VEGETATION COMMUNITY MAPPING ON SANTA CATALINA ISLAND USING ORTHORECTIFICATION AND GIS

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Abstract—Much remains to be discovered about California's island plant communities, which contain many endemic species and plant communities. A new fine-scale vegetation map was produced for Catalina Island by orthorectifying current color aerial photographs in-house, producing a spatially referenced image which was used in ArcView GIS to digitize the vegetation polygons on-screen. Aerial photography was chosen over satellite imagery due to the detailed scale of map desired. Vegetation types were delineated at the community level following a review of five primary classification systems previously used for the Channel Islands and mainland California. Three new community types and one habitat type were added to an existing classification system used for Santa Cruz Island. Communities were first identified and delineated on 0.4- x 0.4-m aerial enlargements before digitizing. Mixes between two community types such as coastal sage scrub and chaparral were delineated because of their importance floristically and as habitat. This detailed map was then generalized into a second map based on the dominant of the two habitats, yielding two hierarchical levels of the map to suit various needs. Limited communities such as island woodland, southern riparian woodland, southern beach & dune, and coastal marsh are a high priority for future research and protection. The resulting maps have been used for wildlife habitat analysis, fire planning, and stratification of research sites, as well as inventory and quantification. Future work will include a vegetation change study and floristic series description and classification.

Keywords: aerial photography, hierarchical mapping, orthorectification, plant communities, vegetation classification, vegetation mapping

INTRODUCTION

Vegetation maps are useful not only for inventory and quantification of habitat types, but also for change detection, fire planning, wildlife habitat analysis, stratification of research sites, and rare species searches (Callaway and Davis 1993, Holzman 1993, Keith 2000, Sweitzer et al. 2003, USGS-NPS 2003). The Catalina Island Conservancy, which owns and manages 88% of Catalina Island, desired a current, detailed vegetation map to meet all of these needs and more. In particular, with changing cover and species composition resulting from the removal of introduced animals such as feral goats (*Capra hircus*) and feral pigs (*Sus scrofa*), tracking landscape-level changes in Santa Catalina's plant communities is important in order to guide management decisions. Repeated vegetation mapping at a fine scale can be used to capture these changes. This paper describes the classification and methods used to create a new vegetation map for Santa Catalina Island, California (hereafter Catalina), summarizes the results of the mapping process, and identifies future goals.

MATERIALS AND METHODS

Modern vegetation maps are commonly produced using either aerial photography or satellite (digital) imagery. The most appropriate technique to use is determined by the purpose of the map and its desired scale (Millington and Alexander 2000). Catalina Island Conservancy ecologists agreed upon a fine scale of mapping (~4 ha) in order to reduce intra-polygon heterogeneity and best capture localized vegetation change and wildlife habitat. Such a scale is rarely used for mapping large areas such as Catalina (over 19,400 ha).

Photographic and digital imagery have the respective advantages of better spatial resolution vs. better spectral resolution, usually in an inversely proportionate relationship (Lachowski et al. 1996). Satellite imagery is attractive for its ready availability, low cost, and less labor-intensive map production as compared to photographic imagery (Felinks et al. 1998). Although satellite imagery is useful for mapping large areas at coarse spatial or phytosociological scales, it is not as well suited for mapping at more detailed scales, due in part to the coarse resolution available prior to 2000 (Waller 1999, Wyatt 2000). Ancillary data from aerial photographs, topographic information, multitemporal imagery, modeling, or field data are generally necessary to produce an accurate vegetation map using satellite imagery, which may be quite labor intensive (Davis et al. 1994, Lachowski et al. 1996, Waller 1999, Millington and Alexander 2000, Wyatt 2000, Townsend and Walsh 2001). Even with the use of such data, some plant communities may be too similar spectrally for distinction on satellite images and the level of accuracy may not compare to that available from air photo interpretation (Treitz et al. 1992, Waller 1999). On Catalina, where plant communities often mix, this may be especially problematic. For the above reasons, as well as the training, equipment, and data storage required for the use of satellite imagery, aerial photography was chosen as the medium to use for this vegetation mapping project.

