Proceedings
California Exotic Pest Plant Council Symposium
Volume 5: 1999

Edited by

Mike Kelly
California Exotic Pest Plant Council

Melanie Howe
Kelly & Associates, San Diego, Ca.,

and

Bill Neill
Riparian Repairs, Anaheim, Ca.

October 15 – 17, 1999
Sacramento Inn
Sacramento, California

CALIFORNIA
EXOTIC
PEST PLANT
COUNCIL

Disclaimer

The views and opinions expressed in the articles making up the content of this publication do not necessarily reflect the position of the California Exotic Pest Plant Council.

Other copies of this proceedings are available by sending $10 to:
CalEPPC '99 Proceedings
c/o Sally Davis
32912 Calle del Tesoro
San Juan Capistrano, CA 92675-4427

California Exotic Pest Plant Council can be reached by writing to Sally Davis at the above address or by emailing: sallydavis@aol.com

To reach the editors: ; Mike Kelly, P.O. Box 26523, San Diego, CA 92196;

Cover weed: *Arundo donax* (Giant reed)

Printed in the United States
First printing September 2000

Recommended sample citation. DiTomaso, J. 1997. Risk Analysis of Various Weed Control Methods. *In,* M. Kelly, M. Howe and B. Neill (eds.). Proceedings of the California Exotic Pest Plant Council Symposium. Vol. 5:1999. pp. 34–39.

Contents

Papers Presented at the CalEPPC '99 Symposium

Posters & Abstracts

Instructions for Collecting and Submitting Exotic Plants for Identification

Ellen A. Dean, UC Davis Herbarium and G. Frederic Hrusa, California Dept. of Food and Agriculture

Imagine that you are out walking in what you believe to be pristine forest, and you see what you think may be a newly introduced weed – what should you do? A new partnership between The California Exotic Pest Plant Council (CalEPPC), the California Department of Food and Agriculture (CDFA), The University of California at Davis (UCD) and The University of California at Riverside (UCR) provides help and information for those who need it. The following article is a summary of how to submit specimens for identification.

The identification program

Andrew Sanders (UCR), Fred Hrusa (CDFA), and Ellen Dean (UCD) have volunteered to identify samples of unknown weeds submitted by CalEPPC members. We already perform plant identifications as part of our job -- Fred mainly identifies plants sent in by CDFA agents, while Andy and Ellen do so for UC Cooperative Extension and university affiliates, as well as the general public. We see the CalEPPC plant identification program as more than us providing a plant identification for you. We would like you to participate in an activity that will provide lasting benefit to CalEPPC, the state of California, and the scientific community. We are asking you to provide us with herbarium-quality specimens that will be permanent vouchers of any collection information that you send us. These specimens will be deposited in the UC Davis Herbarium, the UC Riverside Herbarium, or the CDFA Herbarium, depending on where you send the specimen for identification.

Now, you may be asking, what is an herbarium specimen, and what is its value? Herbarium specimens (Fig. 1) are dried and flattened plants mounted with archival glue onto 11 x 17 inch archival paper; also attached to the paper is a label (Fig. 2) that contains data on the plant such as where and when it was collected. Herbarium specimens prepared with archival materials can last for centuries. They are the basis for all work done on plant classification and identification around the world. If you open a flora – for example the most recent flora of California, the Jepson Manual (Hickman 1993) – all the plant measurements and distribution information given for each species in that book were taken from herbarium specimens. Each specimen can be thought of as a slice of history that can be viewed and used by the general public and scientific community at any time.

The goal of our program is to create herbarium specimens from the plants and collection information that you send us. Once your specimens are deposited in an herbarium, they will serve as a lasting record of your work. You will preserve not only the plants that you collected, in case questions about their identity crop up at a later date, but you will preserve your collection data in the form of specimen labels. Your specimens may document the first collections of newly introduced exotic plants, and the data you collect will help us track their distribution and hopefully their eradication.

How to collect plant specimens:

I. What parts of the plant and how much should you collect?

In terms of what plant parts you should collect, you need to send us a representative sample of the plant. Usually, this means just one plant, but if it is a very small plant, we may need five or six, to have sufficient material to dissect. In addition, keep the following points in mind:

1. In general, flowers and fruits are important for identifying most plants, because identification keys emphasize those parts. Therefore, please try to collect flowers and/or fruits (even flower buds can be helpful, if flowers are unavailable). Note: If you have reason to suspect that you are collecting an invasive exotic plant species, be careful not to spread the seeds or other propagules, during the collection process.
2. For some plants, underground parts are important for identification – this is especially true of grasses, sedges, ferns, and lilies.

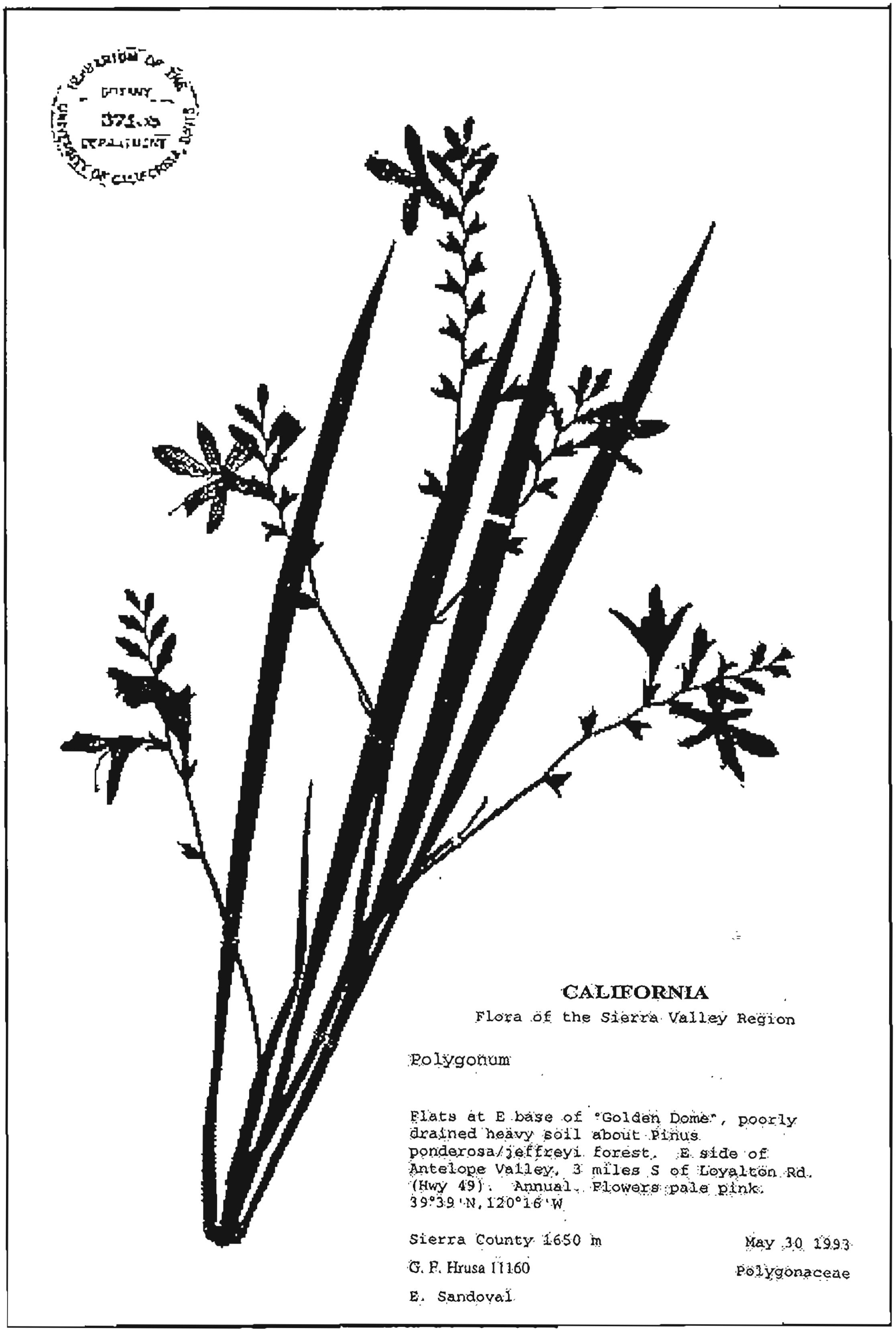

Fig. 1. Xerox of a photograph of an herbarium specimen.

3. If the plant is small, you will be able to collect the entire plant, including roots. If the plant is large, you will only be able to take selected parts, and you will have to choose those carefully. With trees and shrubs, you will need to clip off a representative branch. A piece of the bark is sometimes helpful as well. If you are sampling a large herb, make sure that you have pieces of the plant that are representative of the total variation in leaves and stems on the plant. Sometimes lower leaves are very different than upper leaves, and both may be important in identification. You may want to sample the plant from the base, middle, and tips.

II. Collecting equipment and data collection

At a minimum, the general collecting tools that you will need are clippers, a digging tool, plastic bags, data collection sheets, a writing tool, and a plant press. If you want very exact location data, a GPS unit is needed.

Your plant press (Fig. 3) will consist of two pieces

CALIFORNIA

Flora of the Sierra Valley Region

Polygonum

Flats at E base of "Golden Dome", poorly drained heavy soil about Pinus ponderosa/jeffreyi forest. E side of Antelope Valley, 3 miles S of Loyalton Rd. (Hwy 49). Annual. Flowers pale pink. 39°39'N,120°16'W

Sierra County 1650 m　　May 30 1993

G. F. Hrusa 11160　　Polygonaceae

E. Sandoval

CALIFORNIA

Flora of Snake Lake Vicinity

Sanicula

Occasional individuals on lightly shaded slopes and somewhat open sites in coniferous forest surrounding Snake Lake. Perennial, flowers yellow. 39°58'N,120°59'W

Plumas County 1250 m　　May 30 1993

G. F. Hrusa 11138　　Apiaceae

E. Sandoval

Fig. 2. Examples of two herbarium specimen labels made by G.F. Hrusa.

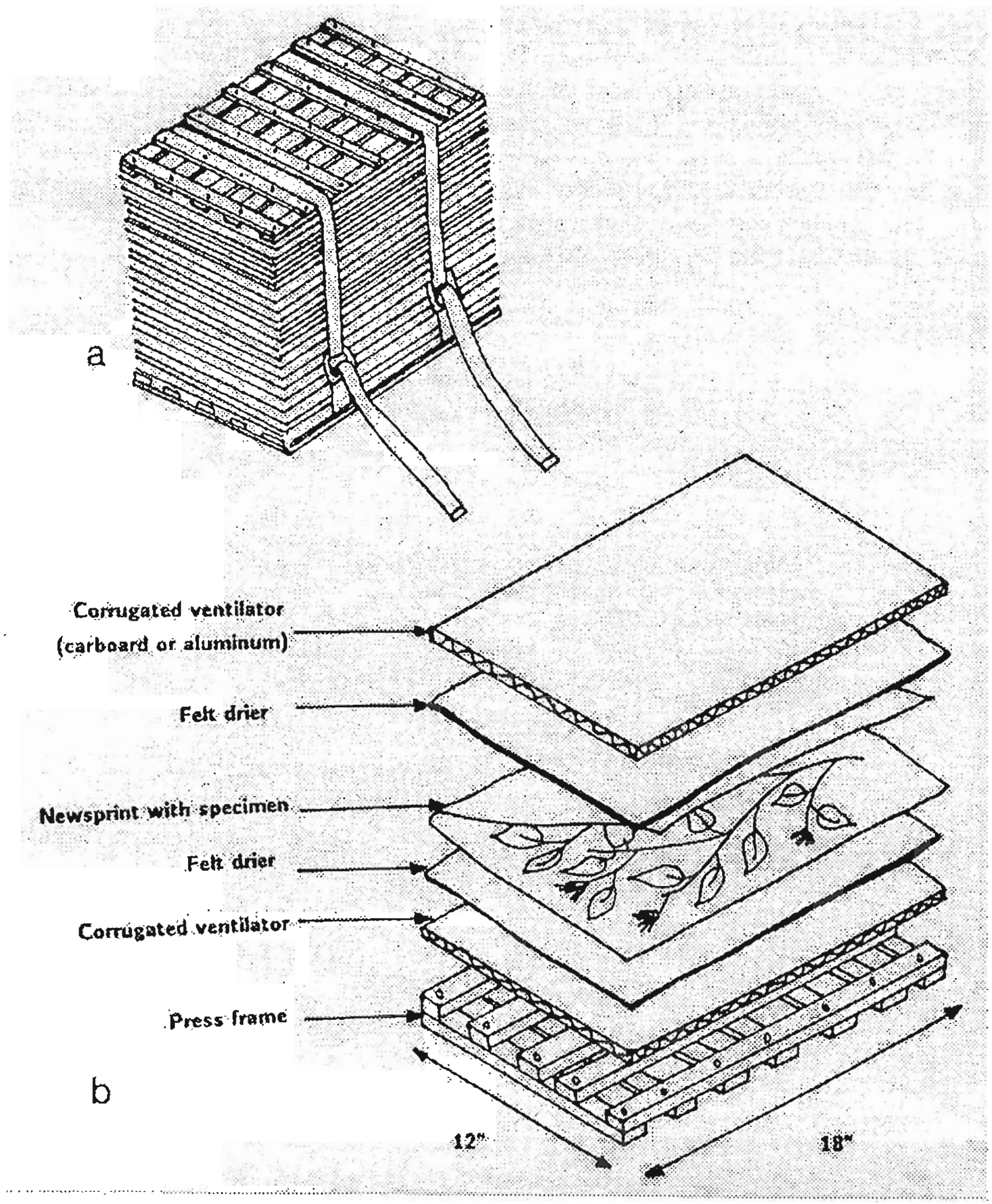

Fig. 3. Illustration of a plant press and its component parts. Illustration taken from Miguel N. Alexiades, 1996. "Standard techniques for collecting and preparing herbarium specimens," in Selected Guidelines for Ethnobotanical Research, A Field Manual (M.N. Alexiades, editor), The New York Botanical Garden Press. Used with permission.

of wood, 2 straps, and layers of cardboard, blotting paper, and newspaper. The plant specimen to be pressed is placed in a single-thickness of folded newspaper that is no larger than 11 x 13 inches (when folded). Any plant that you collect needs to fit in that space within the folded newspaper. On either side of the newspaper is placed a single sheet of blotting paper, and to the exterior of these sheets of blotting paper are placed cardboards. Thus, within the wooden press, the parts alternate as follows: cardboard, blotter, newspaper with specimen, blotter, cardboard, blotter, newspaper with specimen, blotter, cardboard, etc., until one reaches the bottom of the press. The straps hold the press together and are pulled tightly and secured, so that the plants within the newspapers are pressed flat. Some herbaria rent presses, if you need to borrow one.

We have provided a sample data sheet that has blanks to fill out (Table 1). Each plant species that you collect should be assigned a unique number that we can use when we communicate about the specimen; you should write the unique number on both your data sheet (in the blank provided) and on the newspaper that contains the plant in the plant press. Next, record the date of the collection in the proper space. Finally, there are instructions on the data sheet as to what type of locality, habitat, and plant description data are important. At a minimum, we need good locality data. Plant data such as height (for large plants) and flower color (a characteristic that can change as the plant dries) are also important.

III. How to press a plant

As mentioned above, if the plant that you are collecting is relatively small, you can collect and press the entire plant (folding the plant if necessary to fit in the 11 x 13 inch space). Make sure that some leaves face up, while others face down. Spread out the parts, so that leaves lie flat and flowers are pressed open. If you need to collect a large herb, for example a 5 ft tall herb, this is how you might go about it. First, clip a stem of the plant at ground level. Then use your clippers to cut the stem into sections – selecting the better stems that have flowers and or fruits and good leaves. Select sections of the stem that show how the leaf varies from the base of the plant to the top. If you end up with more material than will fit into one folded newspaper, then put the pieces of the plant into several folded newspapers, marking each newspaper with the same unique number. If you don't want to take your press to the field, you can place your plant specimens in plastic bags (writing the unique numbers on the bags) and put the plants in your press later in the day.

Once your plants are in your press, you need to tighten the press and leave it in a warm, well-ventilated area. This can be as simple as leaving it in a warm car, or you can leave it on its side in front of a fan. Check your plants every few days to make sure that they aren't molding. Plants with thick leaves and stems can take a long time to dry, and you may have to change the blotters in the press. Normally, plants take from 3-5 days to dry. Re-tightening the press after a day or two can improve specimen quality.

Sending your plant samples for identification

Your dried plant samples can be sent through the mail for identification. Place your data sheets inside the folded newspapers of the appropriate plant specimens, then bundle your specimens together tightly between cardboard. Place the cardboard bundle inside of a box with padding around it. Make sure that you filled out your contact information on the data sheets, so that we know how to get hold of you. Usually, we can identify the specimens within a week of receipt, however, there may be times when we are out of town or teaching. If you don't hear anything from us for several weeks, then you should contact us to find out if we received the specimens.

Contact information

Ellen Dean, Plant Biology,
UC Davis, Davis, CA 95616;
eadean@ucdavis.edu;
530-752-1091.

Andrew Sanders, Botany and Plant Science Dept.,
UC Riverside, Riverside, CA 92521-0124;
andrew.sanders@ucr.edu;
909-787-3601.

Fred Hrusa, Botany Laboratory, Plant Pest Diagnostics Center, 3294 Meadowview Rd.,
Sacramento, CA 95832-1148.

Literature Cited

Hickman, J.C., ed. 1993. The Jepson Manual: Higher Plants of California. Univ. of Calif. Press, Berkeley.

Data Sheet for Plant Collections

INFORMATION ON COLLECTOR:

Collector's name:______________________ Collector's email or preferred method of contact:______________________

____

INFORMATION ON PLANT COLLECTION:

Unique Number:________ Date of plant collection: ______________

LOCATION (IN U.S.A.) WHERE PLANT COLLECTED:

State______________________ County______________________

Township/Range: T________ R________ Sect.________, ________ ¼

Quadrangle Map:______________________

or

Latitude/Longitude: ______°, ______', ______'' N; ______°, ______', ______'' W or E Elevation____________ feet or meters (circle one)

Exact Location in words, giving "road distance" (using your odometer) or "as the crow flies distance" (using a map) from a major landmark or road intersection. Be as specific as possible. Rather than using a term such as "near", use the terms "west of, south of", etc:

____

____

____

____

HABITAT: Give information such as slope, aspect, soil type, plant community type, dominant plant species, associated species, moisture level, light level:

____

____

PLANT DESCRIPTION: Give information such as abundance, flower color, pollinator type, plant height, habit, life form (annual or perennial herb, shrub, etc)

____

____

CONTACT INFORMATION: Send this sample to: Ellen Dean, Plant Biology, UC Davis, CA 95616; or Fred Hrusa, Botany Laboratory, Plant Pest Diagnostics Center, 3294 Meadowview Rd., Sacramento CA 95832-1148; or Andrew Sanders, Botany and Plant Science Dept., UC Riverside, Riverside, CA 92521-0124.

IDENTIFICATION (for Herbarium Use Only):

Family______________________ Scientific name:______________________

____

Common name:______________________

Is this an introduced species of concern?:______________________

Table 1. Sample data sheet for label data (to be filled out at the time a plant is collected).

There's More to Tumbleweed (Russian Thistle) than Meets the Eye

Frederick J. Ryan, Debra R. Ayres, and Deanne E. Bell
USDA ARS HCRL, 2021 South Peach Avenue, Fresno, CA 93727 and
Division of Evolution and Ecology Univ. of California
One Shields Avenue, Davis, CA 95616

Although tumbleweed or Russian thistle (*Salsola tragus* L.) seems like an archetypal component of the western landscape, it is a relatively recent introduction. It was first noted in California in the 1890's, after introduction into North America two decades earlier (Shinn 1898). Confusion concerning the identity and proper botanical name of Russian thistle has persisted from then until the present. Mosyakin (1996) summarized the history of *Salsola* species in North America and their taxonomic status.

According to Hickman (1993) four *Salsola* species are present in California; *S. soda* L. and *S. vermiculata* L. are limited to restricted areas while *S. paulsenii* Litv. and *S. tragus* are found more generally throughout the state. Mosyakin (1996) noted that *S. kali* ssp. *pontica* (Pallas) Mosyakin was found on a channel island. Beatley (1973) first recognized *S. paulsenii*, the Russian barbwire thistle, in the deserts of California and Nevada and suggested that hybridization might occur between this species and *S. tragus*. Two variants of *S. paulsenii* have been described (Arnold 1973); one with a spinose beak on the perianth, the other with a lax tip. The spinose form had a chromosome number of 2n=36 while the lax form had 2n=54, suggesting that these were actually different species. According to Arnold (1973), the lax form of *S. paulsenii* was found in the Central Valley of California and the deserts of Nevada and Utah while the spinose form was in the Mojave desert. In addition, the records at the Herbarium at the California Academy of Sciences, San Francisco, indicate one introduction of *S. collina* at Lucerne, Lake County (CAS 639197, October 1980; in folder *S. collina*). Chromosome numbers of *Salsola* species found in California are given in Table 1.

The actual number of introductions of *Salsola* species from overseas is not known. It seems unlikely that a single introduction would have been responsible for *S. tragus* and the two variants of *S. paulsenii*, yet no evidence for additional introductions after that of the early 1870's has been cited. It has generally been assumed that the widespread *S. tragus* is a single species although variability in descriptions of key characters can be noted. For instance, Crompton and Bassett (1985) give a diameter for the calyx wings of the fruit of 3 to 6 mm while Arnold (1973) states a diameter of 2 mm and Mosyakin (1996) gives a range of 8 to 10 mm. The red or purple striped stem has been used as a key character for *S. tragus* (Arnold 1973, Crompton and Bassett 1985), although it was noted that this is not invariant. These differences may reflect response to edaphic conditions but may also be the result of genetic variation within the species or may represent interspecific differences if more than a single species is present.

Regardless of taxonomic identity, Russian thistle in general is a nuisance plant, causing problems ranging from interference with highway traffic to serving as a reservoir for diseases of horticultural crops. Previous attempts to control the population size through introduced agents, two species of *Coleophora* (Coleophoridae, Lepidoptera) were unsuccessful although the moths became established (Müller et al. 1990).

Table 1. Chromosome numbers for *Salsola* species in California.

Species	Chromosome number	Reference
S. soda	2n=18	Mosyakin 1996
S. vermiculata	2n=18	Mosyakin 1996
S. kali ssp. *pontica*	not given	
S. tragus	2n=36	Mosyakin 1996 Arnold 1973
S. paulsenii, spinose form	2n=36	Arnold 1973
S. paulsenii, lax form	2n=54	Arnold 1973

This work was undertaken to determine genetic variation in *S. tragus* in California with molecular markers. Knowledge of the genetic variation in a plant pest population is a useful component of an effective biocontrol strategy. A second goal of this work was to compare *S. tragus* in California to accessions of *Salsola* species from Europe and Asia, to determine populations that are most similar to those within the state. These overseas populations may be sources of insect and disease organisms for biocontrol of the plant.

Materials and Methods

Plant material

Plant material was collected along roadsides at 10 m intervals but large infestations were sampled at 400 m intervals. Plants from overseas were dried by the collectors then shipped to the USDA ARS HCR Laboratory in Fresno for analysis.

Isozymes

Plants were assayed within two weeks of collection with storage at 4°C. Fifty mg fresh tissue were ground in a mortar and pestle in 500 to 700 µl 50 mM Tris Cl, pH 7.8, with 15% (V/V) glycerol and 0.1% 2-mercaptoethanol. After centrifugation for 5 min at 12,000 rpm in an Eppendorf Centrifuge, 15 µl of the supernatant was applied per well on a 6.0 x 8.5 cm x 0.75 mm gel comprising 7.5% total acrylamide. Gel and tank buffers were those of Davis (1964). Electrophoresis was at 125 V for approximately 1.5 hr. Determination of informative isoenzymes is described elsewhere (Ryan and Ayres in press). Staining for 6-phosphogluconate dehydrogenase (6PgluDH) and aspartate aminotransferase (AAT) was as described (Wendel and Weeden 1989).

RAPD assay

DNA was isolated by the method of Saghai-Maroof et al. (1984) using cetyltrimethylammonium bromide. Partially purified DNA was precipitated from isopropanol then ethanol, and quantified by UV absorbance. DNA preparations were examined after electrophoresis on 0.8% agarose (see below) to determine integrity.

The RAPD assay was carried out with 15 ng DNA in a 25 µl reaction volume containing 4 mM MgCl2, 200 µM each dATP, dGTP, dCTP, and dTTP in Buffer II (Applied Biosciences, Foster City, CA) overlaid with mineral oil. Primer concentration was 10 pmoles per reaction. Determination of useful primers is described elsewhere (Ryan and Ayres in press). Primers utilized were C-18, G-11, G-12 and F-9 from Operon (Emeryville, CA) and 724 from University of British Columbia Protein Service Unit (Vancouver, BC, Canada). Additionally a dodecameric primer, (GATA)4, was used. One unit of Taq DNA polymerase was added to the reaction during an initial heating to 94°C. Amplification proceeded through 39 cycles of 94°C, 30 sec; 38°C, 30 sec; 72°C, 1 min followed by an extension at 72°C for 8 min for the dodecameric primers. Analysis of amplified product was by electrophoresis in 2% agarose (FMC, Rockport, ME) in 89 mM Tris borate , 2 mM ethylenediaminetetraacetic acid, pH 8.0, followed by staining in 0.5 µg ethidium bromide L-1. Products were photographed in UV light using Polaroid 667 film (Cambridge, MA) or the image was recorded in an Alpha-Innotech Image Analyzer (San Leandro, CA). Molecular weight standards (FMC) in the range 2500 to 50 base pairs were run in one lane of each gel and used to estimate the size of the amplified bands.

Polymorphic amplified bands were scored as present or absent to produce a binary matrix for an experiment. A matrix of similarities was calculated using the Jaccard coefficient in the NTSYS-pc program, version 2.0, of Rohlf (1997). A dendrogram was constructed using UPGMA clustering in the same program

Fruit weight and size

Fruit were collected at 2 sites at the USDA ARS Horticultural Crops Research Laboratory in Fresno, separated by less than 100 m and having the same soil type. Fruit were removed from plants by shaking or stroking with a forceps. The term fruit describes the seed, seed coat and attached perianth with the calyx wings. Weights of 150 individual fruit of each type were determined. Diameters of 50 fruit were measured by placing individuals on graph paper ruled in mm intervals and estimating the diameter. Values of both weights and diameters were log transformed to equalize variances between the groups. Comparison of means was by the unpaired Student-t test. Means of untransformed values are reported in Table 3. N

Mention of a brand name or supplier by the USDA does not constitute a guarantee or warranty nor imply an endorsement over other equivalent products.

Results

Isoenzymes

The isoenzyme systems AAT and 6PgluDH showed two covarying patterns within what was originally thought to be the single species S. tragus; the plants of these different multienzyme phenotypes were termed Type A and Type B (Fig. 1). The Type A pattern had more bands of activity than did Type B, in addition to having bands of different mobility, suggesting that the two types might have different ploidies. Over three years, almost 600 accessions from 67 sites in California were characterized by patterns of AAT and 6pGluDH. Of these, 62% were Type A and 28% were Type B. Other patterns were observed in 7% of the samples. Some of these were later shown to be *S. paulsenii* and the remainder, collected in late summer 1995, displayed multiple bands of activity. More extensive sampling at these sites during the next growing season failed to reveal the presence of isoenzyme phenotypes other than Type A and B and it was concluded that the initial results in these cases were artefactual.

In one case, the presence of additional bands in electrophoretograms for AAT and 6PgluDH indicated another genetic entity. A collection was carried out in Coalinga in February, 1999. Most plants in the area appeared to be typical Type A as judged from plant size, internode distance, and the appearance of the fruit. Some plants in the area, however, had differed from the Type A plants, with shorter internode distances, longer spines and larger fruit. When seedlings from these fruits were subject to electrophoretic analysis, additional bands were present in the patterns of AAT and 6PgluDH, especially in the faster region of the AAT (Fig. 1). The different isoenzyme pattern was repeatable, although band intensities change with development from seedling to plant. This suggested that these plants were different from Type A or Type B, and may have a higher ploidy than Type A or a different genetic composition.

The results of determination of isoenzyme patterns in recent accessions of fresh material from nearby states are shown in Table 2. Both Type A and Type B plants were present among these accessions.

Table 2. Isoenzyme analysis of recent accessions of *Salsola tragus*. Type was assessed by the patterns of AAT and 6PgluDH.

Location	Number of plants	Date	Type
Albuquerque, NM	6	August 1997	A
New Mexico at Texas border	5	August 1998	A
Quartzite, AZ	5	December 1998	B
Mesa, AZ	6	December 1998	B
Phoenix, AZ	12	December 1998	B
Tempe, AZ	6	December 1998	B
Riverside County, CA	6	December 1998	A and B
Indio, CA		December 1998	A
Spokane, WA	14	August 1999	A

RAPD analysis

In the first RAPD analysis, 96 accessions of *Salsola* were screened using 6 primers that produced polymorphic amplification products (Ryan and Ayres in press). Of these, 42 were from plants known to be Type A by isoenzymic analysis and 24 were known to be Type B. Additionally, four of these accessions were *S. paulsenii* ; the remainder were dried *Salsola* collected either in France or in Turkey. In the dendrogram generated by cluster analysis of the similarity matrix (Fig. 2), plants of Type A and Type B were well separated. Accessions from Turkey and France clustered with the Type A plants and *S. paulsenii* was more similar to Type A than to Type B.

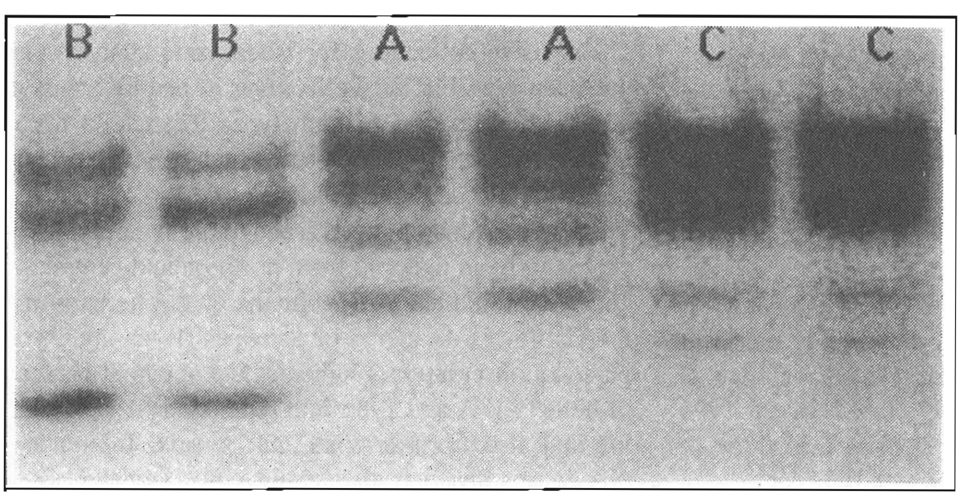

Fig. 1. Patterns of aspartate aminotransferase for plants of Type B (B), Type A (A), and the unnamed accession from Coalinga (C).

A second analysis was conducted with 4 primers and 62 accessions (Fig. 3). These accessions included plants from California known to be Type A or Type B by isoenzyme analysis, dried material from Washington State, Oregon, Uzbekistan, Italy and China (Inner Mongolia) as well as *S. paulsenii* from Searchlight, Nevada in the Mojave desert. Since the latter material had fruit, it was identified as the lax form described by Arnold. The dendrogram representation of cluster analysis indicated that Types A and B were well separated. Samples from Oregon and Washington State were included in the Type A cluster as well accessions from Uzbekistan and Italy. The material from China, identified as *S. collina* by the collector, formed a separate group allied with Type A as did *S. paulsenii* (lax form). Ten plants of Type A from a single large infestation in Fresno had nearly as much variation as the entire Type A cluster.

Chromosome numbers and genome size

The chromosome numbers of Type A and Type B have been determined to be 2N=36 and 2N=18 (John Bailey, University of Leicester, England, personal communication). This indicates that Type A is a tetraploid while Type B is a diploid. Genomic sizes of plants of Type A and Type B are being determined by flow cytometry (D. R. Ayres and E. Krotkoff, personal communication) and these are roughly in accord with the suggested teraploid and diploid levels indicated by the chromosome numbers. Flow cytometry indicates that the material from Coalinga with the unusual patterns of isoenzymes has an even larger genomic size than Type A. The only higher chromosome number known within *Salsola* is 2n=54, which is manifest by the lax form of *S. paulsenii* and the so-called *Salsola* X from Utah described by Arnold (1973).

Fruit characters

Fruit weight and diameter were compared for plants of known Type A and B growing 100 m apart at the USDA ARS Horticultural Crops Research Laboratory in Fresno in 1998. The fruit of Type A were heavier than those of Type B while Type B had a greater diameter than those of Type A (Table 3). The situation in which the plants are growing can be described as very nearly a common garden so these differences may reflect genetic differences between the two types. Fruit were collected from a number of Type A or Type B plants from a number of different sites between 1994 and 1998; those of Type A were heavier than those of Type B in every case (data not shown).

Table 3. Fruit weights and diameters from collections of Type A and B in 1998.

	Fruit wt, mg	Diameter, mm
Type	Mean ± sd	Mean ± sd
A	2.49 0.76 (N=150)	3.2 1.0 (N=50)
B	1.64 0.54 (N=150)	4.8 1.4 (N=50)
	t-value = 9.280, P <0.0001	

Discussion

How many widespread *Salsola* species are there in California?

The consistent and strong differentiation between Type A and Type B in both the isoenzymic and the RAPD analysis, the differences in chromosome number and genome size and the difference in flowering phenology and fruit character suggest that these are two different species. The diploid chromosome number of 2n=36, and the size and appearance of the seeds, lead us to conclude that Type A is *S. tragus* as described by Mosyakin (1995) and others. The identity of Type B is currently obscure. Further work on the plants from Coalinga is required to draw a firm conclusion concerning taxonomic status in this case but present evidence from isoenzymes and genome size suggests that another taxon is present in this area, perhaps the lax form of *S. paulsenii*. This would indicate that there may be as many as four widespread species of *Salsola* in the state.

How general are Type A and Type B in western North America?

Extensive collections for isoenzymic analysis have not been possible but collections in nearby states establish the presence of both types throughout the region (Table 2). Type A isoenzymic pattern has been observed in accessions from New Mexico, Arizona and Washington State. Type B isoenzymic pattern was observed in fresh material from northern and central Arizona. Examination of specimens at the herbarium of the California Academy of Sciences (Ryan and Ayres, personal observations) indicates the apparent presence of both Type A and Type B in collections from California and also from Arizona and Nevada. Inference of type in this case was made from calyx diameter.

