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Editor's Note: The photographs submitted to illustrate this paper could not be reproduced in color. Black and white reproduction resulted in considerable loss of detail. Color Xeroxes can be requested from the authors.

A Study on the Natural History of *Cytisus* on Santa Catalina Island with an Emphasis on Biological Control

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Abstract – Exotic introduced species can disrupt native ecosystems and be particularly devastating on islands. Two brooms, Dyers' greenwold (*Cytisus linifolius*) and French broom (*C. monspessulanus*) (Fabaceae) may potentially outcompete native and endemic species on Santa Catalina Island. Re-establishment of these introduced invasive weeds is rapid following fire and disturbance. Seeds of these species may lay dormant in the soil for several years, although experiments show that abrasion of the seed coat enhances germination response.

Phytophagous larvae of the Genista moth (*Uresiphita reversalis*) (Lepidoptera: Pyralidae) are showing considerable promise in controlling the weeds and could be considered in the future for biological control.

Introduction

The spread of escaped exotic weeds can ruin the integrity of native California plant communities. *Cytisus linifolius* (L.) Lam. and *C. monspessulanus* L. (Fabaceae) may prove to be such weeds on Santa Catalina Island.

These two species, commonly referred to as Dyers' greenwold (see Thorne 1967) and French broom respectively, have become invasive introduced pests on Santa Catalina Island and in places, far outnumber native and endemic plants. Chemical or mechanical methods of control are not feasible due to watershed and habitat problems (streambeds or steep slopes). Biological control is a viable option, but a baseline study on the natural history of *Cytisus* must first be undertaken before considering or implementing a biological control.

Biological control of weeds may involve the introduction of natural enemies, the manipulation of the environment to increase the impact of natural enemies, and the release of natural enemies against naturalized weedy pests. The Klamath weed (*Hypericum perforatum* L.) was controlled by natural enemies in the western United States by the leaf-feeding chrysomelid beetle (*Chrysolina quadrigemina* (Suffrian)) and 60 million acres of prickly pear cacti (*Opuntia* sp.) were destroyed in Australia by the imported Argentine moth (*Cactoblastis cactorum* (Berg.))(see Andres 1976).

Before beginning a search for a biological control agent, the following basic information on a weed should be established, if possible: 1) taxonomic position, biology, ecology and economic importance; 2) native geographic distribution; 3) total present distribution; 4) probable center of origin and that of its close relatives (section, genus, tribe); 5) coextensive occurrence of related species; 6) occurrence of related and ecologically similar species in regions where the weed does not occur, but where exploration for an enemy agent seems desirable and 7) the literature record of the weed's natural enemies (National Academy of Sciences 1968).

In northern California, efforts have been made to control French broom through public education workshops, broom-pulling parties and agreements with Caltrans to discontinue the use of aggressive, non-native plants for highway planting (Mountjoy 1979). Bravo (1985) reported the return of native plants including species of *Lupinus*, *Calochortus*, *Baccharis*, *Dodecatheon* and *Lonicera* (genera all found on Santa Catalina Island) within a 4 yr period in a broom-removal area near Muir Woods.

The objective of biological control is never eradication; it is a reduction of a weed's density to noneconomic or manageable levels. When an effective agent is available, the method is cheap and permanent and does not involve repeated treatments year after year. When considering biological control, it is important to establish confidence that an adequate population of the target host will always occur to maintain the agent population. If sufficient host plants are not available, alternate hosts may be sought by the agent. In addition, if the host plant population is not adequate and the agent population is not able to sustain itself, the same weed problem may occur again when seed reserves in the soil germinate. Thus, information on seed viability and required treatments for germination is useful.

Due to the economic importance of many legumes, several studies have investigated the role of impermeable seed coats (Roberts 1972; Brant *et al.* 1971; Crocker 1916; Vegis 1964; Hamly 1932; Heit 1967). The presence of a hard waxy covering may prevent the absorption of water and limit germination. This may be a desirable trait for the continuance of the species as such seeds may remain viable for long periods of time (Crocker & Barton 1953). McClintock (1985) reports this trait is found in *Cytisus monspessulanus*. Under natural conditions seeds become permeable at different periods, so any one years harvest is capable of producing seedlings over a period of several years (Crocker & Barton, 1953).

The purpose of this study is to: 1) determine distribution of the species on Santa Catalina Island; 2) gather pertinent ecological information for future management use in control of *Cytisus linifolius* on Santa Catalina Island; 3) test the hypothesis that *C. linifolius* has an effect on native and endemic vegetation and 4) gather information on potential biological agents and those factors which would enhance augumentation of natural enemies.

Methods

To establish the distribution of *Cytisus linifolius* and *C. monspessulanus* on Santa Catalina Island, a survey of the island was conducted. Previously recorded locations as well as new and suspected sightings were investigated. This survey indicated that *C. linifolius* was much more abundant throughout the island compared to *C. monspessulanus* which was limited to only a few locations. Therefore, the remainder of my study was focused on *C. linifolius*.