Historic Vegetation Maps

Three vegetation maps were produced for Catalina between 1975 and 1980 by the Santa Catalina Island Company (1975), the Center for Natural Areas (1976), and Southern California Edison (1980). The 1975 map delineates basic plant communities such as coastal sage scrub, oak woodland, and grassland, and is mapped at a coarse scale (average polygon size is 65 ha). The 1976 map (Minnich 1980) defines broad physiognomic classes and communities such as grassland, coastal sage scrub, and woody vegetation (chaparral and woodland community dominants). The polygon sizes are highly variable, with the mean size estimated at over 12 ha. The 1980 map delineates dominant species such as island scrub oak (*Quercus pacifica*), coastal prickly pear (*Opuntia littoralis*), and chamise (*Adenostoma fasciculatum*). The mean polygon size of this map is 10 ha. However, species shown in this map appear to be incomplete and inaccurate, based on community composition and species lists known for the island both today and at the time of the most recent flora for the island (Thorne 1967). None of these maps provide either the spatial scale or detail of classification needed by the Conservancy.

Classification System

Five classification systems previously used for the Channel Islands and mainland California were reviewed for this mapping project. These include Thorne's (1976a) vascular plant communities of California, Philbrick and Haller's (1995) communities for the southern California islands, Holland's (1986) terrestrial natural communities of California, Junak et al.'s (1995) communities of Santa Cruz Island, and Sawyer and Keeler-Wolf's (1995) series-based classification system for California. Sawyer and Keeler-Wolf's system is ideal because it utilizes floristic-level units for mapping which are particularly useful for capturing and tracking rare plant assemblages, and can be combined into coarser levels of classification for higher-level mapping. This system is also consistent with the National Vegetation Classification System (Jennings et al. 2002). It is not always possible to identify floristic-level units from aerial imagery, however, and because it was previously determined that this project would use aerial photography to create the map, and because resources needed to collect data at the scale required for floristic-level mapping were unavailable, project managers decided to select a classification description at the community level. Plant community classification places plant assemblages into communities based on a combination of physiognomy, species composition, and habitat characteristics, and such a map would provide the Conservancy with the information required for ongoing restoration and species recovery efforts.

Of the existing community classifications, none completely described the plant communities on Catalina Island. Holland's (1986) designations for the terrestrial natural communities of California are somewhat more detailed than the community-level classification system developed by Philbrick and Haller (1995) for the southern California

Islands, and Junak et al. (1995) used a combination of these classifications for their description of Santa Cruz Island. Thorne's (1976a) classification of the vascular plant communities of California is similar in description to those mentioned above, but the community names were different than used previously for island descriptions and there was no description of island woodlands other than for island oak (*Quercus tomentella*). The community system as described by Junak et al. (1995) was therefore chosen for the first stage of this mapping project because, of the existing classifications, it came closest to describing the communities of Catalina Island. However because it was created for Santa Cruz Island, several adjustments were made to the classification to better include all the plant assemblages on Catalina.

First, the maritime cactus scrub community is not present on Santa Cruz Island (Junak et al. 1995), but does occur on Catalina. This community was included in Philbrick and Haller's system (1995), and was added as a community type for the Catalina map. Secondly, three new communities were described by the author for this project: non-native woodland, non-native scrub, and non-native herbaceous. These communities, which are dominated by invasive and/or horticultural plants, cover sizable portions of the landscape on Catalina, and form habitat significantly different from the native vegetation that they have replaced in terms of structure, species composition, and value to wildlife. These communities are described as follows. Non-native woodlands include areas of eucalyptus (*Eucalyptus* spp.), pines (*Pinus* spp.) and other conifers such as cedar (*Cedrus deodara*, *Calocedrus decurrens*) and cypress (*Cupressu*s spp.) that dominate discrete areas on Catalina. These species were planted to line steep roads, at areas of settlement, or as part of a 'reforestation' program by the California Department of Forestry, and are not included in previous classifications. Non-native scrub primarily describes areas dominated by invasive flax-leaf broom (*Genista linifolia*). This species was introduced in Avalon as a horticultural plant early in the last century. It had not yet spread as of 1923 (Millspaugh and Nuttall 1923), but was 'abundantly established along roadsides on the Southeast half of the island' by 1967 (Thorne 1967). A distribution map of this species created from low elevation aerial photographs taken during the blooming period aided in mapping this community. Non-native herbaceous includes areas dominated by invasive non-woody species such as fennel (*Foeniculum vulgare*), Harding grass (*Phalaris aquatica*), wild radish (*Raphanus* spp.) and mustards (*Brassica* and *Hirschfeldia* spp.). Many of the areas where this community is found have been disturbed in the past, such as the Middle Ranch hayfields, which were formally used for cultivating livestock feed, or areas of the Bulrush Canyon area which were cleared in order to plant Harding grass for forage material (Herman Sladaña pers. comm.).

