Pages 229–244 in Damiani, C.C. and D.K. Garcelon (eds.). 2009. Proceedings of the 7th California Islands Symposium. Institute for Wildlife Studies, Arcata, CA.

A SPATIAL DATABASE OF SANTA CRUZ ISLAND VEGETATION

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Abstract—In 2006, The Nature Conservancy (TNC) contracted with Aerial Information Systems (AIS) to create a spatial database of vegetation on Santa Cruz Island, a 243 km^2 island jointly owned and managed by TNC and the National Park Service (NPS). AIS and TNC developed appropriate vegetation categories down to the alliance level, based on plot and transect data provided by USGS-Biological Resources Discipline, NPS, and TNC; *The Manual of California Vegetation*; and site visits conducted during the course of the project. A minimum mapping unit of 0.5 ha was established for the delineation of a visible alliance or mapping unit. AIS used 1:12,000 natural color aerial photographs from 2005 for the manual delineation of polygons. The delineation protocols established specific methods and criteria for each alliance or mapping unit and documented them for future updates, creating the foundation for tracking changes over time using sequential mapping techniques. The resulting vegetation database is discussed in relation to the changes that have occurred on the island over the last 20 years, specifically the removal of feral ungulates on the island, and is compared to earlier vegetation mapping efforts. The specific attributes developed for the database, particularly the cover measure and location of fennel, enable the exploration of more sophisticated and robust research questions.

INTRODUCTION

Mapping and tracking changes in vegetation patterns are essential to the management and long-term protection of landscape-scale biodiversity and ecological processes. The Nature Conservancy (TNC), which owns and manages 76% of Santa Cruz Island (SCI), was particularly interested in documenting changes in vegetation as a result of feral ungulate removal programs over the last 25 years. To that end, TNC contracted Aerial Information Systems (AIS) in 2005 to create an island-wide spatial vegetation database at a high spatial and categorical resolution and to document the methods sufficiently to allow for future updates. This paper describes the methodology used to create this database, discusses the information collected on vegetation types and cover, and compares the new database to earlier mapping efforts of the island.

Sheep, pigs, and cattle were introduced to SCI in the mid-1850s (Hochberg et al. 1980; Junak et al. 1995), marking the beginning of severe ecological degradation of the island (NPS 2002). All three ungulates ate native plant species, including some that were unique to the island (Hochberg et al. 1980). After acquiring an interest in the island in 1978, TNC began a program to eradicate sheep, and later cattle and pigs, from their portion of the island. Beginning in the 1990s, the National Park Service (NPS) conducted a similar eradication of feral animals from their portion. Over 46,000 sheep were removed from SCI between 1981 and 2001 (Morrison 2008), and between 1988 and 1989 nearly 2000 head of cattle were rounded up and shipped to the mainland (P. Schuyler, personal communication) Finally, over 5000 feral pigs were eradicated from the island between 2005 and 2007 (Morrison et al. 2007).

The removal of non-native grazers was expected to have significant ecological consequences, especially on vegetation. Photomonitoring conducted between 1980 and 2006 has already shown increases in native plant cover at several sites around the island (P. Schuyler, personal communication). To better understand these changes, we embarked on a program to develop a cost-effective, large-scale vegetation monitoring methodology to provide information supporting long-term adaptive management of the island's resources. Previous vegetation mapping efforts of the island (Minnich 1980; Jones et al. 1993) provide a general overview of the vegetation communities. However, they do not have enough accuracy or precision to describe the island's subtle and complex community compositions. The methodologies employed in these mapping efforts are also not documented in enough detail to sufficiently replicate them, and therefore have limited value for supporting current and future management decisions. In this paper, we describe the development of a vegetation database at high spatial resolution that will facilitate the monitoring, management, and recovery of distinct plant communities.

STUDY AREA

SCI is situated 55 km west of Los Angeles and 40 km south of Santa Barbara, and is the largest of the California Channel Islands. The island trends east to west, and has roughly 124 km of coastline. The 249 km^2 island includes two mountain ranges flanking a central valley, a long east-west isthmus, and an eastern end fairly isolated by a high and steep ridge. It sustains more than 625 plant species (Junak et al. 1995), 198 bird species (Jones et al. 1998), and 12 species of native reptiles, amphibians, and terrestrial mammals (Laughrin 1980).

In 1978, a 90% interest in SCI was purchased by TNC, and outright ownership was gained in 1987. TNC transferred 8,500 acres (14% of the island) to the National Park Service (NPS) in 2000, adding to the 10% of the island that had been designated a National Park in 1980. The island is managed cooperatively by both land owners.

METHODS

Based on the desired level of spatial and categorical specificity, and the amount of funding available, aerial photo interpretation was selected to create the database. Knapp (2005) described the following reasons for selecting aerial photo interpretation versus remote sensing for the vegetation mapping of another Channel Island, Santa Catalina Island: 1) aerial photography provides higher resolution than satellite imagery; 2) satellite imagery requires extensive ancillary data and additional labor to classify plant communities; and 3) some plant communities are too spectrally similar to be differentiated in satellite imagery. Knapp also suggested that mapping at very high resolution provided reduction of intra-polygon heterogeneity, as well as capturing of localized vegetation change. IK Curtis Inc. (Burbank, CA) was contracted to acquire and print 156 1:12,000 stereo pair, true color aerial photographs of the island. The flights to acquire these images were conducted in November 2005.

To generate the vegetation map, photo interpreters reviewed aerial photographs to identify photo signatures—unique combinations of color, texture, tone, and pattern associated with each land cover feature. By observing the context and extent of the photo signatures associated with specific vegetation types, the photo interpreter is able to identify and delineate boundaries between plant communities, resulting in the creation of mapping units or polygons with distinctive photo signatures. These photo signatures are then linked to vegetation attributes (e.g., type, cover, and the fennel mapping unit) observed in the field using a classification system and photo interpretation key. In the following sections, we describe the methods for field data collection and development of the classification system, photo interpretation, data conversion of the final map layers, and accuracy assessment.