To test the effects of *Cytisus linifolius* on native plant communities on Santa Catalina Island, 16 plots were established throughout areas where *C. linifolius* occurs. Six control plots (plots not containing *C. linifolius*) were included along with 10 plots containing *C. linifolius* and island natives and endemics. The plots ranged in size from 4 x 4m to 10 x 10m depending on the terrain and accessability of the plots.

To test the rate of re-establishment of *Cytisus linifolius* in burned areas, two 5 x 5m plots were established in an area above Pebbly Beach shortly after a fire on 2 July 1985. One of the two plots was established in the hottest area of the burn where there was no apparent living vegetation. Plots were initially checked for the number of individuals per species and checked again at 19 mo and 28 mo.

To aid in developing a plan for biological control of *Cytisus linifolius* on Santa Catalina Island, I examined factors which may influence seed germination. To test the hypothesis that there are no special treatments required for seed germination of *C. linifolius*, I subjected seeds to different treatments analogous to those found in native habitats. Seeds of *C. linifolius* were harvested from mature plants in Avalon Canyon on Santa Catalina Island during the summer of 1985. Seeds were separated from the dry pods and allowed to dry for 1 wk before storage in tightly sealed glass bottles. Treatments consisted of: 1) 6 hr in concentrated sulfuric acid; 2) 10 min in concentrated sulfuric acid; 3) immersion in

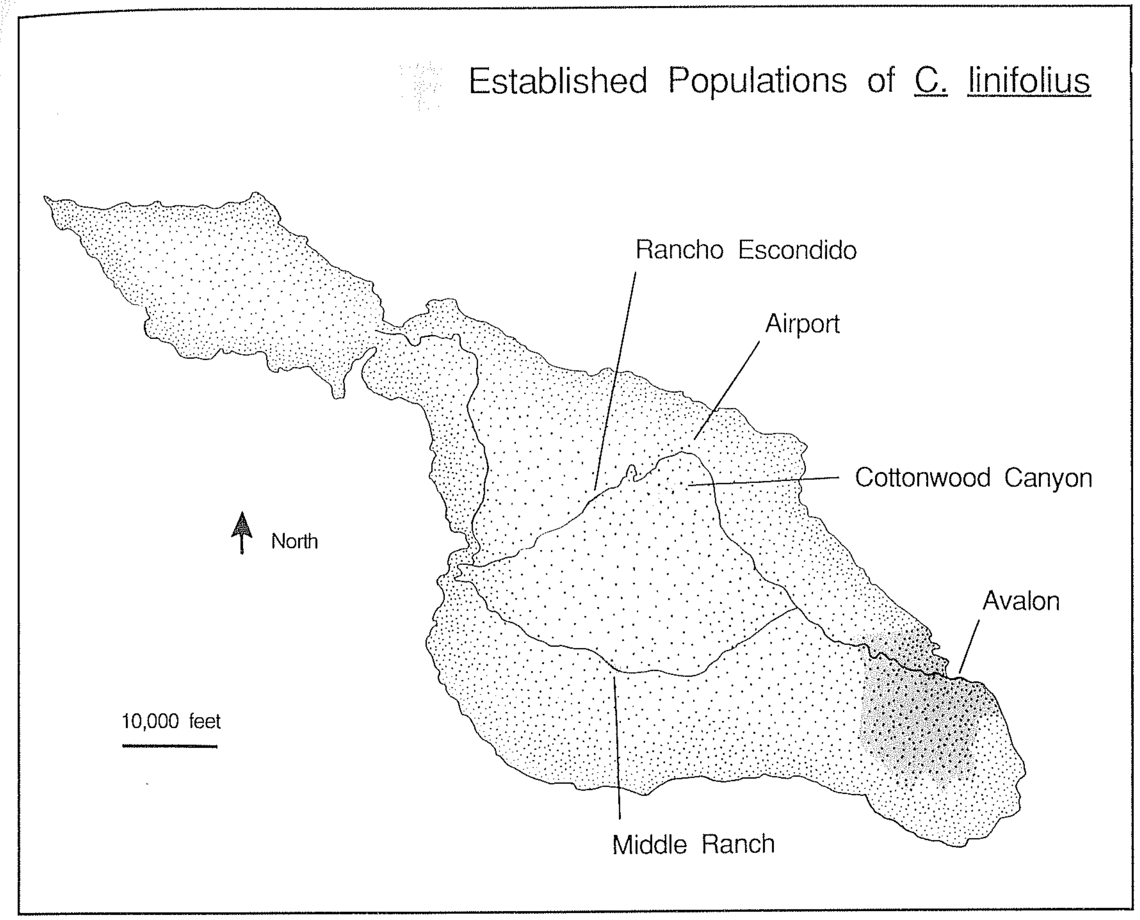

Figure 1. Established populations of *Cytisus linifolius* on Santa Catalina Island.