Finally, urban or settled areas were designated as developed, while predominantly unvegetated soil or rocky areas were designated as bare. Bare streambed areas were not included in the Junak et al. (1995) classification but were added here because even though they may not have vegetation currently they are distinct ecologically from upland bare areas. These streambeds may regain vegetation as pressure from introduced herbivores in reduced, and it is important to identify these areas for tracking future change.

Map Production

The Catalina Island Conservancy commissioned color aerial photographs from I.K. Curtis Services, Inc. in October 2000. The fall season was chosen for maximum separability between annual, perennial, and deciduous communities. The entire island was photographed in stereo at a scale of 1:30,000. In addition to 23- x 23-cm (9- x 9-in.) contact prints, 0.4- x 0.4-m (48- x 48-in.) enlargements were produced, resulting in prints at a scale of 1:4,800. Contact prints were scanned at a high resolution (800 dpi) using an Epson 1640XL flatbed scanner. These photographs were then corrected for distortion and spatially referenced (orthorectified) using ER Mapper software (Earth Resource Mapping, San Diego, California). This process utilized camera information, such as focal length and lens type, along with a Digital Elevation Model (DEM, generated from 20-m topographic contours) and Ground Control Points (GCP's). A combination of readily identifiable road intersections and shoreline features provided enough GCP's for this process (at least six per aerial photograph).

The spatially referenced photographs were mosaiced together into one relatively seamless image using ER Mapper, which balanced the color and intensity of each photograph. Positional accuracy of the resulting image was estimated using Root Mean Square Error (RMSE) (Green and Hartley 2000, USGS-NPS 2000). To do this, 14 road/vegetation intersections distributed throughout the island at varying elevations were used to calculate X and Y differences by comparing their position on the mosaiced image and their position as mapped using a Trimble ProXR Global Positioning System (GPS) post-processed to achieve sub-meter accuracy. GCP locations were not used for this positional accuracy analysis, as they were the basis of the spatial correction process.

The orthorectified, mosaiced image was then used as a background in the Catalina Island Conservancy's Geographic Information System (GIS) and the vegetation polygons were digitized on-screen. By digitizing vegetation boundaries on-screen in a GIS using an orthorectified image as a background, errors resulting from registration and edgematching procedures (necessary when digitizing directly from multiple photographs) were avoided. Performing the orthorectification process in-house on recently commissioned aerial photographs as opposed to using orthophoto quads available from the United States Geological Survey allowed us to use enlarged versions of up-to-date, color photographs, which enabled the most accurate possible image interpretation.

Prior to digitizing, plant communities were identified and delineated using the photo enlargements with clear vellum overlays and a Sharpie pen. Community delineation was done by an ecologist with detailed field-based knowledge of Catalina vegetation. The superior detail in the enlarged photographs as compared to the digital mosaic made it easier to initially identify vegetation types and served as a sort of "proofreading" when these polygons were digitized and labeled at the computer. ArcView 3.2 GIS software (Environmental Systems Research Institute, Inc., Redlands, CA) was used to digitize the individual lines of each polygon, then the Edit Tools extension (Ianko's GIS Page 2004) was used to build polygons from the lines.

Polygons were assigned to the most appropriate community type based on texture and color on the aerial photograph and on field knowledge of the vegetation. As a training exercise, research areas where the author was most familiar with the vegetation were mapped at the beginning of the project. Questionable mapping units identified during the hand-mapping process were subsequently ground-truthed in several days of field work. Rare plant GIS layers for Catalina Island ironwood (*Lyonothamnus floribundus* ssp. *floribundus*), island oak, and velvet cactus (*Bergerocactus emoryi*) were utilized to aid in identifying island woodland and maritime cactus scrub plant communities, which can be difficult to distinguish from adjacent communities on aerial photographs.