Field Data Collection and Classification System

We selected a floristic-level classification system based on Sawyer and Keeler-Wolf's (1995) and the newly revised alliance-based classification system for California (Sawyer et al. 2009). This was determined suitable for the management needs of island projects based on the system's ability to capture rare plant assemblages, its ability to be combined into coarser levels of classification (Knapp 2005), and its consistency with the National Vegetation Classification System (Grossman et al. 1998; Jennings et al. 2003). This system is being adopted by the Federal Geographic Data Committee (FGDC 2008) in the draft National Vegetation Classification Standard (Version 2.0), and is becoming more widespread in vegetation mapping projects in California (D. Johnson, personal communication). We considered it to be important to add to the developing statewide body of knowledge of vegetation, while maintaining the ability to compare with earlier vegetation maps and vegetation databases of other Channel Islands. It is important to note, however, that the classification used for this project was derived from field sampling and analysis, and then expanded based on expert opinion, and thus did not rest completely upon the field-based classification process used in other recent studies. Therefore, although the shape and size of each mapped polygon are likely to remain constant, their nomenclature may formally change in the future if further field classification and data analysis are done.

The classification system for SCI is arranged hierarchically from class to formation, to mapping unit or alliance, and finally sub-alliance or potential association, with class being the most inclusive category and sub-alliance being the least inclusive (Table 1). Primary sources of data used to determine the floristic composition of each mapped polygon and develop the classification system were data from a series of 362 relevé plots, field reconnaissance, and *A Flora of Santa Cruz Island* (Junak et al. 1995).

Relevé Plots: The relevé plots are a series of 362 locations spread non-systematically across the island, developed and maintained by the USGS and the NPS. At each point a visual survey is undertaken to record a variety of aspects of the plot location, including the physical characteristics of slope and aspect, soil depth, and elevation; community type or types, size, and distance to nearest adjacent stand; animal disturbance; substrate; species information including coverage and phenology, stratum, and tree diameters; and associated species. Each plot is 40 m by 10 m, with the long axis parallel to the major landscape slope. The community types are derived from those detailed in *A Flora of Santa Cruz Island* (Junak et al. 1995).

Field Reconnaissance: Two field reconnaissance trips were made to SCI to identify the floristic composition of vegetation types to be used in the classification system. The first trip was conducted in July 2006 to the west side and the isthmus (TNC side of the island), and the second was made in August 2006 to the east side of the island (NPS side). Field reconnaissance was performed by AIS photo interpreters and the senior ecologist from California Department of Fish and Game's Vegetation Classification and Mapping Program (Todd Keeler-Wolf), who served as a reconnaissance advisor and expert on the classification of California vegetation types. TNC ecologists also accompanied the reconnaissance team on field visits. The field reconnaissance visits served two major functions. First, they allowed the photo interpreter to key the signature on the aerial photos to the vegetation on the ground at each site. Second, they allowed the photo interpreter to become familiar with the flora, vegetation communities, and local ecology that occur in the study area. Understanding the relationship between

Table 1. Hierarchy of vegetation classification used to map Santa Cruz Island in 2006 compared to other established vegetation classification hierarchies.

Sawyer et al. (2009) classification	U.S. National Vegetation Classification	AIS (2007) level of vegetation classification	Example (Code – Type)
Formation subclass	Class	Class	1000 – Forest
Formation	Subclass		
Division	Group		
Macrogroup	Subgroup		
Group	Formation	Formation	1200 - Temperate Needleleaf Evergreen Forests
Alliance	Alliance	Mapping unit or alliance	1210 – Bishop Pine Alliance
Association	Association	Sub-alliance or potential association	1213 – Bishop Pine / Island Scrub Oak – Island Manzanita

the vegetation units and the environmental context in which they appear is useful in the interpretation process, and familiarity with regional differences aids interpretation by establishing a context for a specific area.

Prior to the field reconnaissance trip, each aerial photo was reviewed under a stereoscope for representative signatures of different vegetation types; geographic variables (% slope, aspect, shape of the slope, elevation); and other abiotic variables noted on the photography. Field check sites and associated notations were annotated directly onto a photo field acetate overlay, thereby correlating the field site to a specific location and photo signature. Multiple sites were chosen to provide alternatives if one or more sites proved inaccessible. Additional field sites included areas encountered in transit between initially selected sites, areas of noteworthy or unusual significance, and other vegetation types the photo interpreter or field ecologist deemed important. Field routes were then planned to accommodate a variety of factors including: maximizing the number of vegetation communities and elevation zones visited, responding to any recommendations of project staff, addressing time constraint considerations, and accessibility.

A total of 350 ground control points were taken in the field with a GPS unit. Distance and direction data measured by laser range-finder and compass in the field were then used to correct these locations. The environmental setting, dominant vegetation, and potential alliance were described for each ground control point. Color ground photos were taken with a digital camera at selected locations, to be compared later to the aerial photographs and the field site notes. Using information derived from the field reconnaissance and any existing field plot data, Keeler-Wolf developed a preliminary mapping classification and photo interpretation signature key based on the rules of the National Vegetation Classification system and existing information from other parts of California. Photo interpreters used *A Flora of Santa Cruz Island* (Junak et al. 1995) to aid in the development of the preliminary mapping classification. In addition, the vegetation map created by Richard Minnich in 1980 (*Vegetation of Santa Cruz Island*) was used to help photo interpreters further correlate aerial photo signature with previously mapped vegetation stands, with the understanding that the 1980 mapping product was created under a different set of criteria over 25 years ago. This system was revised based on realistic concerns of size and discernability of the different vegetation types. Not all of the categories could be mapped from the aerial photography. Mapping of these categories therefore relied on plot data, field visits, personal expertise, and other ancillary information, including IKONOS multi-band satellite imagery from April 2005.