water at 98° C; 4) 25 min agitation in a beaker lined with 60 grit sandpaper; 5) one scrape across the seed coat with 60 grit sandpaper; 6) 10 min in an oven at 104° C and 7) no special treatment as a control. Seeds were placed on moist filter paper in petri dishes (50 seeds/dish, 2 dishes/treatment, 2 trials 1 wk apart) and placed in an incubator at 25° C with a 12 hr photoperiod for 10 days. Seeds were checked daily and the number of seeds germinated (radicle emerged) were recorded. No further germination occurred after that period and after 2 wk, many seeds were destroyed by fungi and bacteria. Data were analyzed using a One-Way Analysis of Variance. A regression analysis was calculated using percentage germinated and time.

When considering biological control as a possible means of weed control, a survey of the naturally occurring enemies should first be undertaken. For this reason, plants of *Cytisus linifolius* were periodically sampled for presence of potentially damaging insects.

Results

On Santa Catalina Island, *Cytisus linifolius* is abundant (> 50 plants) in three major canyons surrounding Avalon (Avalon Canyon, Descanso Canyon and Hamilton Canyon). Large populations also occur at Wrigley Reservoir, Haypress Reservoir and along Pebbly Beach Road. Separate small established populations of *C. linifolius* away from Avalon occur in: 1)

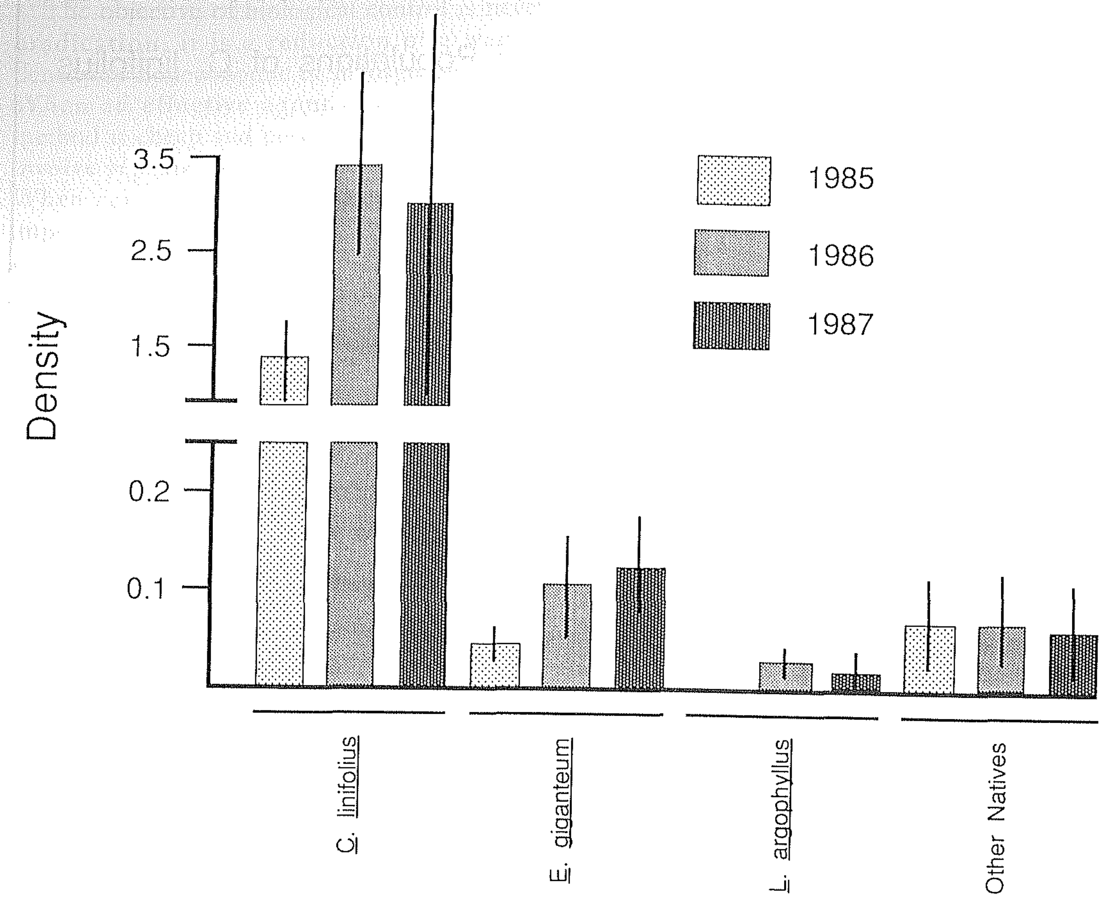

Figure 2. Density (n/m^2) ± 1 SE for plots containing *Cytisus linifolius* during the 3 yr study. *Eriogonum giganteum giganteum* and *Lotus argophyllus ornithopus* are Santa Catalina Island endemics. All other native species were lumped together. There is no significant difference (Mann-Whitney *t*-test, $P < 0.05$) between the density of a species in plots with or without *C. linifolius*. The density of a species did not change significantly over time (Kruskal-Wallis Analysis of Variance, $P < 0.05$).

