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SANTA CRUZ ISLAND INVASIVE PLANT SPECIES MAP

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Abstract—Effectively managing non-native invasive plants at a landscape scale requires an understanding of species distribution and abundance. Oftentimes land managers lack population data on which to base long-term management decisions, resulting in shifting priorities and the squandering of scarce resources. In 2007, The Nature Conservancy (TNC) contracted Prohunt Incorporated to conduct an island-wide survey of 55 invasive plant species on Santa Cruz Island, a 243 km^2 island jointly owned and managed by TNC and the Channel Islands National Park. This inventory differed from other invasive plant surveys in that the entire island was searched in person, and populations were mapped with a global positioning system. The survey was completed in 41 days. Approximately 95% of the survey was conducted from a helicopter operating between 1.5 and 9 m above ground; the remaining 5% was surveyed by two or more mappers walking parallel to each other along drainages and heavily infested areas to maximize species detection. Aerial surveys used in concert with ground surveys are a fast and effective method for early detection which can provide key data to develop comprehensive management plans, and it has the potential to be utilized for rapid response in remote sites such as offshore islands.

INTRODUCTION

Invasive species are considered the second greatest threat to biodiversity worldwide, and are the leading cause of species extinctions in island ecosystems (Wilson 1999). Invasive plants are a significant factor affecting the preservation of native biodiversity—one of the major challenges of this century (D'Antonio and Meyerson 2002). Land managers entrusted with protecting natural resources must often manage weeds through a form of triage, where they hastily identify which species will be targeted for control and which ones will be left to possibly spread. These decisions are often based on anecdotal and unverified data (P. Holloran 2006, U.C. Santa Cruz Environmental Studies Department, personal communication). Diverting limited resources to survey and inventory weed populations might appear to be a waste of time and money when the impacts caused by weeds are readily apparent. Yet land managers often function as physicians who are entrusted with healing their patient (the land), and a good doctor should give his or her patient a proper examination before prescribing a remedy to cure an illness (Knapp and Knapp 2005). Likewise, a proper inventory of local weed populations can provide a sound scientific foundation for future management actions.

Weed infestations are never static, and there are often too many to keep track of with the human brain. If key species and population information are not recorded in a database, that organizational knowledge can easily be lost when the land manager relocates or dies. The epitaph of a land manager's tombstone could read, "Here lies all the institutional weed knowledge of the preserve." (Schoenig et al. 2002). By creating a computer database of weed populations, key information on abundance, distribution, and rates of spread will be readily available to all future weed managers who will be able to use it to analyze changes in populations, develop monitoring schedules, evaluate control efficacy, and record the appearance of new populations in the long term.

Invasive species are the greatest threat to Channel Island ecosystems as a whole (Donlan et al. 2003). During the period of intensive ranching and crop production from the 1840s to 1980s, many invasive plant species became established on Santa Cruz Island (SCI), the largest (24,864 ha) of the

eight California Channel Islands. The weeds were largely held in check by cattle, sheep, and pigs. However, they appear to have been released from browsing and grazing pressure following the recent removal of these introduced ungulates by the Channel Islands National Park (CINP), who owns 24% of the island, and The Nature Conservancy (TNC), a non-profit conservation organization that owns and manages 76% of the island.

TNC has conducted select treatments and control experiments for a suite of weed species since the early 1990s (R. Klinger, U.S. Geological Survey Biological Science Division, personal communication), and is currently in the process of developing an invasive plant management plan and program to comprehensively address the next greatest conservation challenge—large-scale weed eradication and control. One of the main objectives of TNC's developing weed program is to target priority weeds that are now in limited abundance before they become widespread and unmanageable species. TNC contracted Prohunt Incorporated (Ventura, California) to survey the entire island for 55 weed species, to develop a detailed baseline of the current state of weed abundance and distribution on the island. This map will provide the foundation for the development of TNC's Santa Cruz Island Weed Management Strategy, enabling managers to prioritize each species for eradication, reduction, or control by systematically evaluating each species based on their known impacts, invasiveness, distribution, and abundance. In this paper, we describe the island-wide survey of Santa Cruz Island, and the construction of the weed map.

