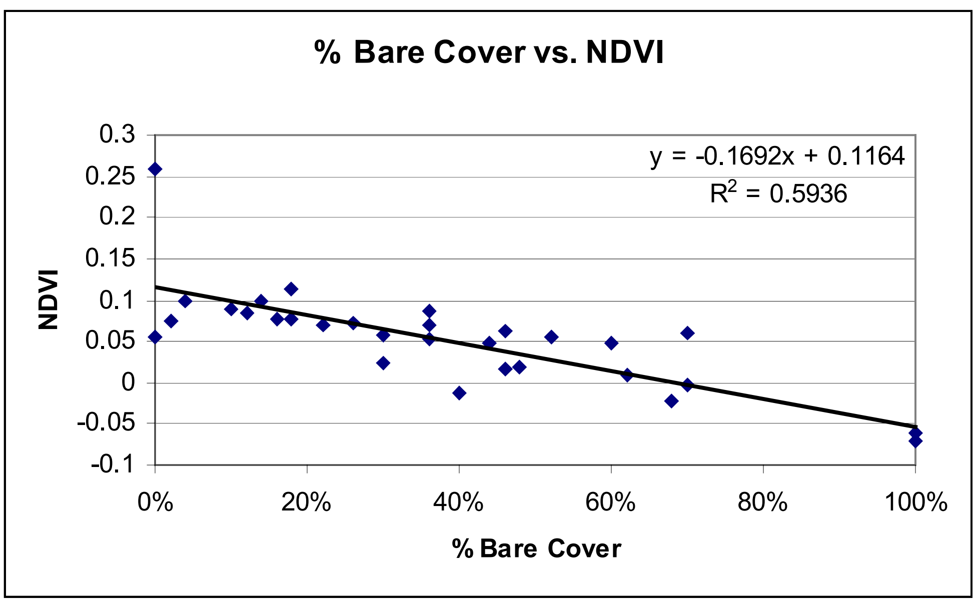

Figure 7. Relationship between percent bare cover and NDVI.

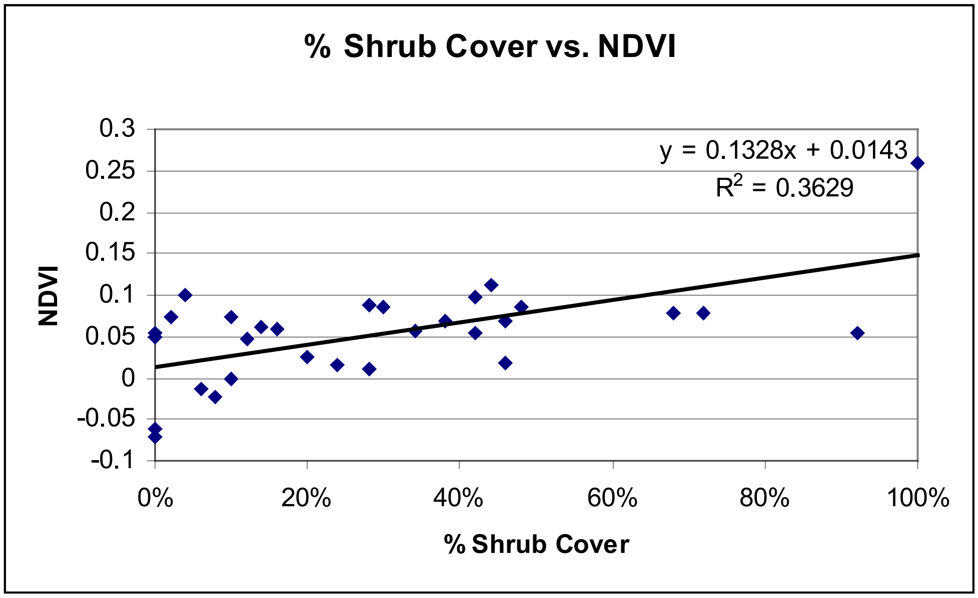

Figure 8. Relationship between percent shrub cover and NDVI.

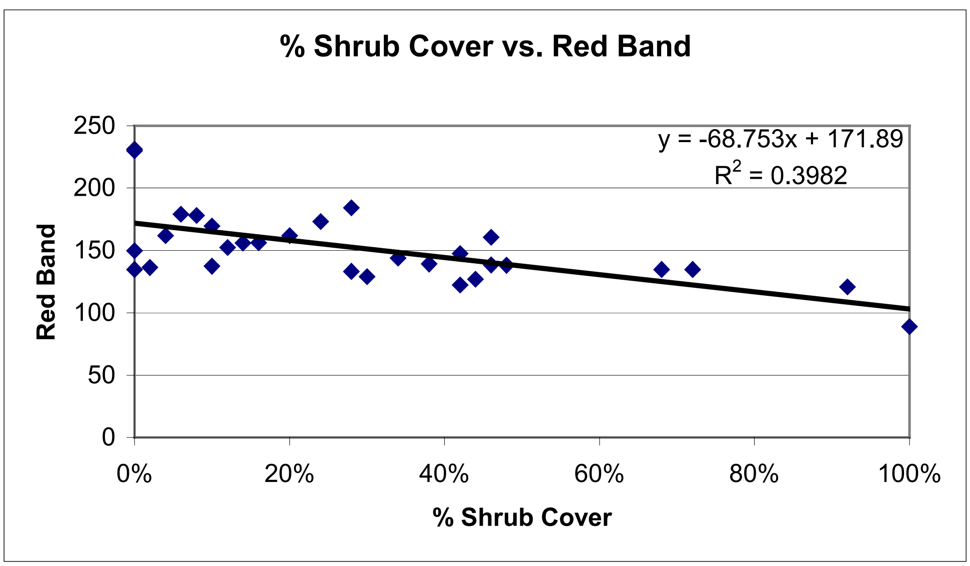

Figure 9. Relationship between percent bare cover and red waveband digital numbers.

