ARTIFICIAL AND BIOLOGICAL CONTROL OF TANSY RAGWORT, *SENECIO JACOBAEA* L., IN REDWOOD NATIONAL PARK, CALIFORNIA

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ABSTRACT

The invasion of a disturbed coastal prairie by the noxious weed, *Senecio jacobaea* L., has been dramatic during the past decade. Interim control techniques currently used in the park include mowing, prescribed burning, plowing, discing, grass reseeding, and hand pulling. Even with treatment, large numbers of seeds mature and are wind dispersed. Prescribed fire plays an important role not only in killing ragwort seeds and consuming mulch but in promoting the germination of buried seeds of some native species. The effectiveness of these control practices has been monitored during three field seasons. A single, late mowing followed by burning reduces flowering and seed production. Additional interim treatment for dense ragwort aggregations includes plowing/discing and grass reseeding to *Festuca rubra* L. Long-term eradication is dependent upon the success of tansy flea beetles, *Longitarsus jacobaeae* Waterhouse. The less mobile cinnabar moths, *Tyria jacobaeae* L. defoliate portions of plants, and provide additional stress, but alone do not make significant impact on population size.

INTRODUCTION

The Eurasian weed, tansy ragwort, *Senecio jacobaea* L. is widely distributed along the Pacific coast from California to British Columbia, Canada. Ragwort (including *S. sylvaticus* L.) infestations are commonly found on lands of marginal agricultural value such as abandoned fields and cutover areas (West and Chilcote 1968). Population size is affected by the number of habitable sites and the nature of the disturbances which preceded the invasion. The primary infested area lies west of the Cascade Range in the Pacific Northwest. New areas of invasion are in central and northeastern Oregon (McEvoy, pers. comm.). Historic global distributions include rangelands of Australia, New Zealand, Tasmania, South America and South Africa (Poole and Cairns 1940).

Ragwort is a serious noxious weed because of its toxicity to horses and cattle (Muth 1968) and its competition with desirable forage plants. Ragwort possesses pyrrolizidine alkaloids (PAs) which may fatally poison livestock by causing liver diseases. Other *Senecio* species such as *S. vulgaris* L. in California and *S. longilobus* in the U.S. Southwest are implicated in livestock poisoning (Cheeke 1979). The toxicities are of great interest to both veterinary and human medicine. Although sheep appear immune to these alkaloids, both horses and cattle may develop a lethal addiction to the weed (Harper and Wood 1957). Intensive sheep grazing can effectively reduce the flowering and seed production of ragwort populations (Sharrow and Mosher 1982).

Increased densities of ragwort reduce the cover of favorable forage plants (Cameron 1935). The combined effect of forage plant exclusion and livestock deaths account for an estimated four to five million dollar annual loss in Oregon (Isaacson 1974). Also, pyrrolizidine alkaloids may concentrate in honey obtained by bees visiting ragwort flowers, but the implications for human health are not fully known (Deinzer et al. 1977). PA poisoning is a health problem in various parts of the world primarily through the deliberate use of herbal teas and the accidental contamination of food (Huxtable 1979).

Various treatments have been employed to reduce the densities of ragwort (Evans 1980). Mowing, plowing and discing and handpulling all have value depending on the nature of the infestation. Biological control agents, however, provide the best long-term management strategy for control. For example, Klamath weed, *Hypericum perforatum* L. was successfully controlled through the introduction

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of *Chrysolina* beetles (Huffaker and Kennett 1959). An important limiting factor in this case is that these insects do not oviposit in the shade with the result that Klamath weed has been reduced only in open habitats (Harper 1977).

During the past decade, a dramatic invasion of a disturbed coastal prairie by *S. jacobaea* has occurred. The study area bordering Crescent Beach and Bluff Road is situated south of Crescent City, California. Prior to the establishment of Redwood National Park in 1968, various agricultural practices were common. Included among these disturbances were the cultivation of areas for Easter lily bulb production, grazing and haying. Sufficient disturbance existed to favor the establishment of weed populations. The primary objective of the park's Tansy Ragwort Control Plan is to eradicate aggressive, exotic weeds such as ragwort which are displacing native species or well-established introduced grasses and forbs. The long-term goal is to re-establish the elements of native prairie ecosystems and processes, and to eradicate all noxious weeds.