METHODS

The reference *A Flora of Santa Cruz Island* by Junak et al. (1995) identifies over 177 naturalized non-native plants on Santa Cruz Island, and served as the baseline dataset of known taxa on the island. The list also contains a few species known to exist on adjacent Channel Islands but not yet recorded from SCI (e.g., *Delairea odorata*). Not all 177 non-native plant species are considered to be invasive or a threat to the island. The objective of TNC's invasive plant management program is to address species that pose the greatest risk to the island, but are also relatively manageable. The list of 177 non-native species were compared with the California Invasive Plant Council's (Cal-IPC) "Invasive Plant Inventory" of weeds in California (Cal-IPC 2006) in order to derive a preliminary list of 111 invasive weed species found on the island. The winter of 2006–2007 delivered very little rain to Santa Cruz Island, and some herbaceous plants, both native and non-native, were not conspicuous in the landscape in the spring of 2007. These species were thus removed from the list of 111 species considered for the survey.

The Delphi method (Matlack 2002) was utilized to narrow down which of the remaining weed species posed the greatest risk to the island, and are considered manageable (for instance, species such as Mediterranean annual grasses are highly invasive, but were considered to be unmanageable at the landscape level due to their widespread distribution and abundance). The Delphi method involves submitting a list of suspected weed species to qualified individuals such as botanists, plant ecologists, weed scientists, and land managers for review based on their professional experience. Of the 14 individuals invited to submit suggestions, 7 submitted species candidates, while others acknowledged the selections of others. The list was then narrowed by managers from TNC and the CINP, who identified 55 weed species that would be appropriate for an island-wide survey. The 55 weed species selected are known to negatively affect wildlands, and could be detected from the air and on the ground by surveyors during the time period of the survey. Fifty-five species were considered to be the maximum number of targets that surveyors could easily scan for and keep track of while conducting the survey.

Survey methods previously utilized to map 76 weed species on Catalina Island in 2003 (Knapp 2004) were adapted for the island-wide weed survey on Santa Cruz Island. A discrete weed population was defined by a distance of 30.5 m (100 ft) from one population edge to another or between two single plants. This distance between populations is approximately the greatest distance at which a ground surveyor can detect low growing small individual weeds. The minimum mapping unit was an individual plant. Ground and aerial surveyors visually estimated population size and density in square feet, phenology, plant height, and habitat type invaded, and each population was recorded

with a sub-meter accuracy Trimble GeoExplorer® Series global positioning system (GPS). All populations were captured as point or line features with a GPS at a speed of 10 to 30 seconds per infestation.

A significant difference from the previous mapping methodology was the use of a two-person Schweizer 300 helicopter owned and piloted by Prohunt Incorporated. Initially, the three-month survey was to be conducted 80% from the ground by five mappers, with the remaining inaccessible areas (20%) such as coastal bluffs to be surveyed from the air with a helicopter. During the first hour of flight over island chaparral and coastal scrub communities, it became clear that the perspective from the helicopter provided a superior vantage point from which to survey vegetation. A greater area could be covered in less time. Thereafter, it was decided to survey as much of the island from the air as possible, and the ground mappers would be redirected to survey roadsides, developed areas, and sites with a large number of weed species and infested areas. The survey was conducted continuously from April 2 to May 13, 2007, only 41 days, with 95% of the island surveyed from the air and 5% from the ground.

Approximately 4281 linear km (2660 miles) (Fig. 1) were surveyed across the entire island. The aerial survey, covering 3349 linear km (2081 miles), was flown at altitudes between 1.5 and 9.1 m (5 to 30 ft) above the ground. The height of the helicopter was determined by topography, weather, and vegetation. A trained mapper recorded weed locations and indicated to the pilot when a better vantage point was required to assure weed identification. The helicopter was flown between 13 to 17.4 knots (15 to 20 mph), but would hover when confirming species identification, and mapping. Ground surveys covering 932 linear km were conducted by two or more trained ground mappers walking abreast of one another to ensure maximum species detection.