Cottonwood Canyon; 2) at the airport; 3) 3 mi from the gate at the airport on the road to Rancho Escondido (390 seedlings and young plants up to 4 ft tall were pulled from this area during July 1987) and 4) 0.3 mi west of the bump gate at Middle Ranch (Fig. 1). *Cytisus monspessulanus* is found only at Wrigley Garden and Descanso Beach (where populations numbered < 50 individuals) and occasionally along the road between Avalon and Haypress Reservoir.

The effect of *Cytisus linifolius* on native and endemic plants appears minimal. There is no significant difference (Mann-Whitney *t*-test, $P < 0.05$) between a species density in plots with or without *C. linifolius* (Fig. 2 and 3). Also the species' density did not change significantly over time (Kruskal-Wallis Analysis of Variance, $P < 0.05$)(Fig. 2 and 3).

Density of *Cytisus linifolius* drastically increased in the burn area over the 2 yr study period. In the first plot, there were 39 alive plants after the fire in 1985. One yr later, there were 148 plants followed by the second yr total of 160 individuals. In the second plot which was established in the hottest area evidenced by no living vegetation, there were 159 *C. linifolius*

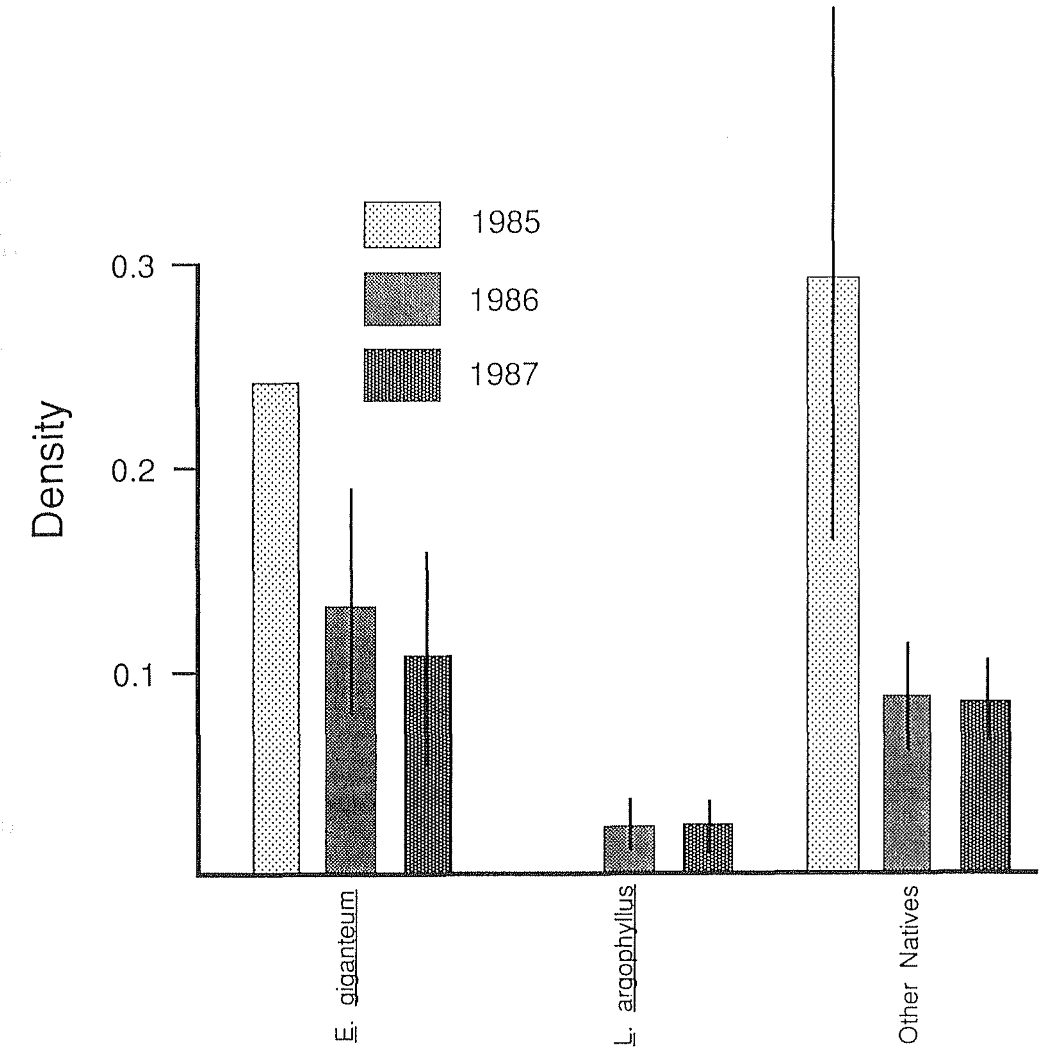

Figure 3. Density (n/m^2) ± 1 SE for plots without *Cytisus linifolius* (control plots) during the 3 yr study. *Lotus argophyllus ornithopus* is a Santa Catalina Island endemic. All other native species were lumped together. There is no significant difference (Mann-Whitney *t*-test, $P < 0.05$) between the density of a species in plots with or without *C. linifolius*. The density of a species did not change significantly over time (Kruskal-Wallis Analysis of Vairnace, $P < 0.05$).

plants the first yr and 145 individuals the second yr. Native and endemic species also appeared in the plots but did not approach the density of *C. linifolius* (Fig. 4).

Figure 5 shows the percent germination for *Cytisus linifolius* for the 7 treatments. A One-Way ANOVA showed significant differences between treatments ($P < 0.01$). Figure 6 shows the percent swollen for the same seeds. The germination rate for those seeds soaked in concentrated sulfuric acid for 6 hr was linear and significantly correlated with time (Fig. 7) ($P < 0.05$, $r = 0.89$).

Discussion