The lower variance explanation for shrub/subshrub cover is likely due to confusion between herbaceous (i.e., understorey) vegetation that was also green at the time of the ADAR image acquisition. The ability to estimate shrub/subshrub cover should improve for images captured later in the spring, or in early summer, when most of the herbaceous plant cover has senesced. However, herb senescence at this time will likely reduce the contrast between bare ground and herbs, reducing the reliability of estimates of bare ground cover at this time.

These results suggest that at a minimum, reliable maps of cover fraction interval classes (e.g., 0-10%, 11-20%…) can be generated over time, to monitor changes in bare ground and shrub/subshrub cover. We anticipate that future studies will focus on quantifying shrub/subshrub cover of coastal sage scrub species, with aim at determining quantitatively the degree of disturbance. This will likely entail coordinated sampling of cover for growth form types with ADAR image acquisition during the month of June.

Image-based Monitoring Approaches

Analyses of very-high resolution digital imaging technologies for habitat monitoring focussed on the utility of the Airborne Data Acquisition and Registration (ADAR) System 5500 (Stow et al., 1997; Stow et al., 1998). SDSU owns and operates an ADAR system, which for this project, was utilized to capture digital multispectral camera images in visible and near infrared wavelengths from fixed-wing and helicopter platforms. This type of imagery can be viewed and/or processed to provide information on the following in decreasing order of certainty: vegetation versus bare ground cover; green vegetation, woody vegetation, litter, bare ground, and shadow cover fraction; vegetation community types; canopy structure; and species type/cover.

Image data with 1 m spatial resolution were acquired from fixed-wing aircraft in May, 1999 and 2000 for the MTRP and CHR study areas. Experimental image data were captured from a helicopter in May/June 2000 to achieve sub-meter spatial resolution imagery. The three specific objectives associated with remote sensing of habitat within the MSCP were: 1) assess the processing requirements and utility of image-based change detection, 2) identify relationships between image products and environmental indicators of habitat quality, and 3) assess the utility of image data for identifying and mapping unauthorized trails within reserve systems.

Radiometric and Geometric Pre-processing

Change detection with multitemporal imagery requires precise radiometric and geometric registration between data sets. Building on results from a companion NASA-funded study, radiometric and geometric pre-processing routines were applied to several of the ADAR data sets to generate image mosaics for an extensive portion of MTRP (archived 1998,1999 and 2000) and the entirety of CHR (1999). Change detection techniques were developed using 1999 and archived 1998 ADAR 1 m imagery from MTRP and were implemented at CHR with 1999 and 2000 imagery to test the transferability of the approach.

Radiometric pre-processing included normalization (or balancing) of across-frame variations in brightness and radiometric registration of digital number (DN) values between the multitemporal data sets. Some of the across-frame variations in brightness are due to a phenomenon called anisotropic reflectance, where the magnitude of solar radiation reflected from cover materials within the scene varies as a function of sun-scene-sensor geometry. Vegetation has a stronger back-scatter than forward-scatter, and this often results in a brightness trend across aerial image frames in the direction of the principal plane of the sun. Through the NASA-funded study, our project team developed a model that corrects for the across frame brightness trend caused by anisotropic reflectance. This model was applied to the Mission Trails ADAR data sets, which were significantly affected by anisotropic reflectance. The model uses sun-scene-sensor geometric relationships to generate an image with multiple zones of varying scattering characteristics. The model identifies brightness trends between zones and then uses this information to de-trend the input data.

Radiometric registration between multitemporal image data sets is necessary when absolute differences in image DN values are sought and is recommended when performing change detection. Methods for radiometric registration include: histogram matching; pseudo-invariant features; and dark object subtraction. The pseudo-invariant features (PIF) technique is generally recommended as it uses stable radiometric values common to both dates of imagery to register DNs from multitemporal datasets. However, the PIF technique is time-intensive and can cause change results to be significantly affected by phenological differences. The histrogram matching technique matches the mean and variance of one input data set to a reference data set and tends to reduce overall phenological differences and highlight areas of localized change. Radiometric registration of the Mission Trails data sets was performed using a histogram matching and the 1999 data set was selected as the reference, as this data set had the greatest DN range.

Geometric processing included orthorectification, georeferencing, and mosaicking of the individual ADAR frames associated with each year's data sets. For change detection at Mission Trails, the 1998 data set was chosen as the geometric base and individual frames from other years were registered to this ADAR mosaic. Orthorectification and georeferencing was performed using Orthobase, a product of ERDAS, Inc. Orthobase enables automatic generation of control points between individual ADAR frames and between the ADAR frames and the base, given a minimum number of manually place starting control points. Orthobase also utilizes digital elevation models to remove geometric distortions resulting from terrain displacement. Orthobase required between 1 and 3 hours per frame to register multitemporal ADAR mosaics with a root mean square error (RMSE) or 3-5 pixels.