METHODS

Initial attempts to control the ragwort invasion were restricted to handpulling and mowing. This activity occurred within the County Ordinance Zone of 150 ft paralleling roads and park boundaries. Ragwort densities vary depending upon the nature of previous disturbances. The total area of 180 ac (72 ha) was divided into treatment units ranging in size from a few to 22 ac (8.8 ha).

In 1980, ten 30-m transects were established to monitor the status of ragwort cover. Preliminary cover data were compiled using the line intercept method (Canfield 1941, Table 1). An additional ten transects were inventoried in 1981. Transects were subjectively located in areas with various densities. Most of the management units were mowed once in late July at the beginning of the flowering phase. Portions of three units were not mowed and serve as controls.

The plowing and discing phase was specific to areas of very dense ragwort aggregations. Grass reseeding using two species, *Festuca rubra* L. and *Dactylis glomerata* L., was carried out in late autumn. During the autumn drying periods, portions of many units were burned using a general fire prescription (Appendix I). Burned areas also were treated by grass reseeding. One plot (10 m x 30 m) was established in a stand of dense ragwort to test the effectiveness of the propane flame torch. Within this plot, each area (10 m x 20 m in 1980 and 1981; and the 10 m x 5 m only in 1981) was intensely burned to mineral soil to determine maximum heat effects in controlling ragwort. A control area (10 m x 5 m) was not burned. Each area was reseeded to *Dactylis glomerata* late in 1981.

Three areas designated as flea beetle nurseries (one colony each established in October 1978, in 1979 and in 1981 by R.S. Westing) were not disturbed beyond a single mowing in late July. Also, local ragwort stands displaying concentrated cinnabar moth larvae were not mowed. Five additional flea beetle colonies were established in the park during September and October 1982.

A ragwort seed germination test was carried out in the greenhouse to determine if seeds mixed with mulch could survive burning. Mature ragwort seed were collected in late summer from several sites, and mixed with dry, cured hay mulch. The treatment consisted of burning the mixture in the lab, and collecting the ash residue which was distributed among 14 pots and planted within the upper cm of soil. The control consisted of no burning, but the same planting procedure in 10 spots.

RESULTS AND DISCUSSION

Management of natural areas in national parks and similar reserves include programs to control or eradicate alien species as a significant early step toward the restoration of altered ecosystems. Alien species characteristic of disturbed prairies are highly specialized and represent successful invaders because of specific adaptations favoring seed dispersal and seedling establishment (Harper 1965). Ragwort behaves as a biennial or a short-lived perennial with a stout root crown and displays secondary growth having flowers and seeds despite extensive damage to aerial portions of the plant. In addition, there are two types of seeds (Baker 1982, McEvoy 1983): the disk achenes (average 58/head) are lighter and equipped with a pappus which functions like a parachute to colonize new areas. The seed pericarp also has trichomes which aid in transport via fur or feathers. The second seed type is the ray

Table 1

Annual Coverage Change in *Senecio jacobaea* L., Crescent Beach Coastal Prairie, Redwood National Park

Transect	Remarks	Percent Coverage[1] by Inventory Year (August through October) 1980	1981	1982[3]	1983
Flea Beetle[2]	Flea beetle establishment period estimated to be three to four years (nursery area not mowed or disturbed)	80%	76%	less than 5%	less than 3%
Unit A					
901	Mowed in 1980 Burned in 1980 and 1981	11	8	14	9
902	Mowed in 1980 Burned in 1980 and 1981	34	43	66	4
903	Burned in 1980 and 1981 Dense grass cover	0	0	0	1
904	Mowed in 1981 Burned in 1980 and 1981	38	8	7	0
905	Mowed in 1981 Burned in 1980 and 1981	64	39	15	8
Unit B					
906	Mowed in late 1980 Burned in 1980	17	5	9	82
907	Control	20	30	42	46
908	Control	32	28*	43	49
909	Control	28	20*	40	55

[1] Line intercept method along 30 m transect.

[2] Located near the 1978 flea beetle colony and mowed once each year.

[3] No mowing or burning in 1982.

* = Average of two readings.