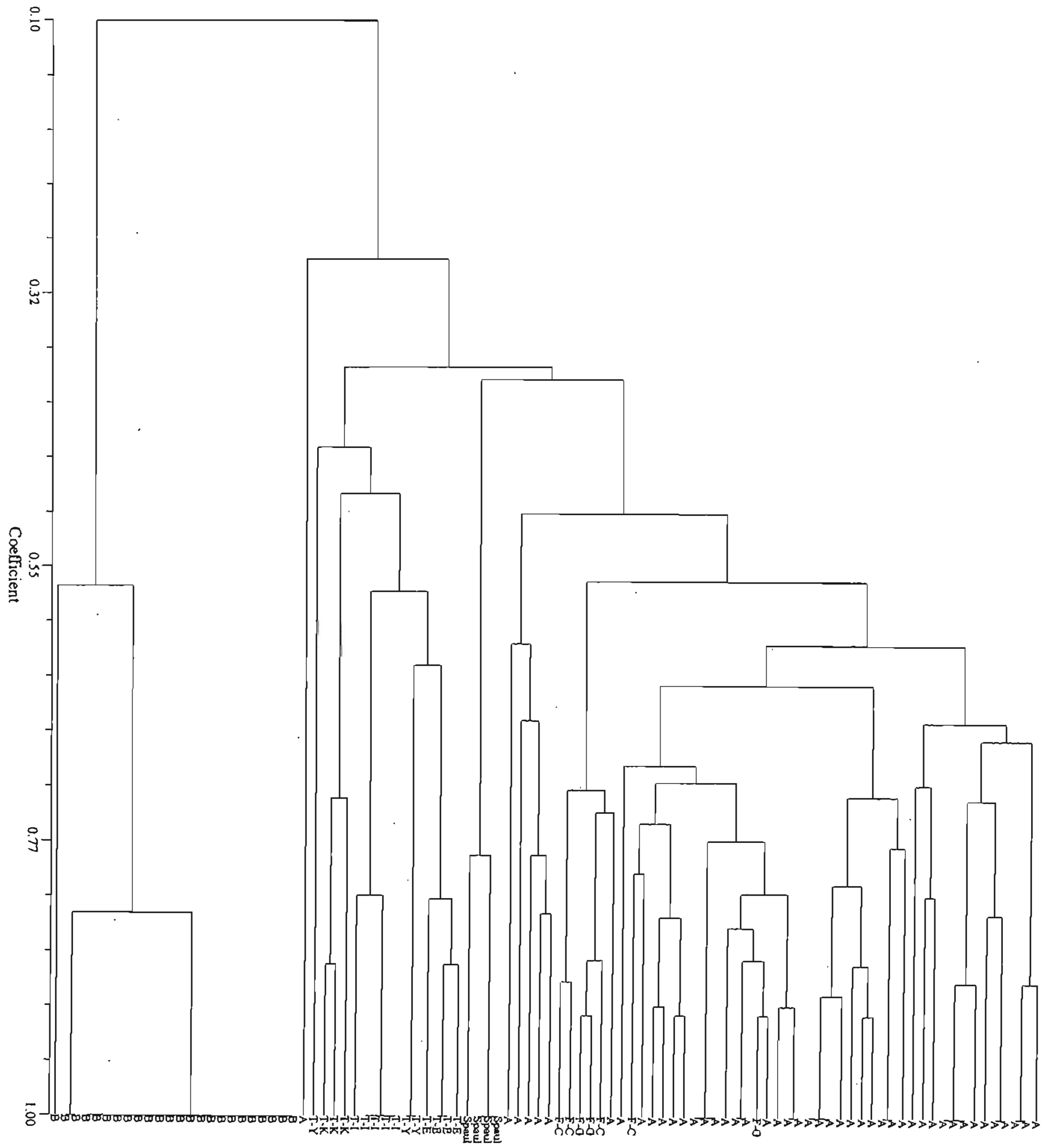

Fig. 2: Dendrogram from UPGMA analysis of similarity from RAPD assay of 96 accessions of *Salsola* with 6 informative primers. Plants from California known to be Type A or Type B from isoenzymic analysis are designated A or B. F-G and F-C indicate plants from two locations in France while T-K, T-E, T-I and T-Y designate plants from 4 locations in Turkey. Plants identified as *S. paulsenii* are designated Spaul.

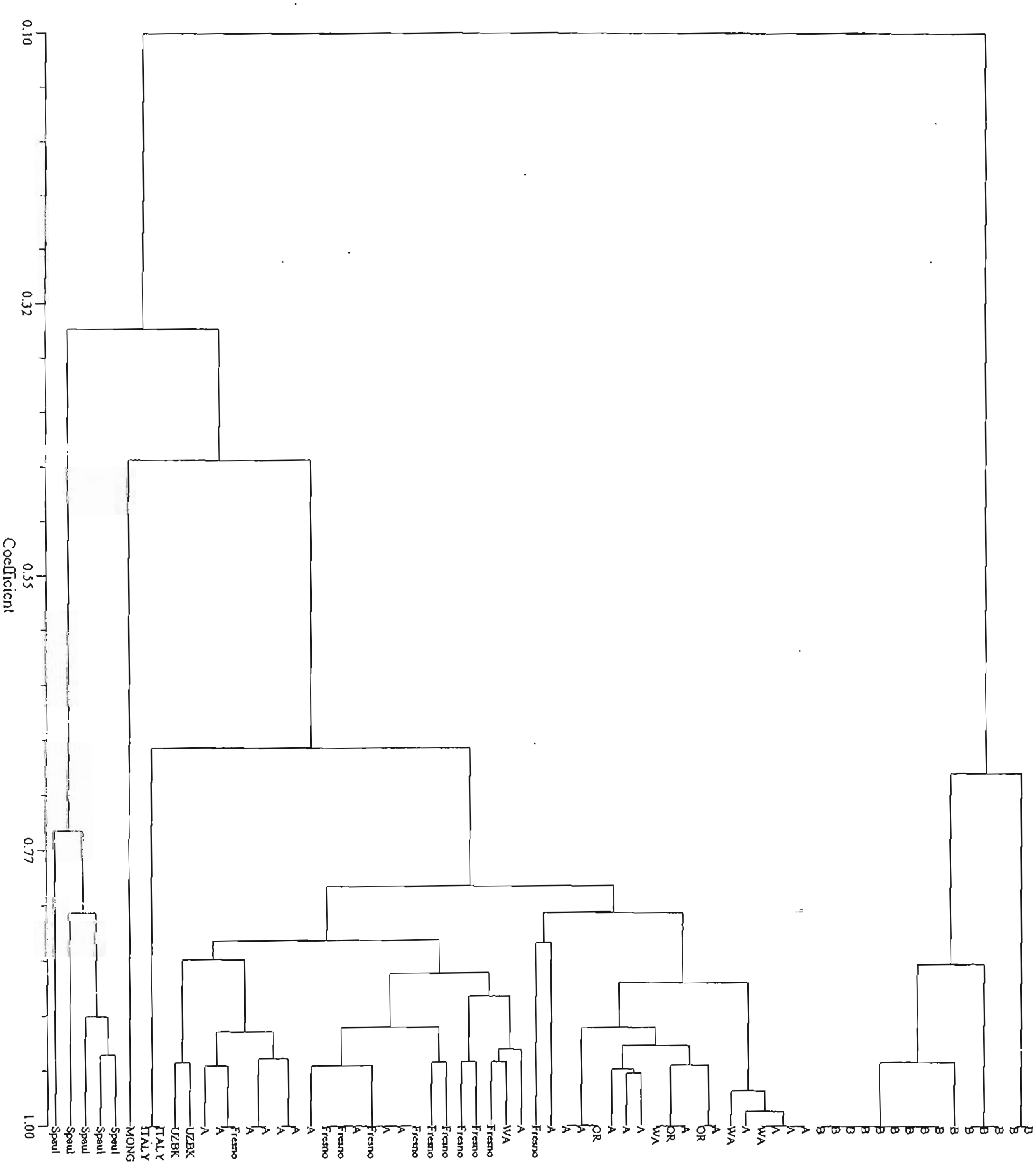

Fig. 3: Dendrogram from UPGMA analysis of similarity from RAPD assay of 66 accessions of *Salsola* with 4 informative primers. Plants from California known to be Type A or Type B from isoenzymic analysis are designated A or B, except plants from a single large infestation, designated Fresno. Plants marked OR or WA were from Oregon or Washington State, respectively. Mong designates a plant collected in Inner Mongolian Province of China, and UZBK is designates plants from Uzbekistan. Plants of the lax form of *S. paulsenii* are denoted Spaul.

DNA analysis of herbarium specimens

A specimen of *S. tragus* (taken as a synonym for *S. pestifer* A. Nels.) deposited by Arnold in 1968 as plant number 110 from his dissertation work was located in the Herbarium at University of California, Davis. The specimen was ground in ethanol (Adams et al. 1999) then DNA was extracted and precipitated as usual. The yield of DNA was good, 1.5 μg/ g dry wt., however, analysis by electrophoresis in agarose indicated that the DNA was extensively degraded with almost no material present with molecular weight greater than 500 base-pairs. Analysis by RAPD has not yet been attempted although experience indicates that amplification would not be expected to succeed. Other techniques that produce relatively small amplified fragments would be successful in this case, such as DAF (Caetano-Anollés et al. 1991) or AFLP™ (Vos et al. 1993). The ability to extract and amplify DNA from archival specimens would be a valuable adjunct technique in tracing the movement of different species of *Salsola* and is preferable to inferring species identity from the diameter of the calyx wings of the fruit.

Relationship between *Salsola* in California and in Europe and Asia

Both RAPD analyses that have been completed indicate that Type A, which we believe to be *S. tragus*, is closely related to material from Europe and Asia. Accessions from France, Italy, Turkey, and Uzbekistan clustered rather closely with Type A and were clearly differentiated from Type B. No foreign accessions have been found that are similar to Type B. Additional accessions have been obtained but not yet analyzed from China, Central Asia, Pakistan, and Tunisia, but, lacking a molecular taxonomic study of *Salsola* species in their native ranges, it is impossible to predict whether the identity or at least, the native range of Type B, will be discovered.

Implications for biocontrol

The fact that the range of Types A and B in California are identical suggests that any agent that controls one but not the other will simply shift population composition. Casual observations suggest that the population densities of the two Types are approximately equal so, even if the population components shift, no appreciable change in the total pest population is to be expected. Recently, Bruckart et al. (1999) have shown differential susceptibility to the fungal disease agents *Uromyces salsolae* and *Colletotrichum gloeosporioides* among North American *Salsola* species, including Types A and B. With appropriate caution in the selection of biocontrol agents and with consideration of genetic variation in the subject population, it may yet be possible to reduce the population of this important pest plant with the result of less tumbleweed to meet the eye.

Acknowledgements

Thanks to Drs. Lloyd Knudsen, Rouhollah Sobhian and Luca Fornasari of the USDA ARS European Biocontrol Laboratory, Montpellier, France for samples from three continents; to Drs. Mike Pitcairn and G. Fred Hrusa, California Department of Food and Agriculture, for critical comments. This work was supported by contract 94-0537 from California Department of Food and Agriculture.

Literature Cited

Adams, R. P., Zhong, M., and Fei, Y. (1999). Preservation of DNA in plant specimens; inactivation and re-activation of DNAses in field specimens (technical note). Molecular Ecology 8: 681-684.

Arnold, H. L. 1973. An analysis of the taxonomic status of a new taxon in the genus *Salsola*. Ph. D. dissertation, University of Utah, Logan, Utah.

Beatley, J. C. 1973 Russian thistle (*Salsola*) species in the Western United States. Journal of Range Management 26: 225-226.

Bruckart, W. J. Luster, D. G., Ryan, F. J., Vajna, L., and Sobhian, R. (In press) Getting a grip on the target: experience with *Salsola* diseases. Proceedings of the International Symposium on the Biocontrol of Weeds. Bozeman, MT. July 1999.

Caetono-Anollés, G., Bassham, B. J., and Gresshoff, P. M. 1991. DNA amplification fingerprinting using very short arbitrary oligonucleotide primers. Bio-Technology 9: 553-557.

Crompton, C. W. and Bassett, I. J. 1985. The biology of Canadian weeds. 65. *Salsola pestifer* A. Nels. Canadian Journal of Plant Science 65: 379-388.

Davis, B. J. 1964. Disc electrophoresis II. Methods and application to human serum proteins. Annals of the New York Academy of Science. 121: 404-427.

Hickman, J. C. 1993. The Jepson Manual. Higher Plants of California. University of California Press, Berkeley, Calif. 1400 p.

Mosyakin, S. L. 1996. A taxonomic synopsis of the genus *Salsola* L. (Chenopodiaceae) in North America. Annals of the Missouri Botanical Garden. 83: 387-395.

Müller, H. Nuelly, G. S., and Goeden, R. D. 1990. Natural enemies and host-plant asynchrony contributing to the failure of the introduced moth *Coleophora parthenica* Meyrick (Lepidoptera: Coleophoridae) to control Russian thistle. Agriculture, Ecosystems and Environment 32: 133-142.

Rohlf, F. J. 1997. NTSYSpc. Numerical taxonomy and multivariate analysis system, version 2.0. Exeter Software, Setauket, New York.

Ryan, F. J. and Ayres, D. R. 1999 (in press). Molecular markers indicate two cryptic, genetically divergent populations of Russian thistle (*Salsola tragus*) in California. Canadian Journal of Botany.

Saghai-Maroof, M. A., Solimon, K. M., Jorgensen, R. A., and Allard, R. W. 1984. Ribosomal DNA spacer length polymorphisms in barley: Mendelian inheritance, chromosomal location and population dynamics. Proceedings of the National Academy of Science U.S.A. 81: 8014-8018.

Shinn, C. H. 1898. The Russian thistle in California. Report of the Work of the Experiment Stations of the University of California, 1894-1895. University of California Experiment Station Bulletin 107, pp. 277-291.

Wendel, J. F. and Weeden, N. F. 1989. Visualization and interpretation of plant isozymes. Pages 5-45 in D. E. Soltis and P. E. Soltis, editors, Isozymes in Plant Biology. Dioscorides Press, Portland, OR.

Vos, P., Hogers, R., Bleeker, M. Reijans, M., van de Lee, T., Hornes, M., Frijters, A., Pot, J., Perelman, J., Kuiper, M., and Zabeau, M. 1995. AFLP: a new technique for DNA fingerprinting. Nucleic Acids Research 21: 4407-4414.

Weeding the Wilderness: Non-native Plant Management at Point Reyes National Seashore

V. Kimberly Cooper & Barbara J. Moritsch
National Park Service, Point Reyes National Seashore
1 Bear Valley Road, Point Reyes, CA 94956

Point Reyes National Seashore supports over 873 vascular plant species. Of these, 292 are non-native. Invasive non-native plants are believed to be one of the most significant immediate threats to the integrity of the native flora and fauna of the Seashore. In addition to crowding out common native plants, their encroachment seriously threatens rare plants, wildlife habitat and uncommon plant communities, including wetlands, coastal dunes, and perennial grasslands.

Seashore boundaries encompass over 71,000 acres, and staff are responsible for managing an additional 15,000 acres of adjacent Golden Gate National Recreation Area (GGNRA) land. Current management boundaries include a 17,040-acre pastoral zone, and the 32,730-acre Phillip Burton Wilderness Area. The pastoral zone was established to allow the continued use of existing ranchlands for cattle ranching and dairy purposes. Permits, leases and reservation of use and occupancy restrict use of the lands to traditional ranching operations and are periodically amended to address natural and cultural resource concerns.

Managing this great diversity of non-native plants on 86,000 acres is a daunting task. This paper discusses the 20-year history of non-native plant management at Point Reyes National Seashore, summarizes our vision of future management practices, and provides recommendations for those developing similar programs.

A Brief History of Non-native Plant Management at the Seashore

The first non-native plant formally managed in the Seashore was giant plumeless thistle, *Carduus acanthoides*. Removal efforts, instigated by the Marin County Agricultural Commissioner, began on this plant in 1979. It is listed as an "A" rated noxious weed by California and Marin County departments of agriculture. The numbers and geographic extent of this species are limited on Seashore lands, and its control continues to be a high priority.

In 1983 a non-native plant field survey was conducted and an Exotic Plant Management Plan was published in 1989. From 1979 through 1995 the top priority plants for control were giant plumeless thistle, gorse (*Ulex europaea*), African capeweed (*Arctotheca calendula*) – particularly fertile plants, which are "A" rated weeds, yellow star thistle (*Centaurea solstitialis*), Pampas grass (*Cortaderia jubata*), oblong spurge (*Euphorbia oblongata*) and French and Scotch broom (*Genista monspessulana* and *Cytisus scoparius*, respectively). These taxa were controlled when funding or staff time was available.

In 1994 the Habitat Restoration Project (HRP), a volunteer group dedicated to non-native invasive plant removal, was created by an inspired and talented park naturalist. The group meets two Sundays per month to remove non-native plants from sites targeted by vegetation managers. The program was modeled loosely after GGNRA's Habitat Restoration Team. HRP quickly developed its own special character and dedicated core group of volunteers.

Herbicides were used, particularly for Pampas grass and giant plumeless thistle, until early in 1995. Since then all non-native plant control has been done manually or through prescribed burning.

The Vision Fire – a Turning Point

In 1995, the Vision Fire burned over 12,000 acres. It was the largest wildfire to occur in Point Reyes in sixty years. Fire suppression relied heavily on bulldozer line construction. Much of this line was constructed on steep slopes or through known non-native plant occurrences. During the fire, a Department of the Interior Burned Area Emergency Rehabilitation (BAER) Team was assembled to assess fire and fire suppression impacts that would require mitigation. Seashore staff and other local experts worked closely with the team, providing information and field assistance. The team recommended monitoring and mitigation of impacts on vegetation, with particular emphasis on non-native plants. Funding was obtained from FIREPRO to implement the BAER team's recommendations and a six-person vegetation crew was hired to conduct the work over a three-year period. This represented the most significant, focused funding effort to control non-native plants in the Seashore's history.

The FIREPRO vegetation crew, in conjunction with Americorps National Civilian Conservation Corps (NCCC), HRP, and other volunteer groups, monitored and removed priority non-native plant species within the burned area, focusing on areas disturbed by fire suppression (e.g., bulldozer lines, hand lines, and safe areas). Fortunately HRP was in the formative stages prior to the Vision Fire. FIREPRO and Marin Community Foundation funding allowed us to expand the program to include school, corporate, and community groups. This proved to be an excellent way to channel the many offers of help we received after the fire and allowed HRP to develop further into the dynamic program it is today.

Prior to the Vision Fire, preliminary steps had been taken to develop a plant community map as part of Point Reyes' Inventory and Monitoring Program. The need for such a map became readily apparent during the fire. The map would have been invaluable for emergency logistics, for predicting fire spread and behavior, and for post-fire rehabilitation planning. Given these factors, combined with the fact that a plant community map would form the basis for many of the park's future fire and fuels management programs, FIREPRO contributed resources to assist with completion of the mapping project. The draft map is undergoing accuracy assessment as of this writing, with an expected completion date of October 2000.

Since 1995, in areas of the Seashore outside of the burn perimeter, non-native plant management activities have been the responsibility of one individual, who worked creatively with limited funding and loyal HRP volunteers to keep high priority species under control. Control efforts have focused on small, rapidly-growing infestations, with special attention paid to species known to be problems elsewhere in the region, such as giant plumeless thistle, gorse, yellow star thistle, purple star thistle (*Centaurea calcitrapa*), and distaff thistle (*Carthamus lanatus*). When assistance has been available from Americorps, Marin Conservation Corps, California Department of Corrections crews, HRP, Landmark Volunteers, and the Fire Management Fuels Reduction Crew, efforts have focused on new populations and outliers of larger infestations, especially if these were expanding rapidly or were located in the Wilderness Area.

Current Projects

In addition to the ongoing control efforts discussed above, several area- or species-specific non-native plant management projects currently are underway at the Seashore. In concert with GGNRA, we will be working for the next three years to contain or remove all cape-ivy (*Delairea odorata*) occurrences. To begin rehabilitation of the coastal dune habitat at the Seashore, we are developing detailed maps of the location and the extent of native dunegrass (*Leymus* sp.) plant communities. These data, combined with data on rare plant occurrences, will be used to prioritize our efforts to remove iceplant (*Carpobrotus edulis*) and European beachgrass (*Ammophila arenaria*). The maps are linked to a Microsoft Access database that includes information on vegetation characteristics of the dune communities. We began field-testing removal techniques for European beachgrass in September 1999. Iceplant occurrences also are being mapped at the Point Reyes Lighthouse to facilitate planning for removal in coastal bluff plant communities.

Pampas grass removal efforts have been ongoing since 1985. We are currently updating Pampas grass maps into our GIS system to facilitate future removal and tracking.

We are developing study plans to assess the effects of fire on spread of non-native plants, including purple velvetgrass (*Holcus lanatus*). Future research will assess the effectiveness of prescribed fire at containing, controlling or eradicating selected species of non-native plants such as Scotch and French broom.

There is reason for optimism relative to future non-native plant management at the Seashore. California State Assembly Bill 1168 (Cooperative Noxious Weed Management Program), the Federal Executive Order on Invasive Species of February 3, 1999, and the 1st Annual International Workshop on Weed Risk Assessment, February 12-22, 1999 are all signs of increasing state, national and international concern over invasive non-native species. Hopefully, this concern will result in an increase in resources to control and eradicate non-native plant species.

Recommendations for Developing Non-native Plant Management Programs

In retrospect, we believe four key elements have formed the cornerstones of Point Reyes National Seashore's non-native plant management program: mapping, prioritization, communication and working with volunteers. These elements and their application at the Seashore are discussed below.

Mapping

Mapping is the essential first step as the geographical extent of targeted species must be known to effectively plan removal or containment efforts. Without this knowledge, it is easy to waste valuable resources. For example, efforts may be directed toward removing large French broom populations while small satellite populations expand unchecked into previously uninfested areas.

Mapping of non-native plant populations at the Seashore began in 1983. Information was recorded on photocopied USGS topographic maps. This method is reliable and is still used in many cases. Currently, we are working in ArcView, with links to a Microsoft Access database. When this system is completely integrated we will be able to track control and follow-up efforts more efficiently, which will streamline project planning and reporting. When the vegetation map is completed, it will provide a foundation onto which we will add more refined plant community data and non-native plant informat. This will be useful for identifying priorities for removal, particularly for ubiquitous species such as velvet grass that threaten high priority native plant resources.

Prioritization

Prioritization of species and populations to target for control is the next step in program planning. Systems for setting priorities have evolved over the last 20 years, and all of them require comprehensive knowledge (e.g., maps) of the geographic extent of non-native populations. Setting priorities is challenging, as many variables must be assessed. The following four elements capture many of the key variables involved in effectively prioritizing control efforts.

1. Current extent of the species within or near the management area.
2. Current and potential impacts of the species.
3. Ecological or social value of the infested areas or areas that may be infested.
4. Difficulty of control.

Information on the geographical extent of individual species at Point Reyes has allowed us to devote resources to preventing further spread of priority species by immediately addressing incipient infestations. With experience, we have found this strategy to be most efficient when resources are limited. When assessing impacts of non-native plants, we have labeled species that alter ecosystem processes as very high priorities (e.g., European beachgrass, which changes dune morphology), as these species can completely alter ecosystems and rapidly exclude native species.

When considering the ecological value of infested areas, or areas with potential to be infested, we assess the relative proportion of native species presently in the areas. We generally deem areas already infested with a variety of other non-native plants (e.g., ruderal, highly disturbed habitat) of lower priority than areas with a significant component of native species, unless a particular non-native species under consideration will make the situation significantly worse.

It has been our experience that certain species, such as eucalyptus (*Eucalyptus globulus*) or Pampas grass (which often is found in steep remote drainages), are so difficult or expensive to effectively control that often they are given a lower priority for removal despite having significant ecological impacts. At Point Reyes, it has been effective to work on these taxa slowly over time. Often new opportunities present themselves, such as partnerships with other parks or new funding sources, so it is wise to set priorities for difficult to control species based on the first three elements listed above and address them when feasible.

Our criteria for prioritization are similar in many respects to those defined by the California Department of Food and Agriculture, The Nature Conservancy (TNC) and others. We find TNC's Site Weed Management Plan Template the most applicable to our program and we highly recommend its use.

Our present strategy for large non-native plant populations is to contain them at the perimeter, then remove plants and schedule follow-up visits for outlying, satellite populations. Research and field trials for landscape-scale management are being developed at the Seashore. Methods under consideration include managed grazing, heavy equipment use, and prescribed fire.

For medium-sized populations we work with groups such as Marin Conservation Corps, Americorps, and HRP. These groups have focused on Pampas grass, cape-ivy, larger patches of distaff thistle, and purple star thistle. Smaller populations of widespread non-natives also are best managed with groups, such as satellite broom populations, and iceplant and European beach grass in coastal dune communities.

It is important to note that when working with volunteers and other work groups, the age and physical fitness of group members must be considered. For example, Limantour Beach at Point Reyes Natio Seashore supports easily accessible iceplant populations, which are good worksites for school groups, while more remote Pampas grass sites on Mt. Vision require mature, very fit groups who are skilled with tools. Small, controllable populations that are extremely invasive in surrounding areas are managed by vegetation management staff or interns.

Communication

Communication is of primary importance in non-native plant management. Resources become more available as people share information, proving again that "the whole is greater than the sum of its part " Effective management in an area as large as Point Reyes National Seashore would be impossible without our "spies", comprised of park staff from outside the Division of Resource Management, voluners, visitors, and local residents who notify us of small populations before they spread beyond our ability to control them. This network has been invaluable in helping us stay abreast of conditions throughout the Seashore.

Prioritization criteria, information on species biology and control methodology, and opportunities for funding continue to evolve and the new information must be shared. Additionally, non-native plant management often can be overwhelming and discouraging, and communication with others who are struggling with similar issues is good for morale.

To enhance our ability to control non-native plants at the Seashore, we have become a party to a formal Weed Management Area (WMA) agreement. The Marin County WMA, formed in May of 1999, provides assistance to Marin County landowners and agencies, offering a venue to meet and discuss mutual management issues. Marin County has a long history of public opposition to herbicide use so there has been much discussion of this controversial issue. We have a Memorandum of Understanding in place, and are mapping occurrences and sharing ideas for prioritization. We are preparing funding proposals and planning for cooperative non-native plant control, education and outreach.

Volunteers

Volunteers are critical to non-native plant management at Point Reyes. HRP in particular has become a passionate and skilled group of non-native plant managers. They are an excellent resource for follow-up work as they are thorough, experienced and committed to the long-term maintenance of sites. In addition, we support several interns, individual volunteers who typically work for two to six months. The interns are given larger projects, including mapping and control objectives for the seasons they work. They complete a map and a report, and gain field and computer experience in exchange for their efforts.

School and scout groups often make up for lack of skill with enthusiasm and sheer numbers. All of our volunteer programs offer an opportunity to foster a sense of stewardship of Seashore resource. Non-native plant management is a long-term process, subject to vicissitudes of funding, and we especially value the long-term interest and commitment that develops when people volunteer their time help.

It is important to note that volunteers are not free labor. They require and deserve a significant amount of supervision and guidance. Planning and recruitment require significant lead time, oftes much as a year in advance. Volunteer management is a big job, and requires organizational and human resource management skills.

In summary, non-native plant management at Point Reyes National Seashore has focused on the following three components:

1. monitoring and controlling all occurrences of eight very high-priority species;
2. containing large populations or eradicating satellite occurrences of more ubiquitous non-native species; and
3. monitoring to ensure detection and control of incipient populations of new species.

Through our efforts, we have learned that in spite of limited resources, critical non-native plant infestations can be effectively managed. Our success can be attributed, in part, to the application of the four key strategies discussed in this paper: mapping, prioritization, communication and working with volunteers. As additional funding becomes available, we will be able to use these four cornerstones to work toward eradication of all of our highest priority non-native plant species.

Invasiveness of Alien Plants: Some Aspects of the Impact of Scotch Broom (*Cytisus scoparius* (L.) Link) on Douglas-fir Seedlings and Its Control

Raj Prasad and Sonia Naurais
Canadian Forest Service Natural Resources Canada 506 West Burnside Road Victoria, British Columbia V8Z 1M5

Abstract

Scotch broom (*Cytisus scoparius* (L.) Link) and gorse (*Ulex europaea* L.) are two alien plants that pose a serious threat to forested and other landscapes in southern British Columbia, Canada. Both were introduced over a century ago and have established themselves by virtue of unique characteristics: reduced leaves, active stem photosynthesis, nitrogen fixation, profuse seed production, rapid vertical growth, adaptability to varying ecological niches and lack of natural enemies. There are no data regarding impact of these two exotic species on conifers in British Columbia nor is there any satisfactory information on their methods of control. Therefore, experiments were conducted in a field nursery to determine the effects of competition on Douglas-fir seedlings (*Pseudotsuga menziesii*) and in the greenhouse to determine impact of a biocontrol agent (*Chondrostereum purpureum*) on resprouting behaviour of Scotch broom. Results indicated that Scotch broom suppresses the growth and development of 4-year-old Douglas-fir seedlings by over 30% and that this seems to be achieved by blocking the inception of photosynthetically active radiation. The bioherbicide agent was very potent in inhibiting the resprouting of Scotch broom.

Introduction

Scotch broom (*Cytisus scoparius* (L.) Link) and gorse (*Ulex europaea* L.) are two related exotic weeds which pose a serious threat to forested and other landscapes in southwestern British Columbia (B.C.), Canada. Scotch broom was introduced to Vancouver Island in 1850 by Captain Walter Grant as seeds planted near Sooke, B.C. and gorse is recorded to be thriving in Victoria, B.C. since 1915 (Henry 1915, Clements et al. 1999). After nearly one and a half centuries, Scotch broom has expanded its range, occupying many roadsides, riparian rights-of-way, and other disturbed areas along coastal B.C. and some isolated patches along Kootenay Lake and Castlegar areas in the interior of the province. Scotch broom has several characteristics which promote its invasiveness and displacement of native plant species: (a) reduced leaves and active stem photosynthesis during unfavorable periods; (b) nitrogen fixation capability; (c) profuse seed production and longevity of seed banks; (d) rapid vertical growth and intense spatial competition; (e) adaptability to varying ecological niches and (f) lack of natural enemies (parasite - predator complex).

Various control measures (Peterson and Prasad 1998) have been suggested but none were found to be completely satisfactory. Therefore, greenhouse experiments were conducted to determine the effect of a bioherbicide agent, Cp (*Chondrostereum purpureum* Pouzar – a fungus) on resprouting capability of Scotch broom. Recently this agent was patented and registered for hard wood control in Canada (Wall, Prasad & Sela 1996) and found to be efficacious against alders, aspen, birches and poplars. Also, it is environmentally-friendly and easy to apply (Prasad 1996).

The objectives of the present research were to monitor the influence of Scotch broom on growth and development of Douglas-fir seedlings under nursery conditions in B.C. and to evaluate the potency of this new bioherbicide (Cp) on broom control, under the greenhouse conditions.

Materials and Methods

Impact of Broom on Conifer Growth

To determine this, a controlled field (nursery) experiment was set up at North Arm, Cowichan Lake Research Station, B.C. Three plots, each of 20 x 20 ft containing ten Douglas-fir seedlings (1 + 0) were selected. Seedlings were planted 5 feet apart and a border of 5 feet was left in between each plot to avoid shading.

One-year-old Douglas-fir seedlings (9 inches) were obtained from the nursery grown from local seeds and under healthy conditions of nutrition, temperature and light. Around each Douglas-fir seedling, two Scotch broom seedlings were also planted. These broom seedlings were raised from seeds in a container with a mixture of soil and peat moss under the greenhouse for 6 months. When these seedlings were 9 inches high, they were lifted and planted next to the Douglas-fir seedlings. Care was taken not to damage the roots of the Douglas-fir seedlings while planting the Scotch broom on the same site. To prevent weeds (grasses) from growing in these plots, a canvas mulch (ground cover, Evergro, Canada) of the size 20 x 20 ft, was installed by pegging with nails at each corner. Holes (6" x 6") were punctured in the mulch to accommodate each conifer plus 2 broom seedlings. Any other weeds were removed. The experiment was conducted for three years and the growth of Douglas-fir (height and root collar diameter) was monitored each year. Measurement of broom (height root collar diameter and branching) was also recorded. Branching (Table 1) was determined by measuring the maximum distance between two branches in east-west and north-south directions. A ceptometer (Decagon Inc., Washington) was used to measure the incident light intensity PAR (photosynthetically active radiation) falling on the conifer and broom. Three plots had conifer seedlings while 3 plots had conifer + broom seedlings.

Evaluation of the Bioherbicide Agent (Cp) on Broom Under Greenhouse Conditions

For this experiment, broom seedlings were first grown in the greenhouse under constant condition of light, temperature and relative humidity. When 9" high, they were transplanted into pots containing the soil + peat moss mixture and removed to a shadehouse to grow for 2 years. Forty-five broom plants of uniform growth (3 ft high and 1.0" diameter) were selected, 30 stems of these were 9" above the soil level in the pot, and immediately treated with a blank (15 plants) or formulated product of Cp (15 plants) according to a method described by Prasad (1998). To effect comparison, 15 cut plants were treated with a commercial triclopyr herbicide (Release, triclopyr, Dow Canada) at full strength (480 gms/L). Only cut ends were treated and care was taken to apply an ample amount (1.5 ml) of each formulation with a hand brush. The cut ends of each treated stem was fully covered with the Cp formulation or the herbicide. Treatments were made in late August and all resprouting was measured after one year. Data were analyzed statistically by standard procedures.

Table 1. Growth characteristics of the planted Scotch broom in the open nursery at Cowichan Lake, B.C.

Height (cm)	Basal diameter (mm)	Branching (cm)	Number of branches
135.4 ~: 17	35.4 + 5.1	east-west 125 +- 10.5 north-south 114+11.2	3.8 + 0.3

Results and Discussion

Impact of Broom on Conifer Growth

Data are presented (Table 2) from this experiment to show that broom is competitive with Douglas-fir seedlings and reduces the growth (height and basal diameter) by 28 and 32% respectively. When light (PAR) was measured, it was found that this reduction (49%) was higher than the reduction in height and diameter growth. This probably indicated that light infiltration was not the major factor inhibiting growth but other factors (moisture, space, etc.) may also be involved. Ter-Mikaelian et al. (1999) investigating the effect of light as a competitive factor in growth of jack pine (*Pinus banksiana* Lamb) found a similar result. Scotch broom is known to fix nitrogen and whether additional supply of nitrogen added to extra growth, remains to be investigated.

It is also possible that two brooms planted per Douglas-fir seedling were not competitive enough,

Table 2. Effect of planted Scotchbroom on growth of Douglas-fir seedlings and light infiltration after three years under open nursery conditions (Cowichan Lake, B.C.)

Treatment	Height (cm)	(%)	Basal diam. (mm)	(%)	PAR (CIE)	(%)
Broom + fir seedlings	62.8	(72)	12.9	(68)	510	(51)
No Broom + fir seedlings	86.1	(100)	19.8	(100)	1015	(100)
Least significant difference, LSD (0.05)	10.2		2.1		78	

probably planting 5-10 brooms per Douglas-fir seedling may have provided greater competition and reduction in growth. This was demonstrated in another field experiment (Prasad 1999) where a dense cover of broom reduced the growth of Douglas-fir by more than 50%.

Evaluation of the Bioherbicide (Cp) on Broom Growth in the Greenhouse

Measurements taken one year after treatment with the bioherbicide and herbicide formulations, clearly demonstrate that Cp formulation was very efficacious (Table 3) and matched the effectiveness of the chemical herbicide triclopyr. Whereas, resprouting was not 100% in the control as some cut stems died or did not sprout, there was absolutely no resprouting in all treatments, confirming that both agents were potent and efficacious. Similar results were found by Prasad (1996) and Wall (1994) on other hardwood treatments by *Chondrostereum purpureum*. However, before any firm conclusion can be reached, it is important to carry out further field work on the efficacy of this bioherbicide on Scotch broom.