Preliminary Photo Interpretation

Photo interpretation (PI) is the process of identifying polygons based on their photo signature. Photo interpretations for the SCI map were done using aerial photography at a scale of 1:12,000 (1" = 1000 feet). Photo interpreters used 3X ocular lenses to enhance line detail to a scale of approximately 1:3000. Viewing the final rectified linework over imagery at scales larger than 1:3000 may show spatial errors, which are beyond the resolution of the input scale at which the interpretation was originally performed. Each aerial photo was prepared with a 9" x 9" frosted Mylar overlay for the photo signature delineations. Study area boundaries were drafted onto each photo overlay, defining the area within the photograph to be interpreted. The study area boundaries were edge matched to adjacent photos to ensure complete coverage. Data from additional collateral sources (existing vegetation maps, supplemental imagery, soil data, plot data, etc.) were added to the overlay in order to document all locations and information within the study area on an aerial photograph.

Using a mirror stereoscope, with a 3X ocular lens, photo signature units were delineated onto the overlay. These initial photo delineations were based on a number of signature characteristics including color, tone, texture, relative height, and cover. Environmental factors such as elevation, slope, and aspect were also considered in the photo interpretation decision-making process. Attribute codes were assigned to each polygon and annotated onto the overlay. The vegetation polygons and codes were edge matched to the adjoining photo overlays. Areas of land use were also mapped during the mapping of the vegetation units. In addition to the criteria for defining each community or alliance, the interpretation was conducted in accordance with the preliminary mapping classification created as a result of the field reconnaissance trips. Any questionable photo signatures encountered during this phase of the mapping effort were sent to the TNC field ecologist (Coleen Cory). This required her to either use her existing knowledge of the area or go out into the field to the site in question to get an answer.

Attributes assigned to each polygon included a vegetation classification type, a fennel category, and a cover rating. Specific management needs related to the concern over the status and trends of problematic pest plants required the inclusion of a primary category for fennel (*Foeniculum vulgare*), along with an attribute modifier that described a categorical estimate of fennel cover for areas that contained fennel. If fennel was interpreted as the dominant species for a polygon, that polygon was assigned the specific fennel category. Other areas that contained fennel were assigned a value (#) corresponding to <5% (1), 5% to 10 (2), or > 10 (3).

Vegetative cover is a quantitative estimate of plant cover derived from viewing the aerial photography in stereo magnification. Each polygon had a cover rating assigned to three different categories: conifer, hardwood, and shrub. The three cover estimates assist in describing the vegetation characteristics of each polygon. Photo interpreters used six categories to define vegetative cover: 1 = Greater than 60%; 2 = 40%–60%; 3 = 25%–40%; 4 = 10%–25%; 5 = 2%–10 %; 9 = Not applicable. Photo interpreters can only quantify the vegetation that is visible on the aerial photography and therefore total vegetative cover may differ from assessments done on the ground by field crews. Using aerial photography at scales smaller than about 1:12,000, photo interpreters generally cannot see the amount of vegetation that is obscured by a higher canopy, regardless of its life form. Understory vegetation that is not visible on the aerial photograph cannot be quantified when assigning the total cover of vegetation for that polygon. Assigning cover values to the polygons required AIS to develop a series of rules for assigning these values:

1) To determine vegetative cover, assign percentages to the different life forms visible on the aerial photo, including non-vegetated areas. The total percent cover of conifer trees, hardwood trees, shrubs, herbaceous, and non-vegetated must add up to 100%. The cover percentages are then converted into the six cover categories described above.

2) Do not code non-vegetated areas unless they meet the 0.5 ha minimum mapping resolution and can be mapped as a stand-alone polygon. Otherwise, it was assumed that all vegetation polygons contain some non-vegetated areas.

3) Consider the coverage pattern of the life form before assigning a cover code to the polygon. Estimating cover is more straightforward when plants occupying the same strata are evenly distributed throughout the polygon. However, when polygons contain populations of plants that are clumped or occur only in portions of the polygon, the area that is not occupied by plant cover is considered when determining total cover. To ensure consistency, count the plants in polygons with clumped and unevenly distributed vegetation and then compare them to similar sized polygons with an even distribution of plant cover.

4) Use vegetation stature and the scale of the aerial photography to determine the visibility of individual plants. With larger scale photography, trees and shrubs were usually visible as individuals. Grasses were rarely seen as individual plants, regardless of the scale of the photography.

5) In the case of trees and shrubs, the percent cover at a cover break was adjusted downward. If the percent cover was at about 25%, the polygon was assigned a cover category of sparse (10%–25%) instead of dispersed (25%–40%).

6) Dry grasses tend to be less dense than they appear on the aerial photography. To more accurately depict the cover, the percent cover for dry grasses was adjusted downward. If the percent cover fell at the lower end of a cover class, the polygon was assigned the next cover class down. For example, if the percent cover was 25%, the polygon was assigned a cover category of sparse (10%–25%) instead of dispersed (25%–40%).

7) The date that the aerial photography is flown also influences the cover assigned to vegetation types, especially for herbaceous dominated vegetation types. Subsequent field verification and accuracy assessments must take into consideration the following factors that can cause apparent discrepancies between the cover evident on the photo and those visible in the field:

a) Seasonality—The cover of most herbaceous plants is variable due to their annual growth cycle. Depending on the season the aerial photography was taken, a mapped polygon could show a different cover on the aerial photographs than is observed during an on-site visit at a different time of the year. Another effect of seasonality is "leaf on/off" conditions. Photos of forest or woodland areas with "leaf on" conditions obscure the understory. Photos of leaf off conditions would allow photo interpretation of the understory, but make it difficult to identify the overstory species since there is no foliage present.

b) Annual variability—The environmental conditions at the time of the photography (wet vs. drought years, flooding, etc.) may affect the cover seen during the on-site field visits.