According to a list compiled by Butterfield (1964), *Cytisus monspessulanus* has been in California since at least 1871, when it was listed in a catalog for Belleview Nursery in Oakland. *Cytisus linifolius* was recorded as naturalized on Santa Catalina Island in 1938 (E. McClintock pers. comm.) and is currently the more predominant of the two species. *Cytisus monspessulanus* is a serious problem in northern California while *C. linifolius* currently is known only to occur on the mainland in Romero Canyon in Santa Barbara County (Smith 1976).

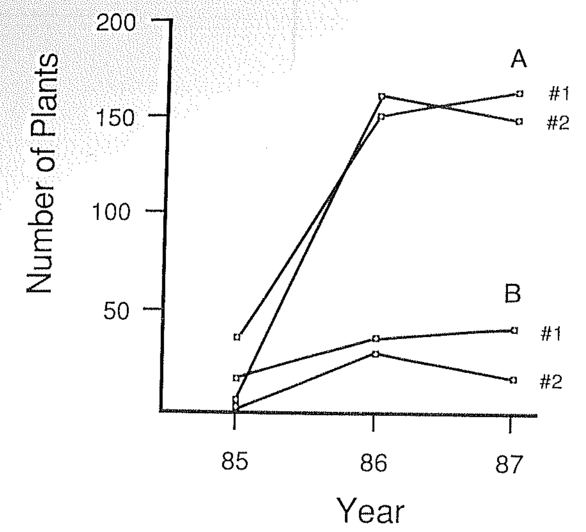

Figure 4. Number of individuals per plot that germinated or crown-sprouted in plots established after a 2 July 1985 fire. Plot number two was established in the hottest area of the burn. A = *Cytisus Linifolius*; B = other species.

A description of several different species of *Cytisus* used in horticulture and that have shown no naturalizing tendencies was published in 1978 in *Pacific Horticulture* (Hawkins, 1978). In the nursery trade, the few brooms with naturalizing capabilities are often sold. Other horticultural species are not always correctly identified or labeled (Hawkins 1978).

To date, little work has been done on *Cytisus linifolius* other than to document the few localities where it occurs in California and its taxonomic characteristics. Although commonly known under the genus *Cytisus* and listed as such in the flora for Santa Catalina Island (Thorne 1967), these two species also are referred to as *Teline monspessulana* (L.) K. Koch and *T. linifolia* (L.) Webb & Berth. (Gibbs & Dingwall, 1971) as well as *Genista monspessulana* and *G. linifolia* L. (Gibbs & Dingwall 1971; Polhill 1976).

Santa Catalina Island endemic plants potentially threatened by *Cytisus linifolius* include *Crossosoma californicum* (Crossosomataceae), *Lotus argophyllus ornithopus* (Fabaceae), *Eriogonum giganteum giganteum* (Polygonaceae) and *Rhamnus pirifolia* (Rhamnaceae). Besides being threatened by the spread of *C. linifolius*, other Santa Catalina Island endemic plants are threatened by feral animals (Coblentz 1980).

Two related species found on other California Islands are currently listed on the State of California List of Rare and Endangered Species. The Santa Cruz Island bird's foot trefoil (*Lotus argophyllus niveus)* is listed as endangered and the Santa Barbara Island buckwheat (*Eriogonum giganteum* var. *compactum)* is listed as rare. A third plant, the San Clemente Island buckwheat (*Eriogonum giganteum* var. *formosum*) is not state listed but is still considered endangered by the California Native Plant Society (1984).