In summary, these data demonstrate that Scotch broom, reduces the early growth of Douglas-fir seedlings and that it can be prevented from resprouting by application of a bioherbicide agent (*Chondrostereum purpureum*) and triclopyr formulations.

Table 3. Effect of a new bioherbicide (*Chondrostereum purpureum*) and triclopyr on resprouting of Scotch broom under greenhouse conditions

Treatment	Resprouting (percentage)
Cut- untreated	70~L7
Cut - treated with Cp	0.0+0
Cut - treated with triclopyr	0.0~0

Acknowledgements

The authors thank Katherine Oliver and Jaxon Gerald for technical help.

Literature Cited

Clements, D., D. Peterson and R. Prasad. 1999. The biology of Canada weeds. 118. *Ulex europaea* L. Can. J. Pl. Sci. (in press). m.s. 18 pp.

Henry, J.K. 1915. Flora of southern British Columbia. W.J. Gage & Co. Toronto, Ont. 363 pp.

Peterson, D. and R. Prasad. 1998. The biology of Canadian weeds. 109. *Cytisus scoparius* (L.) Link. Can. J. Pl. Sci. 78: 497-504.

Prasad, R. 1996. Development of bioherbicides for integrated vegetation management in forestry. Proc. II Intl. Weed Contr. Cong. 4: 1197-1203. Dept. Pesticide Ecology, Flakkenberg, Denmark.

Prasad, R. 1998. Biological control of forest weeds - prevention of resprouting in red alders by a bioherbicide agent (*Chondrostereum purpureum*). Proc. III Intl. For. Veg. Mgmt. Conf. Sault Ste Marie, Ontario. FRI paper #141: 263-265.

Prasad, R. 1999. Some aspects of the impact and management of the exotic weed, Scotch broom (*Cytisus scoparius*) in British Columbia. J. Sust. For. (in press) M.s. 5 pp. Univ. of Yale, U.S.A.

Ter-Mikaelian, M.T., R.G. Wagner, F. Waynebell and C. Shropshire. 1999. Comparison of photosynthetically active radiation and cover estimation for measuring the effects of interspecific competition on Jack pine seedlings. Can. J. For. Res. 29: 883-889.

Wall, R. 1994. Biological control of red alder using stem treatments with the fungus *Chondrostereum purpureum*. Can. J. For. Res. 24: 1527-1530.

Wall, R., R. Prasad and E. Sela. 1996. Biological control of weed trees. U.S. Patent 5, 587,158. Washington, USA.

The State of California's Noxious Weed Eradication Programs

Ross A. O'Connell
California Dept. of Food and Agriculture, Integrated Pest Control Branch
1220 N Street, Rm. A-357 Sacramento, CA 95814

The California Department of Food and Agriculture has three weed control programs, all within the Division of Plant Health and Pest Prevention Services, Integrated Pest Control Branch. These are the Biological Control, Hydrilla, and the Weed and Vertebrate Programs.

Biological Control Program

The Biological Control Program primarily targets weeds that are generally widespread and not amenable to eradication. Some biocontrol agents have been released on weeds that are considered to be under eradication. Agent releases on these weeds are done primarily due to size of infestation, difficulty of terrain, or their occurrence in sensitive areas that preclude the use of pesticides.

Hydrilla Program

Hydrilla (*Hydrilla verticillata* (L.f.) Caspary), is a noxious non-native submersed aquatic weed. Since its initial discovery in California, in 1976, in a thirty-acre lake in Marysville, Yuba County, it has been found in seventeen counties. Eradication has been achieved in nine of these counties; Los Angeles, Monterey, Riverside, San Bernardino, San Francisco, Santa Barbara, Sonoma, Sutter and San Diego. The other eight counties where eradication efforts are still being conducted are; Calaveras, Imperial, Lake, Madera, Mariposa, Shasta, Tulare and Yuba. For a more complete overview of this program, please refer to the 1997 CalEPPC Symposium Proceedings.

Weed and Vertebrate Program

The primary objective of the weed program is the early detection and control or eradication of certain noxious weeds given an "A" rating under "Pest Ratings of Noxious Weed Species and Noxious Weed Seed," published by the California Department of Food and Agriculture, Plant Health and Pest Prevention Services. The Food and Agricultural Code of California (Division 4, Chapter 1, Article 1, Section 5004) defines noxious weed as "any species of plant which is, or is liable to be, detrimental or destructive and difficult to control or eradicate." Noxious weeds are rated as either "A", "B" or "C" in California, under the following descriptions based on distribution within the state. "A" rated weeds are of limited distribution within the state and "C" rated are generally widespread.

"A" rated – Eradication, quarantine or other holding action at the state/county level. Quarantine interceptions to be rejected or treated at any point in the state.

"B" rated – Intensive control or eradication, where feasible, at the county level. Quarantine or other holding action at the discretion of the County Agricultural Commissioner.

"C" rated – Control, or eradication, as local conditions warrant, at the county level. Quarantine or other holding action at the discretion of the County Agricultural Commissioner.

The noxious weed program is a cooperative effort with the County Agricultural Commissioners. Eight District Biologists and support staff conduct detection surveys of high hazard areas, such as roadsides and other likely areas of introduction of noxious weeds.

Twenty-six "A" rated weeds are currently under eradication, control or containment within the state. These are:

1. Biddy Biddy (BB) - *Acaena novae-zelandiae*
2. Punagrass (PG) - *Achnatherum brachychaetum*
3. Camelthorn (CT) - *Alhagi maurorum*
4. Alligatorweed(AW)-*Alternanthera philoxeroides*
5. Fertile capeweed (FC) - *Arctotheca calendula*
6. Plumeless thistle (PT) - *Carduus acanthoides*
7. Musk thistle (MT) - *Carduus nutans*

8. Diffuse knapweed (DKN) - *Centaurea diffusa*
9. Iberian starthistle (IST) - *Centaurea iberica*
10. Spotted knapweed (SKN) - *Centaurea maculosa*
11. Squarrose knapweed (SqKN) - *Centaurea squarrosa*
12. Skeletonweed (SKW) - *Chondrilla juncea*
13. Yellowspine thistle (YSPT) - Cirsium ochrocentrum
14. Wavyleaf thistle (WT) - *Cirsium undulatum*
15. Bearded creeper (BC) - *Crupina vulgaris*
16. Leafy spurge (LS) - *Euphorbia esula*
17. Halogeton (HN) - *Halogeton glomeratus*
18. Dalmatian toadflax (DTF) - *Linaria genistifolia* spp. *dalmatica*
19. Scotch thistle (ST) - *Onopordum acanthium*
20. Illyrian thistle (IT) - *Onopordum illyricum*
21. Taurian thistle (TT) - *Onopordum tauricum*
22. Harmel (HL) - *Peganum harmala*
23. Smooth groundcherry (SGC) - *Physalis virginiana* var. *sonorae*
24. Wormleaf salsola (WS) - *Salsola vermiculata*
25. Golden thistle (GT) - *Scolymus hispanicus*
26. Perennial sowthistle (PST) - *Sonchus arvensis*

Fourteen weeds have been eradicated from the state. They are: whitestem distaff thistle (*Carthamus leucocaulus*), dudaim melon (*Cucumis melo* var. *dudaim*), giant dodder (*Cuscuta reflexa*), serrate spurge (*Euphorbia serrata*), Russian salttree (*Halimodendron halodendron*), blueweed (*Helianthus ciliaris*), tanglehead (*Heteropogon contortus*), creeping mesquite (*Prosopis strombulifera*), meadowsage (*Salvia virgata*), heartleaf nightshade (*Solanum cardiophylum*), Torrey's nightshade (*Solanum dimidiatum*), Austrian peaweed (*Sphaerophysa salsula*), wild marigold (*Tagetes minuta*) and Syrian beancaper (*Zygophyllum fabago*). Other weeds approaching eradication at the statewide level include camelthorn, golden thistle, smooth groundcherry, Illyrian thistle and perennial sowthistle.

District Weed Eradication Programs

Redding District

This district includes 12 counties in the northernmost section of the state which includes Modoc, Siskiyou, Shasta and Lassen counties in the eastern part of the district and Del Norte, Humboldt, Trinity, Tehama, Butte, Plumas/Sierra and Glenn counties in the western portion. This district has the most "A" rated weed pests (18 species - biddy biddy, fertile capeweed, plumeless thistle, musk thistle, diffuse knapweed, spotted knapweed, squarrose knapweed, skeletonweed, yellowspine thistle, wavyleaf thistle, bearded creeper, leafy spurge, halogeton, Dalmatian toadflax, Scotch thistle, Taurian thistle, smooth groundcherry and perennial sowthistle from the weed list) and the highest net and gross acreage of any other district.

During 1998, 36 new "A" rated weed locations were identified and control measures taken. Seven of these locations consisted of less than 10 plants, found mostly along state or county highways and other roads or along powerline corridors. The majority of the other finds were small patches that should easily be eradicated. Nine "B" rated weed infestations were also found and reported to county personnel.

Weeds under containment in this district include biddy biddy in Humboldt County, halogeton in Lassen and Modoc counties, Dalmatian toadflax along the Klamath River Basin in Trinity, Humboldt and Del Norte counties, squarrose knapweed in Lassen and Siskiyou counties and diffuse knapweed in Trinity County. Containment refers to weeds not being treated or are under biological control in a certain area, but eradicated when found outside of that area. For example, biocontrol agents are well established in Siskiyou County for the control of musk thistle in the Mount Shasta area, chemical or physical treatments are conducted to eradicate weeds found outside of that area. Biocontrol agents have also been released to control spotted knapweed in Shasta County and diffuse knapweed in Trinity County.

Smooth groundcherry has not been reported for four years in Siskiyou County. Perennial sowthistle has not been found in Modoc County for three years. The preceding two weeds are the only known locations within the state. Next year an intensive survey will be conducted to see if these weeds can be declared eradicated from California. Dalmatian toadflax was declared eradicated from Glenn County.

Two noxious weed tours were given by district personnel in 1998. Twenty-six individuals attended, representing the United States Forest Service, Bureau of Land Management, California Department of Fish and Game and local ranchers. The tour participants received training on plant identification, plant biology and control methods available. In addition, two county fairs and a wildflower show were attended by district biologists with a booth on noxious weeds as a public outreach.

The Transline® herbicide demonstration plots on yellow starthistle (YST), treated in March 1997, were re-evaluated in the summer of 1998. These plots were initially treated with low rates of Transline® (1/3 pint and 1/6 pint per acre). Control was excellent in 1997, however, by the summer of 1998, YST had returned to pre-treatment densities. This indicates, at least at this site, annual treatments would be necessary using the lower rates of herbicide.

Butch Kreps is the District Biologist for the eastern district and Rick Keck for the western district. They may be reached at (530) 224-2425. Please report any suspect "A" rated weeds to the district biologist or to the local County Agricultural Commissioner.

Sacramento West District

The Sacramento west district consists of the following nine counties: Colusa, Lake, Mendocino, Napa, Sacramento, San Joaquin, Solano, Sonoma and Yolo counties. This district has nine "A" rated weed pests (biddy biddy, plumeless thistle, Iberian starthistle, spotted knapweed, skeletonweed, bearded creeper, Dalmatian toadflax, Scotch thistle and punagrass).

Three weeds in this district are not under eradication. They are skeletonweed in Sacramento County, due to the weed being widespread, and heavily infesting four adjoining counties. Biocontrol agents were released years ago and have at least slowed the spread of this noxious weed, however, it is still increasing in population. The skeletonweed infestations in Napa and Yolo Counties are still under intensive eradication efforts. The infestations of biddy biddy and bearded creeper in Sonoma County are also not under eradication, however, they are periodically observed.

The district biologist conducted a weed identification tour for County Agricultural Biologists. Twelve individuals from six counties attended the week-long training in Northern California.

The infestation of punagrass in San Joaquin County, that infests alfalfa fields, a dairy, some roadsides and a safflower field, was completely delimited. Physical removal of punagrass clumps, bagging and disposing for deep burial at a landfill has been very effective in lightly to moderately infested fields. Two fields where heavy infestations occur were given a fall treatment with Poast®, a grass herbicide. The grower currently does a spring treatment to control grasses and other weeds. An additional fall treatment was conducted by the grower. The San Joaquin County farm advisor recommended the fall treatment based on a series of test plots using various herbicides applied the previous year. This cooperative project involves CDFA, San Joaquin County Agricultural Commissioner, San Joaquin County farm advisor and the grower.

Robin Breckenridge is the district biologist for this area. She can be reached at (916) 654-0768.

Sacramento East District

This district consists of eight counties: Alpine, Amador, Calaveras, El Dorado, Nevada, Placer, Sutter and Yuba counties. Seven weeds are under eradication or containment in this district; plumeless thistle, musk thistle, diffuse knapweed, spotted knapweed, skeletonweed, Dalmatian toadflax and Scotch thistle.

Skeletonweed is widespread and not under eradication in several of the counties in this district, including El Dorado, Nevada and Placer counties. Biocontrol agents were released and established many years ago and have slowed the spread of this weed, but infested areas continue to increase. Eradication work is still performed in Amador and Calaveras counties.

Rod Kerr is the district bioiogist for this area. He can be contacted at (916) 654-0768.

San Jose District

This district includes nine counties: Alameda, Contra Costa, Marin, Monterey, San Benito, San Francisco, San Mateo, Santa Clara and Santa Cruz counties. Ten "A" rated weeds are found in this district; biddy biddy, fertile capeweed, golden thistle, Iberian starthistle, Ilyrian thistle, plumeless thistle, punagrass, Scotch thistle, skeletonweed and Taurian thistle.

The district biologist working with the Monterey County Agriculture Department personnel conducted test plots on punagrass using a propane torch last year. The plots were monitored this year to evaluate the degree of control at killing the basal seeds in this shallow rooted perennial bunch grass. The results were that the treatment was no more effective than herbicides, but was much more labor intensive. Some regrowth was noted from the basal seeds.

The golden thistle infestation in Alameda County continues to be reduced. This project began in 1968 with 49 acres being treated over a 700 acre gross acreage. Continued vigilance by the Alameda County

Agriculture Department on this project has prevented plants from going to seed since the early 1970's. Five plants were found in 1998, the same as in 1997, down from 16 in 1996, and 31 in 1995.

The National Park Service at the Golden Gate National Recreation Area in Marin County reported 11 fertile capeweed plants were found and destroyed. They also reported that plumeless thistle numbers at Point Reyes National Seashore were 50 percent less than last year, following an intensive manual removal project.

Ed Finley is the district biologist and can be reached at (408) 254-8573.

Fresno District

This district is divided into a north and south district. The north district has six counties: Stanislaus, Merced, Madera, Mariposa, Tuolumne and Fresno counties. The only "A" rated weeds in this district are spotted knapweed in Tuolumne County, skeletonweed in Fresno County and Iberian starthistle and diffuse knapweed in Mariposa County. New finds for 1998 were, one spotted knapweed plant along Highway 41, in Madera County and 0.25 net acre of spotted knapweed on private land, in Foresta, in Yosemite Park. This infestation was most likely brought in with a log home kit from Montana.

Denis Griffin is the district biologist for this area. He can be reached at (559) 445-5031.

South District

The south district consists of the following six counties: Inyo, Mono, Kern, Kings, San Luis Obispo and Tulare counties. The nine "A" rated weed pest found in this district include alligatorweed, camelthorn, Dalmatian toadflax, halogeton, harmel, wormleaf salsola, Scotch thistle, skeletonweed and spotted knapweed.

Camelthorn was not found at the site in Inyo County, near Olancha, or the two locations in Tulare County.

The cooperative *Salsola vermiculata* eradication project in San Luis Obispo County continues to see a reduction in plant numbers. Several surveys were conducted by CDFA, United States Department of Agriculture, Animal and Plant Health Inspection Service and San Luis Obispo County Agricultural Commissioner's personnel. Only 12 plants were found and removed. This is a very significant reduction from the more than six net acres treated at the beginning of this project.

Tom Patrick is the district biologist for this area. He can be reached at (559) 445-5031.

Riverside District

The Riverside district is comprised of eight counties: Imperial, San Diego, Orange, Riverside, San Bernardino, Santa Barbara, Ventura and Los Angeles counties. Ten "A" rated weeds are found in this district; alligatorweed, camelthorn, Dalmatian toadflax, halogeton, harmel, punagrass, Scotch thistle, skeletonweed, spotted knapweed and yellowspine thistle.

A new infestation of camelthorn was found in Imperial County this year. The infestation may have come from baled hay brought in from Arizona. This infestation after delimitation by state and County Agricultural Departments and the Imperial Irrigation District, who owns the property, was found to be 0.1 net acre over one gross acre. Treatments were made several times using Roundup Pro and Diuron.

One of two infestations of spotted knapweed in San Bernardino County was declared eradicated following four years of negative surveys. This location was on State Highway 18, just south of Big Bear Lake. One of three locations of spotted knapweed in San Diego County was declared eradicated. The eradicated site was at Cuyamaca Forest Ranch.

The alligatorweed project, in Los Angeles County, is conducted in cooperation with the Los Angeles County Agricultural Commissioner's Office, the Flood Maintenance Division of the Los Angeles County Department of Public Works, the Los Angeles County Department of Parks and Recreation, the United States Army Corps of Engineers and the CDFA. Four Seasonal employees working part time expended almost 2,700 man hours and found 61 plants, or approximately 0.01 net acre. This was a 93 percent reduction in plant numbers as compared to 913 plants found in 1997. Plants were physically removed and Casoron®, a soil herbicide, was applied when appropriate.

Further delimitation and treatment of alligatorweed plants occurred in the Santa Ana River in Riverside and San Bernardino counties. Only two plants, with a surface area of three square feet total, were found and removed in San Bernardino County and no plants were found in Riverside County. More than 2,000 man hours were expended in surveying the drainage system. Meetings were held with other agencies and other stakeholders to determine available resources to control this infestation.

Alfredo Acosta is the district biologist for this area. He can be reached at (909) 782-4190.

Although the ultimate goal of the Weed and Vertebrate program is the statewide eradication of the "A" rated weeds, hundreds of these weeds have been eradicated at the county level.

In addition to the aforementioned programs, the CDFA-IPC Noxious Weed Information Project undertakes a variety of tasks that support all the programs. These tasks include: assisting in the California Interagency Noxious Weed Coordinating Committee (CINWCC), producing the Noxious Times weed newsletter, developing the CALWEEDS control project inventory, developing training and support material, supporting the formation of weed management areas, producing maps, updating and developing data bases, procuring and supporting information technology, assisting and supporting Global Positioning System (GPS) weed surveys, grant writing, and providing talks, training and articles.

Private and Public Funding Opportunities: Sources of Funding for Weed Management Programs

Carri B. Benefield
Integrated Pest Control Branch, California Dept. of Food and Agriculture
1220 N Street, Room A-357 Sacramento, CA 95814

Introduction

Funding is the nourishment that keeps existing programs running and gets new projects off the ground. The main challenge is finding funding that might apply specifically to weed control and management efforts. Funding may come from several sources: state and federal agencies, non-profit organizations, private foundations, and industry. Additionally, funding can be separated into funds allocated towards research, on-the-ground control, or education and prevention funding. The focus will be on the latter two.

While there are only a handful of weed-specific funding opportunities (highlighted in this paper), the majority of available funds fall under the more general "catch all" categories of restoring ecosystem health and preserving and protecting California's environment. Such funding might address fisheries, wildlife, and waterfowl habitat preservation, watershed protection, or rangelands, wildlands, and wetlands restoratian/conservation. Overall, a project proposal that emphasizes restoring the entire system and includes exotics control as a part/section within the proposal could stand a good chance of obtaining invasive weed project funding "through the back door." Ultimately, groups such as The California Exotic Pest Plant Council (CalEPPC) should work towards creating and lobbying for more invasive weed management/project funding from state and federal, non-profit, and private foundations sources. There are many specialty grants that a weed management agency or group can tap into. It may just be a matter of tailoring or matching funding to a group's needs or situation. For example, specific funds might be applicable for groups in the following situations: a group battling tamarisk could tap into grants supporting resource conservation, soil erosion and water pollution.

Individuals developing strategies for yellow starthistle might apply for funding addressing rangeland management, livestock production, or using fire as a tool to control vegetation.

Watershed improvement funds, aquatic habitat restoration, or improvement of public access funds could be utilized in situations where invasives such as Cape ivy (formerly known as German ivy) or water hyacinth are impeding water flow and obstructing waterways.

Funds are available for projects conducted in particular regions of California and additional funds are accessible if endangered species are affected by weed infestations.

Tagged funds are available for habitat destruction (mitigation)/environmental protection on Indian tribal grounds and Department of Defense lands.

Yet another specialty category of funding is directed towards projects aimed at environmental education in schools and at the local county levels.

Funds Directly Allocated Towards Weed Management Projects

CALFED Bay Delta Program

CALFED is a group of state and federal agencies that came together to cooperatively develop and implement a long-term comprehensive plan that will restore the ecological health and improve water management for beneficial uses of the Bay-Delta system. The Ecosystem Restoration Program (ERP) is the principal program component designed to restore and mimic ecological processes and to increase and improve aquatic and terrestrial habitats. CALFED has come to recognize the threat non-native invasive species represent to healthy ecosystems and restoration efforts. As part of the ERP, the U.S. Fish and Wildlife Service has accepted the responsibility of developing, implementing, managing, and coordinating a Non-native Invasive Species Program. The program objectives include: development of long-term strategy, support of prevention-oriented and control-oriented management, and research projects. Monies are available to extend existing programs, on a competitive grants basis, and to go directly towards projects. A final draft of the strategic plan is completed and work on an implementation plan is underway.

Environmental Quality Incentives Program (EQIP)

The Natural Resource Conservation Service (formerly known as the Soil Conservation Service) was established in the 1996 Farm Bill to provide a single, voluntary conservation program for farmers and ranchers to address significant natural resource needs and objectives. The Environmental Quality Incentives Program (EQIP) combines four of the USDA's former conservation programs, including Agricultural Conservation and Water Quality Incentives Programs. EQIP is a voluntary conservation program to assist farmers and ranchers of private agricultural lands to install cost-effective and technically sound natural resource management systems. EQIP is designed to address resource concerns that have been identified at the local level to conserve and improve soil, water, air, and related natural resources.

The Education Assistance Component af EQIP is intended to complement the technical and financial assistance components by meeting the educational needs of land care providers. More specifically it is intended to identify and share information about tools and techniques for sound resource conservation and to plan, design, implement, operate, and maintain conservation-enhancing land management systems and/or practices. The education assistance and outreach component promotes conservation education in terms of workshops, tours, and demonstrations. Local working groups-including NRCS, Farm Service Agency, Resource Conservation Districts (RCD's) and other private groups and government agencies-define the resource priorities for their areas and all educational proposals must first receive concurrence from their local group. Therefore, Weed Management Areas are encouraged to invite members of such working groups to actively participate in their weed management efforts and to cooperate on project proposals.

National Fish & Wildlife Foundation (NFWF)

The National Fish and Wildlife Foundation (NFWF) is a private, non-profit organization established by Congress in 1984. NFWF works to foster cooperative partnerships to conserve fish, wildlife, and plant resources. NFWF stimulates private funding for conservation through the use of challenge grants. General grant criteria include: project scope (on-the-ground habitat conservation projects that demonstrate a landscape/ecosystem approach), innovation (projects that encourage public involvement, and develop new strategies, or teach habitat restoration methodologies), leverage (projects that demonstrate federal matching funds), partnerships (projects that encourage multi-partner and multi-agency involvement, and federal agency benefit (projects with direct benefits to fish, wildlife, and other biotic resources on public lands or lands that directly affect federal agency lands).

Pullng Together Initiative

The Pulling Together Initiative (PTI) provides a means for federal agencies to be full partners with state and local agencies, private landowners and other parties interested in developing long-term weed management projects within the scope of an integrated pest management strategy. The goals of PTI are: 1) to prevent, manage, or eradicate invasive and noxious plants through a coordinated program of public/private partnerships and 2) to increase public awareness of the adverse impacts of invasive and noxious plants. The initiative provides support on a competitive basis for the formation of local weed management area (WMA) partnerships. These partnerships will be financed by funds from federal agencies together with matching funds from state, local, and private partners. Additional grant criteria include: statements of support for the long-term establishment of a WMA, a specifically defined WMA, an outline of a long-term management plan, and a project WMA steering Committee.

Native Plant Conservation Initiative

Native Plant Conservation Initiative (NPCI) provides a framework and strategy for linking resources and expertise in developing a coordinated national approach to the conservation of native plants. NPCI seeks funding for on-the-ground conservation projects that protect, enhance, and/or restore native plant communities on public and private lands. NPCI is a cooperative program created in partnership with NFWF, several federal agencies, and more than 55 non-governmental organizations.

"War on Weeds" Mini-Grants

In 1996 the California Interagency Noxious Weed Coordinating Committee, (CINWCC), comprised of state and federal agencies throughout California formed an understanding to control noxious weeds in

Private and Public Funding Opportunities: Sources of Funding for Weed Management Programs

Carri B. Benefield
Integrated Pest Control Branch, California Dept. of Food and Agriculture
1220 N Street, Room A-357 Sacramento, CA 95814

Introduction

Funding is the nourishment that keeps existing programs running and gets new projects off the ground. The main challenge is finding funding that might apply specifically to weed control and management efforts. Funding may come from several sources: state and federal agencies, non-profit organizations, private foundations, and industry. Additionally, funding can be separated into funds allocated towards research, on-the-ground control, or education and prevention funding. The focus will be on the latter two.

While there are only a handful of weed-specific funding opportunities (highlighted in this paper), the majority of available funds fall under the more general "catch all" categories of restoring ecosystem health and preserving and protecting California's environment. Such funding might address fisheries, wildlife, and waterfowl habitat preservation, watershed protection, or rangelands, wildlands, and wetlands restoratian/conservation. Overall, a project proposal that emphasizes restoring the entire system and includes exotics control as a part/section within the proposal could stand a good chance of obtaining invasive weed project funding "through the back door." Ultimately, groups such as The California Exotic Pest Plant Council (CalEPPC) should work towards creating and lobbying for more invasive weed management/project funding from state and federal, non-profit, and private foundations sources. There are many specialty grants that a weed management agency or group can tap into. It may just be a matter of tailoring or matching funding to a group's needs or situation. For example, specific funds might be applicable for groups in the following situations: a group battling tamarisk could tap into grants supporting resource conservation, soil erosion and water pollution.

Individuals developing strategies for yellow starthistle might apply for funding addressing rangeland management, livestock production, or using fire as a tool to control vegetation.

Watershed improvement funds, aquatic habitat restoration, or improvement of public access funds could be utilized in situations where invasives such as Cape ivy (formerly known as German ivy) or water hyacinth are impeding water flow and obstructing waterways.

Funds are available for projects conducted in particular regions of California and additional funds are accessible if endangered species are affected by weed infestations.

Tagged funds are available for habitat destruction (mitigation)/environmental protection on Indian tribal grounds and Department of Defense lands.

Yet another specialty category of funding is directed towards projects aimed at environmental education in schools and at the local county levels.

Funds Directly Allocated Towards Weed Management Projects

CALFED Bay Delta Program

CALFED is a group of state and federal agencies that came together to cooperatively develop and implement a long-term comprehensive plan that will restore the ecological health and improve water management for beneficial uses of the Bay-Delta system. The Ecosystem Restoration Program (ERP) is the principal program component designed to restore and mimic ecological processes and to increase and improve aquatic and terrestrial habitats. CALFED has come to recognize the threat non-native invasive species represent to healthy ecosystems and restoration efforts. As part of the ERP, the U.S. Fish and Wildlife Service has accepted the responsibility of developing, implementing, managing, and coordinating a Non-native Invasive Species Program. The program objectives include: development of long-term strategy, support of prevention-oriented and control-oriented management, and research projects. Monies are available to extend

California. An initial focus of this Interagency Group was to develop a noxious weed database. In 1997, the BLM California State Office requested and received extra funds for this database project. Additional funds formed a grant pool to solicit weed project proposals, thus creating a "War on Weeds" mini-grant program.

The War on Weeds mini-grant program provides funding opportunities on a competitive basis for weed projects within California. A total of $10,000 has been made available by the BLM for 1999. In order of priority, funding categories are: (1) Cooperative weed projects that involve federal agencies, state & county agencies, non-profit groups, and private landowners (e.g. Weed Management Areas), (2) Research projects that will develop new technology or approaches useful for on-the-ground projects, and (3) Educational projects that have statewide benefits. Proposals must be submitted or endorsed by one or more agencies of the CINWCC (see page 2 for signatory agencies and representatives) to be considered. In addition, all projects must provide at least a 1:1 funding match. As emphasized by the overwhelming response to the "War on Weeds" mini-grant program, there exists a TREMENDOUS need for more funding specifically allocated towards weed management throughout the state.

Weed Specific Program Highlights

Calfed Bay Delta Program

Agency: CALFED-DFG, DWR, CalEPA, WRCB, NMFS, EPA, FWS, BOR, CDFA (NRCS)

Goals of Program: to develop a long-term comprehensive plan to restore ecosystem health and improve water management for beneficial uses of the Bay-Delta system. The four primary objectives are water quality, ecosystem quality, water supply reliability, and Bay-Delta system vulnerability.

Eligible Recipients: Anyone in the Bay-Delta and tributary watersheds, including agencies, individuals, or non-profit organizations.

Available Funds: $18+ million available; 8 topic areas;Introduced Species in one area

Funding Cycle: Proposals spring (April/May)

Contact Person: Rebecca Fawver (916) 654-1334 (CALFED), Kim Webb (209) 946-6400 (Non-native Invasive Species Program coordinator)

Internet: http://calfed.ca.gov

Environmental Quality Incentives Program (EQIP)

Agency: USDA (NRCS)

Previously funded projects: Noxious weed ID pamphlet & posters, Mojave Desert RCD Website, Noxious weed control demonstrations, Bio-control of yellow starthistle & other invasives meeting

Goals of Program: Voluntary conservation program to assist farmers and ranchers of private agricultural lands to install cost-effective and technically sound natural resource management systems. The Education Assistance Component of EQIP is intended to complement the technical and financial assistance components by meeting the educational needs of land care providers.

Eligible Recipients: Non-profit conservation, agricultural, commodity, and environmental organizations including RCD's, Cooperative Extension, private non-profits and others.

Available Funds: $540,000 (1999, Education Assistance Grants)

Funding Cycle: Proposals due spring

Contact Person: Anita Brown (530) 792-5644 (State) or local NRCS offices & RCD's

Internet: http://www. ca. nrcs. usda.aov, http://ceres.ca.aov/foreststeward/funding.html. EQIP web site currently under construction

National Fish and Wildlife Foundation (NFWF) Pulling Together Initiative

Previously funded projects: Lassen County Noxious Weed Project, Fort Ord, Save the Native Fish: Afton Canyon Saltcedar control

Sponsors: NFWF, FWS, BLM, FS, NPS, DOD, and BOR

Goals of Program: To provide a means for federal agencies to be full partners with state and local agencies, private landowners and other interested parties in developing long-term weed management projects within the scope of an integrated pest management strategy.

Eligible Recipients: Established or start-up local weed management area (WMA) partnerships *Recommended to partner with a Federal Agency

Available Funds: 1.3 million (10 California projects funded, last funding cycle)

Funding Cycle: Proposal due in fall (November)
Contact Person: Eric Hammerling (415) 778-0999 (CA office) or Gary Kania (202) 857-0166
Internet: www.nfwf.org

"War on Weeds" Mini-Grants

Agency: California Interagency Noxious Weed Coordinating Committee (CINWCC) (1999 funds contributed by the BLM and CDFA)
Previously funded projects: Weed prevention flier, Lassen County Yellow Starthisle SWAT Team; ID handbook & tamarisk video, East Sierra WMA; Regional weed video, Battle Creek Watershed Conservancy
Goals of Program: Provide funding opportunities for cooperative weed projects, research projects, and educational projects within California.
Eligible Recipients: Federal, State, and County Agencies, non-profit groups, private landowners (Weed Management Areas). *Must be endorsed by one or more signatory agencies of CINWCC
Available Funds: $15,000
Funding Cycle: Applications due in spring (March/April)
Contact Person: Management of mini-grant proposals has recently been turned over from Anne Knox at BLM to Steve Schoenig at CDFA/CINWCC, sschoenig@cdfa.ca.gov (916) 654-076. Send proposals to Steve Schoenig, CDFA, 1220 N St Room A357, Sacramento, CA 95814.

Additional back door ways of getting funding

U.S. Environmental Protection Agency (EPA) www.epa.gov/region09/funding
State Tribal-Local Wetlands Protection Grants 104 (b)(3)
Sustainable Development Challenge Grants (SDCG)
Five-Star Restoration Challenge Grants www.epa. gov/owow/wetlands/restore/5star
Department of Defense (DoD) Strategic Environmental Research & Development Program (SERDP): Natural Resource Management Control of Non-Indigenous Invasive Species (Conservation) http:/www.serdp.gov/funding
The Great Valley Center http://www.greatvalley. org/ LEGACI grants (Land use, Environment, Growth, Agriculture, Conservation, & Investment)
Resource Conservation Districts, partnering with your local RCD
California Environmental Protection Agency (CalEPA) Department of Pesticide Regulation Pest Management Grants-Demonstration
U.S. Department of Agriculture (USDA)
Wildlife Habitat Incentives Program (WHIP)
Wetlands Reserve Program (WRP)
Forestry Incentives Program (FIP)
Biological Control Implementation Grant and cooperative Agreement Program (National Biological Control Institute)
Regional Integrated Pest Management Grants Program-Western Region
Research & Extension staff at Land Grant Universities
California Department of Conservation, Division of Land Resources Protection Competitive Grants Programs to improve and sustain healthy watersheds, awarded to Resource Conservation Districts (RCDs), partnering with your local RCD is encouraged
California Forest Improvement Program Grants for improving enviromental quality of forest lands, encouraging variety of management activities.

The Foundation Center-Private Monies

Private/foundation monies are another potential source of funding, often overlooked simply due to the overwhelming volume of over 40,000 existing foundations/corporate funding opportunities. This daunting volume of potential private monies can easily be narrowed down by tapping into The Foundation Center resources. The Foundation Center, a non-profit, disseminates current information on foundation and corporate giving through their national collections in New York City and Washington, D.C., their field offices (San Francisco included), and their network ofcooperating libraries in all 50 states. Through these library collections, grant seekers have free access to Center databases (grant and grant-maker directories) and Guides (e.g. Funding the Environment and Animal Welfare) in book or CD-ROM format. Typical foundation entries include purpose and activities statements, fields of donor interest, past projects funded, funding limitations, donor information, and application information. Indexes help grant seekers target potential funders by donor name, subject field, and/or geographic area. In preparation for this article, the knowledgeable Foundation Center Staff, located at the downtown

Sacramento Central Public Library, assisted the editorial staff in running subject searches for environment, restoration, and bio-diversity related funding, both specific to California and inclusive of the entire U.S., via the Center's CD-ROM Database. The list of foundations in the side bar were some of the foundations targeted as potentially being interested in funding environmentally focused (restoration, bio-diversity included) projects. It should be emphasized that each foundation has stated requirements and preferences in terms of specific locations and project/subject areas where funding support is allocated. Such specifications for the Foundations mentioned in this article can be obtained directly from the Foundation Center locations or will soon be on a CDFA-Integrated Pest Management, California Weed Management Area Web site (construction in progress).