The size of a minimum mapping unit was 0.5 ha (5000 square m). This minimum mapping unit represented a compromise between the desire to have as much spatial and categorical detail as possible, and the reality of available funding. Exceptions to this minimum mapping unit were made for unique vegetations types and features that are often smaller than 0.5 ha in the landscape (Table 2). Distinct vegetation polygons smaller than 0.5 ha that were surrounded by spatially larger vegetation types were incorporated into the surrounding dominant vegetation type. The delineated vegetation boundaries represent the photo interpreter's estimate at defining the modal break point between two communities, whether at a detailed association level of mapping or at a more general habitat level (AIS 2007).

AIS created detailed documentation that describes how each category was delineated. These descriptions include mapping descriptions, environmental setting, distribution, and photo interpretation signature—mapping characteristics. This documentation is too large to include in this paper, but can be acquired from: http://www.tnccalifornia.org/gis/.

Data Conversion

Data automation was conducted using Mono Digitizing Stereo Digitizing (MDSD) software. Control points were identified both on the IKONOS imagery and the aerial photography and were input into an ARC/INFO point coverage. The MDSD software captured the vegetation linework, automatically georeferenced the data into real world coordinates using the control points generated in the previous step, and converted the linework into an

Table 2. Vegetation features mapped at scale less than 0.5 ha.

Type	# of polygons	Min. polygon size (ha)	Max. polygon size (ha)	Avg. polygon size (ha)	Total area (ha)
Australian Saltbush Mapping Unit	52	0.13	30.34	2.16	112.56
Big Leaf Maple Alliance	4	0.16	0.61	0.44	1.77
Bracken Fern Alliance	3	0.11	3.44	1.41	4.24
Coastal Salt Pan Mapping Unit	4	0.25	0.65	0.42	1.66
Fremont Cottonwood – Black Cottonwood Superalliance	32	0.06	2.07	0.53	16.86
Giant Wildrye – Creeping Wildrye Superalliance	14	0.17	1.55	0.61	8.56
Harding grass	14	0.06	12.52	2.33	32.61
Ironwood Alliance	483	0.03	3.73	0.37	178.94
Saltgrass Alliance	39	0.05	14.07	1.52	59.25
Sea Blite San Miguel Island Locoweed	33	0.19	3.88	0.86	28.33
Silver Beachbur – Beach Sand – Verbena Alliance	23	0.07	3.02	0.89	20.45

ARC/INFO coverage. The coverage was checked for open polygons, data registration, and any spatial edge match problems between photos. Spatial refinement was performed in ARCEDIT sessions using various user-defined tools. Lines depicting boundaries representing minimal ecotones (for example—land use interface, water bodies, life-form interface) were refined.

The vegetation mapping type, conifer cover, hardwood cover, shrub cover, and fennel component modifier codes were input for each polygon based on those created by the photo interpreter during the mapping phase. Automated quality control measures that AIS created were run to check for code validity.

A hard copy edit plot of the converted spatial data was produced and compared to the aerial photo overlays. Each plot was checked for cartographic quality of the arcs defining the polygon features and the accuracy of the label assignments. Line and code corrections were noted directly on the edit plot. All edit plots were edge matched to verify line and code accuracy across the entire project area. Processors conducted interactive ARCEDIT sessions to make the necessary corrections to the coverages. The final vegetation layer was examined by the senior photo interpreter. Final checks were conducted to test for invalid codes, duplicate labels, missing or extra lines, edge match problems, verification of the registration of linework to the IKONOS base imagery, and review of the distribution of species mapped within the study area.

Accuracy Assessment

Upon completion of the preliminary photo interpretation, the senior photo interpreter reviewed each photo for polygon delineation, PI signature code, cover codes, and fennel modifier accuracy. Each photo overlay was checked for completeness, consistency, and adherence to the mapping criteria and guidelines established by AIS. A rigorous quality control/ field verification effort was undertaken in order to assure consistency throughout the mapping product and to ensure photo signatures were accurately depicting what was noted on the ground. This effort was accomplished by creating hard-copy plots at a scale of 1:8400. These depicted the polygon data over the CIR imagery, with a 1000 m UTM grid draped over the entire map. All relevant data including the floristic code, density, and other modifiers were labeled in the polygon. Using a GPS along with a rangefinder, compass, and the hard copy plots, photo interpreters accompanied the island ecologist, Coleen Cory, on a 1-week effort to locate and check over 300 polygons within a ½ mile buffer from most of the travelable roads on the island. This represented slightly fewer than 3% of the total polygons mapped. Once this effort was completed, photo interpreters made corrections to polygons that were noted in the field verification effort. In addition, any incorrect trends between what was mapped to the aerial photo signature and what was actually found on the ground were refined and corrections were extrapolated onto the remainder of the map. Due to financial and time related constraints, AIS was not contracted by TNC to perform a formal accuracy assessment on the final database.

RESULTS

The resulting database contains 10,652 polygons ranging in size from 0.03 ha to 624.19 ha, with a mean of 2.33 ha. The final vegetation map can be downloaded from TNC's Web site: www.tnccalifornia.org/conservation/sciveg.html. The classification system begins with five classes: Forest, Woodlands, Shrublands, Herbaceous, and Land Use/Sparsely or un-vegetated. Shrublands are the dominant class, covering roughly 70% of the island (see Appendix). Herbaceous vegetation is the second largest class, at 21.2%. Forest, consisting predominantly of Bishop Pine forest, covers 3.8%. The Woodlands and Land Use classes make up the remainder of the island, covering 2.8% and 2.4%, respectively.