In addition to recording species infestations in the Trimble GeoExplorer® GPS units, all ground mappers carried a Garmin® Foretrex™ 201 GPS, and the helicopter was equipped with a Garmin®

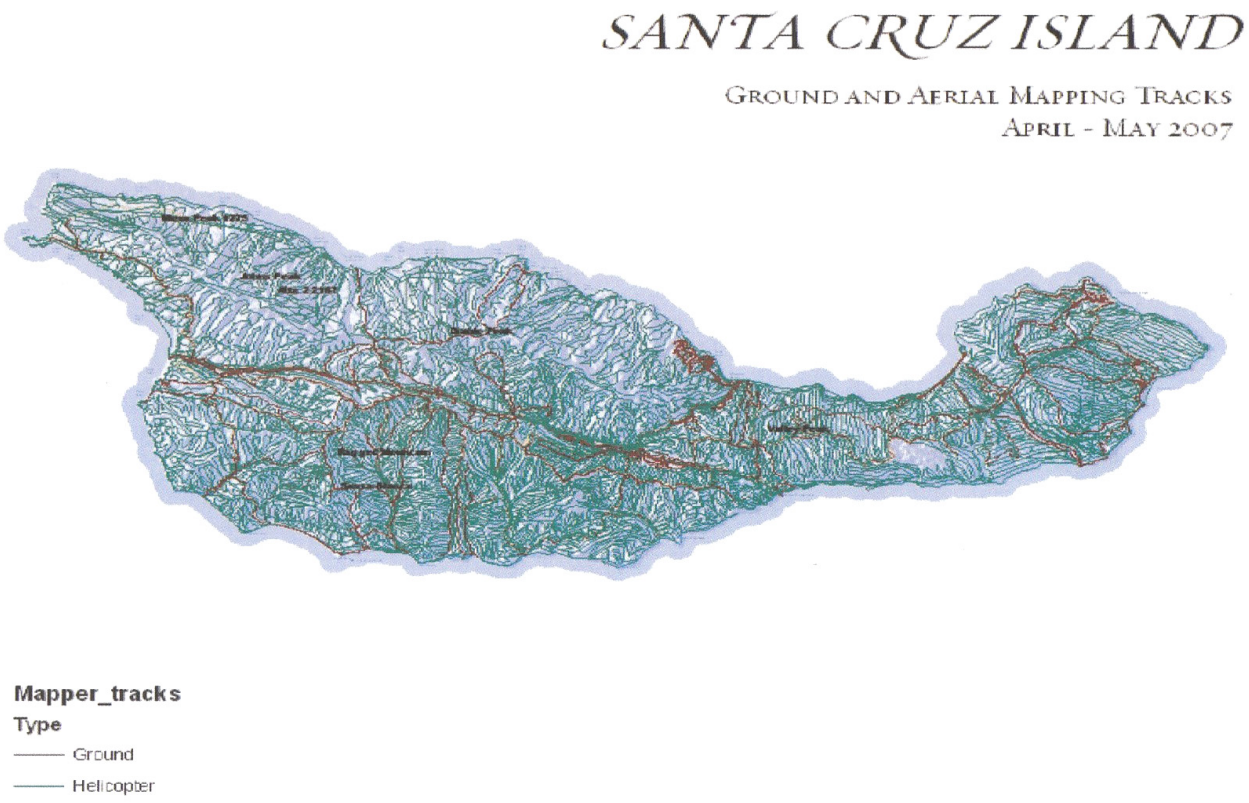

Figure 1. A map illustrating the aerial (green lines) and ground (brown lines) survey tracks.