Environmentally Focused Foundations

David and Lucile Packard Foundation www.packfound.org (650) 948-7658 Los Altos, CA

Richard and Rhoda Goldman Fund www.goldmanfund.org (415) 788-1090 S.F., CA

Marin Community Foundation www.marincf.org (415) 461-3333 Larkspur, CA

The Pew Charitable Trusts www.pewtrusts.com (215) 575-9050 Philadelphia, PA

The San Diego Foundation www.sdfoundation.org (619) 235-2300 San Diego, CA

Weeden Foundation www. weedenfdn.org (212) 888-1672 New York, NY

The San Francisco Foundation www.sff.org (415) 477-2783 San Francisco, CA

The Rockefeller Foundation www.rockfound.org (212) 869-8500 New York, NY

Rockefeller Brothers Fund www.rock@rbf.org (212) 812-4200 New York, NY

The James Irvine Foundation www.irvine.org (415) 777-2244 San Francisco, CA

Evelyn & Walter Haas, Jr. Fund www. omhrc.gov/fund-db/F0022. HTM (415) 398-3744 San Francisco, CA

Columbia Foundation (Environment Policy Center) www.columbia.org (415) 986-5179 San Francisco, CA

Compton Foundation, Inc. www.comptonfdn@igc.org (415) 328-0101 Menlo Park, CA

W. Alton Jones Foundation, Inc. www.wajones.org (804) 295-2134 Charlottesville, VA

John D. and Cathrine T. MacArthur Foundation www.macfdn.org (312) 726-8000 Chicago, IL

Conclusion

To date, there are very few funding sources that have programs specifically for weed education, management, and control efforts. Most available funds fall under the more general category of improving "ecosystem health." Therefore, proposals must be obtained by including invasive weed projects as a portion of a larger landscape level project–in essence securing funds through the back door. I will close with a challenge for CalEPPC to continue to work towards increasing funding that is allocated specifically towards weed management in California. How? Continue to educate: (1) granting agencies and organizations, (2) local, county, and state governments, and (3) the public at large as to the growing economic and environmental threat that non-native exotic species pose.

Additional Resources

Additional Comprehensive Resources Valuable in Locating Potential Funding: Cost Share and Assistance Programs For Individual California Landowners and Indian Tribes http://ceres.ca.gov/foreststeward/funding. html 1 -800-738-TR EE Forest Stewardship Help line

Department of Fish and Game (DFG) http://www.dfg.ca.gov

Sources of Funds for Stream and Watershed Restoration in California Compiled by The Habitat Restoration Group http://www.habitat-restoration.com/funds.htm

California Resource Agency Funding Matrix for Northern California Watershed Activities http://ceres.ca.gov/watershed/funding

Protecting Relatively Uninfested Lands: Reducing Weed Spread Following Fire

Jerry Asher, Bureau of Land Management, Portland, OR 97208
Steve Dewey, Utah State University, Logan, UT 84322
Curt Johnson, Forest Service, Ogden, UT 84401
Jim Olivarez, Forest Service, Missoula, MT 59807

Wildland fire is a natural process that often helps to maintain or improve the health and productivity of native plant communities. However, when invasive exotic plants are involved, fires burn in an unnatural situation. There are two purposes to this presentation: 1) to show how weeds often proliferate following wildland fire, 2) to discuss how reducing post-fire weed spread is one of the best ways to keep relatively uninfested land from becoming seriously infested. It is common knowledge that various plants respond differently to fire. However, all too often weeds rapidly infest burned areas frequently causing vast and permanent damage. Therefore the intent of this presentation is to increase the awareness about this problem along with providing some recommendations - with every intention to support appropriate prescribed fire efforts.

How vulnerable are typical wildland sites following fire?

Factors like an ideal seed bed, reduced competition from native plants, and increased nutrients released by the fire all combine to make conditions ideal for weed seeds to germinate and flourish following fire. So, with conditions ideal, how much weed seed is likely to be available on any burned site? There are about 70 million acres of noxious weeds, primarily wildlands, in the eleven western states (outside Alaska). Consequently, there are roughly 70 million acres of weed seeds produced every year! Much of that seed is making its way to relatively uninfested land by wind, water, wildlife, livestock, people, and equipment. Therefore, after wildland fire in a previously uninfested area, there is a high likelihood for both ideal conditions for weed establishment and the presence of weed seed. Furthermore, biennial and perennial weeds, already present in the fire area, commonly sprout from buds or crowns. Squarrose knapweed, diffuse knapweed and rush skeletonweed, for example, often resprout, flower, and set seed within six weeks of a fire, while most other vegetation is dormant awaiting another season to produce seed. This immediate seed production following fire gives the weeds yet another advantage.

Examples of weed spread following fire

Every year we learn more about the challenge of reducing the spread of invasive wildland weeds.

A multitude of post-fire photographs in many western states make it clear that weeds frequently invade and dominate plant communities following fire, sometimes on a large scale. For example, in the BLM Sand Butte and adjoining Wilderness Study Areas in Idaho, considerable weed surveillance and successful control of leafy spurge had been underway for many years. A 200,000-acre wildfire burned over the area in 1992. Rush skeletonweed was not known to exist there until 1995, when a few rush skeletonweed plants were found and controlled. In 1996 another wildfire, also about 200,000 acres, burned the entire area again. A preliminary detection survey in 1997 found serious rush skeletonweed infestations widely scattered within a 60,000-acre area of the burn.

In a research example from northern Utah, wildfire increased squarrose knapweed abundance by 50 to 120% within just two years. Control of squarrose knapweed from herbicide applied in the first fall after a summer burn was 98 to 100% effective, while the same herbicide treatment achieved only 20% control or less in adjacent non-burned areas. Not only did this study show that invasive weeds can increase dramatically after a fire, but it also shows that post-fire herbicide application is a unique window of opportunity for effective control.

Recommendations

With weeds spreading at about 4600 acres per day on western federal lands alone (outside of Alaska), the overarching goal becomes keeping relatively uninfested land from becoming seriously infested. Capitalizing on the opportunity to prevent weed spread after both prescribed and wildfires is one of the most cost effective and efficient ways to meet that goal.

Readiness and post-fire vigilance

For both prescribed and wildfire consider the following:

1. At the earliest possible time, hopefully before the fire season, ensure that the NEPA process is adequate to cover timely application of herbicides (if needed anywhere on the landscape). The proper process needs to be in place so an environmental analysis update or amendment or whatever documentation is needed does not unduly delay the application of herbicides in order to avoid weed seed set after a fire.
2. Establish procedures that minimize the transport of weeds into or within a proposed fire or burned area.
3. Include existing, or consider involving new cooperators. Weed management efforts have a higher probability of success when adjacent landowners, public land users, agencies, universities, or other interested people are participating.
4. After fires, when weeds begin to "show life" either starting from seed or sprouting from crowns or roots of existing plants, there frequently are outstanding opportunities to control the weeds. Weeds are usually easier to find for hand control or other mechanical techniques, and herbicide application is more effective because weeds are no longer protected by non-target vegetation or debris. Capitalize on this rare opportunity before the weeds have a chance to produce seed.
5. Build the cost of weed management caused or encouraged by the disturbance of the fire into fire rehabilitation plans. In 1998 the Bureau of Land Management, Forest Service, Fish and Wildlife Service and the Park Service were given new authority to use fire rehabilitation funds to control weeds following wildfire, including weed detection and control in subsequent years. Where rehabilitation plans are not intended, use creativity and perseverance to ensure that invasive weeds get the priority they deserve.
6. Approximately one month after any fire, survey the entire fire area for signs of new or sprouting weeds. Repeated surveys will be needed, with the frequency and intensity guided by local conditions.
7. Develop and implement a strategy to control the weeds including follow-up detection and treatments for a few years until the populations are completely controlled or eradicated.

Prescribed fire planning

While planning prescribed burns, evaluate the potential for increased weed populations and consider the following:

A. Check existing weed maps and visit with local weed experts. Then survey the entire proposed burn area for weeds. If a few weeds have been on the site for a year or more it is likely that thousands of unseen seeds are in the ground ready to germinate.

B. Check adjacent land for weeds that may become a seed source following the burn. These areas may provide weed seed to the burn area via transport by people, livestock, wildlife, wind, water, vehicles or other equipment.

C. Enlist the advice of agency weed coordinators, extension agents, Department of Agriculture staff, or county weed supervisors regarding plans to minimize the increase in weeds. Where possible, time the burn to reduce seed production of existing weeds. Make sure that equipment, vehicles and personnel do not bring weed seed in with them from other areas.

D. Ensure that the appropriate NEPA process/ requirements for weed control are addressed before the fire to avoid any delays in timely application of herbicides in the event they are needed.

E. Keep a log of weed management activities so you can share your experiences with others.

Level of urgency

How urgent is it to prevent and then if necessary control weeds following fire? Let us consider the priority in comparison to fire management. Nature often helps put out fires; nature does not help "put out" weeds. Fires are often very beneficial; weeds are not beneficial. If and when there are negative impacts from fire, they are usually short-term, whereas impacts from weeds are long-term and often permanent. Therefore, new infestations or small burned infestations poised to proliferate out of control, truly constitute a state of biological emergency! When preparing NEPA documents, keep that concept in mind regarding the emergency nature of controlling weeds following fire before they have a chance to set seed.

In conclusion, we must keep relatively uninfested land from becoming seriously infested. Future generations of Americans deserve to inherit healthy productive wildlands, not vast landscapes infested with noxious weeds that are unfit for people or wildlife.

Alien Grasses in the Mojave and Sonoran Deserts

Matthew L. Brooks[1] and Todd C. Esque[2]

[1]U.S. Dept. of the Interior, U.S. Geological Survey
Western Ecological Research Center, Box Spring Field Station 41734 South Fork Dr., Three Rivers, CA 93271
phone/fax:559-561-6511 email:matt_brooks@usgs

[2]U.S. Dept. of the Interior, U.S. Geological Survey
Western Ecological Research Center, Las Vegas Field Station 6770 S. Paradise Road, Las Vegas, NV 89119 702-914-2206 x 226 email:todd_esque@usgs.gov

Abstract

Alien annual grasses are widespread and common in public wildlands of the Mojave and Sonoran deserts. They are dominated by red brome (*Bromus madritensis* ssp. *rubens*)and Mediterranean grasses (*Schismus arabicus* and *Schismus barbatus*), along with locally abundant cheatgrass (*Bromus tectorum*) and Chilean chess (*Bromus trinii*). The dominance of alien annual grasses can increase levels of water and mineral nutrients in the soil, and they can effectively compete with native annuals for these resources. Increased levels of atmospheric nitrogen and carbon dioxide may increase their dominance in the future, especially during years of high rainfall. Periods of low rainfall may temporarily reduce the dominance of species that evolved in mesic ecosystems (e.g. red brome). Alien perennial grasses are less widespread and common than alien annual grasses, especially in the Mojave Desert. They are mostly found at urban-wildland interfaces, but have invaded some wildland areas in the Sonoran Desert, especially in Sonora. It is currently unknown if their distributions are stable or in the process of expanding. Dominant species include buffelgrass (*Pennisetum ciliare*), fountain grass (*Pennisetum setaceum*), Natal grass (*Rhynchelytrum repens*) and Lehmann lovegrass (*Eragrostis lehmanniana*). These species appear to be less tolerant of frost and require more summer rainfall than the alien annual grasses, which may explain why they have not spread north into the Mojave Desert.

Alien annual and perennial grasses both facilitate the spread of fire and thrive in post-fire landscapes, possibly due to reduced competition with natives and increased levels of available soil nutrients. Shortened fire return intervals caused by alien grasses pose serious threats to plants and animals in the Mojave and Sonoran deserts. These grasses can also compete with native plants for limiting nutrients, reducing their reproductive potential and possibly their diversity. Control of alien grasses is difficult once they are established, so eradication of new populations is critical for their management.

Alien Annual Grasses

Descriptions

Alien annual plants are particularly successful in the Mojave and northern Sonoran desert regions because they can avoid harsh environmental conditions by remaining dormant as seeds, and they can grow rapidly and produce large numbers of seeds during ephemeral periods of high rainfall (Beatley 1966, Inouye 1991). Three of the four most widespread and abundant alien plants in these deserts are the annual grasses red brome (*Bromus madritensis* ssp. *rubens*) and Mediterranean grass (*Schismus arabicus* and *Schismus barbatus*) (Brooks 1998, Kemp Brooks 1998, Brooks and Berry in press, Peter Stine and Kathryn Thomas, unpublished data).

Red brome is considered an invasive weed in its Mediterranean home range (Jackson 1985, Brooks in press a), and it is on the California Exotic Pest Plant Council's (CalEPPC) "Exotic Pest Plants of Greatest Ecological concern in California", (CalEPPC 1999) A-2 list because it is recognized as an invasive wildland pest in California. Red brome is found throughout western North America from British Columbia to northern Mexico (Wilken and Painter 1993, Pavlick

1995). It was established in cismontane California by 1848, and apparently naturalized there by the 1890s. Red brome became common in the Mojave Desert by 1950, but its spread north into the Great Basin appears to be limited by its sensitivity to low winter temperatures. The dominance of red brome is affected primarily by rainfall and soil nitrogen levels (Brooks 1998), and a period of high rainfall during the late 1970's was followed by a dramatic increase in its dominance in the northern Mojave Desert (Hunter 1991). It is most abundant where soil nutrients are concentrated beneath woody shrubs (Brooks in press b) and across the landscape where fires have occurred (Brooks 1998). Successive years of low rainfall may cause population crashes of red brome (Richard Minnich, personal communication), but these effects appear to be localized at relatively arid low elevation sites (Matt Brooks, personal observation).

Mediterranean grass is not invasive in its home range (Brooks in press c), but it is on the CalEPPC Annual Grass list because many land managers consider it to be a potential wildland pest and virtually nothing is known about its ecology in North America. Mediterranean grass is found in open areas of the central and southern coastal and desert regions of California (Brooks in press c), through southern Arizona and Utah (Esque and Schwalbe in review), and into Texas (Allred 1993). It appears to have spread from Arizona into California during the early 1900s, first appearing in Califomia in 1935 and becoming common in the Mojave and Sonoran deserts and cismontane regions of southern California by the 1950s (Oscar Clarke, personal communication). *Schismus arabicus* is most abundant in arid regions whereas *Schismus barbatus* is most abundant in semi-arid regions (Brooks in press c). Mediterranean grass can germinate and reproduce even during the driest years in the Mojave Desert (Brooks in press c), although its growth can increase dramatically when and where soil water and mineral nutrient levels are high (Brooks 1998, Brooks in press b).

Two other alien annual grasses are locally abundant, cheatgrass (*Bromus tectorum*) and Chilean chess (*Bromus trinii*). The negative ecological effects of cheatgrass are well documented in the Great Basin Desert (Young in press), justifying its inclusion on the CalEPPC A-l list, but its effects in the Mojave or Sonoran deserts remain poorly documented. Cheatgrass was common in the western and central Mojave Desert by the 1930's, and appears to have been replaced by red brome in much of this region since then (Oscar Clarke, personal communication). Chilean chess remains unstudied in North America, and it may be native to western South America (Wilken and Painter 1993, Andy Sanders, personal communication).

Ecological Effects

Alien annual grasses can outcompete native annual plants for limiting resources. Red brome is known to deplete soil water faster and at greater soil depths than native annual species (Lesley DeFalco, unpublished data), and along with cheatgrass, effectively compete with native species for water (Eissenstat and Caldwell 1988, Melgoza and Nowak 1991). Red brome and Mediterranean grass also appear to compete effectively with native annuals for soil nitrogen (Brooks 1998). Experimental thinning of red brome and Mediterranean grass seedlings significantly increased the density, biomass, and species richness of native annuals (Brooks 1998, Brooks in press d). Although cases of exotics displacing natives have not been documented, a University of California Riverside botanist, Oscar Clarke, observed that a previously common native annual grass, *Vulpia octoflora*, became uncommon after the invasion of the ecologically similar Mediterranean grass during the 1940s.

High densities of annual plant seedlings can inhibit germination of Sonoran Desert annuals (Inouye et al. 1980, Inouye 1991), and densely packed alien annual grass seedlings may reduce the subsequent germination of natives in the Mojave Desert. Plant litter created by alien annual grasses is likely to decompose more slowly than that of native annuals because shoot fiber content is higher in aliens than in natives (DeFalco 1995). Accumulated plant litter can impede germination by shading the mineral soil, reducing the amount of water that reaches the mineral soil, and suspending seeds above and out of contact with the mineral soil (Facelli and Pickett 1991). Experimental removal of alien annual grass litter increased the density and diversity of native annuals in the Mojave Desert (Matt Brooks, unpublished data).

Little is known about competition of alien annual grasses with native perennial shrubs. Perennial shrubs such as creosotebush (*Larrea tridentata*) and bur-sage (*Ambrosia dumosa*) can facilitate the establishment and growth of native and exotic annuals (Holzapfel and Mahall 1999). Enhanced nutrient and water availability beneath shrub canopies is associated with high biomass of annuals in general (Charley and West 1977, Romney et al. 1978, Lajtha and Schlesinger 1986), and red brome in particular (Brooks 1998, Brooks in press b).

Alien annual grasses can alter fire regimes in the Mojave and Sonoran Deserts. Red brome and Mediterranean grass stems remain rooted and upright through the summer fire season and into successive years, whereas those of most native forbs crumble soon after senescence (Brooks in press e). High frequency and cover of this standing dead biomass facilitates the spread of fires. Biomass of red brome is positively correlated with frequency and size of fires, especially at higher elevations in the central Mojave Desert (Brooks 1998). Levels of nitrogen can increase after fires in the Great Basin (Blank et al. 1994) and Mojave deserts (Matt Brooks, unpublished data). Increased nitrogen levels lead to greater biomass of alien annual grasses that may promote recurrent fire (Brooks 1998, Brooks in press d).

Alien Perennial Grasses

Descriptions

The alien perennial grasses described here represent a cohort that were imported from Africa (Burgess et al. 1991) to increase production and reduce soil erosion in the arid southwest. Two of the most prominent alien perennial bunchgrasses in the Sonoran Desert are buffelgrass (*Pennisetum ciliare*), and Lehmann lovegrass (*Eragrostis lehmanniana*). Two additional species, Natal grass (*Rhynchelytrum repens*) and fountain grass (*Pennisetum setaceum*), are locally common and may present a problem in the future. Buffelgrass and Lehmann lovegrass are so well integrated into Sonoran desertscrub, semi-desert grasslands, and local agroecosystems that the uninformed would not guess they are alien species. Both species have established in the backcountry of natural reserves such as Saguaro National Park and pose a threat to native biodiversity (Cecil Schwalbe and Todd Esque, unpublished data, Burquez et al. 1999). Our objective for highlighting these perennial species is to increase awareness of their potential importance and to ensure that they do not become a dominant part of the landscape in desert regions of California.

Buffelgrass is native to Africa, Asia, and the Middle East (Ibarra-Flores et al. 1999). Seeds from buffelgrass were selected for drought-tolerance and brought to North America from semi-arid regions of Africa between 1940 and 1945 as part of a program to restore overgrazed grasslands in arid western North America (Cox et al. 1988, Ibarra-F. et al. 1995). Seed stock was multiplied and distributed from Texas and exported to eastern Mexico, Sonora, as well as parts of New Mexico and Arizona (Ibarra-F. et al. 1995). By 1995, 4 million ha of native habitat were mechanically converted to buffelgrass stands in Texas, 6 million ha on the east coast of Mexico, and 400,000 ha of Sonoran Desert in Mexico (Cox et al. 1988; Martin-R. et al. 1995). Buffelgrass is well-adapted to the warm-season precipitation of southern Arizona and northern Mexico (Burgess et al. 1991). Although somewhat intolerant of freezing, buffelgrass is apparently less susceptible to freezing than some Sonoran Desert natives (Burgess et al. 1991). However, efforts are underway to develop strains of buffelgrass that are even more tolerant of low temperatures in order to expand the range of this invasive species (Hussey and Bashaw 1996). In the Sonoran Deserts of northwestern Mexico and southern Arizona, buffelgrass has escaped cultivated sites and naturalized into backcountry areas. Where this occurs, summer precipitation ranges from 150-550 mm and winter precipitation is below 400 mm (Cox et al. 1988). Winter temperatures rarely fall below 5° C where buffelgrass is most successful (Cox et al. 1988). Buffelgrass grows well in loamy textured soil, and not as well in clay and sandy soils (Cox et al. 1988). Buffelgrass grows in roadside riparian habitats west of Tucson (Todd Esque, personal observation) and is identified as a problem at Organ Pipe National Monument, but is not currently known to exist in California (Hickman 1993).

Lehmann lovegrass was collected from South Africa in 1932 and sent to Superior, Arizona to provide the source for seed production programs, the products of which were distributed throughout warm deserts in North America (Cox et al. 1988). This perennial bunchgrass is dominant in a localized area south of Tucson, Arizona where it is experimentally manipulated, but has also been found naturalized at low densities in the backcountry of Saguaro National Park (Todd Esque and Cecil Schwalbe, unpublished data). Lehmann lovegrass may become dominant where summer rainfall exceeds 150 mm and soil textures are sandy or sandy loam (Cox et al. 1988). Lehmann lovegrass occurs in areas that range in elevation between 1100-1540 m, and daily mean minimum and maximum temperatures vary annually from -4° C to 20° C and 13 to 38° respectively (Cox et al. 1988). Active growth occurs during periods of summer precipitation (Cox et al. 1988).

Natal grass was originally brought to North America for erosion control (Kearney and Peebles 1960). Most of the information available on the distribution and ecological effects of natal grass are anecdotal at this time.

Fountain grass is noted in the flora of California (Hickman 1993) and is the only one of the four alien perennial grasses identified as a problem by CalEPPC: it is listed in the A-1 category because of its invasive nature in coastal areas. Although known to be at least locally abundant in coastal areas, fountain grass is not prominent in desert habitats at this time. Fountain grass has been reported in xeririparian habitats in the eastern Mojave Desert (Jim Andre, personal communication), and in the southwestern Mojave Desert near Joshua Tree National Park there is one known infestation numbering several plants (Jane Rodgers, personal communication) and several individual plants were found along a paved highway during spring 1999 (Matt Brooks, personal observation). Control of fountain grass must begin immediately to control this species at the early stages of its invasion into the Mojave Desert.

Ecological Effects

The ecological effects of these alien bunchgrasses in the Mojave and Sonoran deserts are mostly unstudied, but can be easily inferred from the dramatic changes they cause in the structure and function of other native systems. We expect infestations of perennial bunchgrasses that cause monocultures to have both direct and indirect effects on native biota. Of the perennial bunchgrasses, changes due to buffelgrass are the most well documented in warm desert systems. Buffelgrass monocultures that are repeatedly used by livestock may deplete soil nitrogen and carbon rapidly, leaving these systems open to erosion (Ibarra-Flores et al. 1999). Recent studies indicate that livestock production is probably greater when buffelgrass stands are interspersed by native vegetation (Ibarra-Flores et al. 1999). We expect buffelgrass monocultures to change the physical characteristics of soil seedbeds by closing the canopy, thus reducing light and modifying temperatures. It is unlikely that native annual plant populations can coexist within dense stands of buffelgrass. Buffelgrass has the ability to spread into uncultivated areas (Esque and Schwalbe in review). Once established, fires can sweep through buffelgrass stands causing intense fires that selectively reduce densities of arborescent, shrubby, and succulent components of desertscrub communities, increase the dominance of fire-adapted buffelgrass, and thus reduce biodiversity. Buffelgrass is established in several backcountry areas in the arid west including Reserva de la Biosfera El Pinacate y Gran Desierto de Altar, Sonora, Mexico, Cabeza Prieta National Wildlife Refuge, Barry M. Goldwater Air Force Range, and Saguaro National Park (Esque and Schwalbe in review). Although some species will likely benefit from increased productivity in desert habitats, large expanses of alien perennial bunchgrass monocultures are thought to have negative effects on wildlife (Bock et al. 1986), and quail in particular (Hanselka 1988). Lehmann lovegrass is not currently dominant in desertscrub of Sonora (Tom Van Devender, personal communication), but threatens native bunchgrasses in parts of northern Chihuahua (Graciela Melgoza-Hinshaw, personal communication). Lehmann lovegrass is a vigorous perennial bunchgrass capable of escaping cultivated areas even under harsh conditions (Cable 1971) and can dominant plant communities, resulting in changes in their floristic compositions that may be permanent without human intervention (Anable et al. 1992). Lehmann lovegrass is not known to exist in California at this time (Hickman 1993).

Future Trends

Global climate change may increase the dominance of alien annual grasses in the Mojave and Sonoran deserts. Atmospheric concentrations of CO_2 have increased more than 25% since pre-industrial times, and $C0_2$ concentrations in the atmosphere are expected to double before the end of the 21st century (Gammon et al. 1985, Houghton et al. 1990). Large increases in atmospheric $C0_2$ that are characteristic of the past century are known to enhance production of rapidly-growing cool season species such as alien annual grasses (Poorter et al. 1996). The enhancement of alien annual production could ultimately contribute to increased frequency and severity of wildfires in western North America (Mayeaux et al. 1994). Red brome is known to increase total plant production by 20% under elevated atmospheric $C0_2$ with a significant increase in seed production (Lesley DeFalco et al. unpublished data). Increased summer rainfall may also extend the activity period of, or stimulate earlier germination of, exotic annuals thereby increasing their reproductive potentials. Finally, deposition of atmospheric nitrogen from air pollutants may reduce the spatial and temporal heterogeneity of soil nitrogen in the Mojave Desert and alter competitive hierarchies among native and exotic species. For example, experimental addition of nitrogen (3.2 g NH_4N0_3 /m^2/yr) significantly increased density and biomass of exotics and decreased that of natives (Brooks 1998). Species richness of exotics was unaffected, but richness of natives decreased. Deposition rates of 4.5 g/m^2/yr have been recorded in the Los Angeles basin (Bytnerowicz and Fenn 1996), and are associated with high dominance of alien annual grasses and the loss of native shrub communities in that region (Allen et al. 1998). Although current deposition rates are undoubtedly much lower in the Mojave Desert, future rates there will likely increase as human populations and air pollution levels rise.

Management

Preventing invasions is the first and most effective step in managing alien plants. This is especially true for annual plants, which are notoriously difficult to control because of their large seedbanks and efficient modes of dispersal. Remote sensing has been useful in the early detection of alien forb invasions along river drainages in Idaho (Lake 1998), and may be useful in detecting invasions along highways and riparian habitats in the Mojave Desert. Annual grasses such as *Bromus* spp. are best controlled by applying herbicides prior to seedhead formation (Whitson 1998). A naturally occurring black smut often destroys the inner part of the spikelet of red brome (Matt Brooks, personal observation) and may be useful as a biological control agent. Dominance of some alien annual grasses may be minimized by protecting habitat from human disturbances such as sheep grazing and off-highway vehicles (Brooks 1995).

The vast majority of literature about buffelgrass in the desert southwest is focused on the cultivation of this grass rather than its control. However, a control program for buffelgrass has been instituted at Organ Pipe National Monument, and preliminary results from this work will be available soon. In this program participants remove buffelgrass plants by hand (Sue Rutman, personal communication). To date, over 90,000 kg of buffelgrass were removed from the 64 square km treatment area. It took two consecutive years of intensive work to get the upper hand on this species. This program will demand that the treatment area be monitored for signs of re-infestation. Chemical control offers a possibility for the management of buffelgrass, but the results of well-controlled studies of chemical effectiveness are not widely available. This sort of information would be valuable for new control programs. Large control programs are not known in desert habitats of North America at this time.

Isolated fountain grass infestations should be controlled as soon as possible. These grasses are difficult to control once they have established, and can distribute large numbers of wind blown seeds.

References

Allen, E., P. Padgett, A. Bytnerowicz, and R. Minnich. 1998. Nitrogen deposition effects on coastal sage vegetation of southern California. United States Deparhnent of Agriculture, Pacific Southwest Research Station, General Technical Report-164

Allred, K. 1993. *Schismus*. Page 1293 In Hickman J., editor. The Jepson Manual: Higher Plants of California. first edition. University of California Press, Berkeley, California.

Anable, M., M. McClaran , and G. Ruyle. 1992. Spread of introduced Lehmann lovegrass (*Eragrostis lehmanniana* Nees.) in southern Arizona, USA. Biological Conservation 61: 181-188.

Beatley, J. 1966. Ecological status of introduced brome grasses (*Bromus* spp.) in desert vegetation of southern Nevada. Ecology 47:548-554.

Blank, R.R., F.A. Allen, and J.A. Young. 1994. Growth and elemental content of several sagebrush-steppe species in unburned and post-wildfire soil and plant effects on soil attributes. Plant and Soil 164:35-41.

Bock, C., J. Bock, K. L. Jepson, and J. C. Ortega. 1986. Ecological effects of planting African lovegrasses in Arizona. National Geographic Research 2:456-463.

Brooks, M. 1995. Benefits of protective fencing to plant and rodent communities of the western Mojave Desert, California. Environmental Management 19:65-74.

Brooks, M. 1998. Ecology of a Biological Invasion: Alien Annual Plants in the Mojave Desert. Dissertation, University of California, Riverside. 186 p.

Brooks, M. in press a. *Bromus madritensis* ssp. *rubens* (L.) Husnot (*B. rubens* L., Foxtail Chess (Red Brome)). In C. Bossard, M. Hoshovsky, and J. Randall eds. Noxious Wildland Weeds of California, University of California Press.

Brooks, M in press b. Habitat invasibility and dominance by alien annual plants in the western Mojave Desert. Biological Invasions.

Brooks, M. in press c. *Schismus* spp., *Schismus arabicus* Nees and *Schismuus barbatus* (L.) Thell., Mediterranean Grass (Split Grass). In C. Bossard, M. Hoshovsky, and J. Randall eds. Invasive Weeds in California's Wildlands. University of California Press.

Brooks, M. in press d. Competition between alien annual grasses and native annual plants in the Mojave Desert. American Midland Naturalist.

Brooks, M. in press e. Alien annual grasses and fire in the Mojave Desert. Madrono.

Brooks, M. and K. Berry, in press. Ecology and Management of Alien Annual Plants in the California Deserts. California Exotic Pest Plant Council Newsletter.

Burgess, T., J. Bowers, and R. Turner. 1991. Exotic plants at the desert laboratory Tucson, Arizona. Madrono 38:96-114.

Burquez, A., A. Martinez-Yrizar, R. S. Felger, and D. Yetman. 1999. Vegetation and habitat diversity at the southern edge of the Southern Desert. In R. H. Robicheaux ed. Ecology of Sonoran Desert Plants and Plant Communities. The University of Arizona Press.

Bytnerowicz, A., and M. Fenn. 1996. Nitrogen deposition in California forests: a review. Environmental Pollution 92:127146.

Cable, D. 1971. Lehmann lovegrass on the Santa Rita Experimental Range, 1937-1968. Journal of Range Management 24:17-21.

Charley, J. and N. West. 1977. Micro-patterns of nitrogen mineralization activity in soils of some shrub-dominated semi-desert ecosystems of Utah. Soil Biology and Biochemistry 9:357-365.

Cox, J., M. Martin-R., F. Ibarra-F., J. Fourie, N. Rethman, and D. Wilcox. 1988. The influence of climate and soils on the distribution of four African grasses. Journal of Range Management 41:127-139.

DeFalco, L. 1995. Influence of cryptobiotic soil crusts on winter annuals and foraging movements of the desert tortoise (*Gopherus agassizii*) in the northeast Mojave Desert. M.S. Thesis. Colorado State University, Ft. Collins, CO. 48 p.

Davidson, A. 1907. The changes in our weeds. Bulletin of the Southern California Academy of Sciences

Eissenstat, D., and M. Caldwell. 1988. Competitive ability is linked to rates of water extraction. Oecologia 75:1-7.

Esque, T., and C. Schwalbe. in review. Alien Annual Plants and Their Relationships to Fire and Vegetation Change In Sonoran Desertscrub. In Tellman, B., and T.R. Van Devender, eds. Invasive Organisms in the Sonoran Desert. Arizona-Sonora Desert Museum. Publisher to be determined. Tucson, Arizona.

Facelli, J. and S. Pickett. 1991. Plant litter: Its dynamics and effects on plant community structure. The Botanical Review 57:1-32.

Frenkel, R.E. 1977. Ruderal Vegetation Along Some California Roadsides. University of California Press, Berkeley.

Gammon, R., E. Sundquist, and P. Fraser. 1985. History of carbon dioxide in the atmosphere. In J. Trabalka (ed.). Atmospheric Carbon Dioxide and the Global Carbon Cycle. U.S. Department of Energy, Washington, D.C.

Hanselka, C. 1988. Buffelgrass - South Texas Wonder Grass. Rangelands December:279-281.

Hickman, J. (ed) 1993. The Jepson Manual: Higher Plants of California. University of California Press, Berkeley, California.

Holzapfel, C., and B. Mahall. 1999. Bi-directional facilitation and interference between shrubs and annuals in the Mojave Desert. Ecology 80:1747-1761.

Houghton, J., G. Jenkins, and J. Ephraume (eds.). 1990. Climate Change: The IPCC Scientific Assessment. Cambridge Univ. Press. 365 p.

Hunter, R. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. Great Basin Naturalist 51:176-182.

Hussey, M., and E. Bashaw. 1996. Performance of buffelgrass germplasm with improved winter survival. Agronomy Journal 88:944-946.

Ibarra-F, F., J. Cox, M. Martin-R., T. Crowl, D. Post, R. Miller, and G. Rasmussen. 1995. Relationship between buffelgrass survival, organic carbon, and soil color in Mexico. Soil Science Society of America Journal 59:1120-1125.

Ibarra-Flores, F., H. Cox, M. Martin-Rivera, T. Crowl, B. Norton, R. Banner, and R. Miller. 1999. soil Physicochemical changes following buffelgrass establishment in Mexico. Arid Soil Research and Rehabilitation 13:39-52.

Inouye, R., G. Byers, and J. Brown. 1980. Effects of predation and competition on sunrivorship, fecundity, and camnrnity structure of desert annuals. Ecology 61:1344-1351.

Inouye, R.S. 1991. Population biology of desert annual plants. pp.27-54 in G.A. Polis (ed.) The Ecology of Desert Communities. The University of Arizona Press, Tucson, 456 pp.

Jackson, L. 1985. Ecological origins of California's Mediterranean grasses. Journal of Biogeography 12:349-361.

Kearney, T. and R. Peebles. 1960. Arizona Flora and Supplement. second edition. University of California Press. Berkeley, California. 1085 pp.

Kemp, P. and M. Brooks. 1998. Exotic Species of California Deserts. Fremontia 26:30-34.

Lajtha, K. and W. Schlesinger. 1986. Plant response to variations in nitrogen availability in a desert shrubland ecosystem. Biogeochemistry 2:29-37.

Lake, L. 1998. Manager's experiences using remote sensing to locate small weed infestations. Proceedings of National Weed Symposium: Science in Wildland Weed Management. April 8-10, 1998, Denver, Colorado.