...hene which is less abundant (average 13/head), heavier and lacks any dispersal adaptation. ...morphism in ragwort seeds increases the chance of seedling establishment. Although the disk ...henes may travel long distances in theory, the actual dispersal distances are surprisingly short due to ...cal variations of humidity, wind, and vegetation structure (McEvoy 1982). In one study of 280,000 ...eds which were marked and recaptured, 91% traveled less than 5.5 m, and the maximum dispersal ...tance was 14.5 m.

Little information exists on the longevity of ragwort populations (van der Meijden and van der Waals-kooi 1979); however, size of weed aggregations is affected by the nature of the earlier disturbance and the time required for invasion. The buried seed population may be a significant factor in the long-term persistence of the population. Control efforts have been focused on the ground surface, but large ragwort populations survive as seeds in a state of enforced dormancy within the soil (McEvoy, pers. comm.). Therefore, ragwort populations may survive periods of reproductive failure by recruiting new individuals from these seed banks. The viability of these buried dormant achenes is maintained for an unknown period.

Of all the methods employed to significantly reduce ragwort cover, the current prescription was implemented: 1) a single mowing in late July during the flowering phase to allow at least one month for curing. Standing live ragwort features a high moisture content ranging from 200% to 350% of oven dry weight. In a cut, cured condition, dense stems and inflorescences burn readily even with a low cover of associated cured grasses. 2) Burning is important to not only kill ragwort seeds, but to expose mineral soil and to prepare the site for 3) autumn plowing and discing. No actual tests were conducted to determine the effect of fire or high temperatures on ragwort seeds; however, field observations of fires consuming cured mulch mixed with large quantities of seed revealed only ash remaining. Controlled tests of heat and fire on ragwort seeds are planned. Also, germination tests have been carried out on seedheads burned by using a flame-thrower, and no viable seed could be found (Poole and Cairns 1940). Seeds on the surface of moist soil may escape potentially lethal temperatures from a backing fire; however, many seeds are mixed with mulch residues which in a cured condition, are easily consumed by fire. The experiment conducted in the lab to determine fire effects on ragwort seed consisted of two fires consuming mulch mixed with seed. Of the 14 pots planted with ash residues, none yielded ragwort seedlings, whereas the control which consisted of planted unburned material resulted in 9 of 10 pots with ragwort seedlings.

Deep plowing (25 cm - 30 cm) is necessary to insure that all rosettes and root fragments are buried. Surface contour discing prepares the site for autumn grass reseeding following the first soaking rain.[4] These techniques will significantly reduce ragwort cover, but new seedlings may become established on the exposed seedbed either from air-borne seed, buried seed or root fragments. However, a vigorous stand of grass may provide sufficient competition for moisture and nutrients to allow manageable ragwort control through handpulling. A ragwort cover of less than 10% was estimated after 2 yrs for local areas treated by plowing/discing and grass reseeding.

The experimental plot which was totally surface-burned with a flame-thrower and later reseeded to orchard grass displayed the ragwort cover reported in Table 2. Currently little ragwort cover remains within this plot as of 1983. The cover change data in *S. jacobaea* (Table 1) are preliminary and serve as baseline information for the interim treatments implemented to date. All transect ragwort populations have been stressed in various degrees by the cinnabar moth, and several are being stressed by flea beetles. Thus the effect of mowing followed by burning on reducing ragwort numbers is masked by the stress induced by both biological control agents.