The five classes are further broken down into 17 formations. These formations were further broken out into mapping units or alliances, and then even further into sub-alliances or potential associations, where possible (see Appendix). For example, the Shrublands class contains four formations: Temperate Broadleaf Sclerophyll Evergreen Shrublands (Chaparral); Temperate Microphyllous Evergreen Shrublands; Temperate Xeric Mixed Drought-Deciduous Shrublands; and Temporarily Flooded Cold Season Deciduous Shrublands. Nested within the Temperate Broadleaf Sclerophyll Evergreen Shrublands (Chaparral) formation is the

Table 3. Summary of cover estimates.

Cover category*	Conifer (ha)	% of island	Hardwood (ha)	% of island	Shrub (ha)	% of island
1	18.6	0.1%	244.9	1.0%	3398.4	13.6%
2	153.3	0.6%	301.6	1.2%	2101.1	8.4%
3	160.7	0.6%	222.0	0.9%	3109.4	12.5%
4	331.3	1.3%	193.1	0.8%	7158.1	28.7%
5	516.2	2.1%	1904.2	7.6%	6511.1	26.1%
Totals	1180.1	4.7%	2865.8	11.5%	22,278.1	89.5%

*Cover categories: 1 = >60%; 2 = 40%–60%; 3 = 25%–40%; 4 = 10%–25%; 5 = 2%–10%.

Island Scrub Oak alliance. That alliance comprises 26.2% of the area mapped in its class (Shrublands), and 89.2% of the area mapped in its formation. Nested within the Island Scrub Oak alliance are six sub-alliances, the largest of which is Island Scrub Oak–Island Ceanothus, which accounts for 37% of the alliance, 33% of the formation, 9.7% of the class, and 6.8% of the island. The 720.3 ha assigned to the Island Scrub Oak alliance could not be further classified into one of the six sub-alliance and represents 15.8% of that group.

Cover

Assigning one of five cover categories for conifer, hardwood, and shrub cover to each vegetation polygon yields a multitude of combinations between vegetation type and woody species cover. There are 125 possible unique descriptors of woody species cover that could be assigned to each of the 10.652 delineated polygons and 216 combinations if a zero value is one of the cover values.

Conifers, hardwoods, and/or shrubs occurred in sufficient cover over nearly 90% of the island to allow a cover estimate to be assigned to at least one of these woody plant groups (Table 3). The remainder of the island did not have sufficient woody cover to be assigned cover estimates for conifers, hardwoods, or shrubs. Over half of the island was mapped as having a shrub cover <25%. The re-establishment of shrubs into grasslands or barren areas post-grazing may account for these low cover estimates. The cover measures for conifers may also describe regeneration patterns. Over 70% of areas with conifers exhibit conifer cover <25%. Cover values for hardwoods are even lower. Two-thirds of areas with hardwoods show cover <10%.

Fennel

Polygons dominated by fennel account for roughly 1% of the island. Polygons that were given a fennel modifier, indicating some amount of fennel was present, represent another 6% of the island. Nearly 40% of this latter category consists of fennel occurring in the California Annual Grasslands alliance. Another 20% consists of fennel occurring in the Coyote Brush alliance. In total, 3% of the island has vegetation where fennel comprises >10% of the vegetation polygon (Table 4).

Table 4. Summary of area mapped with fennel modifier.

Fennel modifier*	Ha	% of island
4301 Fennel dominant	244.9	1.0%
3 – Severe**	489.1	2.0%
2 – Moderate	335.4	1.3%
1 – Minimal	679.7	2.7%

* 1 = Minimal: Generally less than 5% cover of fennel in the polygon. Photo interpreters may or may not be able to detect these small amounts, and ground based information is often necessary in assigning a fennel modifier of 1.

2 = Moderate: Approximately 5%–10% cover of fennel over most of the polygon. Polygons with this cover class are visible on the aerial photography.

3 = Severe: Over 10% cover of fennel is in the polygon. Fennel is often a co-dominant to other herbaceous vegetation.

** In this table Fennel modifier "severe" does not include polygons in the 4301 mapping unit.

Table 5. Comparison of vegetation classification categories used in previous vegetation mapping of Santa Cruz Island.

Minnich 1980 Based on 1970 photos Physiognomic type	Jones et al. 1993 Based on 1985 photos Vegetation class
Grasses	Grasses
Coastal Sage Scrub	Coastal Sage Scrub
Chaparral	Chaparral
Woodlands	Island Oaks*
	Oaks
	Island Ironwoods
Conifer Forest	Pines
Riparian	Riparian
Woody Exotics	Woody Exotics
Barren	Barren

* Island Oaks refers only to *Quercus tomentella*. All other oaks are included in "Oaks" category.

Accuracy Assessment

While no formal accuracy assessment was performed, the field verification process found a few labeling discrepancies that were subsequently corrected. Of the roughly 300 polygons checked for accuracy, fewer than 10 polygons required changes to their attributes.

DISCUSSION

The spatial database created as a result of this mapping project represents the vegetation conditions on SCI at the end of 2005. As management of island resources continues, we will want to track changes in vegetation that may result from our management. This is best done by conducting an update to the spatial vegetation database in the future. The decision rules described, implemented, and documented by AIS will allow us to reproduce methodology so that future iterations of the database will be both spatially and categorically comparable. Furthermore, the database structure will allow updates and future mapping data to be seamlessly integrated with existing data. In a similar fashion, if other California Channel Islands were mapped using these same protocols, data could be easily compared across islands.

Minnich (1980) created a vegetation map for SCI using 1:22,000 scale color infrared aerial photography dating from 1970. No *a priori* classification system was used. Vegetation was instead grouped by floristic and physiognomic characteristics and assigned to one of eight physiognomic types: Grassland, Coastal Sage Scrub, Chaparral, Woodlands, Conifer Forest, Riparian, Woody Exotics, and Barren (Table 5). These types were further subdivided into one of 36 vegetation sets based on the dominant species as discerned from the photos.

Jones et al. (1993) used 1:24,000 scale aerial photography dating from 1985 to create an SCI spatial vegetation database based on a classification scheme devised by Philbrick and Haller (1977). Island vegetation was assigned to 1 of 11 vegetation classes based on tone, texture, and context of vegetation observed in aerial photos (Table 6).