Plant communities on Catalina are commonly a mix of two vegetation types, such as island chaparral and coastal sage scrub. These mixes provide distinctly different habitats and form different floristic alliances, therefore they have been distinguished separately on the current vegetation map. A community was considered pure if 75% or more of it is composed of characteristic plants of that community. Otherwise, it was characterized as a mix, with the community occupying over 50% of cover being named first. If the cover of each community approached 50% and the dominant was indistinguishable, the taller layer was chosen as the dominant. Where more than two communities were mixed together, the predominant two were used for naming.

The detailed mixed-community map was subsequently used to produce a more generalized version by converting mixed vegetation types to the predominant community in the mix and then merging adjacent polygons with the same name. In addition, in the process of mapping from the aerial photographs, some preliminary floristic-level (alliance) types were identifiable, such as Catalina cherry (*Prunus ilicifolia* ssp. *lyonii*)-dominated island woodland and chamise (*Adenostoma fasciculatum*)-dominated island chaparral. These alliances were delineated for a future map, which can be built upon as other alliances are described and defined. Thus two maps and the beginning of a third were produced: a detailed map which includes community mixes, a generalized map, which presents only the dominant community, and portions of a floristic-level map. A classification accuracy assessment of the detailed map is currently underway, using methods described in USGS-NPS (2000).

RESULTS

The finished vegetation map identifies 15 different vegetation communities as well as three non-vegetated types (bare, bare streambed, and developed). The map builds on existing classification systems, with three additional non-native plant communities (non-native woodland, non-native scrub, and non-native herbaceous) and one additional habitat type (bare streambeds) added. A list of the plant communities and the percent of the island covered for each is provided (Table 1). Various combinations of these communities yield an additional 32 community mixes for a total of 50 different types. A list of these different types and the percent of the island covered for each is provided (Table 2). Both versions of the map are viewable in color through the Catalina Island Conservancy's website (www.catalinaconservancy.org).

The average polygon size is 3.6 ha for the detailed map and 6 ha for the generalized map, with a minimum mapping unit of 0.04 ha. Positional accuracy of the orthorectified image used to digitize the polygons was estimated at 5.59 m; this is well within the United States National Map Accuracy Standards (USGS 1947).

The dominant three communities on the island are coastal sage scrub, island chaparral, and grassland (38.1, 29.4 and 19.5%, respectively), and these also form the most common community mixes. Bare ground also covers a significant portion of the island (9.4%). The island woodland community, dominated by one of three endemic and/or characteristic island species (Catalina ironwood, island oak, and Catalina cherry), is rather limited on the island (0.5% of the island) and is a high priority for further (floristic-level) mapping and protection. Communities such as southern riparian woodland, southern beach & dune, and coastal marsh, which have been greatly reduced and altered on the mainland of southern California (Faber et al. 1989, Holland and Keil 1990), are also very limited on the island (0.34, 0.27 and 0.01% total cover, respectively) and are a high priority for protection and monitoring. Southern beach and dune polygons include both bare beach (sandy and rocky) areas as well as dunes, as greater distinctions could not be made from aerial photographs. Vegetated dune areas, which are extremely limited on the island, will be delineated in future mapping efforts.

Two communities were problematic to map: maritime cactus scrub and coastal bluff scrub. Maritime cactus scrub is a form of coastal scrub dominated by succulents and shrubs such as velvet cactus and cliff spurge (*Euphorbia misera*), which are rare both in California and on Catalina. This

Table 1. Catalina Island plant communities, cover by area and percent of island, and mean polygon size in 2000.

Plant community	Hectares	Percent of island	Mean polygon size (ha)
Coastal sage scrub	7,394	38.10	12.9
Island chaparral	5,696	29.35	7.5
Grassland	3,778	19.47	5.1
Bare	1,825	9.40	2.6
Developed	220	1.13	5.8
Non-native herbaceous	97	0.50	3.0
Island woodland	97	0.50	1.5
Southern riparian woodland	65	0.34	1.7
Non-native scrub	54	0.28	1.5
Southern beach & dune	52	0.27	1.1
Non-native woodland	47	0.24	1.2
Coastal bluff scrub	31	0.16	1.6
Bare streambed	21	0.11	1.5
Vernal ponds & reservoirs	18	0.09	1.4
Riparian herbaceous	10	0.05	1.1
Coastal marsh	1	0.01	0.4
Maritime cactus scrub	1	0.01	0.6
Mule fat scrub	<1	<0.01	0.5

Table 2. Santa Catalina Island plant community mixes: cover, percent of island, and mean polygon size, 2000.