The project team also evaluated the georeferencing and mosaicking capabilities of a software package called Digital Images Made Easy (DIME), which is produced by Positive Systems, Inc. DIME provides an efficient solution for georeferencing and mosaicking large numbers of ADAR frames in a semi-automated environment. DIME was found to provide geometric registration accuracies on the order of 8-10 pixels (half as accurate as Orthobase) in a third to a quarter of the time required with Orthobase. A significant disadvantage of DIME is that it does not perform orthorectification to remove terrain related geometric distortions. We found a direct relationship between slope and spatial registration error with DIME products. Table 1 lists RMSE values associated with Orthobase and DIME products. Scatterplots in Figure 10 and Figure 11 illustrate error as a function of slope for Orthobase and DIME products, as assessed at independent, stratified random check points. It is apparent that Orthobase errors do not increase as a function of slope.

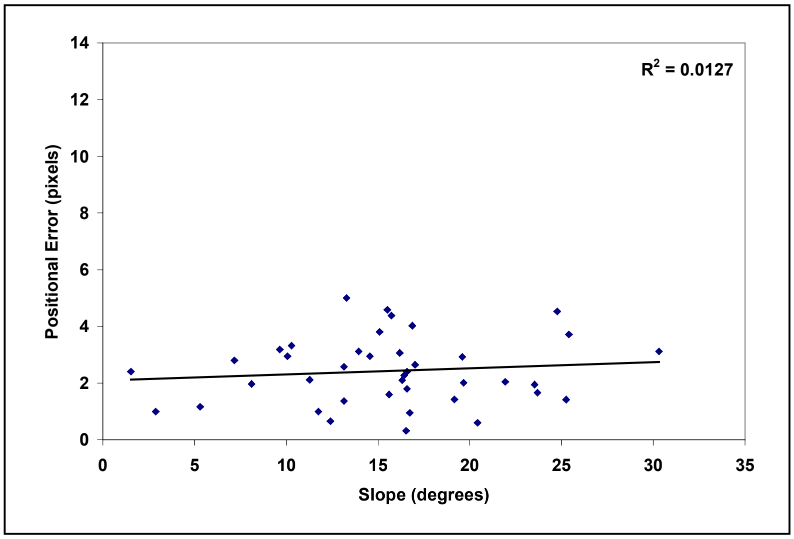

Figure 10. Orthobase errors plotted as a function of slope

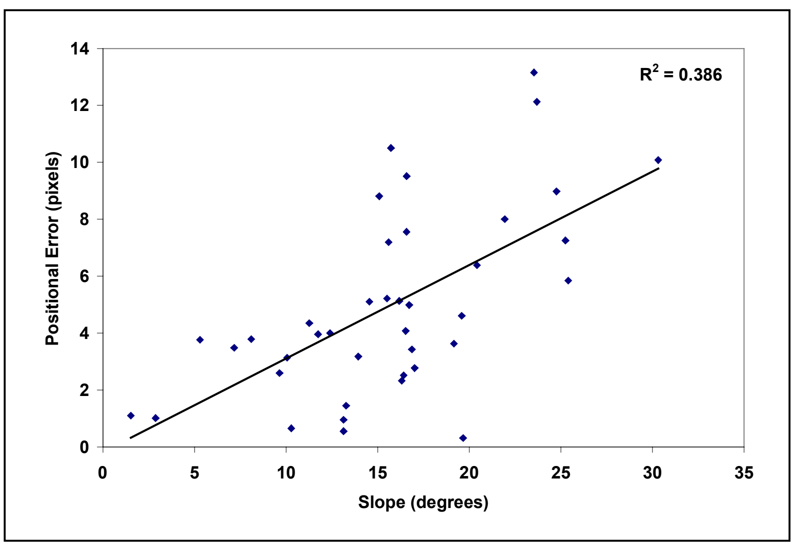

Figure 11. DIME errors plotted as a function of slope.

Image Products and Change Detection

Based on image data sets for MTRP, three types of image-derived products were assessed: (1) change detection images for identifying "hot spots" of land cover change, (2) maps of proportion of bare ground cover and shrub/subshrub cover, and (3) maps of trails, predominantly associated with recreational activity. The most effective and efficiently created change detection images were generated by incorporating multitemporal difference images from red and near infrared wavebands and the normalized difference vegetation index (NDVI) into an unsupervised image classification routine. Land cover changes associated with fires, landscaping, shrub extraction, vegetation removal from recreational disturbances, and exotic plant invasions were detected, some on order of 1 – 2 meters in extent. False change artifacts were commonly associated with misregistration between multitemporal ADAR images, but in most cases, are easy to visually distinguish from actual land cover changes.

The project team explored the information content, technical requirements, and associated processing costs of multiple change detection methods. These included: spectral band, vegetation index, texture, and fraction image differencing. Visual and computer-based techniques for assessing and determining a change/no change condition included: difference image thresholding, difference image overlay composite, and semi-automated classification of continuous difference images (referred to as change vector classification).

Spectral waveband differencing is the simplest form of change detection processing, as multitemporal images are subtracted one from another using image algebra. The result is a continuous image with values that indicate an increase, decrease, or no change in brightness for every ground resolution element (GRE) or image pixel. Image products such as the normalized difference vegetation index (NDVI), texture, and cover fractions can be differenced in the same manner. NDVI and texture products are easily generated using image processing models. Generation of cover fraction images through linear mixture modeling is less straightforward, as image endmembers must be selected and multiple image processing steps are required. The multispectral wavebands of the ADAR sensor and Ikonos sensor support modeling of green vegetation, soil, and shade fractional cover. We found that multitemporal differencing of the multispectral wavebands, in conjunction with NDVI or green vegetation fraction differences provides the greatest information content regarding change in habitat condition. As linear mixture modeling requires complex processing and the selection of image endmembers can be somewhat subjective for sub-meter to one meter resolution imagery such as from ADAR, we recommend that the NDVI be utilized in conjunction with the red and possibly other waveband image data to provide information about vegetation cover condition and change.