With limited data, *Cytisus linifolius* does not appear to be outcompeting the endemic or native vegetation on Santa Catalina Island. However, *C. linifolius* does appear to demonstrate the potential for outcompeting natives in burned areas. Current studies are underway to determine the effects of other disturbances on *C. linifolius* plants, such as pulling up mature plants, thereby creating a disturbed habitat which may be more suitable for seed germination. Although evidence of competition requires much more than a 1-2 yr study, a careful monitoring of the situation on Santa Catalina Island may be wise.

When considering a biological control agent, it is important to understand the weed's developmental cycle in relation to weather and growth rate. The removal of plant biomass by the agent is important, but if done at the wrong time, it will not affect survival of the plant (Andres 1966). Preliminary seasonal data suggest significant differences in biomass for *Cytisus linifolius* for winter and summer.

Keeley (1984) suggests two theories for relatively depauperate shrub and seedling establishment under mature chaparral. Seeds are either: 1) inhibited from germination by chemical components of the environment or 2) the seeds are refractory and require a stimulus from fire (cues that may stimulate germination include heat, which may crack hard seed coats or melt waxy coverings, and chemical stimulants released from charred wood).

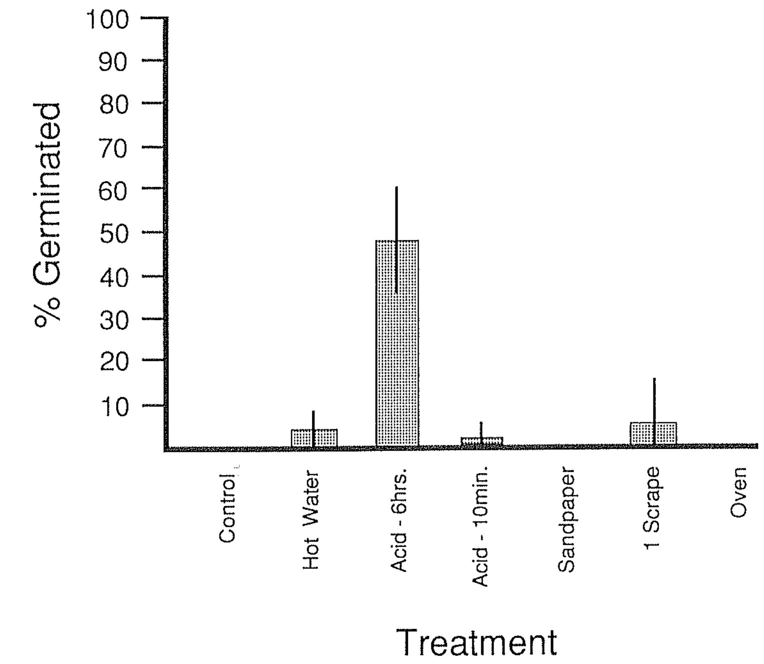

Figure 5. Average percentage germination ± 1 SE of *Cytisus linifolius* seeds. Experimental treatments were 1) control, 2) immersion in 98° C water and allowed to cool for six hr, 3) immersion in concentrated sulfuric acid for six hr, 4) immersion in concentrated sulfuric acid for 10 min, 5) 25 min agitation in a beaker lined with 60 grit sandpaper, 6) one scrape of the seed across 60 grit sandpaper and 7) 10 min in an oven at 104° C. (*n* = 50 with three replicates; SD = 12.8 for the acid at 6 hr).