Plant community	Hectares	Percent of island	Mean polygon size (ha)
Coastal sage scrub	3,918	20.19	8.0
Island chaparral	3,725	19.20	5.6
Coastal sage scrub/Island chaparral	2,497	12.87	4.3
Grassland	2,335	12.03	3.7
Grassland/Island chaparral	1,111	5.72	2.2
Bare	1,011	5.21	2.5
Island chaparral/Coastal sage scrub	994	5.12	3.3
Island chaparral/Grassland	845	4.35	3.1
Coastal sage scrub/Bare	652	3.36	2.5
Bare/Island Chaparral	427	2.20	1.9
Bare/Coastal sage scrub	350	1.81	1.7
Coastal sage scrub/Grassland	325	1.68	3.0
Grassland/Coastal sage scrub	275	1.42	2.3
Developed	220	1.13	5.8
Island chaparral/Bare	105	0.54	1.8
Non-native herbaceous	82	0.42	2.8
Island woodland	73	0.37	1.3
Southern riparian woodland	65	0.34	1.7
Southern beach & dune	52	0.27	1.1
Grassland/Bare	48	0.25	1.7
Bare/Grassland	35	0.18	0.9
Non-native woodland	32	0.17	1.2
Coastal bluff scrub	31	0.16	1.6
Non-native scrub/Island chaparral	30	0.16	1.7
Island chaparral/Non-native woodland	18	0.09	3.6
Vernal ponds & reservoirs	18	0.09	1.4
Non-native scrub	18	0.09	1.1
Island woodland/Grassland	17	0.09	2.1
Bare streambed	16	0.08	2.0
Non-native herbaceous/Grassland	15	0.08	3.7
Riparian herbaceous	10	0.05	1.1
Island chaparral/Island woodland	8	0.04	8.0
Non-native woodland/island chaparral	7	0.04	1.2
Grassland/Island woodland	6	0.03	5.9
Island woodland/Island chaparral	6	0.03	2.1
Non-native scrub/Coastal sage scrub	6	0.03	1.1
Grassland/Non-native woodland	4	0.02	1.2
Non-native woodland/Grassland	4	0.02	1.1
Bare streambed/Mule fat scrub	3	0.02	0.8
Bare/Non-native woodland	2	0.01	1.7
Non-native woodland/Non-native scrub	2	0.01	1.0
Coastal sage scrub/Non-native woodland	2	0.01	0.8
Maritime cactus scrub	1	0.01	0.6
Bare streambed/Southern riparian woodland	1	0.01	0.6
Non-native woodland/Coastal sage scrub	1	<0.01	0.7
Island woodland/Bare	1	<0.01	0.7
Coastal marsh	1	<0.01	0.3
Mule fat scrub	<1	<0.01	0.5
Coastal marsh/Bare	<1	<0.01	0.3
Bare/Riparian herbaceous	<1	<0.01	0.2

community is difficult to distinguish on aerial photographs and must be primarily mapped from the ground. One stand was mapped using existing rare plant locations for velvet cactus, however more work is needed for this limited community.

Coastal bluff scrub was also difficult to map, due to its often sparse nature, mixed growth forms (shrubs, perennial, and herbaceous species), and occurrence on steep shaded ocean bluffs. While forming significant cover measured vertically, this community occupies narrow areas as viewed aerially, and would be more appropriately mapped using a GPS from the shoreline. These difficult-to-access bluffs have been a refuge against feral grazers and browsers on Catalina for many endemic plants, making coastal bluff scrub one of the better-preserved communities on the island (Thorne 1976b).