Categorization of discrete change/no change classes based on continuous difference images requires either: 1) qualitative decisions when viewing individual and/or composite difference images, 2) thresholding of difference images into change and no change classes, or 3) computer assisted classification of difference images. Image overlay composites of the near-infrared, red, and NDVI difference images (displayed in the blue, green, and red color guns, respectively) provided analysts much information as to the locations and types of land cover changes. Figure 12 illustrates a difference overlay composite image. Image overlay composites must be visually assessed for land cover changes, as no hard classification of changes is generated. The difference overlay composite image highlighted such changes as: Vegetation decrease and soil increase from clearing, fire, recreation impacts and placement of wood chips for landscaping (near MTRP visitors center); and herbaceous/mustard increase and change in phenological state.

The most effective and efficient means of categorizing and classifying observed changes was through unsupervised classification of a five band image containing the four spectral band difference images and the NDVI difference image. This classification approach is referred to as change vector classification. The five layer difference image was input into an ISODATA clustering and classification algorithm and 50 spectral cluster classes were specified for the output. Pixels of no change cluster in the centroid of multispectral feature-space and were labeled as such after cross-verification against difference image products. The remaining cluster classes were labeled into change classes based upon the direction of their change (Figure 13). The four final land cover change classes were: green vegetation increase; green vegetation decrease; herbaceous cover decrease; and soil increase. Green vegetation increase was generally associated with herbaceous and riparian increase/phenology between 1998 and 1999, while green vegetation decrease was associated with clearing and localized fires. Recreational impacts and fire in less densely vegetated areas resulted in soil exposure increase and a corresponding reduction of dry vegetation matter. Apparent decreases of herbaceous cover were identified and are attributed to phenological differences at the time of image acquisition. Vegetation phenology mostly resulted in an increase in green vegetation between 1998 and 1999 because the 1998 data was acquired in late June, while the 1999 data was acquired in late May. Change artifacts cause by spatial misregistration of the data sets in areas of high relief are apparent on the change products and are manifested as alternating change classes adjacent to one another.

Change detection was performed at Crestridge to test the transferability of the change vector classification approach. The site was a 2.5 x 3 km area that encompassed the ground sample plots in the central portion of the reserve. The resulting change product is given in Figure 14. The change classes are comparable to those generated at Mission Trails Regional Park. Changes detected at Crestridge included: increased soil exposure at localized areas caused by clearing and other human activity; herbaceous cover decrease and increase likely associated with phenology; vegetation regrowth near a residence; and apparent increase in soil exposure on trails.

Trail Feature Extraction

Trailblazing in off-limit areas within parks and reserves can significantly impact vegetation and soil resources and accelerate habitat degradation. We investigated the utility of 1 m resolution multispectral imagery acquired with the ADAR 5500 system to identify the formation of new and unauthorized trails. Spectral and spatial transforms were employed to enhance subtle trail features that are not apparent when viewing the 1 m multispectral imagery. Spectral transformations included the tasseled cap, principal components, and NDVI. Spectral transform products were subjected to edge enhancement, edge detect, and high pass spatial filters using 5 x 5 and 7 x 7 convolution kernels. We found that trails on the order of 0.25 to 0.50 and greater can be visually detected and mapped through enhancement of 1 m ADAR imagery.

The principal components spectral transform provided the most information as subtle trail features were highlighted in the first and third principal component images. The

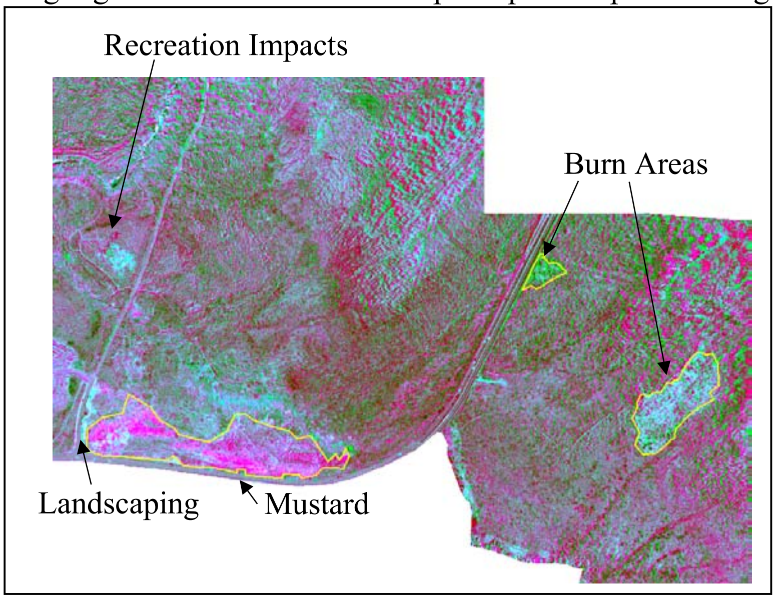

Figure 12. Change detection product for MTRP site generated using difference image overlay technique. Color gun assignments are: red = NDVI difference, green = red band difference; blue = near-infrared band difference.