Martin-R, M., J. Cox, and F. Ibarra-F. 1995. Climatic effects on bufflegrass productivity in the Sonoran Desert. Journal of Range Management 48:60-63.

Mayeaux, H., H. Johnson, and H. Polley. 1994. Potential interactions between global change and Intermountain annual grasslands. Pages 95-110 In s. Monsen and S. Kitchen (eds.), Proceedings of Ecology and Management of Annual Rangelands. Intermountain Research Stations, Ogden, Utah.

Melgoza, G. and R. Nowak. 1991. Competition between cheatgrass and two native species after fire: implications from observations and measurements of root distribution. Journal of Range Management 44:27-33.

Pavlick, L. 1995. *Bromus* L. of North America. Royal British Columbia Museum, Victoria B.C. 160 p.

Poorter, H., C. Roumet, and B. Campbell. 1996. Interspecific variation in the growth response of plants to elevated $C0_2$: a search for functional types. Page 375-412 hn c. Karner and F. Bazzaz (eds.). Carbon Dioxide, Populations, and Communities. Academic Press Inc., San Diego, California.

Robbins, W.W. 1940. Alien plants growing without cultivation in California. University of California Agriculture Experimental Station Bulletin no. 637.

Romney, E., A. Wallace, R. Hunter. 1978. Plant response to nitrogen fertilization in the northern Mojave Desert and its relationship to water manipulation. Pages 232-243 in N. West and J. Skujins (eds.). Nitrogen in desert ecosystems. Dowden, Hutchinson and Ross, Stroudsburg, Pennsylvania.

Whitson, T. 1998. Establishing a sustainable vegetative ecosystem to replace noxious weeds. Proceedings of National Weed Symposium: Science in Wildland Weed Management. April 8-10, 1998, Denver, Colorado.

Wilken D. and E. Painter. 1993. *Bromus*. Pages 1239-1243 in Hickman J., editor. The Jepson Manual: Higher Plants of California. first edition. University of California Press, Berkeley, California.

Young, J. in press. *Bromus tectorum* (L.) Cheatgrass. in C. Bossard, M. Hoshovsky, and J. Randall eds. Invasive Weeds of California's Wildlands. University of California Press.

The Economics of Invasive Species Prevention

Karen M. Jetter
Agricultural Issues Center, 1 Shields Avenue Univ. of Calif. Davis, CA 95616

Every year invasive plants enter California. Given California's diverse climates, its biodiversity and the absence of natural enemies that control invasive plants in their native environments, many invasive plants could become significant weeds if their establishment is not prevented. Invasive plants can affect the productivity of agricultural lands and biodiversity in wilderness areas, and increase landscape maintenance costs for urban residents and public agencies alike.

Two methods exist to prevent the establishment of invasive species. The first is by exclusion. State and federal regulations exist that forbid the importation and dispersion of many plants known to have the potential to become invasive plants within the state. Despite these regulations, many invasive plants do enter. Should an invasive plant be detected within the State, the other method available to prevent its establishment is eradication. Eradication involves the removal of all plants from the landscape. This paper will discuss the economic considerations that are important in deciding to prevent the establishment of invasive plants. It will also examine the costs to eradicate invasive plants in general, and the benefits and costs of controlling a specific weed, yellow starthistle, on rangelands.

Individual and Public Economic Concerns of Invasive Species Prevention

Both individuals and public agencies have incentives to undertake measures to prevent the establishment of invasive species. Individuals should undertake measures to exclude or eradicate when the private benefit a person receives from those measures exceeds her or his cost. Similarly, public agencies should undertake measures to exclude or eradicate when the public benefits are greater than the public costs.

Private Economic Concerns

Invasive plants could affect individuals by changing the productivity of agricultural land, disrupting wilderness areas and increasing pest control costs in urban areas. On agricultural land, invasive plants may reduce the productivity of rangelands and crops. The weeds absorb nutrients that could be used by the crop to grow, or displace higher quality grasses with lower quality weeds. To prevent decreases in yields or productive capacity, growers and ranchers may choose to treat the infestation on their land. The decreased productivity and/or higher control costs may be passed on to consumers as higher prices. While the increased prices compensate in part for the increase in costs, it is usually not the case that rising costs are completely recovered through an increase in prices. Consequently, profitability decreases.

People are also affected by an invasive plant in wilderness areas through changes in use of recreational amenities. People enjoy many recreational activities in wilderness areas. Some examples are hiking through forests, hunting, bird watching, and engaging in water activities such as boating or canoeing. Land and aquatic weeds may limit access to these activities by clogging trails and waterways.

Individuals are also affected by an invasive plant's impact on the biodiversity of the wilderness. As an invasive plant spreads throughout the wilderness, it replaces the natural vegetation. The decrease in plant diversity then causes a reduction in the diversity of living organisms that depend on that plant life.

The displacement of natural vegetation with weedy plants may decrease the aesthetic beauty of wilderness areas or decrease the wildlife in an infested area. To cope with the changes, people may need to travel further, travel to less desirable places, visit the wilderness less often, or give up wilderness activities entirely.

However, even if a person does not engage in recreational activities or use other benefits of wilderness amenities directly, he or she may still value its existence. For example, many people do not visit the Grand Canyon, but still value its existence and support measures to protect it. This existence value is evident in part in donations made to organizations whose mission is to protect wilderness areas. Therefore, the decline in the existence of diversity is a potentially measurable cost to individuals.

Public Economic Concerns

Public agencies must also weigh the benefits of supporting activities to prevent the establishment of an invasive plant species against the costs. Public agencies need to be concerned with the provisionment and protection of public goods, and the indirect effects of invasions.

Public goods are defined to be those goods for which consumption by one person does not prevent consumption by another. Some examples include national defense and clean air. Every person is protected equally by national defense. One person breathing in clean air does not prevent another person from breathing in clean air. Another example of a public good is the creation of a natural park in a wilderness area. One person's use ofthe wilderness does not prevent another person from also using it. Because many people benefit from one amenity, one person is unlikely to provide that amenity for everyone. Consequently, public agencies are charged with the responsibility for providing public goods.

Invasive species affect public goods in many ways. They decrease the aesthetic beauty of the environment in both urban and wilderness areas. They displace native plants and living organisms, including endangered species, that feed on those plants. Invasive species may change watersheds through greater use of water, and decrease or increase the rate of soil erosion.

Public agencies also need to be concerned about the indirect effects of invasive species. These effects include private spillovers onto public goods, the aggregate effects on consumers and producers, employment and tax revenues.

Private spillovers occur when the actions (or lack or action) taken by an individual affect another group. For example, if a rancher does not control an invasive plant on his or her rangeland because it is not beneficial for the rancher to do so, that plant could spread onto public lands and into wilderness areas. Therefore, it might be in the public good for public agencies to provide incentives for individual control efforts.

The aggregate effects on different groups also are a concern for public agencies. As an invasive plant establishes and becomes widespread, it may affect production costs and productivity on agricultural land to the extent that all consumers and producers are affected The effects on consumers and producers are measured by changes in consumer welfare and producer welfare.

Figure 1 represents the market for a good such as beef. The demand curve is downward sloping because as prices increase, people will buy less. The supply curve is upward sloping because as prices increase, producers will provide more of the good to capture the higher prices. Q is produced at market price P. Consumer welfare is represented by the area with the lighter shading in Figure 1. It measures the difference between what each person is willing to pay, as shown by the demand curve, and what is actually paid in the market. Producer welfare is the darker shaded area and represents the difference between individual costs (which is equal to the price a producer is willing to receive as shown by the supply curve) and the actual market price received.

As an invasive plant spreads, costs increase and shift the supply curve up as shown in Figure 2. Less is produced, consumers pay more, producer costs have risen, but so have prices received.

Consumer welfare is now the lighter shaded region and producer welfare the darker shaded region in Figure 2. The effects on consumers and producers are measured as the change in the areas shown in Figure 1 to the areas shown in Figure 2. The magnitude of this change, plus the effects on public goods, is a consideration in determining the role of public agencies in preventing invasive plants from establishing.

Costs and Benefits of Prevention

The decision to eradicate or exclude is based on the costs and benefits of the next-best alternative. The de-

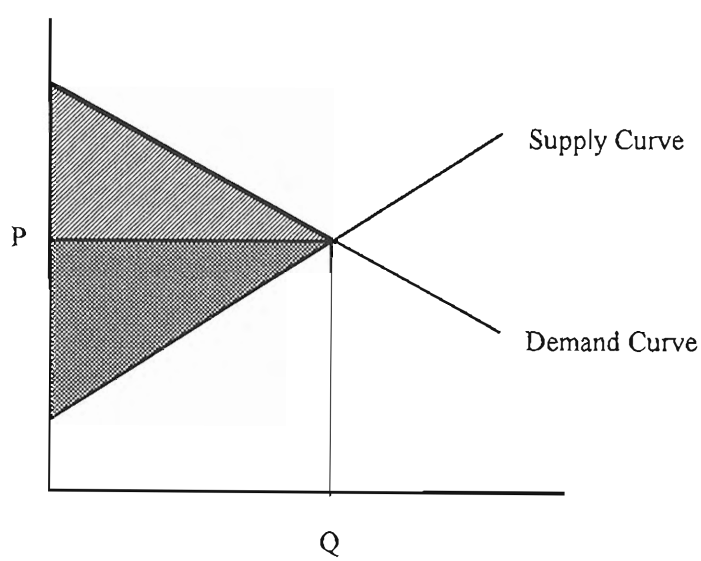

Fig. 1. Market Supply and Demand.

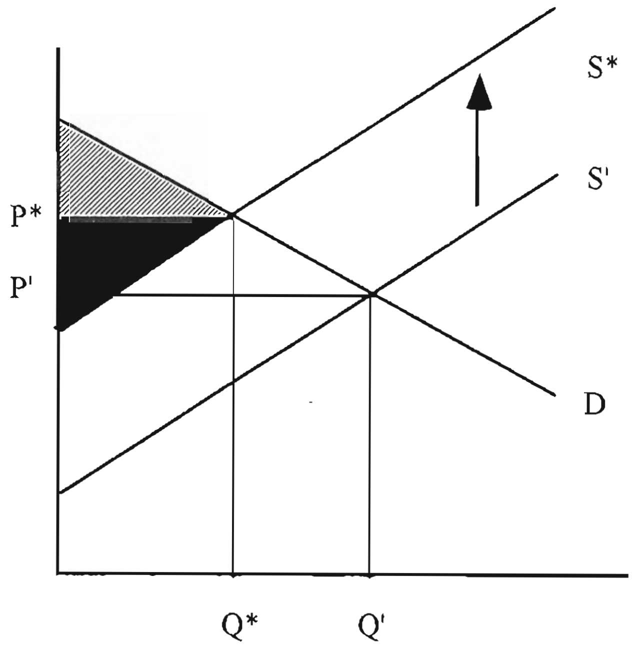

Fig. 2. Supply Curve Shift from an Increase in the Costs of Production

cisions are then: 1) exclusion versus eradication when eradication is feasible; 2) exclusion versus establishment; and 3) eradication versus establishment.

The benefits of exclusion are in the prevention of the costs of eradication or establishment, depending upon which option is the next best alternative. The benefits of eradication are in the prevention of the costs of the invasive plant spreading into uninfested areas, plus the change in the environment where the species has been eradicated. An important consideration in determining the benefits of eradication is that eradication does not necessasily restore the environment to its pre-invasion condition. It is possible that eradication of the invasive plant could, depending on the species and environment, result in further degradation. In that case it is important to consider the costs to the environment, and different groups, of further spread if the plant is not eradicated, as opposed to the costs if eradicated.

Costs to Eradicate Invasive Plants

To estimate the costs of eradication, it is important to know what determines the differences in costs of different eradication programs. A study of the costs to eradicate invasive plants in California looked at the relation between the size of an infestation and the cost to eradicate it (Bayer and Rejmanek 1999).

Figure 3 graphs the relation between the size of an infestation and the cost of eradication.

Because of the wide variation in size and costs (many observations were less than 1 acre and a few observations were between 1,000 and 7,400 total infested acres) the data was scaled by taking the natural logarithm of each variable. A trend line was included to show that, in general, the larger the infestation at the time of detection, the more costly it is to eradicate. It is worth noting that the larger infestations are still undergoing an eradication program.

An estimation of the variables that influence the cost of eradication show that not only does the size of the infestation matter at the time of detection, but also how dispersed it is. Data were made available from the California Department of Food and Agriculture on discrete infestations, the total area that was infested, the net infested area (the boundary of the total area less the space with no infestation), hours spent on each discrete infestation, per hour cost estimate of eradication, and whether the infestation had been eradicated

Dispersion was measured as the ratio of net infested acres to total infested acres. The larger the ratio, the closer net acreage is to total acreage and the less dispersed is the infestation. As the dispersion decreases, the costs to eradicate an invasive plant decreases. These results highlight the importance of early detection in increasing the likelihood of successful eradication at a lower cost.

Costs and Benefits of Eradicating Yellow Starthistle on Rangeland

In addition to eradication programs undertaken on public lands, individuals can also choose to eradicate invasive plants on their own land. In this section the effects on consumers and producers of eradicating yellow starthistle on rangeland in California's inter-mountain region were estimated using an equilibrium displacement model (Alston, Norton and Pardy 1995). The equilibrium displacement model is a system of equations specifying the demand and supply interactions between consumers and producers. It takes into account how increases, or decreases, in input costs shifts the supply curve and how that shift affects prices and the supply of beef over time as rangelands are improved.

Because of the costs both to improve, and after the

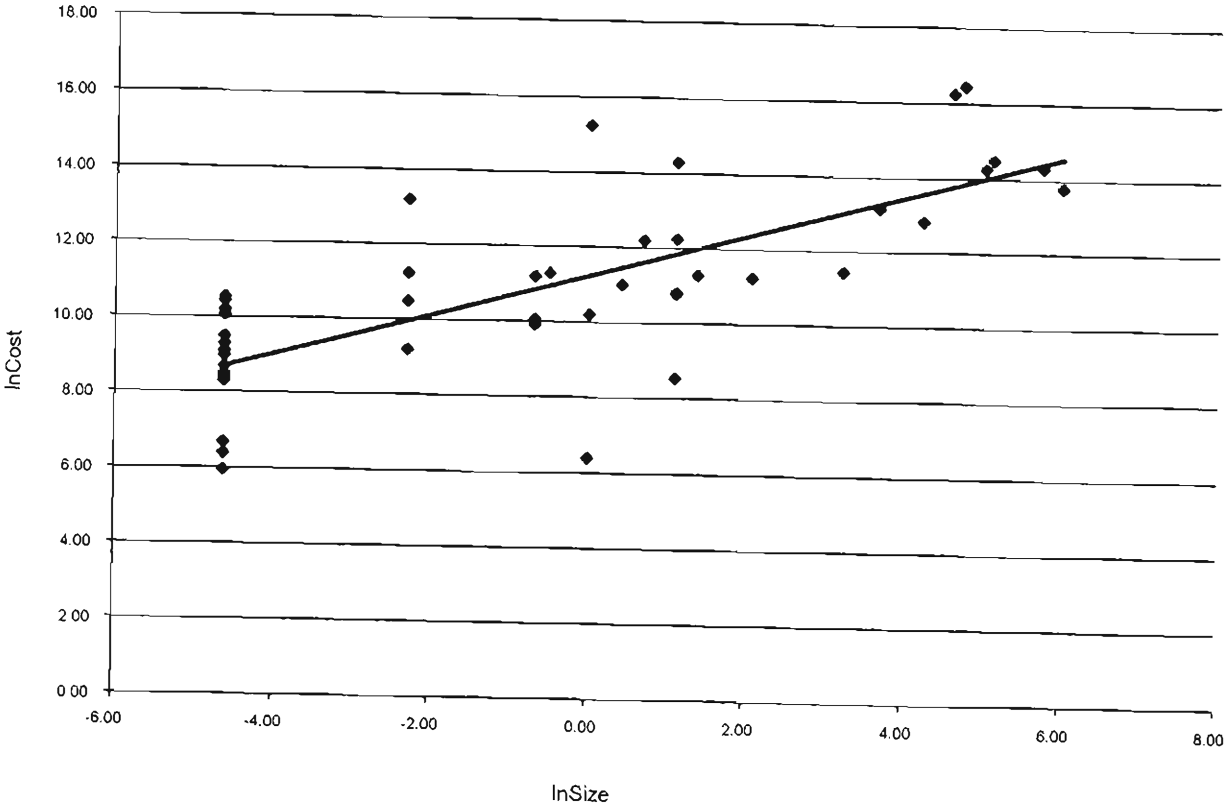

Fig. 3. Size and Costs of Eradication.

improvement is completed, and to determine the effects on consumers and producers, all effects must be considered. It is often the case that just eradicating yellow starthistle does not increase rangeland productivity, nor does it prevent future infestations. As a result, ranchers incur costs without any long-term benefits. In order to obtain benefits, the land must be reseeded in perennial grasses. This system of improving the productivity of rangeland is currently only available for the intermountain region of Northern California and along the Sierra Nevada mountain range. Total production of cattle in these regions accounts for 11% of total production in California.

Not everyone will adopt and use the new system to improve rangeland within the intermountain region. Therefore an adoption rate of 20% of total production over a period of 15 years was used in the base estimation. During the first few years the rate of adoption is low, it increases over time, then levels off as the maximum adoption level is reached.

The equilibrium displacement model is presented below. In the first equation the demand for beef, DB, depends upon the retail price of beef, Pr. California beef production is separated into three regions. The first is the region that is improving rangeland, the second is the region where the land has been improved and the final region is the rest of California. Equation 2 is the supply function for region j and shows that supply depends upon the price received by the rancher, Pg, and the cost of inputs for that region C_{gj}. Equation 3 states that total supply, S_B, is equal to the supply from each region, and equation 4 states that total quantity demanded by consumers must equal totalsupply. Equation 5 states that the price paid by consumers is equal to the price paid growers plus the price paid to process and bring the beef to market, P_m.

$$D_B = d_B(P_r)$$
$$S_B^j = S_B^j(P_g, C_g^j)$$
$$S_B = \sum_j S_B^j(P_g, C_g^j)$$
$$D_B = S_B$$
$$P_r = P_g + P_m$$

The equations were converted into percentage changes and elasticitiesl. An elasticity measures the percentage change in output from a one percentage change in price. For example, the elasticity of demand would estimate the percentage change in quantity demanded from a 1 percent change in market price.

The aggregate changes in producer and consumer welfare were estimated annually over a 25 year period. Because the value of a dollar in the future is not the same as a dollar today, the future benefits need to be discounted to reflect the value that they have in current dollars. The net present value of the all changes in welfare for the 25 year period was calculated using a discount rate of 4% and 7%.

The data used in the analysis are presented in Table 1. The cost to eradicate yellow starthistle raises total costs per animal unit by 53% per year for three years. The costs include the materials and custom application fee to eradicate yellow starthistle, reseed, and the rental costs for rangeland needed to replace the land being improved Once improved, ranchers will need to monitor the land, but it is assumed that the monitoring will take place while doing other activities related to ranching and will not increase production costs.

After the three year restoration period, annual costs to raise beef cattle will decrease by 7.8% a year per animal unit.

For the first 15 years the changes in welfare to consumers and producers are negative. It is only after no more adoption takes place that the change in welfare is positive. Eventually the improved rangelands will increase productivity to the extent that more beef is produced and sold to consumers at lower prices.

The partial adoption and geographical separation of the land that can be improved means that the distribution of the changes in welfare are not the same among different groups of ranchers. In the long run the ranchers who are unable to improve their rangeland suffer a decrease in welfare as market prices decrease. Their costs are unchanged, but market prices have fallen.

The discounted aggregate effects to all groups over time need to be estimated to determine the net effects of improving rangeland. Table 2 shows the net present value of all changes in welfare to ranchers and consumers. The net effect for both consumers and producers of beef is negative. Therefore, the sum of the discounted changes in total welfare is also negative.

To determine the robustness of these results a sensitivity analysis was completed using different levels of adoption (up to 50%), rates of adoption (including immediate adoption) and percentage change in costs to improve rangeland. Changes in either the rate or level of adoption, while influencing the magnitude of the loss, did not change the qualitative results. In general, the higher the level of adoption, the greater the loss in welfare. The quicker ranchers adopted the new technology, the smaller was the loss in total welfare. It was only when the private costs to improve rangeland were decreased by half that the net present value of all changes in welfare to producers and consumers became positive.

The private incentives to improve rangeland by eradicating yellow starthistle and replanting with perennial grasses are not strong. Depending upon the individual conditions of each ranch, some ranchers may benefit over time from improving their rangeland. However, if yellow starthistle is not eradicated from rangeland, it could potentially continue to spillover onto wilderness areas and roadways. Therefore should there be a role for public agencies to assist in improving private rangelands? As discussed earlier, public

Table 1. Data

Variable	Value
Share of production in intermountain region	11%
Adoption Rate	20%
Supply of beef produced in California	78,968 cwt
Rancher price	$140/cwt
Retail price	$280/cwt
Proportional change in costs to improve	53%
Proportional change in costs after improvement	-7.78%
Rancher price/Retail price ratio	0.5

Table 2

	Consumer Welfare	Producer Welfare	Total Welfare
4%	-$450,280	$1,350,840	-$1,801,120
7%	-$413,417	-$1,240,251	-$1,458,759

agencies should undertake public programs to eradicate invasive weeds when the public benefits exceed the costs.

While addressing this question is beyond the scope of the analysis, below are some considerations to keep in mind when determining what, if any, should be the role of public agencies in eradicating yellow starthistle on private land.

To what extent will the absence of control on private land result in the spread of yellow starthistle from private to public or wilderness land?

What types of public goods, such as wilderness areas, would be affected and how will that disruption affect biodiversity, recreational activities, the ecosystem and existence values?

What is the total cost to public agencies if incentives to control yellow starthistle are established for private land owners and what are the costs to public agencies if they are not?

The two studies show that eradicating invasive plants, whether completely or partially, may involve significant costs. The costs include those that are directly born by individuals or public agencies, and also any indirect costs. The benefits of exclusion are in the avoidance of the costs to eradicate. However, should invasive plants enter, given their widespread effects on different groups, prevention through eradication could be a cost-effective alternative to establishment.

References

Alston, Julian M., George W. Norton, and Philip G. Pardey. 1995. Science Under Scarcity, Principles and Practice for Agricultural Research Evaluation and Priority Setting. Cornell University Press. Ithaca, New York. 585 p.

Bayer, David and Marcel Rejmanek. 1999 (forthcoming). Case Studies: Weeds and Yellow Starthistle. Chapter in Summary Report of a Conference on California and the Threat of Exotic Pests & Diseases: Biology, Economics, Public Policy. Ray Coppock and Marcia Kreith, Editors. Agricultural Issues Center, University of California.

Prescribed Burning and Competitive Reseeding as Tools for Reducing Yellow Starthistle (Centaurea Solstitialis) at Pinnacles National Monument

Eveline L. Martin and Ian D. Martin
Pinnacles National Monument, 5000 Highway 146, Paicines, CA 95043

Introduction

Yellow starthistle (*Centaurea solstitialis*) is a native of Eurasia that arrived in California in the mid-1800's as a contaminant in alfalfa seed (Thomsen et al. 1996). It has since spread steadily and is estimated to infest over 12 million acres throughout the state (DiTomaso 1996). Yellow starthistle is one of California's most noxious weeds, invading disturbed areas created by activities such as road construction and maintenance, cultivation, over-grazing, and poorly timed mowing. Once established in a disturbed area, it can spread to adjacent undisturbed land (Roche et al. 1994). Yellow starthistle has been reported in 35 of the 50 states in the U.S., extending as far east as New York, and north into Canada from British Columbia to Ontario (DiTomaso 1996, Westbrooks 1998). Although it is widespread in North America, primary infestations occur in the western United States.

Yellow starthistle seeds can germinate over a wide range of temperatures, but appear to be dependent upon light, resulting in high rates of germination and extremely dense seedling populations in exposed areas. Seeds are viable in the soil three to five years in California, but have been reported elsewhere to have a longevity of up to 10 years (Callihan et al. 1993). Yellow starthistle is an annual plant with a vigorous taproot which allows it to invade dry sites. The deep taproot extends below the zone of root competition of associated annual species and allows growth well into the summer after other annuals have dried up. Seed output (700 to 10,000 per plant) and viability (95%) are very high, but can vary depending on the level of infestation, soil depth, and moisture availability (Thomsen et al. 1996). The competitive characteristics (i.e. large reproductive output, rapid germination, and high productivity) and traits that allow it to avoid interspecific competition (i.e. summer maturing and deep rooting habit) give yellow starthistle an enormous advantage over most herbaceous species, making its proliferation a serious threat to the biological diversity of California plant communities.

Pinnacles National Monument is a 16,000 acre wilderness park located in the Gabilan Mountains of the Central Coast Range in western San Benito and eastern Monterey counties. The Monument was created in 1908 to preserve unique geologic resources. Preserved within the park are the remains of an ancient volcano whose explosive eruptions 23 million years ago spread layer upon layer of volcanic rocks. The pinnacles in the center of the Monument are the exposed weathered remnants of this ancient volcano. The park preserves a wide variety of other volcanic landforms, including volcanic domes, crags, balanced rocks, and talus caves. The Pinnacles landscape is semi-arid consisting primarily of chaparral vegetation communities. Oak woodlands and savannas, riparian corridors, grasslands, and scree communities make up less than 20% of the Monument.

At Pinnacles National Monument, yellow starthistle grows in small patches and is found primarily in open, disturbed areas such as road and trail sides, stream channels, developed areas, and burned areas. Anecdotal information indicates that the density of yellow starthistle plants and the areas of infestation have increased in the past few years. Lands adjacent to the park are widely invaded by yellow starthistle, indicating that such extensive proliferation is imminent on park lands as well, We are already observing the spread of yellow starthistle into undisturbed locations such as meadows, grassland, and riparian corridors.

The largest infestation of yellow starthistle at Pinnacles National Nonument is a ten-acre wet meadow. The invasion by yellow starthistle has disrupted the soil water balance and the ratio of native perennial plant species to exotic annuals in the meadow. The Entrance Meadow is one of two wet meadows at Pinnacles National Monument and our best example of a wetland, containing both obligate and facultative wetland plants and deep hydric soils. This meadow has been heavily impacted by human activity. The parcel of land containing the Entrance Meadow was acquired by the Monument as part of the 1974 boundary adjustment. Prior to 1974, the meadow was heavily grazed by cattle, resulting in soil compaction and the introduction of exotic plants. An extension of the boundary fence was constructed with the new land acquisition at one end of the meadow, introducing further disturbance into this unique vegetation community. Today, the main park road and a hiking trail border two sides of the meadow. In light of these changes to the natural hydrologic regime and in plant species composition and abundance, resource management staff at the Monument have begun restoring this meadow to an improved and unimpaired condition. Yellow starthistle is the principal disturbance component that needs to be addressed in the restoration of the Entrance Meadow. To successfully control, and possibly eradicate, this noxious exotic plant, timing control efforts to specific stages of plant growth is essential for success.

Prescribed burning has been shown to greatly reduce yellow starthistle plants and seed in the soil (Hastings and DiTomaso 1996). Hastings and DiTomaso (1996) found that fire stimulated germination of seed in the soil, thus a succession of annual burns over a period of several years rapidly depleted both the seed bank and the standing populations of yellow starthistle. For prescribed burning of yellow starthistle to be effective, sufficient fuels must be present (Thomsen 1996), which may present a problem if fuels are depleted with each successive prescribed burn. To address this concern, we planned to provide a fuel source for the second and third burns.

The primary goal of the first phase in the meadow restoration project is to evaluate the effectiveness of repeated prescribed burning in reducing yellow starthistle stem and seed densities at Pinnacles National Monument.

Secondary goals are to:

1. test the effectiveness of post-burn seeding with Regreen to provide fuel for subsequent burns
2. evaluate the competitive effects of seeding with Regreen coupled with burning on yellow starthistle density
3. examine the effects of repeated burning on native and exotic plant cover
4. assess the effects of seeding with Regreen coupled with burning on native and exotic plant cover.

This report discusses the results following one year of prescribed burning in 1999.

Methods

The Entrance Meadow will be completely burned in a succession of three years of burning from 1999 to 2001. Prescribed burning will take place in late spring or early summer after yellow starthistle has bolted, before seed maturation takes place, and after annual grasses on-site have cured to provide fuel for the fire. One half of the burn unit (5 acres) will be seeded in the fall following each burn with 20 - 30 pounds/acre of Regreen, a sterile annual wheat x wheatgrass hybrid. The meadow was divided into four quadrants of roughly equal size (Fig. 1). The NE and SW quadrants were seeded with Regreen. Only half of the burn unit received Regreen to allow for testing the effectiveness of seeding to increase fuel loading for the next burn and to provide competition for yellow starthistle seedlings. Regreen will not be spread after what is anticipated to be the final burn year

Data collection will take place in May each year prior to burning. A random starting point along the north edge of the meadow was used to systematically locate ten reference transects that extended across the width of the meadow. Within each reference transect, two 30 m transects were randomly placed, one in each quadrant, for a total of 20 transects throughout the meadow. Start, end, and center points of each reference transect were permanently marked with rebar for repeatable yearly monitoring. Permanent photo points were located at the start and end points of each reference transect. Forty $1m^2$ plots were systematically arranged with random starting points along the transects, with ten plots in each quadrant. Yellow starthistle density was recorded in each plot. Percent cover for all plant species was measured using the point intercept method (Bonham 1989, USDI 1992) every 0.3 m with a random starting point along each transect. Post-burn fire severity data was collected every two meters along the 20 transects using methodology from the Western Region Fire Monitoring Handbook (USDI 1992). Soil cores to a depth of 5 cm were obtained adjacent to each $1m^2$ plot for seed bank density measurements according to Bullock (1998). Soil cores will be collected in October of each year following prescribed burning.

An unburned control area is located adjacent to the Entrance Meadow prescribed burn unit. Five 30 m transects were systematically located with a random start

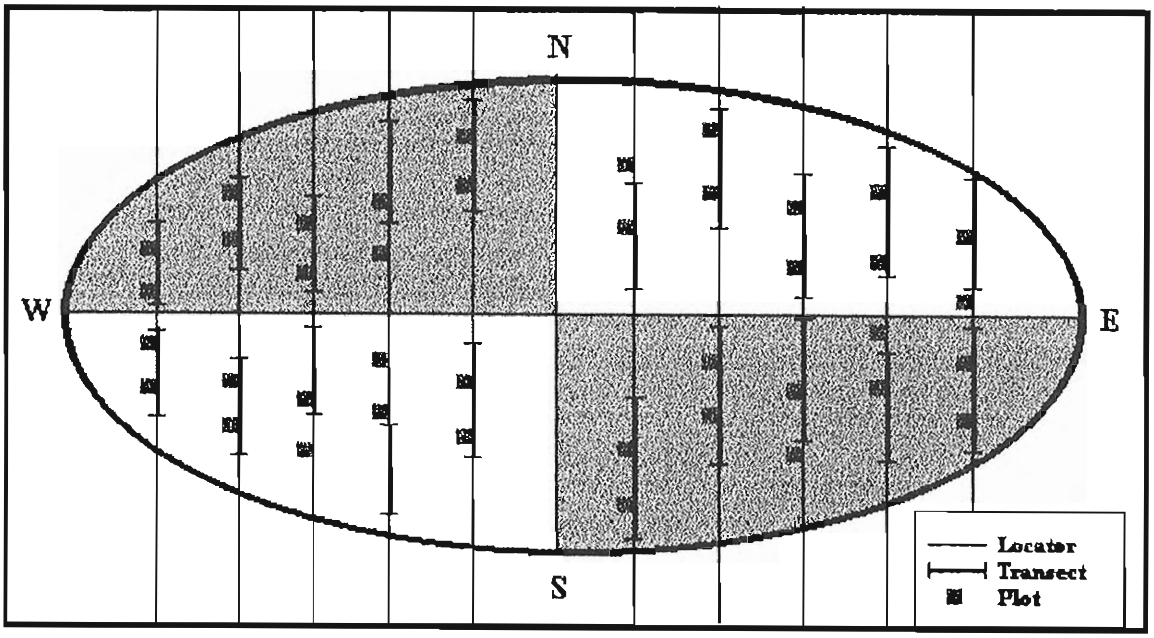

Fig. 1. Schematic of sampling design for the Entrance Meadow prescribed burn site.

point in this area to measure percent cover of native and exotic plant species. Ten $1m^2$ plots were located systematically, with a random start, along each transect. Yellow starthistle stem densities were measured in each plot. Soil cores to a depth of 5 cm were obtained adjacent to each plot for seed bank density measurements.

The first prescribed burn was conducted on June 8, 1999. We used the computer model BEHAVE (Burgen and Rothermel 1984) to develop a prescription for the burn using fuel model 1, unshaded grasslands, developed by Anderson (1982). The day of the burn, air temperature ranged from 21 to 24° C, with a relative humidity of 21 to 27%, and winds out of the NE from 6 to 8 k/hr. The burn was ignited in the southwest corner of the meadow and a backing fire spread to the northeast against the wind. Fuels in the meadow were adequate to carry the fire at a rate of spread of 56.4 m/hr and 1 to 2 meter flame lengths. Fire intensity was hot enough to consume or scorch almost all yellow starthistle plants.

Results

Pre-burn data collection was conducted May 18-20, 1999 prior to the first prescribed burn. Percent cover of yellow starthistle was estimated at 14.42%, exotic grasses at 105.35%, native grasses at 4.03%, other exotic forbs at 3.63%, native forbs at 7.56%, and shrubs at 7.46% (Fig. 2). Other than yellow starthistle, the percent cover for species in each of the other categories was combined. The exotic grasses *Bromus diandrus* (48.5% cover) and *Bromus hordeaceus* (35.6% cover) were the only species in the meadow with greater cover than yellow starthistle.

Density of yellow starthistle plants and growth stage during monitoring was also recorded. The density of yellow starthistle in the rosette stage was 42.7 plants/m2, in the seedling stage there were 49.8 plants/m^2, in the bolting stage there were 3.85 plants/m^2, and in the flowering stage there were zero (Fig. 3). The mean density estimate for the entire meadow is 96.35 plants/m^2 thus for the 10 acre meadow with 14.42% cover of yellow starthistle, this translates to a possible 450,000 plants.