Table 6. Changes in vegetation cover between 1985 and 2005 on Santa Cruz Island.

Vegetation type (from Jones et al. 1993)	Hectares (1985)	Hectares (2005)
Grasses	16,578.8	5037.5
Coastal Sage Scrub	809.7	11,921.7
Chaparral	3585.8	5153.2
Oaks*	1031.0	666.2
Island Ironwoods	103.6	179.1
Pines	292.1	664.0
Riparian	463.8	373.5
Woody Exotics	27.1	33.6
Barren	1665.6	569.6

*The "Oaks" category from 1985 includes several species of oaks (but not island oaks) and thus represents more acreage than the 2005 data, which distinguishes among these oak species and assigns them to different and finer scale mapping units.

NPS (2004) created a vegetation database, using 2-ft digital aerial photography, that classified the vegetation at the formation or sub-formation level where possible. These types included medium tall grassland (35%), mainly deciduous shrubland (25.4%), mainly evergreen shrubland (22.6%), mainly evergreen woodland (9.5%), forb-dominated vegetation (5.4%), mainly evergreen forest (0.25%), mainly deciduous woodland (0.6%), human use (0.1%), and mainly deciduous forest (> 0.1%).

Despite the differing methodology and vegetation groupings, we attempted to conduct a comparison between the 1985 (Jones et al. 1993) mapping data and our 2005 data. We constructed a cross-walk table that assigned each of our 2005 vegetation categories to one of the more inclusive categories from 1985. We assigned these categories based on physiognomic characteristics, species composition, and spatial distribution. Bare ground decreased dramatically during the intervening 20 years while at the same time all types of vegetation expanded across the island (Fig. 1; Table 6). The increase in vegetative cover corresponds to the time period during which more than 46,000 feral sheep and the remaining 2000 head of cattle were removed from the island.

Subsequent mapping can be used to track additional changes that are likely to occur as a result of removing more than 5000 feral pigs from the island between 2005 and 2007. Pigs demonstrated a food preference for certain plants, both native (oaks and bulb plants) and non-native fennel (NPS 2002). Their absence from the island may be reflected in shifting vegetation patterns that can be detected through fine-scale vegetation mapping.

Fennel is a perennial herb native to the Mediterranean basin. It was introduced to SCI

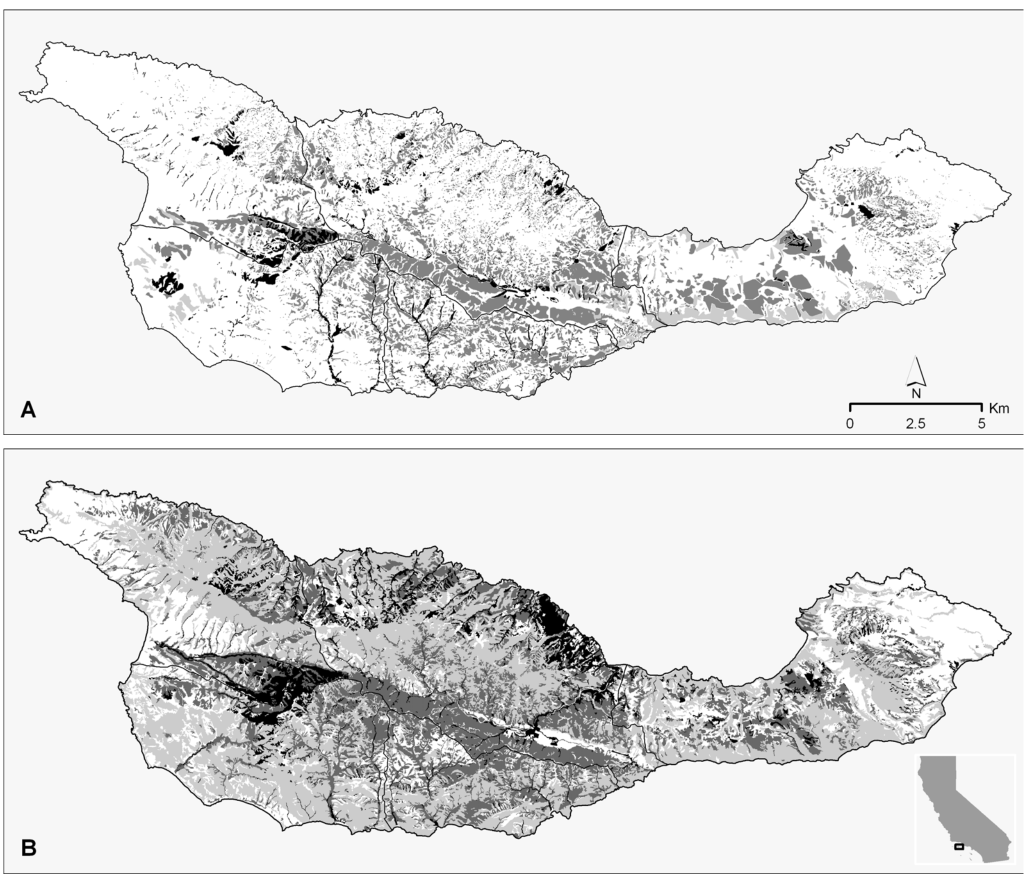

Figure 1. Vegetation change on Santa Cruz Island, 1985–2005. Maps depict generalized vegetation categories: bare ground and herbaceous vegetation, white; scrub and low stature vegetation, light gray; chaparral and medium canopy communities, dark gray; forest and woodland, black. (A) Vegetation prior to/during the eradication of feral sheep (adapted from Jones et al. 1993 and Howarth et al. 2005). (B) Vegetation of 2005. Island location in the state of California shown in inset.

sometime in the mid- to late 1800s. By 1887 it was thoroughly established on the hillsides around Prisoners' Harbor (Junak et al. 1995). Sheep and cattle grazed fennel and spread seeds in their feces and on their hooves. Pig wallows and rooting were numerous in fennel areas (B. Cohen, C. Cory, and J. Menke, personal observation 2006), and pigs were also likely vectors for seeds. It is interesting to note that while sheep and cattle were present, fennel was kept low enough in stature to not be noticed or categorized in previous vegetation maps (Minnich 1980; Jones et al. 1993). With removal of cattle in the mid-1990s, fennel became more conspicuous in the landscape. The current database designates a separate category for fennel-dominated areas (AIS 2007). These fennel polygons were also assigned cover categories. Future vegetation mapping can thus track the extent and cover of fennel. Decreasing fennel cover can indicate recolonization by other plants.