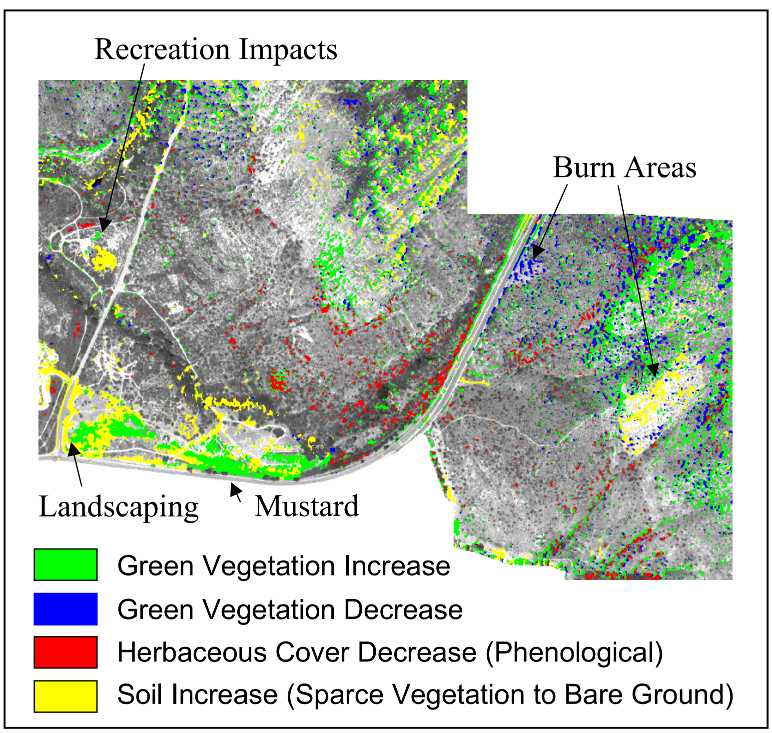

Figure 13. Change detection product for MTRP site generated through change vector analysis.

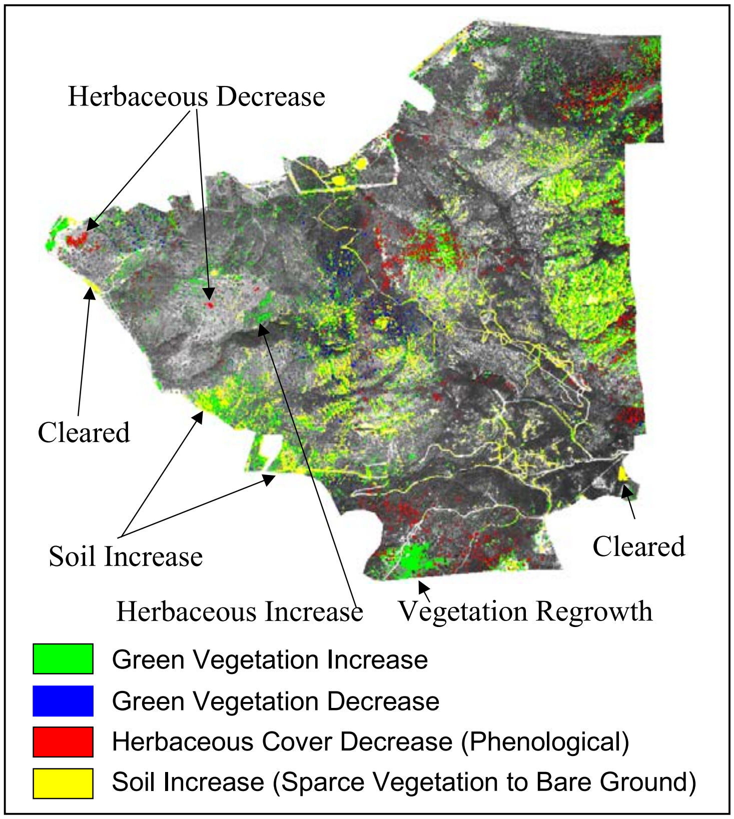

Figure 14. Change detection product for Crestridge site generated through change vector analysis.

"tasseled-cap" transform was found to aide discrimination, but the ability to enhance trail features was site specific and in some areas tended to blend roads with outer areas. The NDVI did not aide discrimination of trails. A 7 x 7 edge enhancement filter was found to be the most useful spatial transform. The edge detect filter did not highlight non-apparent trails. The high pass filter increased image noise and reduced the overall ability to interpret subtle trail features. Figure 14 illustrates an ADAR image and the resulting principal component III product highlighting trail features.

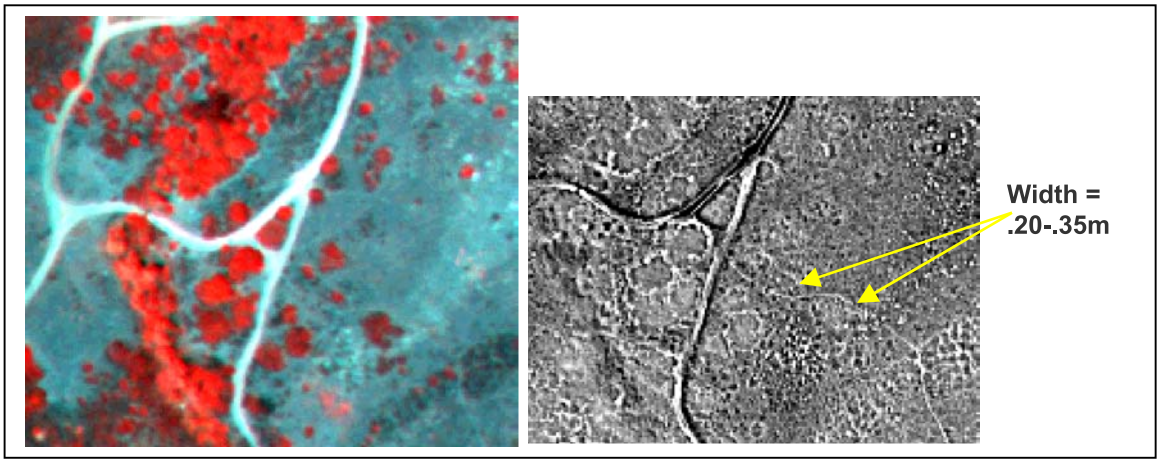

Figure 14. Trail detection with 1 m ADAR 5500 imagery using principal components analysis. Principal component III is illustrated at right. The ADAR image display is 4,3,2.