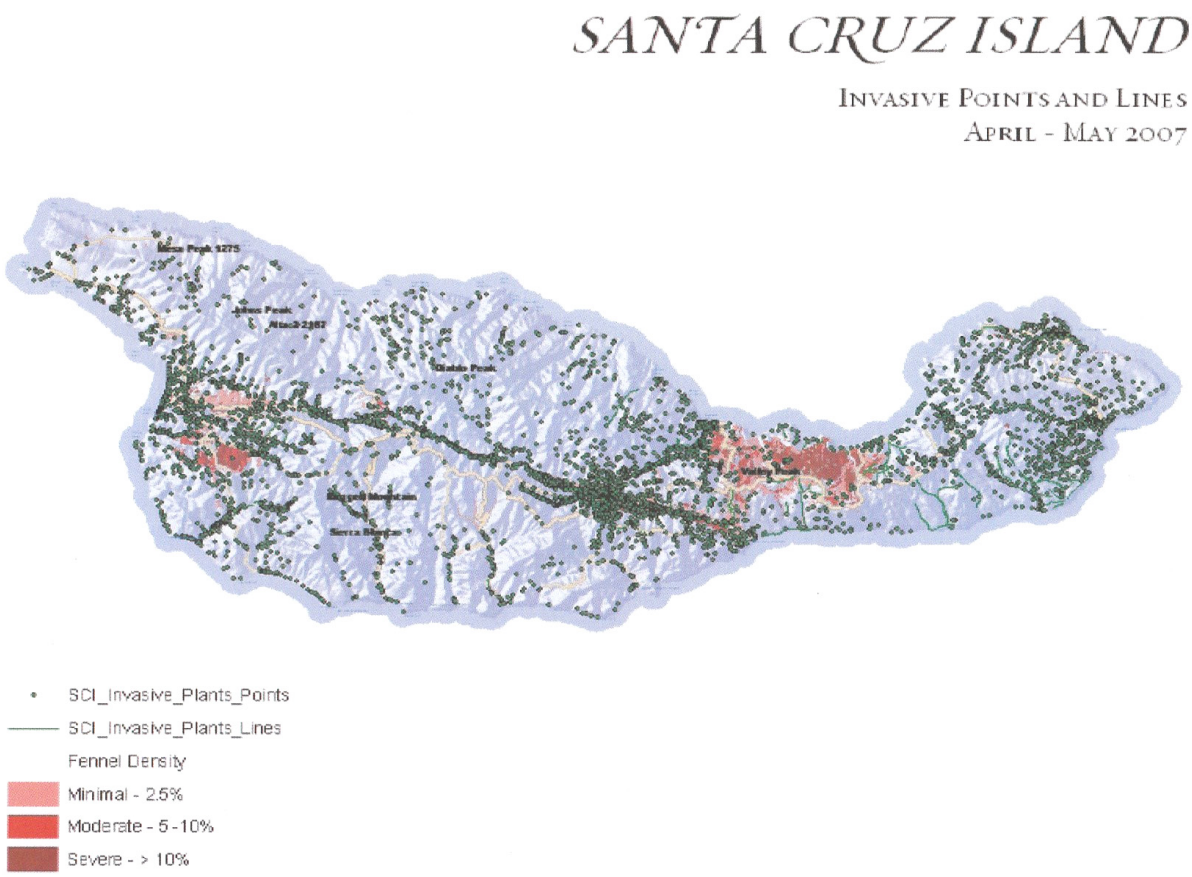

Figure 2. A map illustrating the locations of 52 invasive plant species.

GPSMAP® 196 to record survey routes as line features. Survey tracks were used to identify gaps in area not surveyed, which were then flown the following day.

All points and line features were entered each evening in a Geographic Information System geodatabase (ESRI, ArcMap 9.2, Redlands, CA) and were reviewed for missing or duplicate data. Any anomalies were then addressed the following survey day. The final geodatabase was then submitted to TNC, who then co-developed with NPS, a database to record future weed infestations and weed treatments.

RESULTS

A total of 5942 populations were recorded among 52 weed species (Fig. 2). Table 1 illustrates each species surveyed, along with the associated number of populations and net area infested (area infested multiplied by the density of weeds). Of the 55 species selected for survey, three species (*Araujia sericifera, Delairea odorata,* and *Ricinus communis*) were not detected. The only previously known population of *Araujia sericifera* (bladder flower) was removed by the Channel Islands National Park prior to the survey (S. Chaney 2007, Channel Islands National Park, personal communication). The latter two species had not been seen on the island for several years, but were surveyed for nonetheless due to their invasiveness on the mainland. One new species was recorded for the island, *Cynara cardunculus* (artichoke thistle), consisting of only one population.