Conservation organizations and agencies spend a great deal of public and private money protecting and restoring elements of biodiversity. On SCI this has included removal of feral non-native animals and invasive weed species as well as supporting projects to increase the numbers of native foxes, bald eagles, and rare plants. Tracking and monitoring results and consequences of these actions also require a significant investment of time and money. For land managers of SCI, this type of vegetation map and database represents a cost-effective way to monitor long-term changes across a large landscape. Traditional ground-based vegetation monitoring methods using plots, transects, relevés, etc., can be extremely costly in terms of staff time. While such ground-based data may be very detailed, they are limited in spatial scale, and often limited in scope due to rugged or inaccessible terrain. Unlike vegetation mapping based on plot data that must then be extrapolated to areas not sampled, the methodology presented here essentially samples the entire landscape and provides relatively fine-scale information for any given point on the island. We believe that by employing both fine-scale field methods and larger scale photo-based methods, we have developed a highly sensitive and cost-effective means of monitoring changes to vegetation across a landscape within a broad range of scales.

ACKNOWLEDGMENTS

The authors would like to thank staff members of Aerial Information Systems, Inc., TNC's Santa Cruz Island Project, the Channel Islands National Park Service, the USGS-Biological Resources Discipline, and the California Department of Fish and Game for all of their assistance in making this project happen. We would also like to thank L. Lozier, R. Shaw, T. Keeler-Wolf, D. Garcelon, and S. Solis for their reviews and contributions to this manuscript.

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Appendix . Distribution of vegetation on Santa Cruz Island at all levels of classification.

Class	Formation	Mapping unit or alliance	Sub alliance – Potential associations	Hectares	% of island	% of class	% of formation
1000 – Forest							
	1100 – Temperate Broadleaf Sclerophyll Evergreen Forests			0.1	0.0%	0.0%	0.0%
		1110 – Ironwood Alliance		178.9	0.7%	19.1%	70.2%
		1120 – Eucalyptus Stands Mapping Unit		31.7	0.1%	3.4%	12.4%
		1130 – Island Cherry - (Island Scrub Oak – Toyon)		44.3	0.2%	4.7%	17.4%
	1200 – Temperate Needleleaf Evergreen Forests						
		1201 – Introduced Pines or Cypress Mapping Unit		0.9	0.0%	0.1%	0.1%
		1210 – Bishop Pine Alliance		106.6	0.4%	11.4%	16.1%
			1211 – Bishop Pine –(Island Oak) / (Summer Holly – Toyon)	254.2	1.0%	27.1%	38.3%
			1212 – Bishop Pine / California Huckleberry – (Summer Holly-Toyon)	5.5	0.0%	0.6%	0.8%
			1213 – Bishop Pine / Island Scrub Oak – Island Manzanita	223.4	0.9%	23.8%	33.6%
			1214 – Bishop Pine / Island Scrub Oak – (McMinn's Manzanita – Woolly Leaf Manzanita)	21.1	0.1%	2.3%	3.2%
			1215 – Bishop Pine – Coast Live Oak / (Island Scrub Oak–Island Manzanita)	52.4	0.2%	5.6%	7.9%
	1300 – Temporarily Flooded Cold Season Deciduous Forests			0.5	0.0%	0.1%	2.5%
		1310 – Big Leaf Maple Alliance		1.8	0.0%	0.2%	9.3%
		1320 – Fremont Cottonwood – Black Cottonwood Superalliance		16.9	0.1%	1.8%	88.3%
	Forest Total			**938.1**	**3.8%**		
2000 – Woodlands							
	2100 – Xeric Sclerophyll Evergreen Woodlands						
		2110 – Coast Live Oak Alliance		660.5	2.7%	99.1%	99.1%
		2120 – Canyon Live Oak Alliance		5.7	0.0%	0.9%	0.9%
	Woodlands Total			**666.2**	**2.7%**		
3000 – Shrublands				4.4	0.0%	0.0%	0.0%
	3100 – Temperate Broadleaf Sclerophyll Evergreen Shrublands (Chaparral)			84.5	0.3%	0.5%	1.7%
		3101 – McMinn's Manzanita - (Woolly Leaf Manzanita)		13.2	0.1%	0.1%	0.3%

Appendix (continued). Distribution of vegetation on Santa Cruz Island at all levels of classification.