Prototype Monitoring System

Based on our findings to date, we propose a prototypical monitoring system for the MSCP, with the caveats that our research into the role of geo-spatial technologies will be continuing for at least the next few years and that there are many uncertainties pertaining to the future of public and private sector developments of these technologies. One of the keys to a successful monitoring system is the establishment of a reliable baseline. We support the recommendation of the Conservation Biology Institute to establish GIS compatible data sets portraying vegetation community and land cover types (including disturbance regimes) for each habitat reserve within MSCP. While extensive field mapping efforts will be required to generate such a baseline, costs will be substantially reduced and accuracy increased by incorporating very-high resolution digital color infrared (CIR) imagery, image processing, and GIS techniques. The commercially-provided (3di, Inc.) digital image data set (0.6 m resolution) for San Diego County in Year 2000 (coordinated by SANDAG), should provide a useful image base for such a baseline mapping effort. Another potentially useful image source should be CIR digital orthophoto quarter quadrangles (1 m resolution) for all of southern California (based on 2002 CIR photography), that the USGS is planning to produce.

For long-term monitoring of individual habitat reserves we recommend a top-down monitoring strategy based on very-high resolution, digital, multitemporal CIR image data, from a direct digital imaging system such as ADAR. A temporal sampling interval of three to five years would likely be warranted. Imagery acquired in late-April/early-May should optimize differences between bare ground and vegetation. Alternatively, late-May/early-June acquisitions will enable more reliable quantification of shrub/subshrub cover relative to senesced herbaceous cover. To minimize false detection of habitat change caused by geometric and radiometric misregistration, an image acquisition and processing scheme should be implemented to ensure that digital image frames are captured as close to the same observation points in both time and space, for all pairs of multitemporal images. With image frames captured in this manner, a frame-by-frame image matching process should yield the most reliable and precise change detection products. Images depicting "hot spots" of land-cover change, changes in bare and growth form cover fraction, and disturbance features such as trails and burn scars would be generated and provided to habitat managers via a web-based distribution system. We envisage the habitat manager accessing these data sets in the field with wireless communication devices that include GPS receivers, such that image-based products guide the managers to specific locations of likely changes in land cover and/or habitat condition.

An optimal strategy for monitoring the entire MSCP subregion (i.e., system of reserves) is more difficult to recommend, particularly because it is unclear whether or not there will be management activities and therefore, the information needs pertaining to habitat conditions at this level of the NCCP hierarchy are unclear. A potentially valuable data source for this level of monitoring is Ikonos multispectral imagery (4 m resolution), which is commercially available through SpaceImaging, Inc. An Ikonos image covering about a third of the MSCP subregion was just obtained, but change detection results will not be available for at least another year, until a second, anniversary-date image is acquired and pre-processed. The advantage of Ikonos imagery is the very high image fidelity for quantitative image analysis. Drawbacks are: (1) the cost per unit area is approximately twice that of orthoimages generated from scanned CIR aerial photography, even at the lowest level of geometric processing; and (2) the spatial resolution of Ikonos imagery is four to eight times more coarse than airborne digital imagery, even with the highest spatial resolution from a satellite multispectral system. So until potential commercial competitors of Ikonos are also providing image data that are more affordable than present, the most suitable image source for MSCP-wide monitoring will be CIR DOQQs and similar data sets (e.g., 3Di, Inc./SANDAG CIR mosaic).

Requirements for ground sampling and reconnaissance will likely be reduced by adoption of geo-spatial technologies, but will remain an important component of the prototype habitat monitoring system. We have already alluded to reconnaissance efforts of reserve managers guided by image-derived change detection products. The manner in which ground-level cover data are sampled to support image-derived maps of growth form/bare cover fractions may need to be refined. If managers or conservation biologists determine that species cover monitoring is required, it will primarily be accomplished with ground-level sampling. Even on the highest resolution images, identification of most herbaceous and many subshrub species is not possible. However, changes in the sampling schemes for long-term monitoring plots and/or transects are warranted. Low-level imaging from

ADAR-like sensors mounted on helicopters, provide a very efficient means for quantifying cover fractions of growth form types and some shrub and subshrub species within randomly or systematically located frames across a reserve.

Outreach

As for most of the research activities, outreach efforts were focussed on the MTRP study site. Project scientists provided information about the project at an organizational meeting of agency personnel, consultants, and volunteers associated with CHR, in Spring, 2000. Preliminary project results were presented to members of the TAC and others involved with MSCP implementation at the Mission Trails Visitors Center (MTVC) in October, 2000. Over forty people were in attendance. These results were also presented as part of the City of San Diego's presentation and via a poster presentation, at the annual MSCP program review at the MTVC in November, 2000. For over a year we have been working with the rangers at MTRP to develop educational materials for display at the MTVC. A more elaborate set of posters will be completed and displayed in May, 2001.