DISCUSSION

Invasive plant management decisions are often based solely on the threat(s) the species pose, because obtaining detailed distribution and

Table 1 . Surveyed weed species population data.

Weed species	Number of populations	Net area (m2)	Median population size (m2)
Acacia dealbata	1	136	N/A
Acacia melanoxylon	56	2,284	2
Albizia lophantha	15	529	21
Araujia sericifera	0	0	0
Arundo donax	8	80	20
Cakile maritima	142	4,200	52
Cardaria draba	133	15,886	209
Carduus pycnocephalus	1	418	N/A
Carpobrotus chilensis	140	3,486	37
Carpobrotus edulis	1	0.09	N/A
Centaurea solstitialis	313	91,408	47
Centranthus ruber	7	143	112
Cirsium vulgare	2	2	N/A
Conium maculatum	19	172	11
Cortaderia selloana	98	746	0.4
Cupressus macrocarpa	26	10,703	2
Cynara cardunculus	1	3,832	N/A
Delairea odorata	0	0	0
Ehrharta erecta	2	2	N/A
Erechtites glomerata	146	95	0.09
Eriogonum giganteum	8	592	3
Eucalyptus camaldulensis	43	95,096	0.09
Eucalyptus globulus	72	58,654	60
Festuca arundinacea	2	2	N/A
Ficus carica	23	219	0.09
Foeniculum vulgare	1,837	325,983	23
Genista monspessulana	28	54	0.09
Hedera canariensis	16	1760	7
Juglans regia	29	0.09	0.09
Lavatera assurgentiflora	9	388	3
Mesembryanthemum	46	246	9
Nicotiana glauca	177	80,024	232
Olea europaea	105	107,796	0.09
Opuntia ficus-indica	2	13	N/A
Pelargonium X hortorum	20	66	2
Pennisetum clandestinum	48	30,862	84
Phalaris aquatica	161	272,385	37
Phoenix canariensis	2	0.002	N/A
Pinus pinea	48	4607	2
Piptatherum miliaceum	406	16,246	37
Ricinus communis	0	0	0
Robinia pseudoacacia	15	1,359	2
Rubus armeniacus	11	142	9

Table 1 (continued). Surveyed weed species population data.

Weed species	Number of populations	Net area (m2)	Median population size (m2)
Salsola tragus	62	23,468	149
Schinus molle	178	3,569	2
Silybum marianum	679	22,027	37
Solanum elaeagnifolium	1	1	N/A
Spartium junceum	3	35	0.09
Tamarix ramosissima	50	1,801	0.09
Tetragonia tetragonioides	11	6	1
Verbascum thapsus	604	81,978	9
Vinca major	31	9,937	19
Washingtonia robusta	7	0.09	0.09

abundance data for a suite of species has been cost-prohibitive until now. Knowledge of the threats posed by a species coupled with its population data can be powerful decision making tools to guide long-term management, and are key elements of TNC's Santa Cruz Island Weed Management Strategy. Highly invasive abundant widespread species such as *Foeniculum vulgare* (fennel) or *Centaurea solstitialis* (yellow star thistle) may not be candidates for eradication in the near future, but they could be systematically targeted along dispersal corridors to reduce their spread, and/or in priority watersheds where high-value resources are at risk, which is where TNC is currently managing them. Highly invasive species that have few small populations with undeveloped soil seed banks such as *Carduus pycnocephalus* (Italian thistle), *Cortaderia selloana* (Pampas grass), or *Eriogonum giganteum* var. *giganteum* (Saint Catherine's lace) are ideal candidates for eradication, and are currently being managed for these reasons. Baseline distribution and abundance data on invasive plants could be compared with data collected from future surveys to determine the rate of spread of existing species, and the rate of colonization of new species. Even more powerful analyses can be conducted to evaluate which vegetation communities are most susceptible to invasion, or which sites have the greatest number of new colonizers over time, and thus priority sites to monitor.