DISCUSSION

The vegetation maps described in this paper are already being used in many capacities. They have been used to estimate habitat use by non-native bison (*Bison bison*) on the island (Sweitzer et al. 2003), and are currently being used to determine habitat preferences by feral cats (*Felis catus*), and to determine preferred denning habitats for the endemic island fox (*Urocyon littoralis* ssp. *catalinae*). The plant communities described have been ranked for protection priority based on rarity on the island and mainland, endemism or rarity of the dominant plants, and successional status; these ranks and the mapped locations of these communities are being used to prioritize areas of the island for invasive plant control. The maps are also being used in the production of a fire and fuel management plan for the island (Firewise 2000, Inc. 2003), to stratify plots for oak ecosystem research (Knapp 2004, Stratton 2004), and as an educational tool.

Many plant assemblages on Catalina are indicative of land management and disturbance history, such as the introduction of herbivores. Long-term isolation from grazing on the Channel Islands of southern California has led some plants to lose defenses against herbivores (Van Vuren and Bowen 1999); the introduction of species such as feral goats, feral pigs, and mule deer (*Odocoileus hemionus californicus*) has severely impacted the plant communities, resulting in a reduction in both plant cover and species richness as well as high seedling mortality (Coblentz 1978, 1980, Brumbaugh 1980, Hobbs 1980, Klinger et al. 1994, Laughrin et al. 1994). On Catalina and Santa Cruz islands, grazing has restricted the distribution and reduced the vitality of coastal sage scrub and chaparral communities (Minnich 1980, 1982; Brumbaugh and others 1982), while livestock and wildlife often suppress oak seedling and sapling growth (Griffin 1971, 1973, McBride 1974, Muick 1996, Swiecki et al. 1996).

With the recent removal of both feral goats and feral pigs, the island will be undergoing accelerated changes associated with recovery from these disturbances. Therefore, it is a particularly important time to track landscape-level changes in both community composition and community boundaries, in order to learn more about the effects of feral animal removal and to identify any management issues which may need to be addressed. Tracking these changes will also help to develop an ecological understanding of the dynamics and requirements of these communities. For example, smaller stature riparian habitats such as mule fat scrub, riparian herbaceous, and bare streambed may be an artifact of years of severe browsing pressure from introduced herbivores. These communities should be tracked to determine if they are early successional habitats which may mature as this browsing pressure is reduced.

An accurate analysis of change using the current vegetation map and those produced between 1975 and 1980 is problematic due to their differing classification systems, methods, and scales. Most changes which might be revealed are likely an artifact of these differences rather than a reflection of the dynamics of the plant communities. For instance, grassland is variously reported as 14.0%, 30.4% and 42.2% of the island for the 1975, 1976 and 1980 maps, respectively. The Santa Catalina Island Company map produced in 1975 is the most internally consistent as well as most consistent with field observations, and is the closest in scale and classification system to the generalized version of the 2000 map reported on here; a comparison is provided (Table 3). Changes at the community level will be investigated by the Catalina Island Conservancy by producing maps from historic

Table 3. A comparison of plant community cover from 1975 and 2000 vegetation maps.

Conservancy 2000 (general version)	%	Santa Catalina Island Company 1975	%
Coastal marsh	<0.1	Coastal salt flat	0.1
Southern beach & dune	0.3	Coastal dune grassland	<0.1
Grassland	19.5	Grassland, grassland remnant	14.0
Non-native herbaceous	0.5	Ruderal	0.1
Coastal bluff scrub	0.2	--	-
Maritime cactus scrub	<0.1	Maritime desert scrub	0.3
Coastal sage scrub	38.1	Coastal sage scrub	46.9
		Coastal sage scrub remnant	9.02
Island chaparral	29.4	Chaparral, oak woodland, oak woodland remnant	28.8
Island woodland	0.5		
Non-native scrub	0.3	--	-
Non-native woodland	0.2	--	-
Vernal ponds & reservoirs	0.1	Water body	0.1
Bare streambed	0.1	--	-
Riparian herbaceous	0.1		
Mule fat scrub	<0.1	Freshwater aquatic or marsh	0.1
Southern riparian woodland	0.3		
Bare	9.4	--	-
Developed	1.1	--	-
--	-	Cultivated	0.3
--	-	Marine meadow	0.1
--	-	Surfweed	0.1

aerial photographs as well as future imagery, using the methods and scale described in this paper.

More work is needed to provide floristic-level description and classification of Catalina's plant alliances, including a plot-based sampling effort to describe new series occurring on Catalina. The first of many relevé plots will be established for this purpose in 2005.

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