Percent cover of all plants and density of yellow starthistle was recorded in the control plot as well. Percent cover for yellow starthistle was 34.4%, more than twice as much as in the meadow (Fig. 2). Percent cover of exotic grasses (113.4%), native grasses (3.6%), exotic forbs (2.2%), and native forbs (4.6%) on the control plot were similar to those in the meadow (Fig. 2). Percent cover of shrubs on the control was zero. Density of yellow starthistle plants in the rosette stage on the control plot was 69.9 plants/m^2, almost twice as much as in the meadow. Plants in the seedling stage (51.1 plants/m^2) and in the flowering stage

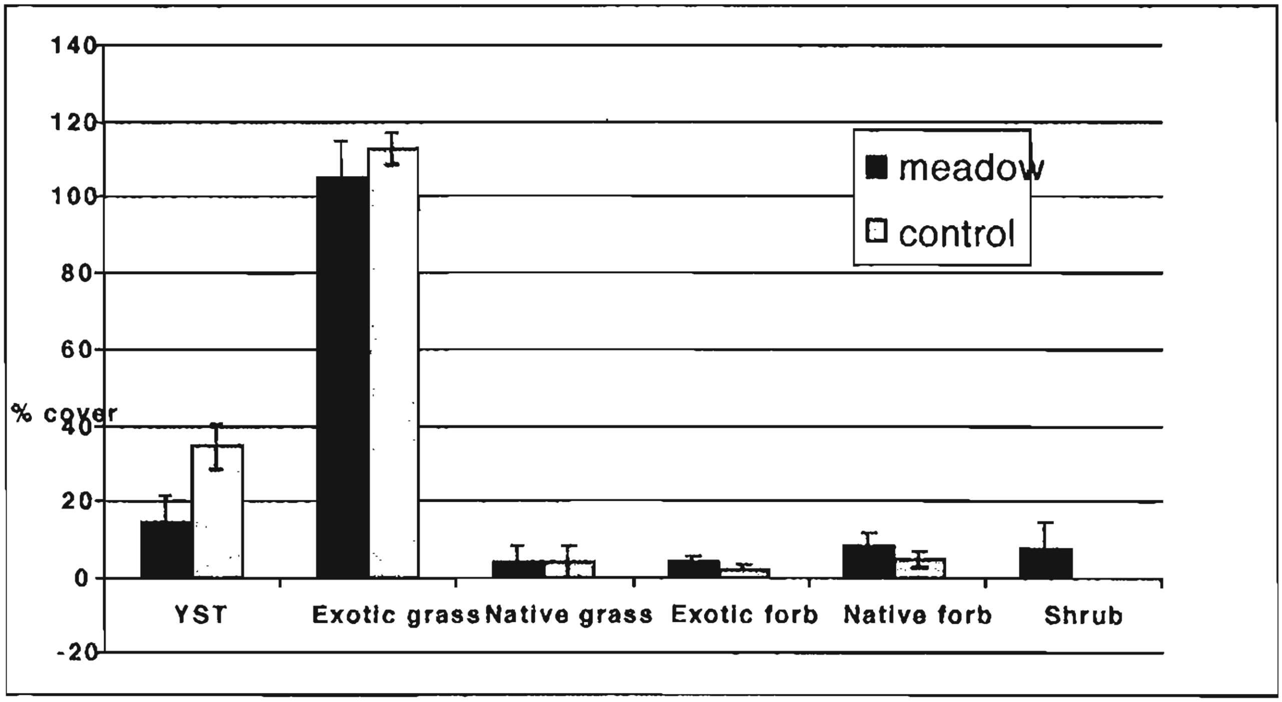

Fig. 2. Percent cover of native and exotic vegetation in the Entrance Meadow and control site prior to implementation of the first prescribed burn.

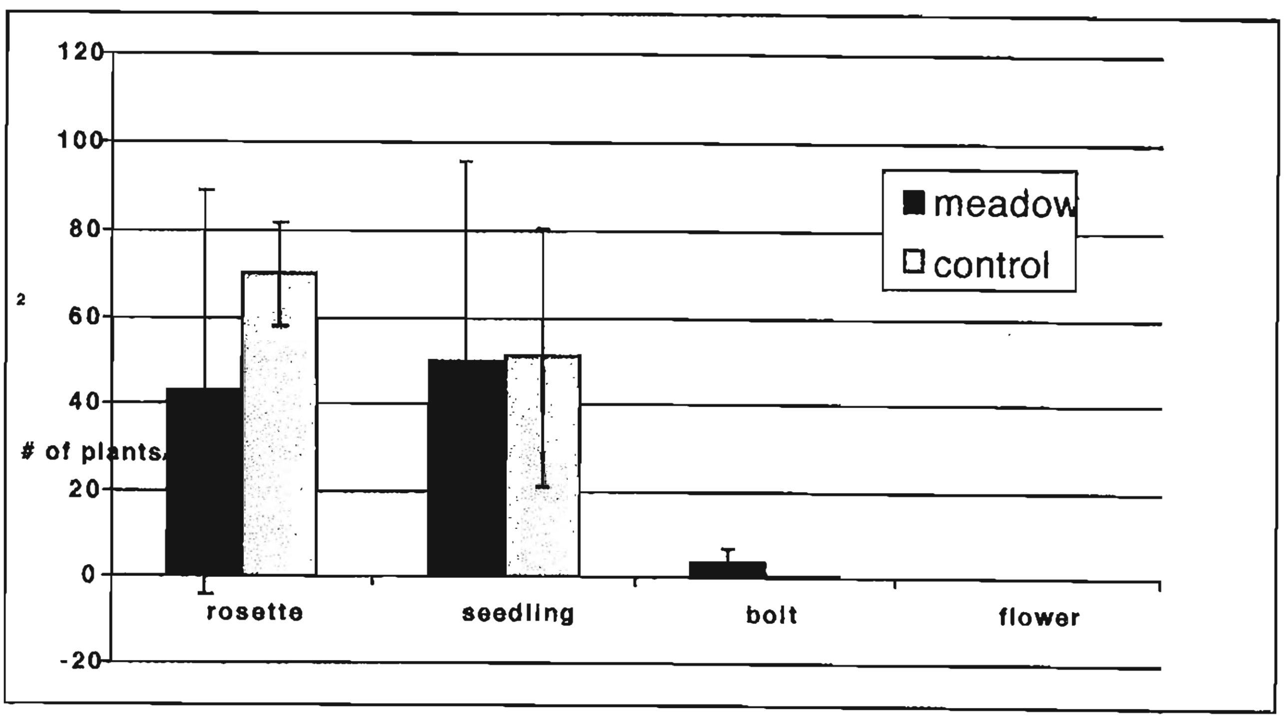

Fig. 3. Density of yellow starthistle by phenological stage in the Entrance Meadow and on the control site prior to the implementation of the first prescribed burn.

(zero), were very similar to the densities found in the meadow (Fig. 3). Density of plants in the bolting stage was one tenth as much in the control (0.55 plants/m^2) as in the meadow (Fig. 3).

Visual estimates indicated that a larger percentage of yellow starthistle growing in the meadow at the time of the burn had bolted than was recorded during monitoring three weeks earlier.

Fire severity data was collected three days post-burn. 56% of the vegetation in meadow was lightly burned (litter partially consumed, wood and leaf structures charred but recognizable), 28% was moderately burned (litter mostly consumed leaving coarse light colored ash, wood and leaf structures unrecognizable), and 8% was heavily burned (litter entirely consumed leaving a fine white ash, mineral soil visibly altered) (Fig. 4), leaving less than 8% of the vegetation in the meadow either scorched (litter partially blackened, wood and leaf structures unchanged) or unburned.

Discussion

The first year of prescribed burning to reduce yellow starthistle in the Entrance Meadow at Pinnacles National Monument appears to have been successful. The fire killed over 98% of the yellow starthistle within the burn unit including plants that had bolted and plants still in the rosette and seedling stages. The burn was within the limits set by the prescription, though on the hotter end of the acceptable range. This resulted in longer flame lengths, a deeper flame front, and a higher intensity burn. Fuel loading from exotic grasses also contributed to supporting a more intense fire than would typically be expected for this fuel model. As shown by post burn severity data (Fig. 4), 92% of the vegetation was lightly to heavily burned, indicating that the fire burned fairly uniformly, Only 3% of the burn unit remained unburned, and 4.5% was scorched.

We monitored the meadow, post-burn, on a monthly basis from June to September 1999 and discovered that yellow starthistle plants that were scorched but not consumed were able to resprout from the base. Additionally, yellow starthistle was found to grow in small unburned patches and along the edges of the meadow where fire intensity was lower than in the center of the burn. On each monthly visit we pulled all yellow starthistle present so as not to allow any seed to mature and enter the soil seed bank. We estimate that we pulled over 5000 plants, a small number when compared to the estimated 450,000 plants that were destroyed by the fire.

These initial results may have important implica-

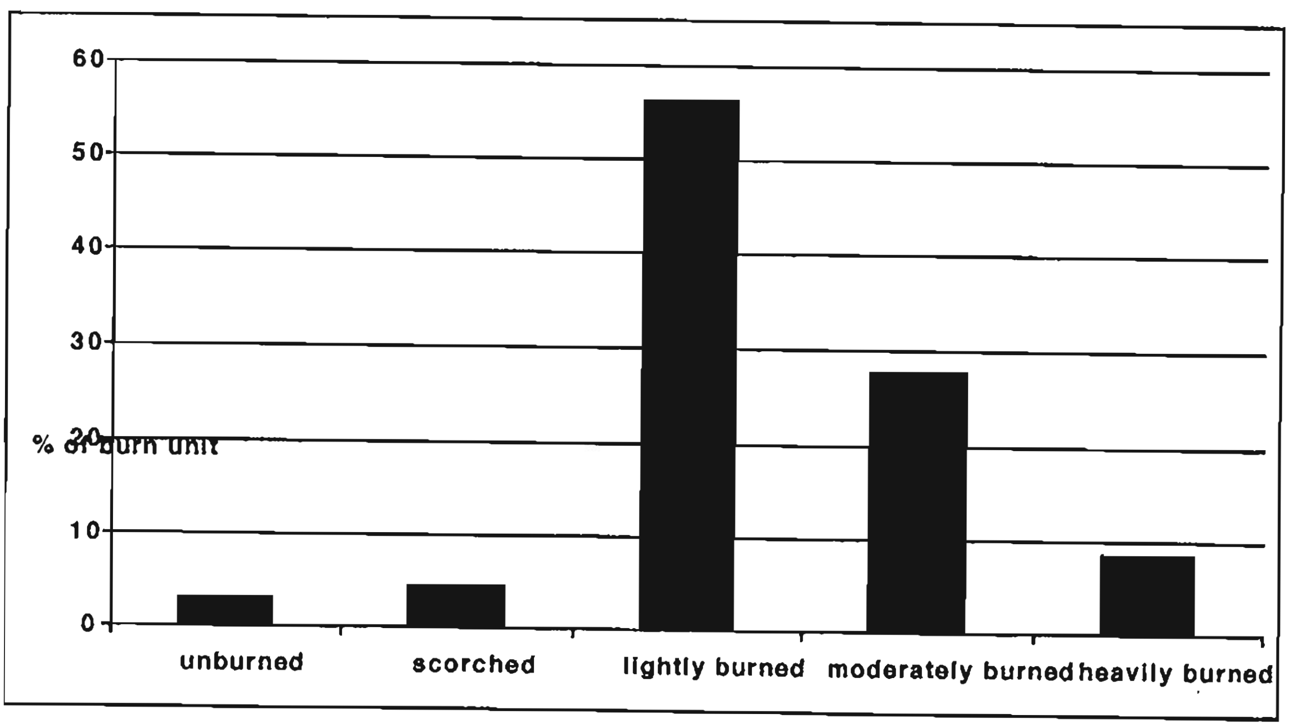

Fig. 4. Burn severity on vegetation in the Entrance Meadow immediately following the 1999 prescribed burn.

tions for the use of prescribed fire to manage yellow starthistle. Our prescribed burn took place earlier in the growth cycle of yellow starthistle than is generally recommended. When we burned in early June, most of the plants were in the rosette and seedling stage, a small percentage had bolted, and none were flowering. However, our data show that the high intensity burn successfully consumed yellow starthistle plants in all of these growth stages with minimal resprouting. By burning early in the fire season when fire danger is moderate, we reduced the risk of having the fire escape control lines in more dangerous burning conditions. Another benefit to burning early is that much of the seed of cured exotic annual grasses on-site are still suspended aerially and can also be destroyed by the fire. This may reduce competition with native species and promote native species recolonization. Lastly, it is crucial to revisit the burn site and remove any yellow starthistle that has resprouted or germinated post-burn in order to prevent any new seed from entering the soil seed bank.

Data collected in the adjacent control area are similar to data from the Entrance Meadow. The main differences are that there is greater percent cover of yellow starthistle in the control than the meadow (Fig. 2) and, accordingly, higher densities of plants. Although the control plot does not mimic the conditions of our burn unit perfectly, we will be able to draw conclusions on the effectiveness of prescribed burning on reducing yellow starthistle vs. no treatment.

Soil cores were not collected prior to the first burn for a baseline estimate of yellow starthistle seed densities. However, we will collect soil samples this year and after each burn to assess whether prescribed fire can reduce the yellow starthistle seed in the soil. We can use seed density data from the control plot to estimate pre-burn seed densities in the meadow, with the understanding that the control plot has higher stem densities, which will most likely translate to higher seed densities, than the meadow.

We have yet to determine the success of spreading Regreen to increase fuel loading for the second and third years of burning. Additionally, we are looking forward to assessing the competitive effects of Regreen on yellow starthistle, effects of multiple prescribed burns on all vegetation components of the meadow, and effects of Regreen coupled with burning on exotic and native meadow plant species.

Pinnacles National Monument will proceed with prescribed burn plans for the Entrance Meadow in 2000 and 2001. After the final burn, the last stage in the restoration of the Entrance Meadow will be to reseeded with native grasses such as *Elymus glaucus*, *Nassella pulchra*, and *Melica californica*, and native herbs such as *Eschscholzia californica* and *Lupinus* spp. After the meadow restoration is complete, park staff will continue to monitor the meadow for any new or remaining yellow starthistle introductions. Mechanical removal, herbicide applications, and prescribed burning will continue to be used as necessary for the continued management of a healthy meadow grassland community.

Acknowledgements

We would like to thank the Whiskeytown Prescribed Fire Module, California Department of Forestry Bear Valley Station, and staff from the USF&W San Luis Wildlife Refuge for assistance with prescribed burning. Funding was provide by the National Park Service through FIREPRO and from the Geologic Resources Division's Small Disturbed Lands Restoration funding.

Literature Cited

Anderson, H. 1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv., Intermt. For. Range Exp. Stn., Gen. Tech. Rep. INT-122.

Bonham, C.D. 1989. Measurements for terrestrial vegetation.New York, NY. John Wiley & Sons.

Bullock, J. 1998. Plants. Pages 111-138 in Sutherland, W.J., ed. Ecological census techniques: a handbook. Cambridge, U.K .Cambridge University Press.

Burgen, R.E. and R.C. Rothermel. 1984. BEHAVE: Fire behavior Prediction and fuel modeling system. USDA For. Serv., Intermt. For. Range Exp. Stn., Gen. Tech. Rep. INT-167.

Callihan, R.H., T.S. Prather, and F.E. Northam. 1993. Longevity of yellow starthistle (*Centaurea solstitialis*) achenes in soil. Weed Technology 7:33-35,

DiTomaso, J.M. 1996. Yellow starthistle: biology and life history. Pages 61-64 in Lovich, J., J. Randall, and M. Kelly, eds, Proceedings California Exotic Pest Plant Council Symposium Volume 2:1996.

Hastings, M.S. and J.M. DiTomaso. 1996. Fire controls yellow starthistle (*Centaurea solstitialis*) in California grasslands. Pages 72-76 in Lovich, J., J. Randall, and M. Kelly, eds. Proceedings California Exotic Pest Plant Council Symposium Volume 2:1996.

Roche, B.F., C.T. Roche, and R.C. Chapman. 1994. Impacts of grassland habitat on yellow starthistle (*Centaurea solstitialis* L.) invasion. Northwest Science 68:86-96.

Thomsen, C.D., W.A. Williams, M.P. Vayssieres, C.E. Turner, and W.T. Lanini. 1996. Yellow starthistle biology and control. University of California Division of Agriculture and Natural Resources, Publication 21541.

USDI National Park Service. 1992. Western region fire monitoring handbook. San Francisco, Western Region Prescribed and Natural Fire Monitoring Task Force, National Park Service, 287 p.

Westbrooks, R. G. 1998. Invasive plants: changing the landscape of America: fact book. Federal Interagency Committee for the Management of Noxious and Exotic Weeds, Washington D.C.

Posters and Abstracts

The Ecology of Parentucellia Viscosa Invasion in Dune Wetlands

Andrea J. Pickart and Kyle S. Wear

U.S. Fish and Wildlife Service Lanphere Dunes Unit, Humboldt Bay National Wildlife Refuge Arcata, CA

Introduction

Parentucellia viscosa (L.) Caruel is a hemiparasitic member of the Scrophulariaceae native to Europe. *Parentucellia* is an erect, sessile-leaved annual less than 50 cm tall, generally unbranched in California (Hickman 1993). It has a yellow, two-lipped corolla, with flowers appearing in the axils of leaves along the upper half of the stem. Leaves are opposite or, near the top of the plant, alternate or offset. The stem and leaves are sticky as a result of glandular hairs. *Parentucellia* flowers in northern California from June through August. *Parentucellia* is self-compatible, but capable of outbreeding, and has previously been determined to lack host-specificity (Atsatt and Strong 1970). Plants can germinate and grow in the absence of hosts. Its congener, *Parentucellia latifolia* (L.) Caruel, does not cause detrimental effects to the host (Alexander and Weber 1984).

Parentucellia has been recognized since at least 1970 as a common weed of roadsides, moist areas, and annual grasslands of California and Oregon (Atsatt and Strong 1970, Taylor 1990). However, it has not been classified as invasive by the California Exotic Pest Plant Council. Rather, the Council include it on their list "Exotic Pest Plants of Greatest Ecological Concern in California" under the category of plants in need of more information (CalEPPC 1996).

The Lanphere Dunes Unit (Lanphere Dunes) of the Humboldt Bay National Wildlife Refuge is a 192-ha site located at the upper end of the North Spit of Humboldt Bay, California. The refuge protects a near-pristine example of a coastal dune system that supports dune forests, wetlands, and vegetated foredunes. *Parentucellia* was present on the Lanphere Dunes as early as 1976 (Barker 1976). By 1985, the species was already invasive in herbaceous dune hollows at the site (Pickart 1987). Dune hollows are seasonally inundated or saturated wetlands that support herbaceous or woody vegetation (Pickart and Sawyer 1998). They occur on the deflation plain behind parabolic dunes, and as dunes migrate eastward the deflation plain elongates. However, the extent to which newly deflated areas are colonized by hydrophytes is dependent on rainfall abundance, which controls water table height. Another critical factor is timing of rainfall. Whereas some dune hollow species, such as *Juncus breweri* Engelm., are rhizomatous, others (including all annuals) depend on hospitable conditions for seed germination and seedling establishment. Both too much or too little flooding can prevent or postpone these events. At the same time, biotic succession and abiotic agents (such as sand deposition) in the adjacent more established deflation plain result in a complex vegetation pattern that undergoes rapid change.

Against this background it is difficult to evaluate the ecological influence of *Parentucellia*. Our three-year research project was designed to shed light on the role of *Parentucellia* as a dune hollow invader by investigating its regional distribution, localized spread, habitat characteristics, frequency of host species, seedbank persistence, and demography. In addition, we carried out experiments to test control methods, and monitored changes in species composition in areas undergoing colonization by *Parentucellia*.

Methods

Regional Distribution

The North American range of *Parentucellia* includes coastal California, Oregon, and Washington (Hitchcock et al. 1959, Hickman 1993, Pojar and McKinnon 1994). Our efforts focused on determining its distribution and invasiveness in dune systems of northern California and southern Oregon. In 1996, during *Parentucellia* flowering (July-August) we visited all major dune hollows on the North and South Spits of Humboldt Bay and the Eel River delta in Humboldt County, Ten Mile Dunes in Mendocino County, Lake Earl Dunes in Del Norte County, and the southern Oregon Dunes National Recreation Area in Coos County, Oregon. At each site we noted presence/absence of *Parentucellia* and qualitatively described its abundance. We also contacted ecologists and managers of major dune systems from Oregon south to Monterey County California to obtain information on the presence and abundance of the species.

Localized Spread

In August 1999 we mapped the distribution of *Parentucellia* on the Lanphere Dunes Unit, following the methodology employed in similar surveys in 1989 and 1995 (Pickart 1995). We delineated areas of its presence on overlays of large-scale color air photos (1:2,400) in the field. The time series was then transferred by hand to three copies of a 1997 orthophoto printed at the same scale. The resulting maps were used to create three shapefiles via on-screen digitizing over the orthophoto (photo scale 1:16,000, scan resolution 1200 dpi) in ArcView 3.0.

Habitat characteristics

In September 1997 we established four 100-m-long east-west transects through herbaceous hollows at the Lanphere Dunes. Transects were placed systematically in the northern, central, and southern regions of the site. We sampled vegetation in 25 cm x 25 cm plots placed every 2 m along the north side of each transect. The plot frame was marked to indicate cover classes, and we visually estimated cover of every species in each plot using a modified Braun-Blanquet cover scale (1 < 5%, 2 = 6-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-100%). A pin flag was placed in the center of each plot, denoting the point at which we would subsequently measure elevation.

Elevations of pin-flagged points were obtained in October 1997. Control traverse points were elevated by a precise level loop survey using a Zeiss level. Holding the elevations of the easterly terminus of transects, and using a Lietz Set 2 Total Station, the sample elevations were then determined by trigonometric means. Elevations were relative, since the survey was not tied to a known elevation. The basis of the elevations was arbitrarily assumed to be 100.00 ft on the easterly terminus of the first (southernmost) transect. The horizontal control for the northings and eastings of the points was an assumed coordinate of North 5,000.00 ft and East 5,000.00 ft on the easterly terminus of the first transect. A magnetic bearing of N15°E was observed between this point and the easterly terminus of the second transect. Assuming a magnetic declination of 18° (approximate for this area), this bearing was held as N3°W as the basis of bearings for this survey. An open traverse of the remaining control points was performed to determine their horizontal location.

Host species

In August 1996, 22 collections were made from subjectively chosen locations within hollows of the Lanphere Dunes. Each collection contained one to several *Parentucellia* individuals together with neighboring plants, including as much root material as was feasible to remove. Sand and debris were carefully removed from roots so as not to disturb haustorial connections, and samples were examined with a dissecting microscope to determine the number of haustoria and to identify host species.

As an indirect measure of relative host benefit, we measured the inflorescence length of all *Parentucellia* individuals (whether or not a host connection had been confirmed) and grouped collections into one of three categories: 1) those in which *Lotus purshianus* co-occurred, 2) those in which *Lotus purshianus* was absent but other species occurred, and 3) those in which no species other than *Parentucellia* were present.

Seedbank persistence

Two different methods were utilized to characterize the seedbank of *Parentucellia*. The first relied on an *in situ* approach. In June 1996 we placed 12 1-m x 1-m plots subjectively (in the spirit of randomness) at the Lanphere Dunes in areas characterized by abundant *Parentucellia*. Eight of the plots were surrounded with a solid wooden barrier approximately 30 cm high. The remaining four plots served as a control and had no barrier. During summer 1996 all *Parentucellia* plants were hand-pulled from enclosed and control plots prior to seed shed. Individual plants were counted as they were removed, and then dried and weighed together to yield total weight for the plot. A 2-m-wide buffer area was cleared of *Parentucellia* around all plots using a weed-eater. On 2 August 1996, when we judged that seed would soon disperse from surrounding areas, we covered non-control plots with a 200-thread-count white cotton sheet. By periodically checking under the covered plots, we determined that new *Parentucellia* seedlings began emerging in early to mid-March of 1997. On 26 March we uncovered the plots, and on 12-15 May we hand-pulled and counted all new plants in both enclosed and control plots. Several subsequent visits were made to check for new recruits.

The second seedbank experiment entailed an *ex situ* approach. Our purpose in including it was to insure against the possibility of damage to our covered plots from winter storms. In the second experiment, we collected 120 soil samples equally distributed among four strata at the Lanphere Dunes in May 1996. Samples were collected using a plastic pipe and were 5 cm deep and 7.7 cm in diameter. The four strata we sampled were: 1) near live plants that had not yet reproduced, 2) near dead stalks from the previous year (no live plants present), 3) in areas that were topographically above, but nearby, *Parentucellia* occurrences, and 4) in areas that were similarly topographically below. Samples were stored in a dry location until the following spring, and then grown out in small rectangular plastic pots. When emergence of *Parentucellia* began in the field, pots were immersed in water in larger flats and allowed to gradually dry. After all seedling emergence had stopped, pots were stirred and re-wetted to encourage any remaining seeds to germinate.

Demography

In late March 1997, at the time of *Parentucellia* emergence, we placed ten 50-cm x 50-cm plots in the southern portion of the Lanphere Dunes in areas where seedlings were abundant but not too dense to monitor. The four corners of each plot were marked and string was used to delineate the plot and to facilitate counting. Plots were visited approximately every other week from 1 April though 10 August 1997, by which time all plants had died. At each visit we recorded the number of live individuals, the range of their heights (measured quantitatively), and their average height (estimated visually with the aid of a scale). Our original intent was to follow a subset of individuals through flowering in order to describe reproductive output, however, survival to flowering was quite small within our plots. To capture this information we established a separate sampling as described below.

In September 1997, when plants were in fruit, we systematically placed three east-west transects to encompass the latitudinal extent of deflation plain. We collected all *Parentucellia* individuals within a 25-cm x 25-cm plot at 4-m intervals, for a total of 42 samples. We measured the length of all plants, the length and number of branches, and the number of fruits/branch. To determine the number of seeds produced per fruit, we separately and randomly sampled one fruit from each of 10 fruiting plants, which were subjectively selected to represent a range of sizes. We counted the number of seeds per fruit using a dissecting scope.

Species control

In July 1996 we established 30 2-m x 1-m plots in dune hollows of the Lanphere Dunes in areas characterized by at least 25% *Parentucellia* cover. Plots were located subjectively in areas of relatively homogeneous vegetation characterized by 40-90% cover of *Lotus purshianus* (Benth.) Clements & E.G. Clements var. *purshianus*, an annual that had been observed to be highly correlated with *Parentucellia*. Most or all of the following species were also present at low cover values: *Juncus breweri*, *Hypochaeris radicata* L., *Epilobium ciliatum* Raf. ssp. *watsonii* (Barbey) P. Hoch & Raven, and *Gnaphalium purpureum* L. We randomly assigned 10 plots each to one of two treatments or a control. Treatments consisted of removal of all *Parentucellia* individuals by 1) hand-pulling and 2) weed-eater. A 2-m-wide buffer was established around each plot, in which all *Parentucellia* was removed using the same treatment applied to the plot.

In ten subplots per plot (for a total n of 100 per treatment), we recorded cover of all species using a modified Braun-Blanquet cover scale (1 < 5%, 2 = 6 – 25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-100%) and a frame marked to indicate cover classes. Subplots were 25 cm x 25 cm and were selected randomly each year. We monitored cover prior to treatment in July 1996. Monitoring followed by treatment was repeated in July 1997, and monitoring alone was conducted in August 1998. During the course of the experiment, a number of plots were lost or damaged, and the final plot sample sizes were 7 (hand-pull), 9 (weed-eater), and 6 (control).

Changes in species composition

In July 1996, following the methods used for species control plots, we established 10 additional plots in areas that met similar vegetation criteria with the exception that no *Parentucellia* was present. These plots were established in order to document the spread of *Parentucellia* into the plots and any subsequent changes in species composition. Monitoring of these plots was conducted annually in July from 1996 through 1999 following the methods described above.

Results

Regional distribution

Parentucellia was present in every major herbaceous hollow of the North Spit, but was absent from herbaceous hollows on the South Spit and Eel River spits, despite its presence along South Spit Rd. and near the Centerville Beach parking area. Nowhere on the North Spit did *Parentucellia* attain the abundance it exhibited at the Lanphere Dunes. The hollows on the south end of the Lanphere Dunes site are uniquely broad, flat, and herbaceous (relatively young) compared to sites even slightly to the south and north.

At the Lake Earl dunes in Del Norte County, *Parentucellia* was found only along roadside ditches in the Pacific Shores subdivision, a grid of roads constructed on the dunes in the 1960s that has never been further developed. *Parentucellia* occurred in these areas in association with two species which were found to be hosts in the Lanphere Dunes hollows: *Lotus corniculatus* L. (another naturalized exotic) and *Trifolium wormskioldii* Lehm. We did not observe *Parentucellia* elsewhere in the dunes, and most dune hollows were either densely vegetated with sedges or with woody vegetation.

No *Parentucellia* was observed in the dunes of Coos County, Oregon, despite the presence of *Lotus corniculatus* and *Trifolium wormskioldii*.

Parentucellia was more abundant at the Ten Mile Dunes in Mendocino County than at the other sites we visited, but still did not appear aggressively invasive. Associated species included *Lotus corniculatus*, *Hypochaeris radicata*, and *Trifolium wormskioldii*. *Parentucellia* was most abundant in a disturbed, moist dune area near Inglenook Fen that had been grazed in the past; this appeared to be the point of dispersal into the dune system, with abundance diminishing to the north and south. Of the dune sites we visited, the dune hollows at Ten Mile were most similar to those at Lanphere Dunes in terms of species composition, topography, and successional stage, with very little woody vegetation present. The most consistent difference between the dune hollows of the North Spit and those elsewhere, including Ten Mile Dunes, was the absence of *Lotus purshianus*, the species most strongly associated with *Parentucellia* on the North Spit.

Localized spread

The extent of *Parentucellia* at Lanphere Dunes increased from 1.7 to 4.8 ha between 1989 and 1995, and then decreased to 3.4 ha in 1999 (Fig. 1). As a percentage of available herbaceous wetland habitat, *Parentucellia* cover increased from 23% in 1989 to 45% in 1995, and then decreased to 41% in 1999. Despite this variation, there was a positive relationship (Fig. 2) between the area of *Parentucellia* and the area of herbaceous hollows (Spearman's $r=1.0$, $p<.01$). Herbaceous hollows, as a percentage of all hollows, remained relatively stable between 1989 (70%) and 1995 (67%), but declined sharply by 1999 (45%) as hollow vegetation succeeded to willows.

Habitat characteristics

The elevations we obtained for our sample points were relative because of the high cost of tying in to an existing monument. For the purposes of reporting results, we have placed elevations into five classes, each representing 0.33 m of elevation change. Elevation increased with increasing elevation class, from 1-5. *Parentucellia* decreased with elevation from class 1 to 3 (Fig. 3), and was essentially absent in classes 4 and 5. Our samples did not encompass the lower elevation limit for the species. Differences in *Parentucellia* cover among elevation classes were significant ($p<.001$) as determined by Analysis of Variance. Post hoc Least Significant Difference tests identified *Parentucellia* cover in classes 1 and 2 as different from each other and from all other classes ($p<.05$). *Parentucellia* was negatively correlated with elevation ($r=.468$, $p<.001$).

Several species were positively correlated with *Parentucellia* (Table 1), including *Lotus purshianus* ($r=.404$, $p<.001$), *Hypochaeris radicata* ($r=.334$, $p<.001$), *Juncus falcatus* E. Meyer var. *falcatus* ($r=.370$, $p<.001$), *Potentilla anserina* ($r=.216$, $p = .002$) and *Eleocharis macrostachya* Britton ($r=.236$, $p=.001$). No species were significantly negatively correlated with *Parentucellia*.

Two other species in the sample were of interest due to their exotic and potentially invasive nature: *Hypochaeris radicata* and *Lotus corniculatus*. As mentioned above, *Hypochaeris* was correlated positively with *Parentucellia*, as well as negatively with elevation ($r=-.276$, $p<.001$), but occurred at significantly higher mean cover values (Fig. 3) as determined by a paired-sample t-test ($p<.001$). The range of cover for both species was not substantially different. However, *Parentucellia* was absent from more plots than *Hypochaeris* (70.4% compared with 33.7%). *Lotus corniculatus* was found only in the lowest elevation class (Fig.3). Within this class, its mean cover signifi-

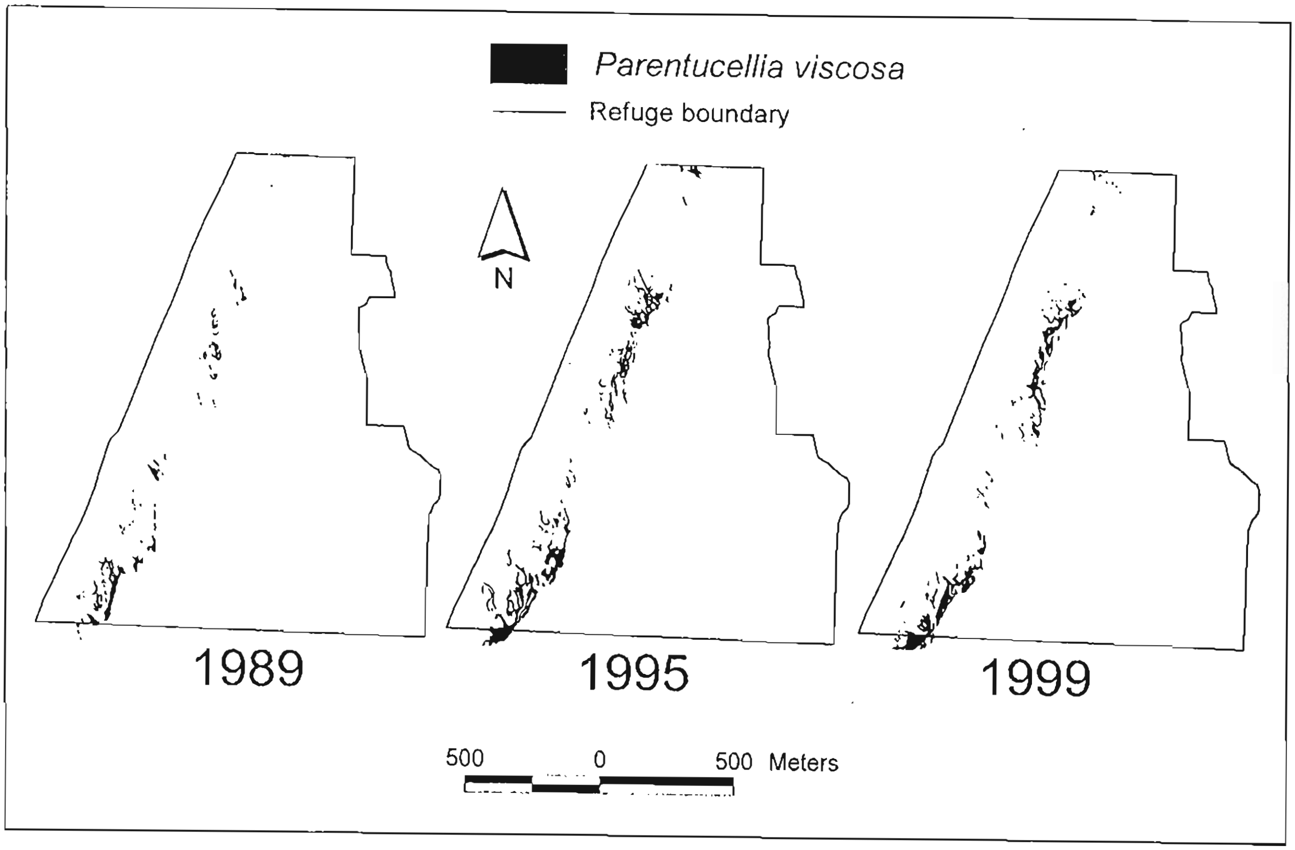

Fig. 1. Changes in area occupied by *Parentucellia viscosa* at the Lanphere Dunes Unit, Humboldt Bay National Wildlife Refuge, between 1989 and 1999.

cantly lower than from *Parentucellia* (p<.001). *Lotus corniculatus* exhibited a significant negative correlation with elevation (r=-.346, p<.001) and was not correlated with *Parentucellia* (r=.092, p=.196).