Table 2

Flame-Thrower Burned Transects (10m)
Percent Cover of Seedlings and Rosettes

	Burned in 1980 and 1981			Burned in 1981
Control	1	2	3	4
89	26	9	29	43

The cinnabar moth, *Tyria jacobaeae* L., was introduced into the Pacific Northwest in 1960 and currently is the common defoliator (Isaacson 1973a,b). Whenever cinnabar larvae occur in large numbers on foliage and flowers they can completely defoliate plants. However, even severe defoliation by cinnabar larvae may not kill the plant. During late summer after the larvae have formed pupae, ragwort plants may produce secondary flowers and some viable seeds. The dynamics of the ragwort population are controlled primarily by environmental variables including those of climate and plant competition. The size of cinnabar moth egg batches is related to the size of flowering plants during the previous year (Meyers 1980). The insect dynamics are thought to be controlled by the variation of the ragwort population. The full potential of the cinnabar moth to reduce ragwort infestations is most apparent during drought years (Cox 1981, Cox and McEvoy 1983). Thus, in regions with high summer rainfall, additional biological control agents may be essential to attain a manageable level of control. If any factor causes starvation of the cinnabar larvae, ragwort density may increase; therefore, there is the possibility that ragwort populations may be recolonized following a period of high mortality in the moth population. The cinnabar moth and ragwort have co-evolved, thus the activities of the moth have been a significant selective force in the evolution of ragwort so that defoliation has little effect on numbers of plants in the absence of other stress factors (Dempster 1982). The moth can cope with the plants' poisonous alkaloids, and may use these toxins as a predator defense.

At Oregon State University, the dynamics of ragwort and moth interactions have been studied with the aid of a system simulation model (Stimac 1977). Model simulations were employed to determine the conditions under which cinnabar moths can reduce ragwort populations to low levels. The following five conditions are of importance and are interrelated so that a compensatory effect occurs (Stimac 1977):

1) defoliation greater than 95%,
2) ragwort re-growth following defoliation of 90% or less,
3) seed germination rate of 1% or less if re-growth is good,
4) cinnabar moth mortalities of less than 25%,
5) the period for moth emergence extended (assuming at least 40 eggs per plant).

Site specific environmental conditions determine the potential of cinnabar moth as an effective control agent (Stimac 1977). The model predicts decreases in ragwort biomass when plant growth and re-growth is stressed (for example, by low soil moisture) under high defoliation. Thus ragwort control may be achieved if some additional factor operates against the plant during cinnabar moth defoliation (Dempster 1982).

Another insect, the European flea beetle, *Longitarsus jacobaeae* Waterhouse, was established in the study area during 1978 and 1979. Three to four years are required for substantial population increases (Frick 1970b). Optimum biological control is attained by employing a combination of the two insects. Flea beetle adults feed on foliage in the autumn, and their larvae may feed in the roots during the winter (Frick 1970a). Actually in very moist or wet environments, larvae activity may be confined to the petioles of leaves (McEvoy, pers. comm.). There is a preference for rosette petioles where larvae activity disrupt the plants' transport system. The most comprehensive information available on the life history and host specificity of both the Swiss and Italian biotypes of flea beetles is provided in Frick and Johnson (1972) and Frick (1973). Currently, studies are underway to determine the impact of the observed flea beetle distributions on ragwort performance. At the time an inventory of cover was made in 1981, there was moderate observable impact by the flea beetles (Table 2). However, by autumn 1982 major flea beetle dispersal was occurring with a substantial decrease in ragwort cover within approximately 50 m of the nursery core area.

Another alien species, *Chrysanthemum leucanthemum* L. invaded the flea beetle nursery area in a circular pattern following high ragwort mortality. Similarly, another weed, *Silybum marianum* (L.) Gaertn., greatly increased in cover in an area where dense ragwort had been mowed and later burned. Ragwort cover prior to mowing and burning treatments was estimated at 80% in 1981. In 1982, following a mowing of both *Silybum marianum* and ragwort, another re-growth cover estimate was made. Ragwort cover was reduced to approximately 35%. Mowing treatments alone are known to cause little or no ragwort mortality. In addition, many ragwort plants are currently experiencing stress from flea beetles. The variability in the dynamics of the ragwort population under stress by several interacting factors make it difficult to predict how long the population will persist (Forbes 1977).