Class	Formation	Mapping unit or alliance	Sub alliance – Potential associations	Hectares	% of island	% of class	% of formation
		3110 – Chamise Alliance		19.3	0.1%	0.1%	0.4%
		3120 – Island Scrub Oak Alliance		720.3	2.9%	4.1%	14.1%
			3121 – Island Scrub Oak – Island Manzanita (Chamise - Bigpod Ceanothus)	1201.0	4.8%	6.9%	23.5%
			3122 – Island Scrub Oak – Summer Holly	45.4	0.2%	0.3%	0.9%
			3123 – Island Scrub Oak – Island Ceanothus	1687.2	6.8%	9.7%	33.0%
			3124 – Island Scrub Oak – (Island Manzanita – Chamise–Bigpod Ceanothus) Maritime	136.4	0.5%	0.8%	2.7%
			3125 – Island Scrub Oak – McMinn's Manzanita – (Woolly Leaf Manzanita – Chamise)	204.5	0.8%	1.2%	4.0%
			3126 – Island Scrub Oak – Coastal Sage Scrub Transition	562.0	2.3%	3.2%	11.0%
		3130 – Island Manzanita Alliance		213.9	0.9%	1.2%	4.2%
		3140 – Birch-leaf Mountain Mahogany Alliance		11.8	0.0%	0.1%	0.2%
		3150 – Lemonadeberry Alliance		209.4	0.8%	1.2%	4.1%
	3200 – Temperate Microphyllous Evergreen Shrublands						
		3240 – Coyote Brush Alliance		986.6	4.0%	5.7%	87.5%
		3250 – Mulefat Alliance		140.8	0.6%	0.8%	12.5%
	3300 – Temperate Xeric Mixed Drought-Deciduous Shrublands			10.8	0.0%	0.1%	0.1%
		3301 – Coastal Bluff Scrub Habitat		650.3	2.6%	3.7%	6.0%
		3302 – Australian Saltbush Mapping Unit		112.6	0.5%	0.6%	1.0%
		3303 – Inland Bluff Scrub Habitat		2716.0	10.9%	15.6%	24.9%
		3310 – California Sagebrush Alliance		650.3	2.6%	3.7%	6.0%
			3311 – California Sagebrush Pure Stands	7.9	0.0%	0.0%	0.1%
			3312 – California Sagebrush – Santa Cruz Island Buckwheat	980.7	3.9%	5.6%	9.0%
			3313 – California Sagebrush – Lemonadeberry	804.1	3.2%	4.6%	7.4%
			3314 – California Sagebrush - Coastal Bluff Scrub Transition	276.6	1.1%	1.6%	2.5%

Appendix (continued). Distribution of vegetation on Santa Cruz Island at all levels of classification.

Class	Formation	Mapping unit or alliance	Sub alliance – Potential associations	Hectares	% of island	% of class	% of formation
			3315 – California Sagebrush – Island Bush Monkeyflower	349.9	1.4%	2.0%	3.2%
			3316 – California Sagebrush – Coyote Brush	357.4	1.4%	2.1%	3.3%
		3320 – Santa Cruz Island Buckwheat Alliance		2634.2	10.6%	15.1%	24.2%
		3330 – Saint Catherine's Lace Alliance		56.5	0.2%	0.3%	0.5%
		3340 – Island Bush Monkeyflower - Island Bristleweed – Paintbrush Mapping Unit		1291.0	5.2%	7.4%	11.8%
	3400 – Temporarily Flooded Cold Season Deciduous Shrublands			1.4	0.0%	0.0%	0.6%
		3401 – Mixed Arroyo Willow – Mule Fat Mapping Unit		178.4	0.7%	1.0%	76.7%
		3410 – Arroyo Willow Alliance		53.0	0.2%	0.3%	22.8%
	Shrublands Total			**17,404.2**	**69.8%**		
4000 – Herbaceous				0.3	0.0%	0.0%	0.1%
	4100 – Saturated Temperate Perennial Graminoids						
		4101 – Bulrush – Cattail Mapping Unit		0.1	0.0%	0.0%	100.0%
	4200 – Seasonally or Temporarily Flooded Graminoids						
		4201 – Seasonally or Temporarily Flooded Springs, Seeps, Vernal Ponds Mapping		0.8	0.0%	0.0%	100.0%
	4300 – Tall Temperate Annual Graminoids			24.8	0.1%	0.5%	0.5%
		4301 – Fennel Mapping Unit		244.9	1.0%	4.6%	4.8%
		4310 – California Annual Grasslands Alliance		4817.9	19.3%	91.2%	94.5%
		4320 – Giant Wildrye - Creeping Wildrye Superalliance		8.6	0.0%	0.2%	0.2%
	4400 – Tall Temperate Perennial Graminoids						
		4401 – Coastal Salt Pan Mapping Unit		1.7	0.0%	0.0%	3.0%
		4402 – Needlegrass					0.0%
		4410 – Silver Beachbur - Beach Sand-Verbena Alliance		20.5	0.1%	0.4%	37.4%
		4420 – Harding Grass		32.6	0.1%	0.6%	59.6%
	4600 – Tidally Flooded Grasslands			1.3	0.0%	0.0%	2.1%
		4610 – Saltgrass Alliance		59.3	0.2%	1.1%	97.9%
	4700 – Tall Temperate Forblands			7.6	0.0%	0.1%	7.4%
		4701 – Sea Blite – San Miguel Island Locoweed		28.3	0.1%	0.5%	27.7%
		4702 – Tejon Milk Aster - (Coastal Goldenbush)		62.3	0.3%	1.2%	60.8%

Appendix (continued). Distribution of vegetation on Santa Cruz Island at all levels of classification.

Class	Formation	Mapping unit or alliance	Sub alliance – Potential associations	Hectares	% of island	% of class	% of formation
		4710 – Bracken Fern Alliance		4.2	0.0%	0.1%	4.1%
	Herbaceous Total			**5325.0**	**21.3%**		
9000 – Land Use – Sparsely or Unvegetated							
	9100 – Built-up			30.4	0.1%	5.0%	100.0%
	9400 – Sparsely Vegetated or Unvegetated Areas			6.8	0.0%	1.1%	1.2%
		9410 – Landslides		12.9	0.1%	2.1%	2.3%
		9420 – Cliffs – Rock Outcrops – Steep eroded slopes		510.1	2.0%	83.7%	89.6%
		9430 – Stream Beds and Flats		39.8	0.2%	6.5%	7.0%
	9600 – Planted trees & shrubs			9.5	0.0%	1.6%	100.0%
	Land Use – Sparsely or Unvegetated Total			**609.5**	**2.4%**		