Host species

The roots of *Parentucellia* were reddish brown and coarse, making them easy to distinguish from other species. Numerous (10-20) haustorial connections occurred within 10-30 mm of root length, with haustoria clustered in groups of two to three. Roots of *Parentucellia* bearing haustoria were thinner than the roots of the plants to which they were connected.

A total of 25 species of plants were present in the collections taken from around *Parentucellia* individuals (Table 2). Of these, six were identified as hosts: *Lotus purshianus, Lotus corniculatus, Juncus falcatus, Epilobium ciliatum, Polypogon monspeliensis* (L.) Desf., and *Trifolium wormskioldii*. Among these six species we detected 16 cases of parasitism. *Lotus purshianus* accounted for 50% of these cases (Table 2).

The results of our indirect assessment of relative host benefit are shown in Table 3. Mean inflorescence length was higher for *Parentucellia* individuals growing among *Lotus purshianus* than for those growing with other species or alone (one-way ANOVA p<.001, followed by Least Significant Difference test at p<.05).

Seedbank persistence

In situ

Density of emerging plants in enclosures was highly variable, ranging from 0-1,514/m^2 . The mean density was 558 plants/m^2 (+ 242 SE). Emergence in control plots ranged from 264 - 3,474/m^2 with a mean of 1,232/m^2. Given the high variability, it is not surprising that difference in density was not significant (p=.317). Nor was the change in density from the previous year significant for either enclosed (p=.213) or control (p=.251) plots. Correlations (Pearson's) between emergence in 1997 and abundance in the previous year were not significant in both enclosed (r=.257, p=.578) and control (r=.829, p=.171) plots.

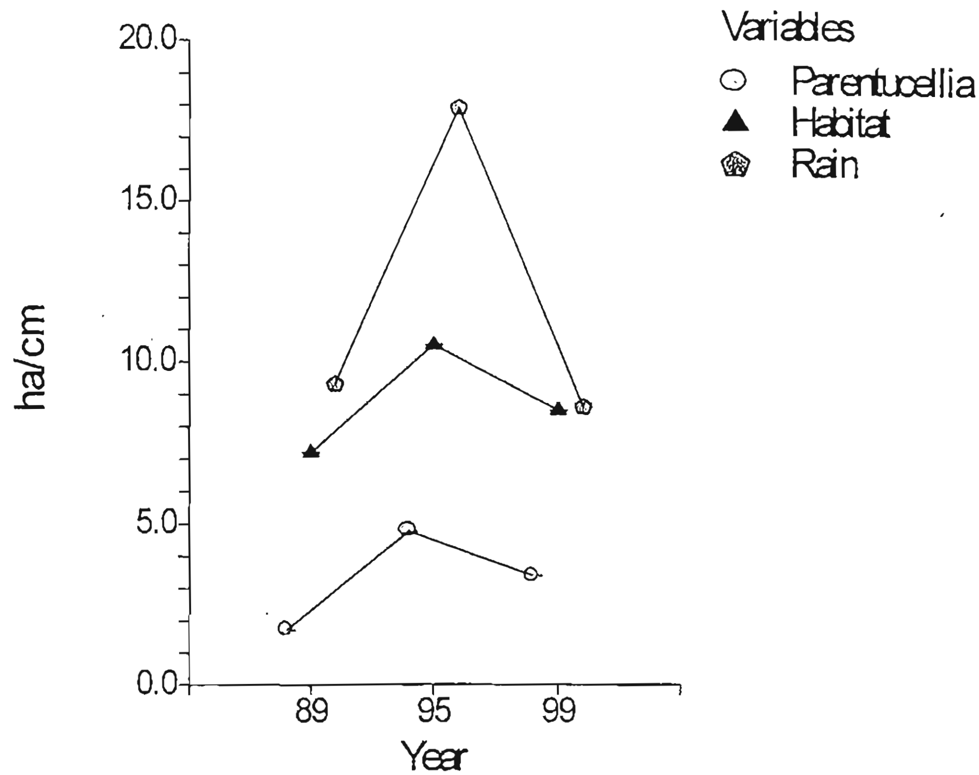

Fig. 2. Rainfall (in cm) and area (in ha) of *Parentucellia viscosa* and herbaceous wetlands from 1989 through 1999.

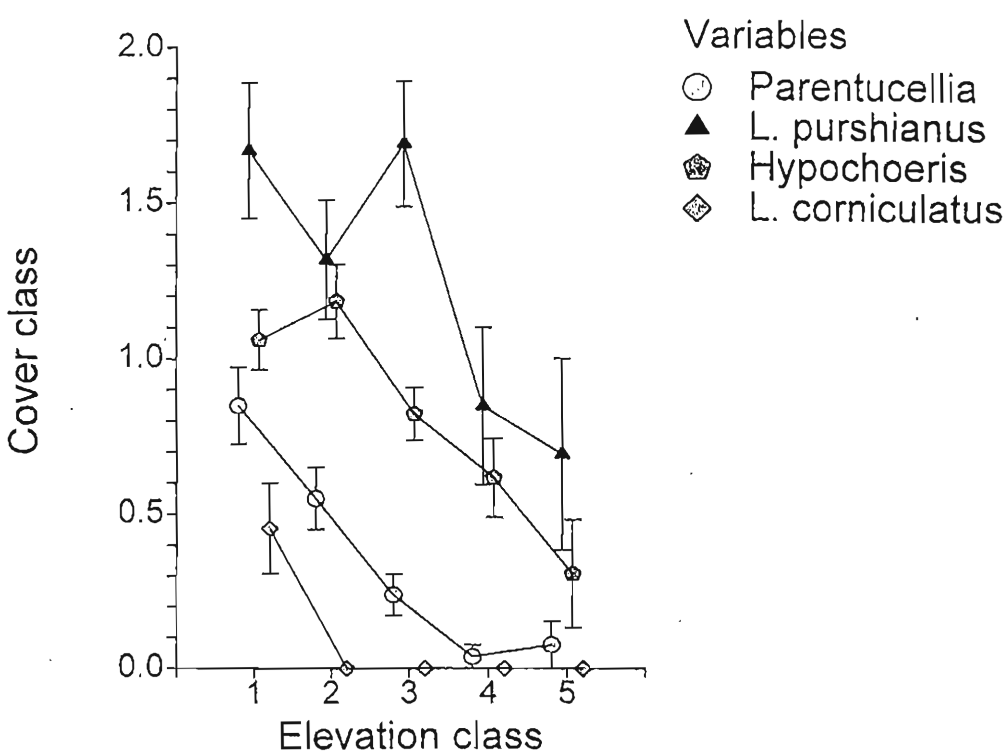

Fig. 3. Mean cover class of four species by elevation class from lowest (1) to highest (5) elevation (error bar = SE).

Table 1. Spearman's rank correlation coefficients for elevation and vegetation variables (*p≤.05, **p≤.001)

	Lotus corniculatus	*Hypochaeris radicata*	*Potentilla anserina*	*Eleocharis macrostachya*	*Juncus falcatus*	*Lotus purshianus*	*Parentucellia viscosa*
Elevation	-.346**	-.276**	-.320**	-.112	-.516**	-.141*	-.468**
Parentucellia viscosa	.092	.334**	.216**	.236**	.370**	.404**	
Lotus urshianus	-.023	.429**	-.007	.162*	.167*		
Juncus alcatus	.098	.193**	.266**	-.066			
Eleocharis macrostachya	-.066	.113	-.058				
Potentilla anserina	.534**	.100					
Hypochaeris							

Table 2. Species present in collections of *Parentucellia viscosa*, and number of cases of parasitism detected. Nomenclature follows Hickman (1993).

Species	**Native status**	**Life History**	**Cases of parasitism detected (n=16)**
Achillea millefolium	Native	Perennial forb	
Agrostis microphylla	Native	Annual grass	
Aster chilensis	Native	Perennial forb	
Carex obnupta	Native	Perennial sedge	
Epilobium ciliatum ssp. *watsonii*	Native	Annual forb	1
Fragaria chiloensis	Native	Perennial forb	
Gnaphalium palustre	Native	Annual forb	
Hypochaeris radicata I	ntroduced	Annual forb	
Juncus breweri	Native	Perennial rush	
Juncus bufonius	Native	Annual rush	
Juncus falcatus var. *falcatus*	Native	Perennial rush	2
Lathyrus littoralis	Native	Perennial forb	
Lotus corniculatus	Introduced	Perennial forb	3
Lotus purshianus var. *purshianus*	Native	Annual forb	8
Lupinus arboreus	Introduced	Perennial shrub	
Mentha pulegium	Introduced	Perennial forb	
Polypogon monspeliensis	Introduced	Annual grass	1
Potentilla anserina ssp. *pacifica*	Native	Perennial forb	
Rumex acetosella	Introduced	Perennial forb	
Salix hookeriana	Native	Perennial shrub	
Scirpus cernuus	Native	Annual sedge	
Sisyrinchium californicum	Native	Perennial forb	
Solidago spathulata ssp. *spathulata*	Native	Perennial forb	
Trifolium wormskioldii	Native	Perennial forb	1
Vulpiabromoides	Introduced	Annual grass	

Table 3. Mean inflorescence length of *Parentucellia viscosa* individuals growing: 1) in association with *Lotus purshianus* and other species, 2) without *Lotus purshianus* and in association with other species, and 3) in the absence of all other species.

Parentucellia collected with:	No. of collections	No. of *Parentucellia* individuals	Mean inflorescence length (cm)	SE
Lotus purshianus and other species	15	24	19.0	2.3
Other species, no *Lotus purshianus*	4	16	9.6	2.6
No other species	3	26	2.5	0.6

Table 4. Mean seedlings emerging in ex situ seedbank samples (seedlings per 238 cm3).

Stratum	Mean	SE	n
Old fruits	12.70	4.1	30
New plants	0.80	0.3	30
Above habitat	0.17	0.1	30
Below habitat	0.03	0	30

Ex situ

Seedlings emerged in 70% of samples collected from around dead stalks, 23% of samples collected from around new (not yet reproducing) plants, and 3% and 6% of samples collected from below and above *Parentucellia* habitat respectively (Table 4).

Demography

Emergence and Survivorship

Emergence and death of *Parentucellia* individuals in demographic plots is shown in Fig. 4. Seedlings began emerging in late March and new plants continued to appear until late May, despite the onset of mortality in mid April. This overlap of emergence and mortality did not permit us to measure true densities, but maximum observed densities ranged from 708-4,928/m^2 (= 2,878, SE= 447). The mortality curve was steepest between late May and early June, when rainfall declined abruptly. This early mortality was not due to flowering, since no plants flowered before 2 June. Rather it was influenced by rainfall; survivorship at each two-week interval was positively correlated with rainfall in the preceding interval (r=.78) at p=.069. Since we did not mark individual plants due to high densities, we could not calculate survivorship to flowering. However, minimum mortality had reached 82% before any flowering occurred. Peak flowering was in late June, when nearly all surviving plants were in flower or fruit. By 10 August, all plants had died. However, we observed flowering plants on other parts of the site as late as September.

Reproduction

Reproductive plants averaged 19.8 cm in height (+.58 SE). The number of branches ranged from 1 to 15, with 91% of all plants lacking branches. Plant height and number of branches were significantly correlated (r=.35, p<.01). Reproductive output (number of fruits) was predicted by length of all branches summed (r^2 =.78, p<.001) using the equation fruits = -10.052+1.33 (length). When only the primary branch of each plant was considered, the relationship between length of that branch and the number of fruits on that branch only was stronger (r^2 =.82).

The number of seeds per fruit was a function of the number of fruits on the plant (r^2 =90.8, p<.001) and was predicted by the equation seeds/fruit = 242 + 3.47 (fruits/plant). Mean seeds per fruit was 504.2 (+ 85.6 SE). For the 343 plants in our sample, the mean total

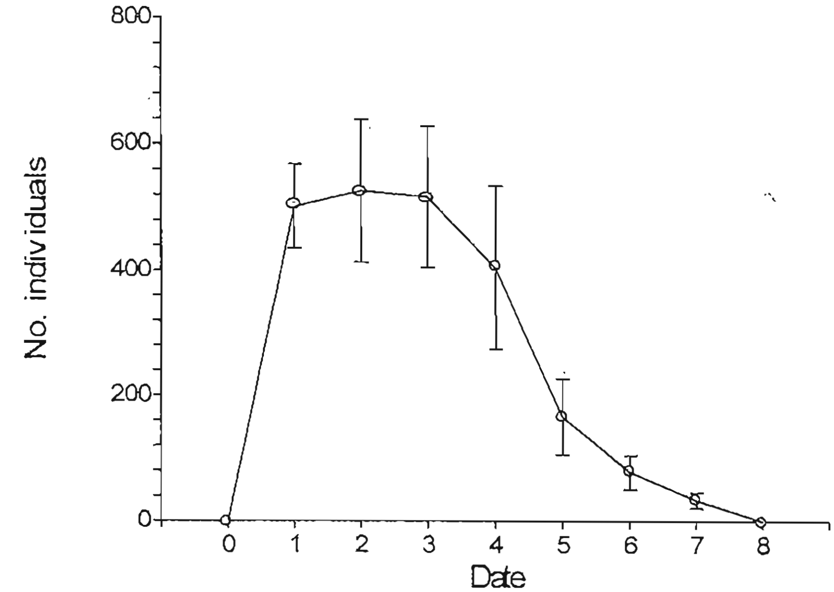

Fig. 4. Mean number of individuals of *Parentucellia viscosa* in demographic plots by by monitoring date (error bar = SE). Date codes: 1=3/20, 2=4/7, 3= 4/21, 4=5/20, 5=6/2, 6=6/30, 7=8/1, 8=8/10.

length (of all branches summed for each plant) was 24 cm. Using our regression equations, we predicted that the plants in our sample would produce a total of 7,581 fruits and a total of 4,108,536 seeds, or an average of 11,978 seeds/plant.

Species control

A one-way Multivariate Analysis of Variance (MANOVA) was carried out with dependent variables limited to the six most abundant species (Stevens 1986). Treatment was the between-subjects factor, and Type III sums of squares was used for an unbalanced design. The test was done on 1998 results, representing vegetation response over two years (1996-1998). The MANOVA was significant at $p<.001$ (Roy's Largest Root). We followed the significant MANOVA with pair-wise multivariate tests (Hotelling's T2) for each treatment pair using a Bonferroni correction ($\alpha'=.016$) (Scheiner and Gurevitch 1993). The weed-eater treatment was significantly different than both the hand-pull and control, while the hand-pull treatment did not differ from the control. For each significant pair, we conducted t-tests for each of the five species at the 0.05 significance level (Stevens 1986). T-tests were significant ($p<.05$) for *Lotus purshianus* and *Juncus breweri* in both significant pairs, and for *Epilobium ciliatum* in the weed-eater vs. hand-pull comparison only. Differences in cover of these three species among treatments is illustrated in Fig. 5. *Lotus purshianus* was higher and *Juncus* lower in the weed-eater treatment than in the other two.

Changes in species composition

A MANOVA (Type III sums of squares) with year as factor was significant (Roy's Largest Root) at $p<.001$ using the five most abundant species as response variables. Pair-wise multivariate tests using a Bonferroni correction ($\alpha'=.008$) revealed that all possible differences between years were significant. Significant species ($p<.05$) contributing to pair-wise differences were *Parentucellia* and *Lotus purshianus* (six of six comparisons), *Juncus breweri* and *Epilobium ciliatum* (fix of six comparisons), and *Hypochaeris radicata* (four comparisons).

Discussion

Regional Distribution

Our investigation revealed the surprising fact that *Parentucellia* invasion in dune hollows is a highly localized phenomenon, restricted to the North Spit of Humboldt Bay and particularly to the Lanphere Dunes. The relative abundance of *Parentucellia* on the Lanphere Dunes may be a function of topography. Dune hollows at this site are uniquely broad and flat, as the result of a large sheet of moving dunes present nowhere else on the spit. The eastward migration of this large, continuous sand sheet has left behind a wide, relatively flat deflation plain, unlike the more discrete dune hollows that form behind single parabolic features. Aerial photographs reveal that this deflation plain was largely unvegetated until the 1980s. Hence, a very large expanse of habitat ideal for *Parentucellia* was being created just as the *Parentucellia* invasion was gathering momentum.

We did not observe *Parentucellia* in or near the dune hollows of southern Oregon, so potentially its lack of invasiveness there could either be due to the fact that it has not yet reached these sites, or to a lack of suitable habitat. However, despite its presence in other dune areas we visited in California, *Parentucellia* was not noticeably invasive. The most abundant occurrence, near Inglenook Fen in Ten Mile Dunes, was in an area that was the most similar topographically to the Lanphere Dunes deflation plain. Another similarity was the stage of development of this dune system. Ten Mile dunes exhibit relatively young dune features, with few woody hollows and abundant bare sand. These conditions are similar to the southern end of the Lanphere Dunes site when *Parentucellia* first became established there.

There are several possible explanations for why *Parentucellia* was noticeably less invasive at Ten Mile than at Lanphere Dunes. First, Ten Mile (and all other dune systems we visited with the exception of the North Spit) lacked *Lotus purshianus*, the species that is the most frequent host for *Parentucellia* at Lanphere Dunes. Although *Parentucellia* is known to lack host specificity, a fact confirmed by our study, it is possible that some hosts confer a greater benefit than others. Legumes are known to be capable of hosting a luxuriant growth of hemiparasites (Atsatt and Strong 1970). If *Lotus purshianus* is a more beneficial host than other dune hollow species, its abundance at the Lanphere Dunes could explain the concomitant abundance of *Parentucellia*. However, a second interpretation is possible and should be considered. If topography and successional stage are important, and in the event that other hosts, particularly legumes such as *Lotus corniculatus* are capable of supporting large populations of *Parentucellia*, then Ten Mile Dunes could simply be in an earlier stage of invasion, in keeping with its earlier successional stage.

Localized Spread

The area occupied by *Parentucellia* increased dra-

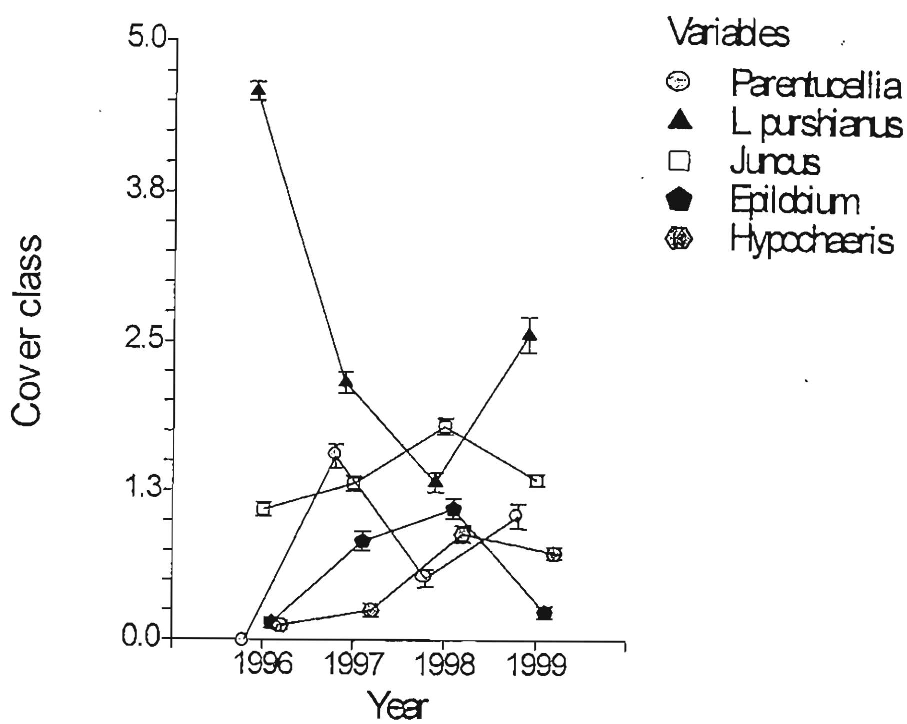

Fig. 5. Changes in mean cover class by year in species composition plots (error bars = SE).

matically from 1989 to 1995 (276%), and then declined in 1999. Over the 10-year period there was a net increase of 202%. Apparently, the factor most strongly controlling the area of *Parentucellia* is the amount of habitat (herbaceous hollows) available. Our habitat studies (below) show that not all herbaceous wetland is equally suitable for *Parentucellia*, which explains why the percentage of hollows occupied by *Parentucellia* varied among years. In 1995 *Parentucellia* occupied the largest percentage of hollows. Perhaps conditions during this year, which was marked by particularly high rainfall in April and May, were particularly suitable for the emergence and/or survival of *Parentucellia*. Herbaceous wetlands at the site increased from 1989 to 1995 due to the expansion of the deflation plain, i.e. new habitat was being created. From 1995 to 1999 herbaceous wetland decreased as hollows succeeded from a primarily herbaceous to a primarily woody condition.

Habitat characteristics

Our transects did not encompass the lower elevation limit of *Parentucellia* in 1997. The species occurred at highest abundance at the lowest elevation measured. Within our transects *Parentucellia* occupied approximately a 1-m elevation band. The correlation between *Parentucellia* and elevation was low, indicating that other factors in addition to elevation explained *Parentucellia* distribution and abundance. If the extent of spring flooding controls the establishment of *Parentucellia*, then the elevational band it occupies could shift and/or expand or contract in response to different rainfall patterns. For example, in a year of lower early spring water tables, *Parentucellia* could establish in the deepest areas of hollows, while in a year characterized by more prolonged flooding it might be restricted to the edges, resulting in a bathtub ring effect. Annual variation in rainfall is compounded by the rapid changes in dune hollow vegetation, which can succeed from herbaceous to woody vegetation in just a few years.

An interesting result of our study was the determination that *Hypochaeris radicata*, a common weed that is not considered to be invasive (CalEPPC 1997), occurred at higher cover values (and also more frequently and over a wider elevation range) than *Parentucellia* in both our habitat and species control plots. Yet *Parentucellia* excited more interest a priori as a potential invader. We speculate that this bias was due to the difference in their growth habits. *Hypochaeris* has a basal rosette that tends to be hidden under even the low, herbaceous hollow vegetation. Its flowers are relatively small and inconspicuous compared with those of *Parentucellia*, whose bright yellow, clustered flowers overtop the herbaceous vegetation. *Parentucellia*, a vertical, usually unbranched, plant, is more obvious when viewed obliquely than from straight overhead. It is easy to see that *Parentucellia* cover is exaggerated under casual observation, while *Hypochaeris* is underestimated. Both species, however, are relatively low in cover. For the entire sample, the mean cover class was 0.4 for *Parentucellia* and 0.9 for *Hypochaeris* (cover class 1< 5%).

Another species of interest is the non-native *Lotus corniculatus,* which has increased at the Lanphere Dunes since 1985. *Lotus corniculatus* occurred only at the lowest elevation class. Given that the species has been present for a decade and a half it seems safe to assume that its restriction to a relatively narrow elevation band is due to habitat preference and not dispersal. If so, this restriction should serve to keep its spread in check.

Host species

Our study confirmed that *Parentucellia* is not host-specific, as we observed haustorial connections to six species. *Lotus purshianus* accounted for 50% of these cases of parasitism and *Lotus corniculatus* for 19%. The prevalence of *Lotus purshianus* as a host is in keeping with the high correlation observed between the two species in our habitat investigations. Atsatt and Strong (1970) showed that *Parentucellia*, as an autogamous species capable of outcrossing, has a narrower range of host species that confer benefit than would an obligate outcrossing hemiparasite. Since we did not directly measure relative host benefit, it is not possible for us to conclude that *Lotus purshianus* confers a greater benefit to *Parentucellia* than do other dune hollow species. Our indirect evidence is supportive; *Parentucellia* individuals growing among *Lotus purshianus* were characterized by greater fecundity than those growing among other species or alone. Alternatively, these patterns could be explained by shared habitat preferences of host and parasite.

Seedbank persistence

Both of our seedbank experiments confirmed that *Parentucellia* has a persistent seedbank. The *ex situ* experiment was designed to test for differences in emergence (and therefore seedbank density) between areas that had previously been populated by *Parentucellia* (old stalks from the previous year were present) and those that had not (only new plants were present, but had not yet fruited). Emerging seedling density was higher in samples containing old fruiting stalks, despite the fact that seeds are exceedingly small, capable of being wind-dispersed, and presumably ubiquitous. Samples taken from areas that were clearly not suitable habitat had the smallest recruitment. If seeds are in fact dispersed throughout the hollow, then possibly conditions deviating from those that would immediately support the plants are not conducive to seed persistence. This could also explain the relative lack of seedbank where only new plants are present—these areas may have only in the preceding winter received the appropriate amount of flooding for germination and/or emergence.

Emergence in *in situ* enclosed plots did not differ significantly from control plots. However, one substantial limitation of the in situ design was that we did not monitor plants as they emerged, rather we visited plots in mid-summer when the majority of seedlings may have already died (based on our demographic results). This may have contributed to the lack of correlation between density of above-ground *Parentucellia* in 1996 and densities observed emerging from the seedbank in 1997.

Demography

Whereas many dune annuals emerge during late fall and complete their life cycles prior to the onset of summer drought, those found in dune hollows apparently emerge and survive later. *Parentucellia* may be aided in this strategy by its hemiparasitic nature, but its primary host plant, *Lotus purshianus*, is an annual with a similar life cycle. We observed that both *Parentucellia* and *Lotus* emerged just as hollows began to dry up, while the substrate was saturated but no longer submerged. Apparently, these moist but not anoxic conditions are needed for germination (new seedlings continued to emerge only while rainfall was abundant). We did not determine when haustorial connections were formed and to what degree this affected survivorship.

Seedling emergence in demographic plots was extremely high, with close to 5,000 seedlings/m^2 in the densest plot. The high degree of pre-flowering mortality indicates that density dependent effects were present, but the role of parasitism clouds this issue (Marvier 1998). *Parentucellia* is capable of parasitizing members of its own population (Atsatt and Strong 1970), resulting in complex competitive relationships.

The fact that we observed flowering plants later in the year outside our demographic plots indicates that we did not capture the full variation within the population. The area in which our plots were concentrated appeared to dry up more rapidly than some of the other hollows elsewhere. Therefore, the mortality rates we report may be high, and flowering duration may be conservative with respect to the population. Fecundity was exponentially a function of plant size. The size (length of all branches summed) of the plant predicted the number of fruits, and the larger the number of fruits, the greater the number of seeds per fruit. An average plant in our sample had almost 12,000 seeds. Clearly, *Parentucellia* is a prolific seed producer, whose seeds, we have already shown, are able to persist in the soil. These characteristics undoubtedly contribute to its success as an invader.

Species control

Given the abundant production of wind-dispersed *Parentucellia* seeds, as well as its ability to bank these seeds, the lack of effectiveness of our two years of control treatments is not surprising. Our treatment plots had only a 2-m-wide buffer cleared of *Parentucellia*, so presumably both new seed rain and emergence from the seedbank continued to occur. Theoretically, after an undetermined number of years, it would be possible to deplete the seedbank, but unless *Parentucellia* were simultaneously eradicated from all areas within dispersing distance, new seeds would continue to arrive. Even if this were feasible for a site under protective management, it would be impossible to control dispersal from adjacent populations.

Although the non-native *Parentucellia* was not affected by treatment, two native species were. The importance of *Lotus purshianus* cover increased in weed-eater (but not hand-pull) plots compared with control plots, while that of *Juncus breweri* declined. Apparently, the mowing treatment favored the annual species at the expense of the perennial rhizomatous species.

Changes in species composition

As *Parentucellia* invaded our experimental plots over a three-year period, the most abundant native and non-native species underwent significant changes in cover. *Parentucellia*, which was not present, at the start of the experiment, increased to its highest level the first year. It persisted in the subsequent two years at lower cover values. *Lotus purshianus* underwent the most drastic change, plummeting in cover for the first two years and only partially recovering in the third year. *Juncus breweri* and *Epilobium ciliatum*, both native, underwent small but significant increases during the first two years and then declined. *Hypochaeris radicata* did not significantly increase until the second year, and then maintained its higher cover values.

A major limitation on the experimental design was our inability to control the experiment by excluding *Parentucellia* from some plots. The only successful method we identified to prevent seed rain was the use of an opaque fabric sheet and solid wood barrier, which blocked sunlight and would have confounded the experiment with that effect. Since the vegetation of dune hollows evolves rapidly, we cannot separate the effects of natural succession from those of *Parentucellia* invasion. At least part of the steep decline in *Lotus purshianus* could be an effect of parasitism. Marvier (1998) reported such an effect for grasses parasitized by *Triphysaria* in California grasslands.

Alternatively, it could be explained by our observation that *Lotus* is often a primary colonizer of bare sand, establishing at very high cover values. In order to find suitable locations for our species composition plots, we were forced to utilize areas that were newly colonized, otherwise *Parentucellia* would already have been present. As other species became established in these areas, a decline in *Lotus* would be expected regardless of the effects of *Parentucellia.* This explanation is supported by the fact that *Lotus* cover in our species composition plots was substantially higher than in our species control plots. All other principal species, with the exception of another primary colonizer, *Juncus breweri*, were lower in the newly colonized species composition plots than in the more established species control plots. Also, if parasitism were causing decreased biomass of *Lotus purshianus*, we would expect to see a consistent response to the two years of removal of *Parentucellia* in species control plots. Only the weed-eater plots exhibited a relative response.

Conclusions

Parentucellia viscosa is a highly localized invader of dune hollows on the North Spit of Humboldt Bay. It is most abundant at the Lanphere Dunes, where large expanses of herbaceous hollows occupying a broad deflation plain provide ideal habitat. The amount of herbaceous wetland habitat appears to be strongly controlling *Parentucellia*, although spring rainfall may also play a role. The expansion of herbaceous hollows at he Lanphere Dunes between 1989 and 1995 contributed to the explosive spread of the species—*Parentucellia* almost tripled in area during this period. However, during the subsequent four-year period herbaceous vegetation gave way to increasing woody vegetation and the amount of *Parentucellia* declined. Rapid succession in these hollows will continue, and will likely exceed the amount of new herbaceous wetlands that develop as dunes migrate east. Under this scenario we can expect a continued decline in the area occupied by *Parentucellia.*

In 1997 *Parentucellia* occurred within a 1-m wide elevational band that represented the deepest portions of the wide, relatively flat hollows that are characteristic of the southern end of the Lanphere Dunes. However, since the extent of spring flooding controls its establishment, this elevational band could shift and/or expand or contract in response to different rainfall patterns.

Parentucellia occurs most commonly with the native *Lotus purshianus*, which is also its most frequent host. *Parentucellia* growing among *Lotus purshianus* was characterized by greater fecundity, suggesting that *Lotus* confers a greater benefit than other host species, but this hypothesis was not tested directly. The positive association between *Parentucellia* and *Lotus corniculatus* could also be explained by shared habitat preferences. However, *Parentucellia* (while able to establish without a host), generally does not appear until after *Lotus* has become established.

The seedbank of *Parentucellia* is abundant and persistent, contributing to its success as an invader. Seed production is prolific, with an average of nearly 12,000 seeds per individual. Fecundity is exponentially a function of plant size. Seedlings emerge in spring when soil is still moist but no longer submerged. Mortality of seedlings is tied to rainfall, and is steepest before flowering occurs. Peak flowering in 1997 occurred in late June.

Control of an established *Parentucellia* population using any method of eradication other than a biological agent is not feasible given the prolific seed production and persistence and the ease of dispersal. In the early stages of an invasion it may be possible to deplete the seedbank and prevent new seed production. Mowing should not be used to prevent seed set, as it alters species composition of the native vegetation.

Given the difficulty of controlling this species, our conclusions about its effect on the native community are reassuring. *Parentucellia* occurs at very low cover values that are exaggerated under casual observation.

Its congener *Parentucellia latifolia* is not known to cause deleterious effects to its hosts. Vegetation changes that occurred in an area undergoing *Parentucellia* invasion are not unlike those expected under the natural rapid succession of dune hollows, and there are no native species that exhibit a negative correlation with *Parentucellia*. Given the expected ephemeral nature of this invasion and the lack of significant ecological impacts, no management need be undertaken at this time.

Acknowledgements

We thank the following individuals for their contributions: David Cravelli of Oscar Larson and Associates for surveying work, Annie Eicher for sampling and analysis of haustoria, Patti Clifford for on-screen digitizing, and Sydney Carothers, Gina Capser, Abe Walston, and Hal David for assistance in sampling, mapping, or data entry. The California Nature Conservancy generously funded the field work portion of this research. We dedicate this paper to the memory of Oren Pollak, former California Regional Ecologist with The Nature Conservancy. His insight and encouragement greatly contributed to our efforts.

Literature Cited

Alexander, V.T. and H.C. Weber. 1984. Zur parasitischen Lebensweise von *Parentucellia latifolia* (L.) Caruel (Scrophulariaceae). Beitr. Biol. Pflanzen 60:23-24.

Atsatt, P.R. and D.R. Strong. 1970. The population biology of annual grassland hemiparasites. I. The host environment. Evolution 24:278-291.

Barker, L.M. 1976. A vascular plant inventory and vegetation map of the Lanphere-Christensen Dunes Preserve. Unpublished document, Humboldt State University, Arcata, California.

California Exotic Pest Plant Council. 1996. Exotic pest plants of greatest ecological concern in California. Sacramento, California.

Hickman, J.C., editor. 1993. The JepsonManual: higher plants of California. University of California Press, Berkeley, California.

Hitchcock, C.L., A. Cronquist, M. Ownbey, and J.W. Thompson. 1959. Vascular plants of the Pacific Northwest, Part IV. University of Washington Press, Seattle, Washington.

Marvier, M.A. 1998. Parasite impacts on host communities: plant parasitism in a California coastal prairie. Ecology 79(8): 2616-2623.

Pickart, A.J. 1987. Dune hollow enhancement program, annual monitoring report, Lanphere-Christensen Dunes Preserve. Unpublished document, The Nature Conservancy, San Francisco, California.

Pickart, A.J. 1995. Monitoring results for dune hollows at the Lanphere-Christensen Dunes Preserve. Unpublished document, The Nature Conservancy, San Francisco, California.

Pickart, A.J. and J.O. Sawyer. 1998. Ecology and restoration of northern California coastal dunes. California Native Plant Society, Sacramento, California.

Pojar, J. and A. McKinnon. 1994. Plants of the Pacific Northwest coast. Lone Pine Press. Redmond, Washington.

Scheiner, S.M. and J. Gurevitch, eds. 1993. Design and analysis of ecological experiments. Chapman and Hall, New York.

Stevens, J. 1986. Applied multivariate statistics for the social sciences. LEA Publishers, Hillsdale, New Jersey.

Taylor, R.J. 1990. Northwest weeds: the ugly and beautiful villains of fields, gardens, and roadsides. Mountain Press Publishing Company, Missoula, Montana.

Potentially Allelopathic Effects of Poison Hemlock (*Conium maculatum*) on Native Plant Revegetation at Wilder Ranch State Park

Janell M. Hillman
Dept. of Environmental Studies Univ. of California, Santa Cruz 95064
(Current address: P.O. Box 53, Mt. Hermon, CA 95041. E-mail: emerald@cruzio.com)

Invasive exotics negatively impact native species composition in a variety of ways. Often these effects are indirect. For example, exotic species can reduce the fecundity of natives through modification of physical or chemical factors in the environment. These induced effects mainly occur through either of two negative interference interactions. First, competition is a negative interference interaction in which resources are removed from the common environment by one organism, reducing the availability of that resource for another organism (Gliessman 1995). By competing with native plants for limited soil nutrients, moisture, light, etc., an exotic can reduce the supply of these resources and thus interfere with growth and establishment of other species.