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Appendix A

Sample data sheet from 50 m x 100 m sites

site:	MTU	transect: 24	observers: Christine
date:	4/20/00		Mel
meter	top	bottom	ground cover
0.5	————		LG
1.5	Hedypnois cretica		LF
2.5	Hedypnois cretica		BG
3.5	————		BG
4.5	Erodium cicutarium		medicago polymorpha
5.5	————		LS
6.5	————		DU
7.5	————		LF
8.5	Melilotus indica		BG
9.5	Brassica nigra		Brassica nigra
10.5	Erodium cicutarium		Erodium cicutarium
11.5	————		BG
12.5	Erodium cicutarium		LF
13.5	————		BG
14.5	————		LF
15.5	Erodium cicutarium		BG
16.5	Artemesia californica, Viguera lacinta		LS
17.5	Viguera lacinta		LS
18.5	Viguera lacinta		BG
19.5	————		LS
20.5	————		LF
21.5	————		BG
22.5	Eriogonum fasciculatum		LS
23.5	Eriogonum fasciculatum		LS
24.5	Artemesia californica		LS
25.5	Brassica nigra		BG

site: MTU	transect: 24	observers: Christine Mel
date: 4/20/00		
meter	top / bottom	ground cover
26.5	Artemesia californica	RO
27.5	Malosma laurina	LS
28.5	Malosma laurina	BG
29.5	Artemesia californica	LS
30.5	Viguera lacinta (dead)	LS
31.5	————	BG
32.5	Eriogonum fasciculatum	BG
33.5	————	BG
34.5	Malosma laurina, Bromus madritensis	LS
35.5	Malosma laurina	LS
36.5	Malosma laurina	LS
37.5	Malosma laurina	LS
38.5	Malosma laurina, Viguera lacinta	LS
39.5	Viguera lacinta	LS
40.5	Viguera lacinta	LF
41.5	Eriogonum fasciculatum, Calystegia macrostegia	BG
42.5	Artemesia californica	LS
43.5	Artemesia californica	LS
44.5	Malosma laurina	liverwort
45.5	Eriogonum fasciculatum, Lotus scoparius	LS
46.5	Baccarus sarothriodes, Eriogonum fasciculatum	LS
47.5	Eriogonum fasciculatum	moss
48.5	————	LF
49.5	Artemesia californica (dead)	centauria melitensis

Appendix B

Individual species coverage categorizing within growth forms for the Mission Trails Regional Park (MTRP) and Crestridge Plots

MTRP - Plot 1 - Urban

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	18.88	18.88
*Nerium oleanderus**	0.38	0.38
Rhamnus crocea	0.00	0.38
Rhus integrifolia	0.13	0.13

Subshrubs		
Artemisia californica	17.00	24.25
Eriogonum fasciculatum	12.38	20.38
Baccharus sarothroides	4.88	5.88
Salvia mellifera	1.75	5.13
Viguiera lacinata	2.63	3.63
Gutierrezia california	0.38	0.50

Suffrutescents		
Lotus scoparius	0.25	0.50

Vines		
Marah macrocarpus	0.00	1.13
Calystegia macrostegia	0.38	0.75

Herbs		
*Centaurea melitensis**	2.13	3.13
*Erodium cicutarium**	1.88	2.25
*Brassica nigra**	1.25	1.38
*Bromus madritensis ssp. rubens**	0.25	1.38
*Hypochaeris glabra**	0.25	0.50
*Hedypnois cretica**	0.38	0.38
*Brachypodium distachyon**	0.13	0.13
Dichelostemma capitatum ssp capitatum	0.13	0.13
*Erodium botrys**	0.13	0.13
Hemizonia fasciculata	0.13	0.13
*Silene gallica**	0.13	0.13
*Bromus diandrus**	0.00	0.13
*Filago gallica**	0.00	0.13
*Medicago polymorpha**	0.00	0.13
*Melilotus indica**	0.00	0.13
*Sonchus oleraceus**	0.00	0.13

* denotes non-native plant

MTRP - Plot 2 - Mid

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	8.50	8.75
Rhus integrifolia	2.63	2.75
Rhamnus crocea	0.00	0.63

Subshrubs		
Artemisia californica	14.00	19.38
Baccharus sarothroides	12.88	13.63
Eriogonum fasciculatum	8.88	9.25
Salvia mellifera	6.75	7.50
Viguiera lacineta	0.25	1.25
Salvia mellifera x apiana	0.88	1.13
Gutierrezia california	0.50	0.63
Malacathamnus fasciculatus	0.25	0.50
Mimulus aurantiacus	0.13	0.38
Salvia apiana	0.13	0.25
Hazardia squarrosa	0.00	0.25
Ribes malvaceum	0.13	0.13

Suffrutescents		
Lotus scoparius	6.00	9.75
Yucca whipplei	0.63	0.75
Lessingia filaginifolia	0.25	0.25

Vines		
Calystegia macrostegia	1.50	2.00

Herbs		
Centaurea melitensis	1.63	2.25
Selaginella cinerascens	1.88	2.13
Galium nuttalii	1.13	2.01
Hypochaeris glabra	1.13	1.38
Erodium cicutarium	0.88	1.13
Melilotus indica	0.25	1.13
Vulpia myuros	0.38	1.00
Galium aparine	0.00	0.75
Nassella pulchra	0.13	0.38
Bromus madritensis ssp. Rubens	0.00	0.38
Brassica nigra	0.13	0.13
Dichelostemma capitatum ssp capitatum	0.13	0.13
Schismus barbatus	0.13	0.13
Castillega foliosum	0.00	0.13
Filago gallica	0.00	0.13

* denotes non-native plant

MTRP - Plot 3 - Core

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	13.85	14.48
Rhamnus crocea	0.75	1.00