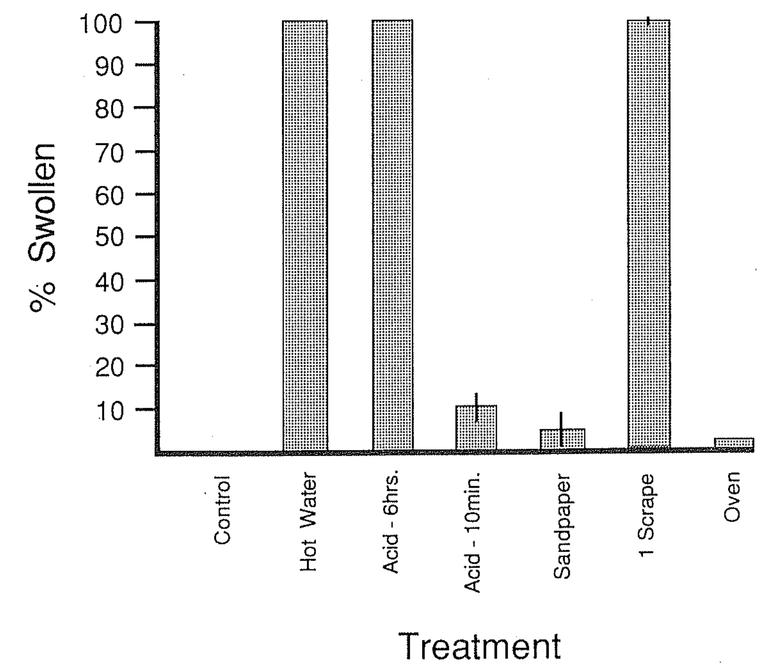

Figure 6. Average percentage ± 1 SE swollen of *Cytisus linifolius* seeds. Experimental treatments were 1) control, 2) immersion in 98° C water and allowed to cool for 6 hr, 3) immersion in concentrated sulfuric acid for 6 hr, 4) immersion in concentrated sulfuric acid for 10 min, 5) 25 min agitation in a beaker lined with 60 grit sandpaper, 6) one scrape of the seed across 60 grit sandpaper and 7) 10 min in an oven at 104° C. (*n* = 50 with three replicates; SD = 2.5 for acid - 10 min, 4.1 for sandpaper, and 1.0 for one scrape).

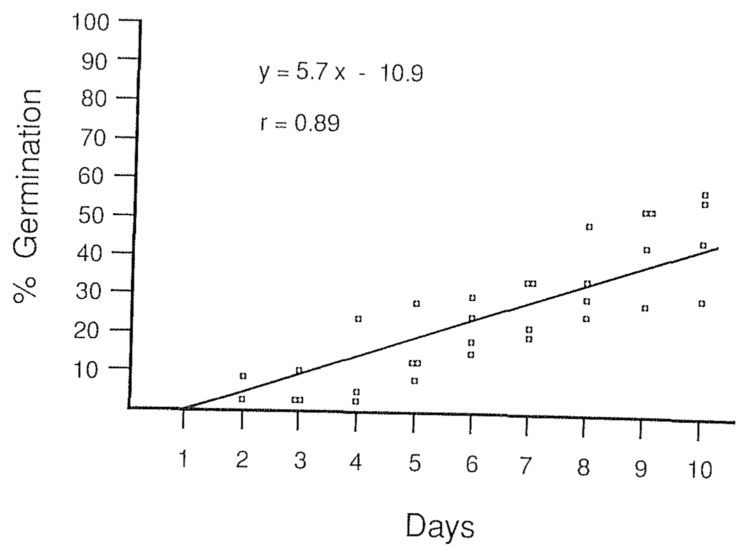

Figure 7. Percentage germination of *Cytisus linifolius* seeds over time when treated with 6 hr immersion in concentrated sulfuric acid.

This study suggests that treatment is required for seed germination in *Cytisus linifolius*. Those treatments which severely altered the seed covering showed the highest percent of swelling and germination. Although seeds given the hot water and one scrape across sandpaper treatments had low percent germination, 100% of the seeds swelled. Since the study was conducted over a 10 day period, it is possible that those two treatments may have required longer periods for emergence of the radicle.

Biotic factors may influence the germination of *Cytisus* on Santa Catalina Island. Birds may eat the seeds and abrade the waxy coat as the seeds pass through the crop. Introduced bison, which are thought to be the only other known vertebrate predators at this time, may alter the seed coat enzymatically during digestion. Isolated occurrences of *C. linifolius* appear to correspond with known animals trails around the east end of the island and into the interior. Soil microorganisms have been shown to break down the seed coat in the soil (Hartmann & Kester 1975). Fungi and bacteria slowly consume the outer covering, but it may be several years before enough of the coat is eroded to allow absorption of water. Mechanical factors also may play a role in seed germination. *Cytisus* plants commonly are found along stream beds, so dispersal in this area may lead to abrasion of the seed coats during spring rains. Plants of *Cytisus* also are found on steep slopes where erosion is a common occurrence. The seed coats may be abraded by the surrounding rocks and soil. Also, physical factors such as fire may cause high soil temperatures and cracking of the seed coats. Although the oven treatment did not show an increase in germination, higher temperatures or longer exposure to the heat may show an effect.

In the United States, biological control was implemented on Scotch broom *(Cytisus scoparius)* in 1960 in El Dorado County, California where 1000 stem- and twig-borer moths (*Leucoptera spartifoliella* (Hubner)), were released (Mobley 1960). The moths, which were originally shipped from France, became well established in California, Oregon and Washington (Andres 1979). However, the project was interrupted by a conflict of interest concerning the ornamental use and economic value of Scotch and French broom (Pemberton 1985). The only other broom species on which the lepidopterous stem- and twig-borer was found was *C. purgans* (L.) Boissier. Tests indicated the moth was unable to develop on or to cause more than slight superficial damage to several crop or native plants (Parker 1964). Frick (1964) conducted host specificity tests for *L. spartifoliella* using four common broom species established in California, including *C. monspessulanus* and *C. scoparius*. No cocoons or evidence of twig mining was found on any of the species except *C. scoparius*. He did report that feeding by *L. spartifoliella* larvae resulted in nearly 50% reduction in seed production and death to many branches of *C. scoparius* plants that were attacked. Another biological control agent for *C. scoparius* is the seed weevil (*Apion fuscirostre* (F.)) which was introduced to the United States from Rome, Italy in the spring of 1964. The weevil is now well established in coastal and Sierra *Cytisus* infestations and has shown some impact on the Scotch broom problem (Andres 1979). However, the seed weevil, like the stem- and twig-borer moth is specific to *C. scoparius* and will not feed or develop on the flowers of *C. monspessulanus* (Andres 1979).