MANAGEMENT RECOMMENDATIONS

Natural area management frequently promotes the eradication of alien species. Since the establishment of aggressive weedy species is favored by the nature of previous disturbances, several techniques and approaches are essential to achieve manageable levels of exotic plants. In the long-term, the most effective biological control agents may be insects which are host-specific and compatible. In the case of flea beetles, at least 3 to 4 yrs of favorable conditions are necessary before high population levels are achieved to allow emigration beyond the core nursery area. Therefore, direct control methods may be necessary during the interim as a means of implementing an active exotic plant control program. Active noxious weed control is required for the park, to be in compliance with Del Norte County Ordinance 77-48. The objective is to reduce ragwort numbers by promoting vigorous grass competition through a sequence of methods. Since the primary long-term management objective is to restore or mimic a coastal prairie, any approach which encourages native species as elements of the prairie composition is appropriate. One of the few native grasses whose seed is available in commercial quantities is *Festuca rubra*. Therefore, it is the primary grass species reseeded on treatment areas. Only a single mowing in late July or early August during the early flowering period is necessary for ragwort populations being stressed by flea beetles. For areas of dense ragwort aggregations, autumn burning followed by plowing/discing and grass reseeding will achieve a manageable level. Obviously, burning and plowing would be detrimental to large numbers of flea beetles, and are only implemented in areas of very low or no existing flea beetle populations.

The primary role of fire is to consume ragwort seeds mixed with mulch and to prepare the site for plowing/discing, and grass reseeding. One favorable fire effect may be to increase the numbers of native fire-tolerant species such as *Lupinus rivularis* Dougl. ex Lindl. Another favorable effect is the killing of secondary flowering shoots of ragwort which results in no additional seed maturation.

Finally, recruitment of new individuals may continue via wind-dispersed seed from adjacent areas in addition to re-growth from buried root fragments and germination of buried seed. Continued monitoring is essential since many variables affect the population dynamics of both weeds and insect herbivores.

ACKNOWLEDGEMENTS

The Protection Division of Redwood National Park executed the prescribed fires; the Resource Management Division implemented treatments; R. S. (Murph) Westing, Farm Advisor for Del Norte County assisted with many phases of the project; Don Bush and Ken Collins of the State Agricultural Commission contributed assistance toward the park's compliance with Del Norte County Ordinance 77-48. Dr. Peter McEvoy and Caroline Cox of Oregon State University, Corvallis, have been very helpful with many questions concerning the dynamics of ragwort-herbivore populations; Robert Hawkes of the Oregon State Department of Agriculture responded to many questions. Special thanks to Susan Richey and Ron Knickerbocker for typing the paper.

APPENDIX I

Prescription Fire Management

All prescribed fires begin with observations of the behavior of small test fires to assess behavior of the larger planned fire. The coastal climate restricts the opportunity for prescribed burning since there is only a relatively narrow burning period from late summer to late autumn depending upon the pattern of the autumn rains. However, since most prairie fuels are in the 1-hr timelag category, several days of sunny, windy weather are sufficient for adequate fuel curing.

The primary firing strategy planned for grassland fuels is a backing fire. A fire backing into the wind fully maximizes fuel consumption, and temperature near the ground. Wide strips in firing speed the burning process and provide some measure of control. In the event of variable winds during the burning, a changed firing pattern to flank fire may be utilized to reduce fire intensity and spread. Since fire behavior is affected by fuel moisture levels, both live and dead fuel moisture are significant variables. Fuel moisture is a key element in defining and refining prescriptions and is a reliable predictor of fire effects.

Coastal Prairie Fire Prescription

Date	15 September to 1 November
Air Temperature	55°F to 75°F
Relative Humidity	Estimated 50% to 90%
Wind	5 mph to 15 mph
Wind Direction	Westerly, north or southwesterly
Sky Condition	Sunny or high clouds
One Hour Time Lag Fuel Moisture	6% to 15%
Ten Hour Time Lag Fuel Moisture	8% to 12%
Days Since Last Rain	At least two days
Herbaceous Fuel Moisture (grasses)	Cured condition
Live Woody Fuel Moisture	110% to 150%

Supplemental Information

Predicted fire behavior according to FIRECASTING Model (NFFL)3, TALL GRASS

Wind—5 mph to 25 mph (at 20 ft height)

Percent Slope—5%

Temperature—60°F

Cover Condition—O, Clear

Fuel Moisture:

CM1-15, CM10-20, CM100-20, CM1000-25, CMWOOD-100, CMHERB-15, Cured.

At 5 mph wind:

5 mph wind (ft/min)	35.6
Rate of Spread (ch/hr)	32.4
Intensity (Byrams, BTU/sec/ft)	370
Flame Length (ft)	7
Growth Rate: Perimeter (ch/hr)	114
Area (sq ac/hr)	97
Heat Load (BTU/sq ft)	625