Subshrubs		
Gutierrezia california	14.75	16.38
Artemisia californica	6.13	8.38
Eriogonum fasciculatum	5.88	6.00
Salvia mellifera	1.38	1.50
Salvia apiana	1.25	1.38
Baccharus sarothroides	0.63	0.63
Salvia mellifera x apiana	0.38	0.38
Malacathamnus fasciculatus	0.13	0.25
Viguiera lacineta	0.13	0.13
Hazardia squarrosa	0.00	0.13

Suffrutescents		
Lotus scoparius	3.50	4.88
Yucca whipplei	0.38	0.63
*Lessingia filaginifolia**	0.00	0.50

Vines		
Calystegia macrostegia	1.13	2.25
Marah macrocarpus	0.00	1.13

Herbs		
Centaurea melitensis	3.25	8.75
Hypochaeris glabra	2.38	6.63
Erodium cicutarium	2.63	3.63
Galium nuttalii	0.50	1.13
Selaginella cinerascens	0.50	1.00
Filago gallica	0.75	0.88
Avena barbata	0.63	0.88
Erodium botrys	0.25	0.38
Hemizonia fasciculata	0.13	0.38
Lotus saliginosis	0.25	0.25
Mirabilis californica	0.25	0.25
Bromus madritensis ssp. Rubens	0.13	0.25
Sonchus oleraceus	0.13	0.25
Daucus pusillus	0.00	0.25
Lepidium strictum	0.13	0.13
Lepidium virginicum	0.13	0.13

* denotes non-native plant

Crestridge - Plot 1 - Urban

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	9.25	10.00
Rhamnus crocea	1.75	2.75
Keckiella antirrhinoides	0.38	0.63
Sambucus mexicana	0.13	0.13

Subshrubs		
Eriogonum fasciculatum	17.38	21.38
Artemisia californica	13.13	14.75
Salvia apiana	0.75	1.13
Baccharus sarothroides	0.25	0.25
Gutierrezia california	0.13	0.13
Viguiera lacinata	0.00	0.13

Vines		
Marah macrocarpus	0.00	0.63
Calystegia macrostegia	0.13	0.13

Herbs		
*Bromus diandrus**	3.13	6.63
*Bromus madritensis ssp. rubens**	1.25	3.63
*Centaurea melitensis**	2.38	3.25
*Erodium cicutarium**	2.00	2.88
*Erodium botrys**	1.63	2.00
*Bromus hordeaceus**	1.00	1.50
*Brassica nigra**	0.88	1.50
*Hypochaeris glabra**	0.50	1.50
Eremocarpus setigerus	0.13	1.00
Hemizonia fasciculata	0.75	0.88
*Vulpia myuros**	0.63	0.88
*Avena barbata**	0.50	0.63
Amsinkia intermedia	0.38	0.63
Mirabilis californica	0.13	0.63
*Filago gallica**	0.50	0.50
*Schismus barbatus**	0.13	0.13
*Silene gallica**	0.13	0.13
Daucus pusillus	0.00	0.13
Melica imperfecta	0.00	0.13
*Sonchus oleraceus**	0.00	0.13

* denotes non-native plant

Crestridge - Plot 2 - Mid

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	14.00	14.63
Keckiella antirrhinoides	6.88	8.88
Rhamnus crocea	3.25	6.13

Subshrubs		
Artemisia californica	21.88	25.88
Eriogonum fasciculatum	10.75	13.88
Viguiera lacinata	2.13	2.88
Baccharus sarothroides	0.50	0.50
Salvia apiana	0.25	0.50

Vines		
Cuscuta californica	0.38	0.38
Cuscuta ceanothi	0.00	0.25
Calystegia macrostegia	0.13	0.13
Marah macrocarpus	0.00	0.13

Herbs		
*Centaurea melitensis**	3.63	7.75
*Bromus madritensis ssp. rubens**	1.25	3.88
Mirabilis californica	1.13	2.00
*Bromus diandrus**	0.00	1.88
Selaginella cinerascens	1.38	1.50
*Erodium cicutarium**	0.50	1.25
*Brassica nigra**	0.63	1.13
*Vulpia myuros**	0.38	0.50
*Silene gallica**	0.25	0.50
Pityogramma triangularis	0.00	0.50
unknown Lotus	0.25	0.38
*Erodium botrys**	0.13	0.25
*Bromus hordeaceus**	0.00	0.25
*Sonchus oleraceus**	0.13	0.13
*Avena barbata**	0.00	0.13
*Filago gallica**	0.00	0.13
Hemizonia fasciculata	0.00	0.13

* denotes non-native plant

Crestridge - Plot 3 - Core

Shrubs	% Top Down Cover	% Total Projected Cover
Malosma laurina	9.38	9.50

Subshrubs		
Artemisia californica	30.88	35.63
Eriogonum fasciculatum	15.75	19.13
Viguiera lacinata	8.50	12.13
Salvia apiana	0.63	0.63

Suffrutescents		
Yucca whipplei	0.25	0.38

Vines		
Cuscuta californica	0.00	0.38
Calystegia macrostegia	0.13	0.13

Herbs		
*Centaurea melitensis**	2.50	6.50
*Bromus madritensis ssp. rubens**	0.38	1.75
*Erodium cicutarium**	0.25	1.13
*Brassica nigra**	0.38	0.50
Mirabilis californica	0.25	0.38
*Avena barbata**	0.13	0.13
*Erodium botrys**	0.13	0.13
*Hypochaeris glabra**	0.13	0.13
Nassella pulchra	0.13	0.13

* denotes non-native plant