On Santa Catalina Island, *Cytisus linifolius* has been the host of very few insects, the most notable being *Uresiphita reversalis* (Guenee 1854), the Genista moth. Prior to September 1986, the moth had only been observed in two locations on the island, Descanso Beach and Wrigley Garden. However, during the fall of 1986, the populations of *U. reversalis* dramatically increased. The insect population increased in such quantity that *C. linifolius* plants at Descanso Beach were defoliated and some eventually died. Larvae also were found in Avalon Canyon and on plants near the burn site.

In northern California, where *Cytisus monspessulanus* is a problem, efforts are currently underway to determine *Uresiphita reversalis* host race formation. This moth, a North American species is capable of extensive damage to the plants.

Alternate hosts for *Uresiphita reversalis* include species of *Genista*, *Lupinus* and other legumes and *Lonicera* of the honeysuckle family (Munroe 1976). Infestations of *U. reversalis* also have been reported on mescal bean (*Sophora secundiflora)* in Arizona (Crosswhite 1985). Although *U. reversalis* has not been found on native vegetation on Santa Catalina Island, host preference tests will be conducted in the future.

With any biological control project, it is necessary to have a land-management follow-up program. The niche left by the weed will be filled by other plants. As Andres (1966) recommends, a program of reseeding with natives can bring pressure against the introduced weed, possibly enhance the effectiveness of the agent, and help stabilize regrowth of the entire plant community.

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Floristic Analysis of Vegetation Communities on Isla de Cedros, Baja California, Mexico

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Abstract — Isla de Cedros lies within an arid climatic region and supports a diversity of vegetation community associations. These range from sarcocaulescent desert, made up of succulent-stem trees and shrubs, to coastal sage scrub, chaparral and maritime pine forest typical of southern and central Alta California. Previous published discussions of the vegetation on Isla de Cedros addressed individual species or were general in nature. The availability of black and white aerial photographs presented an opportunity to analyze the distribution of vegetation in detail. Floristic descriptions of 18 vegetation communities were created from field observations on Isla de Cedros. These communities were mapped utilizing aerial photographs. The distribution and species composition of these vegetation associations is dependent upon the island's topographic diversity, climate and biogeographic factors.

Introduction

Isla de Cedros lies about 23 km northwest of Punta Eugenia in central Baja California, Mexico (28°15' N, 115°15'W). The island is approximately 39 km long and about 15 km wide at the widest point, totalling roughly 348 km^2. From outward appearances, Isla de Cedros is a nearly barren series of ridges and canyons. However, due to its size, topographic variation, geologic history, climate and biogeographical history, it supports a relatively high diversity of native plants, 18 discernable vegetation communities (Appendix 1) and about 224 species (Appendix 2).

Physical Features

Topography: Isla de Cedros is a dominant topographic feature of a 400 km long submerged ridge. The island represents a northwest extension of the Sierra Vizcaino of Baja California and is separated from the mainland by water only 109 m deep (Kilmer 1977, 1979). The highest points on the island are Monte or Cerro de Cedros at 1,194 m on the southern third of the island and Pico Gill at 1,063 m on the northern quarter of the island. The island is cut by a number of deep canyons including Gran Cañon, Cañon de la Mina and Cañon Choyal on the east side, and Cañons Colorado and Vargas on the west side.

Climate: The climate of Isla de Cedros is arid. Average annual precipitation from a station on the southern portion of the island is only 85 mm. Judging from vegetation characteristics, average seasonal rainfall on the upper regions of the island is approximately 200 mm. The majority of the rainfall occurs as the result of winter storm fronts and upper level low pressure systems (71 mm; Fig. 1); however, significant amounts fall in late summer and early fall (13.5 mm). Occasionally, torrential rains occur during the summer and fall due to unstable tropical air masses and chubascos. Heavy storms which caused flash floods and erosion of washes swept the island in October 1983 and September 1984.

The island has a high level of cloudiness during spring and summer (Table 1) due to stratus associated with the cool, California current. These clouds contact mountainous islands such as Isla Guadalupe and Isla de Cedros, producing fog. Contrasts between the windward contact area of fog and the clear, warm surroundings can be extreme. Due to condensation and reduction of evapo-