A study conducted by Rejmanek and Pitcairn (2002) analyzed weed eradication efforts conducted by the California Department of Food and Agriculture over a 30-year period. Results showed that weed eradication success decreased exponentially and the effort (time, money, etc.) increased exponentially as the size of the weed infestation increased. They also found that infestations less than 0.08 ha had nearly 100% eradication success, and that infestations 1 ha and greater had nearly no eradication success. The median population size of the 52 weed species recorded (excluding three species not detected) in spring 2007 was 0.0008 acres; however, this size will not remain static as these highly invasive species continue to expand.

Species that have recently colonized SCI or are becoming established are a high priority for TNC, because these species are relatively easy and cost-effective to eradicate (Zavaleta et al. 2001), and their impacts are minor compared to widespread species (Zavaleta 2000). Species that have small populations are much easier to eradicate than larger ones, due to the limited soil seed bank present.

Advanced techniques and methods to remove non-native feral ungulates have recently been developed and successfully implemented (Morrison 2007; Donlan et al. 2003), and similar techniques need to be developed for successful plant eradications (Donlan et al. 2003). Aerial transport of personnel and equipment by helicopter has played an important role in managing Santa Cruz Island and implementing conservation projects. Projects like the removal of feral pigs in 2005–2006, and the Island-wide Weed Mapping Survey in April 2007 have shown how useful a helicopter can be in remote terrain that is difficult or dangerous to access on the ground, in areas where vegetation impedes ground transportation, or where weed seed might readily be dispersed by ground access.

A helicopter, especially one as small and maneuverable as the one utilized in this survey, and

a highly qualified bush pilot are probably the most effective tools to use for early detection of and rapid response to new weed invasions. A helicopter can provide a perfect vantage point from which to locate an infestation and the means by which to respond quickly to eliminate it. Hiking to remote weed infestations can expend a great deal of time and effort, dispersing weed seed along the access route, and damage recovering or intact vegetation, resulting in erosion. Aerial transport can eliminate these impacts by avoiding contact with weed propagules and taking the weed worker directly to the site. Using a helicopter is also a cost-effective method of surveying the island. The survey was completed in 41 days. When compared to an estimate to conduct the same project with only ground surveyors, the aerial survey is half the cost of a ground-based survey and can be completed approximately eight times more quickly.

The ability of land managers to detect infestations and stay ahead of seed production is a difficult obstacle to overcome when managing invasive plants, but using a helicopter to access infestations allows land managers to exceed the pace of weed seed production and to continually survey the landscape. The most cost-effective method to address weeds is to prevent them before they colonize or become established (Zavaleta 2000). Preventing species introduction or establishment will also eliminate impacts to the ecosystem. Implementing early detection and rapid response programs enable land managers to eliminate future problems by tackling them while they are at manageable levels.

CONCLUSIONS

Following the elimination of landscape-level disturbances caused by introduced ungulates, Santa Cruz Island land managers are entering a new era of island-wide vegetation management and protection. Non-native invasive plant species pose a significant threat to the recovery and integrity of the island ecosystem. The Channel Islands National Park has worked diligently over the last two decades to tackle these threats, and now The Nature Conservancy is dedicating significant resources to weed management.

The results of the island-wide weed survey conducted in the spring of 2007, has provided TNC and CINP with information needed to develop a comprehensive weed management program and strategy. The 2007 SCI Weed Map identified which species can likely be eradicated (based on limited ranges and population sizes) and which ones require a more strategic watershed-based approach. An extensive database of weed distributions and abundance and a comprehensive weed management strategy are in development as a result of this weed survey. Coordinated implementation programs will enable the SCI land managers to effectively tackle the invasive weed crisis island-wide.

Prior to this survey, land managers of large preserves lacked an accurate and cost-effective method to develop a weed distribution and abundance baseline, which includes individual plants and large infestations. The aerial survey methods developed by TNC staff, their project advisor, and contractor Prohunt, Inc. now provide an effective method for land managers to systematically conduct early detection and rapid response programs, especially on other offshore islands.

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