However, suppression of growth cannot always be explained by competition (Altieri 1981). Amensalism is a second type of negative interference interaction. Whereas plant competition occurs through a reduction or removal of a growth factor needed by both plants, amensalism, and specifically allelopathy, occurs by the addition of a toxic factor to the environment (Altieri 1981, Gliessman 1995). Allelopathy is defined by the direct or indirect effect of one plant on another through the release of chemicals from the former into a common environment. Although still a mysterious area of chemical ecology, it is commonly believed that many plants are involved in such biochemical interactions.

Allelopathy assumes special significance when it involves exotic plants and issues of restoration. At Wilder Ranch State Park (WRSP), located near Santa Cruz on the central coast of California, wetland restoration and native plant revegetation strategies must take into account the presence of poison hemlock (*Conium maculatum*), an invasive exotic and highly toxic weed native to Eurasia. Considered "rather rare in California" in 1891 (Greene, qtd. in Robbins 1940), poison hemlock has since become highly invasive, spreading prolifically into disturbed areas along California's central coast (personal observation) as well as into the entire California floristic province (Hickman 1993). Most common in cool, moist regions, hemlock can be found throughout the United States excepting an area between central Montana and northeastern Minnesota (USDA 1971). Abroad, poison hemlock has become naturalized throughout many of the temperate regions of the world, including the Middle East (Ahmad et al. 1987), Australia (Auld and Medd 1987), and less successfully, in eastern Canada and British Columbia (Frankton and Mulligan 1970).

Through a series of both laboratory and field experiments at the Center for Agroecology at UCSC and at WRSP, I sought to test the following hypotheses: first, that the proliferation of poison hemlock in natural areas such as Wilder Ranch is due in part to allelochemicals found in its leaves and stalks which inhibit the recruitment and survivorship of native species of the coastal bluff community; and second, that a particular management practice for hemlock at Wilder Ranch, which involves the cutting but not removal of hemlock just after flowering, merely increases the allelochemical content of the soil and resulting potential inhibition of native plant revegetation.

A leachate bioassay experiment was used as an initial screening technique of allelopathic potential; soil bioassays further examined this potential within soil collected from under a mature stand of poison hemlock; while the field experiment sought to examine potentially allelopathic interactions from an ecological perspective through the manipulation of hemlock vegetation. This research was based on my belief that any effective management program for exotic species must stem from as complete an understanding as possible of the interactions and mechanisms of successful establishment of these species within the community/ies they are affecting.

Materials and Methods

Initial Leachate Bioassays

Fresh leaves and canes from *C. maculatum*, as well as dried, previous season vegetation, were collected at WRSP. Extracts made from the freshly dried as well as previous season material were filtered under vacuum to obtain two leachates of 10% concentration. Forty grams of sand, a piece of Watman's filter paper, and 10 mL of the respective leachate or distilled water as a control were added to each Petri dish. Each of the three treatments was replicated three times. Ten seeds of the appropriate test species were placed in each dish after having been soaked for one hour in the leachate or control. The dishes were sealed with parafilm and incubated in darkness at 25°C for 72 hours. Root measurements and germination counts were taken after 72 hours or after germination took place.

Soil Bioassays

Soil to a depth of approximately one inch was collected from under a mature stand of *C. maculatum* in September and October of 1996 before the first seasonal rains at WRSP. On the same dates, soil was also collected from some distance outside the hemlock stand. This second sample served as the "control" soil. This procedure was repeated again in February 1997 after a significant amount of seasonal rain in order to examine how rainfall would affect the potential allelochemical content of the hemlock soil. All soil samples were sieved through a 5 mm screen to remove large clods of dirt, roots and other vegetative material. Each glass Petri dish was filled with 40 g of soil and a specified number of seeds of each test species. Fourteen mL of distilled water was added to each dish, which was then sealed with parafilm and either incubated in darkness at 25° C or subjected to a 12 hour photoperiod with natural temperature flux. The latter method, chosen when the prior was unsuccessful in achieving germination, involved placing the dishes by night in a glass-enclosed outer room and by day on inside windowsills which received partial sunlight. After germination and growth occurred, germination counts, root, and shoot measurements were recorded. Seed from the eight native test species and *C. maculatum* were collected at or near WRSP.

Field Experiment

The field experiment was set up in October 1996 on the top of a south-facing slope at WRSP. An attempt was made to select a site which contained a well-established or "mature" stand of *C. maculatum* as well as a site near enough to possess similar abiotic conditions but with an absence of hemlock. Thus, nine $2m^2$ plots were located in a mature hemlock stand, while six $2m^2$ plots were located in a nearby grassland. A 50 cm buffer zone was set between plots in each area. Various manipulations of hemlock vegetation on the soil surface constituted five different treatments, each with three replications.

Treatments within the hemlock stand were: (A) All hemlock vegetation removed from soil surface, (B) Hemlock vegetation cut and laid upon soil surface, (C) Control: hemlock vegetation (mostly withered standing canes by October) left undisturbed. Within the nearby grassland, treatments were: (D) All hemlock vegetation removed from Treatment A laid upon grassland surface, (E) Control: grassland left undisturbed. The dominant grassland species was *Leymus triticoides*.

The field experiment was composed of two parts. First, seed of yarrow (*Achillea millefolium*) and coast buckwheat (*Eriogonum latifolium*), two native species common to the coastal bluff area, was sown into subplots within each main treatment replication. Resulting influences of the different treatments on recruitment and survivorship were examined using a G-test, while height and mean number of leaves of these two species and of *C. maculatum* were recorded through time.

Second, a germinating weed seed bank analysis of vascular plants was performed in January of 1997 in order to examine diversity and abundance of the weed seed bank in the different field treatments. For this analysis, five 10 cm rounds of soil were removed from each plot with a coffee can. After pooling the samples, all plant individuals were counted, identified, and weighed. Care was taken to remove soil from roots before weighing. Because the treatments within the hemlock stand showed variation between replications, the following dependent variables were analyzed using a two-way analysis of variance without replication: species richness, abundance, wet biomass, and the Shannon Index of diversity. The two independent variables for this test were treatment and distance from surrounding stand of hemlock.

Statistical Analysis

Unless otherwise stated, all results were analyzed using a single factor analysis of variance, with nonparametric data being log-transformed prior to analysis and a significance level of $P = 0.05$.

Bioassay Results

Effects of *C. maculatum* leachates on germination and root length of several native, exotic, and crop species:

The 10% new season leachate significantly inhibited both germination and root growth of the two crop and three native test species (See Fig. 1 for germination results). In some cases, inhibition was as high as 100% (*Eruca sativa, Nassella pulchra*). The one exception was the stimulation of germination of western dock (*Rumex occidentalis*). Although root growth of the two exotic grasses cultivated oat (*Avena sativa*) and ripgut grass (*Bromus diandrus*) was significantly lower under the 10% new season leachate, neither germination nor root growth was significantly affected under the 10% old season leachate.

Effects of soil collected before and after rainfall from under established *C. maculatum* stand on germination and growth of several native species:

Although shoot growth remained for the most part unaffected in the different soil treatments, root growth was significantly inhibited in before rainfall hemlock soil for five of the eight native test species (Fig. 2). Similar results were obtained in hemlock soil collected after seasonal rains, with inhibition in some cases increased. Although root lengths of yarrow (*Achillea millefolium*) and yellow bush lupine (*Lupinus arboreus*) were not significantly affected in the different soils before rainfall, root length in after rainfall hemlock soil showed significant inhibition. Effects on germination were dependent on species, with some species experiencing inhibition while others, most notably California figwort (*Scrophularia californica*), experienced a higher germination in hemlock soil. Results of the germination and growth of *S. californica* in hemlock soil collected before rain were unique in that there was a significant stimulation of shoot and root growth as well as germination.

There were no significant effects on germination, root, or shoot growth of *C. maculatum* in the different soils. Bioassay results of potential allelochemical effects of *C. maculatum* on itself are inconclusive at this point and require further study.

Field Experiment Results

Effect of manipulation of *C. maculatum* vegetation on recruitment and survivorship of two coastal natives and a weed seed bank:

G-test results from the incorporated natives study indicated that recruitment and survivorship for *A. millefolium* (G = 761.85 and G = 26.01) and *E. latifolium* (G = 179.84 and G = 146.29) were dependent on treatment (at P = 0.01). The highest recruitment for both species occurred in the treatment where all hemlock vegetation was removed from the soil surface, while the lowest recruitment occurred in the treatment were all hemlock vegetation was cut and left to lie upon the soil surface (Fig. 3). Results of seedling survivorship followed a dissimilar pattern, with survivorship for *A. millefolium* being highest in the cut and lay treatment, while for *E. latifolium* highest survivorship occurred in the control treatment of the hemlock stand plots.

Results of the germinating weed seed bank analysis did not indicate any significant differences in species richness, abundance, or Shannon Index of diversity in the different treatments. Effects on *C. maculatum* itself in the different treatments showed an interesting trend of highest mean seedling abundance, but correspond-

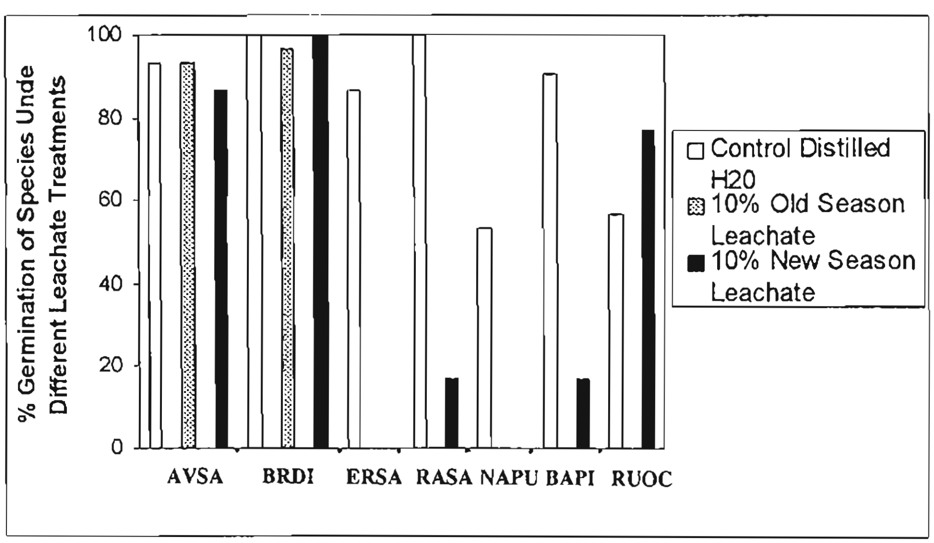

Fig. 1. Percent germination of the following test species under a control distilled water, a 10% leachate concentration made from previous season hemlock biomass (AVSA and BRDI only) and a 10% leachate concentration made from freshly dried hemlock biomass: AVSA = *Avena sativa*, BRDI = *Bromus diandrus*, ERSA = *Eruca sativa*, RASA = *Raphanus sativus*, NAPU = *Nassella pulchra*, BAPI = *Baccharis pilularis*, RUOC = *Rumex occidentalis*.

ingly lowest mass per seedling (Fig. 4) and mean seedling height through time, in the removal treatment of the hemlock stand plots.

Results in the grassland plots were inconclusive due to the influence of the rhizomatous grass *Leymus triticoides*. Few seeds of *A. millefolium* (insufficient for statistical analysis), and none of *E. latifolium*, germinated in the grassland plots. Interestingly enough, there were no significant differences in weed diversity or abundance in the hemlock added versus control treatment of the grassland plots. Addition of *C. maculatum* litter had no effect on mean above-ground shoot abundance or mass of *L. triticoides*.

Discussion

The significant inhibition of root growth and germination of a majority of the species tested in the preliminary leachate bioassays indicate that freshly dried hemlock biomass is potentially allelopathic. However, the lack of significant results with previous season hemlock biomass indicate that any potential allelochemicals do not remain persistent in hemlock vegetation itself, but may instead move fairly quickly into the soil.

In the soil bioassays, the significant inhibition of a majority of the native test species in hemlock soil col-

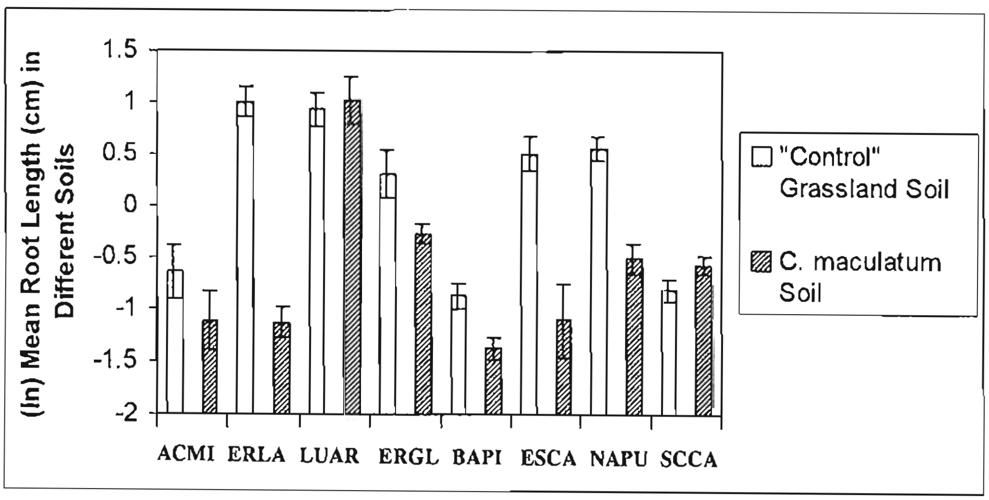

Fig. 2. Logged mean root length in cm (with standard error) of eight native test species in a "control" grassland soil and soil collected from under a well-established stand of *C. maculatum* before seasonal rainfall. ACMI = *Achillea millefolium*, ERLA = *Eriogonum latifolium*, LUAR = *Lupinus arboreus*, ERGL = *Erigeron glaucus*, BAPI = *Baccharis pilularis*, ESCA = *Eschscholzia californica*, NAPU = *Nassella pulchra*, SCCA = *Scrophularia californica*.

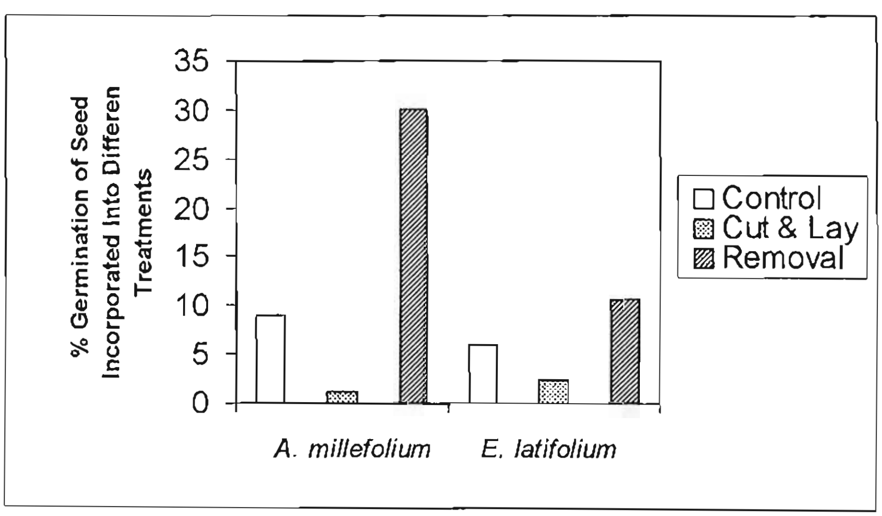

Fig. 3. Percent germination of seed of *Achillea millefolium* and *Eriogonum latifolium* in the control, cut and lay, and removal treatments of hemlock vegetation within a well-established stand of *C. maculatum*

lected before rainfall does indicate an allelochemical presence in soil under a well-established stand of *C. maculatum*. Allelochemicals are commonly released to the surrounding environment through the processes of root exudation, litter decay, and/or precipitation from rainfall or fog. Although root exudation of allelochemicals was not addressed in this research, the allelopathic potential of leaves and stalks (present in a 10% leachate concentration) could very likely be the source for the inhibition present in the soil.

According to Fischer et al. (1994), winter rains often play a major role in the release and transport of allelochemicals. However, the strong level of inhibition experienced in soil collected before seasonal rains may implicate fog as a larger factor in allelochemical release in this case. The coastal location of WRSP is subject to intense summer fog, which could have worked to gradually leach toxins from vegetation into the soil. Results in soil collected after seasonal rainfall may indicate that there is some augmentation by winter rain; that hemlock allelochemicals may remain fairly persistent in soil from season to season; and/or that rainfall maintains a pattern of transport of these chemicals from newly emerging vegetation to replace subsequent leaching from the soil.

Stimulation caused by low quantities of allelochemicals is not unheard of (Rice, in Putnam and Tang 1986; Leather and Einhellig 1988; Gliessman 1995). The increased vigor in hemlock soil of a minority of species in the soil bioassays, most notably *Scrophularia californica,* indicates that a few species are actually stimulated by a potential allelochemical effect.

The greater abundance, yet lower seedling height and mass of *C. maculatum* in the hemlock removal treatment of the field experiment, coupled with a greater mean height through time in the cut and lay treatment, indicates either an allelochemical or physical effect on its recruitment and vigor created by the removal and addition of hemlock vegetation. It is possible that although the disturbance from vegetation removal stimulated seedling recruitment, increased exposure or density dependent factors lowered the overall vigor of hemlock seedlings in this treatment.

Management Implications

As to the second question posed in this research, does the increase in the amount of hemlock biomass in contact with the soil defeat the management goal of controlling the invasive effects of hemlock? In the field experiment, positive results of seedling recruitment of *A. millefolium* and *E. latifolium* under a hemlock removal regime, coupled with negative results when hemlock vegetation was cut and laid upon the soil surface, substantiate the hypothesis that the removal of hemlock vegetation would stimulate the recruitment of native species, while the cutting and laying of vegetation upon the soil would merely concentrate any potential allelochemicals from the vegetation into the soil. However, the low germination rates of both test species (30% and 10.7% for *A. millefolium* and *E. latifolium*, respectively, in the removal treatment) indicate that recruitment within the hemlock stand was generally unsuccessful, as these two species normally have high recruitment.

The lack of a corresponding pattern in survivorship

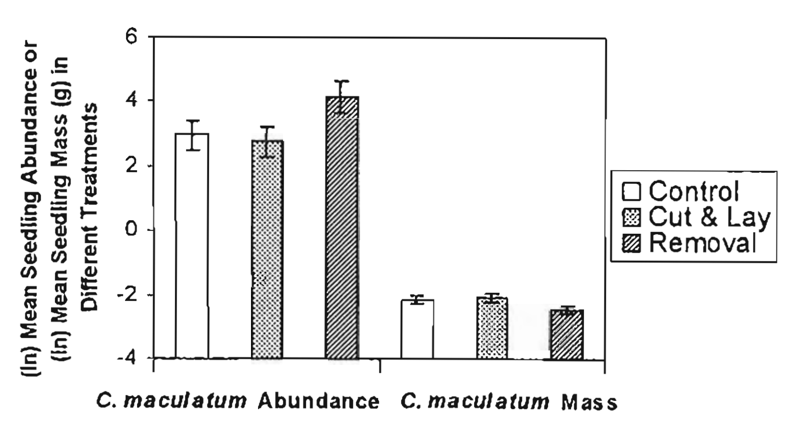

Fig. 4. Logged mean seedling abundance and mean seedling mass in g (with standard error) of *C. maculatum* in the control, cut and lay, and removal treatments of hemlock vegetation within a well-established stand of *C. maculatum.*

and overall "vigor" of the two coastal natives in the different treatments substantiates the earlier hypothesis that allelochemicals present in hemlock vegetation do not long persist, and indicates that such differences from the manipulation of hemlock vegetation were significant only at the onset of the field experiment. Combined with the insignificant effects of treatment on the germinating weed seed bank study, it appears that physical influences were important factors as well and became more significant through time.

From this field experiment it does appear that a management regime of poison hemlock such as that of WRSP has the potential to negatively affect the recruitment of other, native plants. However, effects on native plant survivorship and vigor are questionable at this time. A more accurate depiction of any potential allelochemical effects could be gathered from a repetition of the field experiment in June or July, at the height of hemlock's flowering period. A subsequent examination of seedling recruitment and survivorship in the fall, rather than setting up the experiment in October after the canes have already been significantly weathered, would allow results to be gathered following an entire season of summer fog to potentially leach allelochemicals from freshly cut plant material into the soil. More closely tailoring a field experiment to the phenology of hemlock and the timeline of a typical management plan such as mowing before seed set might shed more light on these issues.

Conclusions

My field observations of the prolific, early seedling vigor of *C. maculatum* in moist, disturbed areas lead me to believe that early competitive advantage is an important factor in its establishment. However, its relatively slow germination rate in the soil bioassays I performed, coupled with the high number of qualitatively unviable seeds (I have noticed an incredible loss of whole umbel heads to insect predation), indicate somewhat of a paradox in its establishment which could be explained in part by allelopathy. In this sense, even if it is not actively being stimulated by allelochemicals, the inhibition of recruitment of other plants through such a mechanism would reduce or even eliminate early competition, offering poison hemlock an advantage until its own recruitment and phenomenal burst of seedling growth.

In summary, I believe that *C. maculatum* is a weed that deserves increased attention and an active management plan. The methodology of such a plan should take into consideration the potentially allelopathic characteristics of this invasive plant. With vegetation that is allelopathic, the mowing or cutting but not removal of such vegetation may pose problems with native seed bank recruitment; similarly, the disturbance favored by hemlock for its own recruitment indicates that a removal regime must be comprehensive through time as well as space until the seed bank itself has been significantly reduced.

A timed mowing regime just after flowering or before seed set is a common management practice used by many land managers; however, according to Huxtable (1993) the alkaloid content of this plant (which is most likely responsible for its potentially allelopathic properties) is concentrated in the flower heads. A study by Fairbairn and Ali (1968) found that during fruit development of *C. maculatum*, plant-produced chemicals are converted "fairly rapidly into coniine and into other bound forms of the alkaloids" (also see Grieve 1931). Thus, a mowing regime at this stage in the life cycle may merely concentrate allelochemicals in the soil.

One interesting management alternative involves the use of a biological control agent. There is some evidence that the leaf-tying moth, (*Agonopterix alstroemeriana,* Oecophoridae), can arrest the growth and seed production of poison hemlock through defoliation and its use of hemlock as a host plant (pers. comm. Ronnie Ryno; Savela 1997).

Further research into this and other management alternatives, coupled with increased attention and focus on the natural history and biochemical processes of poison hemlock, will greatly improve our understanding of its mechanisms of invasion and establishment and will provide the tools for its effective control. In our ongoing efforts to combat the advancement of invasive species, we must recognize the tendency for different factors to work together to interactively affect patterns of species establishment and persistence. The more we explore these factors, the greater will be our understanding of how to manage natural ecosystems to promote ecological integrity.

Acknowledgements

The research presented here is the result of an undergraduate senior thesis in Environmental Studies at the University of California, Santa Cruz. I would like to gratefully acknowledge the help of Dr. Stephen R. Gliessman and Dr. Daniel F. Doak, as well as Walter N. Heady. Partial funding was provided by the David Gaines Committee for Undergraduate Research.

Literature Cited

Ahmad, M., Sabir, A.W., Akhtar, S., and Bhatty, M.K. 1987. Medicinal plants of the family Umbelliferae (part III). Hamdard Medicus 30:3-19.

Altieri, M. 1981. Ecology and management of weed populations. University of California Press, Berkeley.

Auld, B.A. and Medd, R.W. 1987. Weeds: an illustrated botanical guide to the weeds of Australia. Inkata Press, Melbourne.

Fairbairn, J.W. and Ali, A.A.E.R. 1968. The alkaloids of hemlock. Phytochemistry 7:1599-1603.

Fischer, N.H., Williamson, G.B., Weidenhamer, J.D., and Richardson, D.R. 1994. In search of allelopathy in the Florida scrub: the role of terpenoids. Journal of Chemical Ecology 20:1355-1380.

Frankton, C. and Mulligan, G.A. 1970. Weeds of Canada. Dept. of Agriculture, Ottawa. Gliessman, S.R. 1995. Agroecology: ecological principles in sustainable agriculture. Unpublished ms.

Gliessman, S. R. 1995. Agroecology: ecological principles in sustainable agriculture. Unpublished manuscript.

Greene, E.L. 1891. Flora Franciscana, an attempt to classify and describe the vascular plants of middle California. Qtd. in Robbins, W.W. 1940. Alien plants growing without cultivation in California. California Agricultural Experiment Station, Bulletin 637. University of California Press, Berkeley.

Grieve, M. 1931. A modern herbal. In: Electric Newt. 1995. Botanical.com. A Modern Herbal. Common Name Index- Hemlock. http://www.botanical.com/botanical/mgmh/h/hemloc18.html

Hickman, J.C., (ed.). 1993. The Jepson manual: higher plants of California. University of California Press, Berkeley.

Huxtable, R.J. 1993. On the nature of Shakespeare's cursed Hebona. Perspectives in Biology and Medicine 36:262-278.

Leather, G.R. and Einhellig, F.A. 1988. Bioassay of naturally occurring allelochemicals for phytotoxicity. Journal of Chemical Ecology 14:1821-1843.

Rice, E.L. 1986. Allelopathic growth stimulation. In: Putnam, A.R. and Tang, C.S., (eds.). 1986. The Science of Allelopathy. John Wiley and Sons, New York.

Ryno, R.L. Modoc National Wildlife Refuge. Personal communication. 24 May, 1996.

Savela, M. 1997. Host plants index C. Larval food plant information sorted by plant. http://www.funet.fi/pub/sci/bio/life/warp/food-plants-c.html

USDA. 1971. Selected weeds of the United States. Dover Publications, New York.

Asexual Reproduction in *Arundo donax* (Giant Reed)

Jodie S. Holt and Amanda B. Boose
Dept. of Botany and Plant Sciences, Univ. of California, Riverside, CA 92521

Introduction

Arundo donax, giant reed, is a large-statured, invasive perennial plant that has established and spread rapidly in California riparian habitats. The presence of *A. donax* in these areas impacts water conservation efforts and also causes a severe fire hazard during the dry season. *A. donax* replaces native vegetation, which may impact endangered species such as the least Bell's vireo in southern California. Although *A. donax* was introduced into California as an ornamental, it easily escapes cultivation and spreads rapidly along irrigation and drainage canals as well as in riparian habitats. Although there are many real and potential uses of *A. donax* described in the literature, its presence in riparian habitats is a serious problem that outweighs its potential utility. Unfortunately, the extensive literature on its uses does not include any information on its biology, ecology, or any other aspects of its life history.

This research addressed one specific area of *A. donax* biology, vegetative reproduction, which is the most critical process determining its establishment and spread. The objective of the work was to characterize vegetative reproduction of *A. donax,* specifically in relation to potential fates of this weed in the field environment following disturbance or removal events. We studied sprouting potential of aboveground and belowground vegetative propagules that were removed from the parental plant, effects of storage duration and conditions on subsequent sprouting of propagules, and survival and growth of propagules in various soil types and moisture regimes.

Materials and Methods

Arundo donax samples were collected in February and June 1996 at Camp Pendleton US Marine Corps Base for use in vegetative propagule studies. Rhizome and stem sections were collected from a solitary stand of *A. donax*, estimated to be one year old and additional stem segments were collected from a more mature stand in the area.

Effects of propagule size on sprouting.

Stems were cut into one-node pieces of either 2, 5, 10 or 20 cm length, two-node pieces ranging in length from 10 cm to 30.5 cm, and pieces with no nodes ranging in size from 4 cm to 12 cm, with 8 replicates per size. Stem diameters at the nodes were recorded as covariates. Rhizomes were separated into 25 pieces with, and 25 pieces without, visible axillary buds. The length and width of each piece were used to calculate the volume. All propagules were planted in UCR standard potting mix (4:3 sandy loam:peat moss, v/v) in pots in a greenhouse and time to sprouting was recorded for each piece.

Effects of propagule storage on sprouting.

Storage treatments were assigned based on a three-way factorial design, with 6 replicates, to test the effects of temperature, soil moisture, and storage duration on vegetative propagule viability. Rhizomes and stems were kept at one of three temperature regimes representing conditions in Southern, Central, and Northern California (23/19°C, 18/15°C, or 10/9°C); under one of three soil moistures (wet, moist, or dry); and for various durations (2 wks, 1 mo, 2 mo, or 4 mo). After the assigned storage, propagules were planted in UC Riverside (UCR) potting mix in pots in a greenhouse and the number of days until a propagule sprouted was recorded.

Effects of soil type and moisture on sprouting.

This experiment was a three-way factorial design with 8 replicates to test effects of soil type, soil moisture, and propagule type on sprouting. Individual rhizomes or stems were planted in clayey, loamy, or sandy soil in pots and placed outdoors. Half of the pots were watered daily, while the other half were watered once per week. Daily pot water potentials averaged -0.24 megapascals (MPa) for dry clay, -0.19 MPa for wet clay, -0.25 MPa for dry loam, -0.10 MPa for wet loam, -0.02 MPa for dry sand, and 0 MPa for wet sand. The date of sprouting was recorded for each propagule planted.

Effects of planting depth and soil moisture on sprouting.

This experiment was also a three-way factorial design with 8 replicates; factors were depth, soil moisture, and propagule type. Planting depths were 10 cm or 25 cm, while the soil moisture treatments and propagule types were the same as for the soil type experiments. Individual propagules were planted in pots and placed outdoors in ambient conditions at UCR. The soil moisture potential in pots watered daily averaged -0.08 MPa, while in the pots watered weekly the average was -0.23 MPa. Date of sprouting was recorded for each propagule.

Statistical analysis

Analysis of variance was performed on the arcsine, square-root transformed proportion of replicates sprouted in each treatment. The theoretical error variance (MSE) in the ANOVA was calculated as 821/n, appropriate for the angular (arcsine, square root, in degrees), transformed proportion sprouted, where n was the total number of replicates per treatment (Snedecor & Cochran 1967). The mean squares (MS) for the treatment factors and interactions were obtained using SAS (1996) and F-tests were calculated by hand following Steel & Torrie (1980).

Results and Discussion

Effects of propagule size on sprouting.

Ninety percent of stems with at least one node sprouted, while pieces with no node did not sprout. The minimum length for sprouting was 2 cm (Fig. 1). Stem length and time to sprouting were positively related. 100% of rhizomes with at least one bud and 8% with no visible bud sprouted. The smallest rhizome piece to sprout was 3.41 cm long by 1.85 cm in diameter. No relationship was found between rhizome length, diameter, or volume and time to sprouting.

Effects of propagule storage on sprouting.

The main effects of time, temperature, and moisture all affected the ability of *A. donax* stems to sprout. There were significant interactions of time and moisture and of time, moisture, and temperature. Drying reduced stem viability after just two weeks (Fig. 2a). By the fourth week both wet and dry treatments reduced sprouting compared to the moist treatment (Fig. 2a). Stems in moist conditions remained viable longest in each temperature (Fig. 3). However, even in the moist treatment, sprouting was reduced 90% after 16 weeks

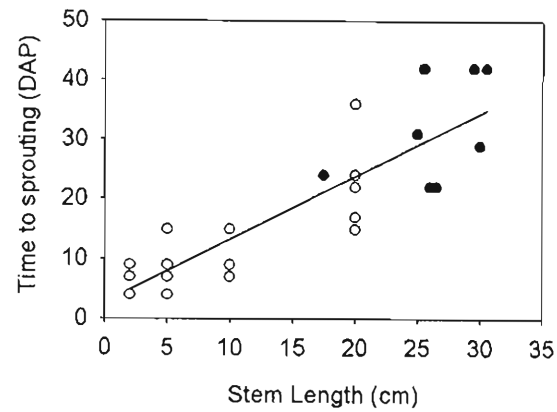

Fig. 1. Time to sprouting by stem length for *Arundo donax*. Regression analysis was performed on log transformed values of time to sprouting ($r^2 = 0.82$, $P < 0.0001$).

(averaged over the three temperatures). Only stems from cool moist conditions sprouted after 16 weeks.

Time and moisture were significant main effects on rhizome sprouting. Interactions of time and moisture and temperature and moisture were both significant. At four weeks the wet treatment reduced sprouting more than either other moisture (Fig. 2b). By 16 weeks rhizome sprouting from wet or dry conditions was reduced to nearly 0%. Sprouting from rhizomes in moist soil was reduced nearly 50% between 4 and 16 weeks. Averaged over storage times, sprouting from rhizomes in moist soil was greater than from rhizomes in wet or dry soil. In the wet condition, cool temperatures promoted greater sprouting (Fig. 4).

Effects of soil type and moisture on sprouting.

The soil types used in this experiment had no effect on propagule sprouting (Table 1). However, rhizomes sprouted better than stems, well-watered propagules sprouted better than less-frequently watered propagules, and stem sprouting was reduced more by less frequent watering than was rhizome sprouting (Table 1). Over all treatments, 98% of the rhizomes sprouted whereas only 54% of the stems sprouted.

Effects of planting depth and soil moisture on sprouting.

Planting depth had no effect on the ability of propagules to sprout. All rhizomes in this experiment sprouted but only 6% of stems sprouted. The dearth of sprouted stems hindered detection of interactions between propagule type and moisture or depth. Since 54% of stems from the same source sprouted in the

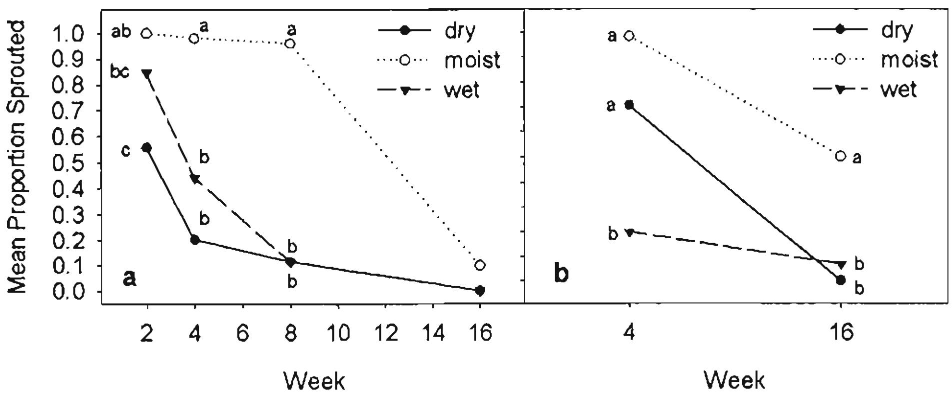

Fig. 2. Proportion of propagules sprouted by week in storage and storage moisture condition, averaged over storage temperatures. Data were arcsine, square-root transformed for analysis. Means in the figures were back transformed. Means sharing the same letter within each week are not significantly different at $\alpha = 0.01$. a) stems (MSE = 136.83, df = 180, n = 3); b) rhizomes (MSE = 136.83, df = 90, n = 3).

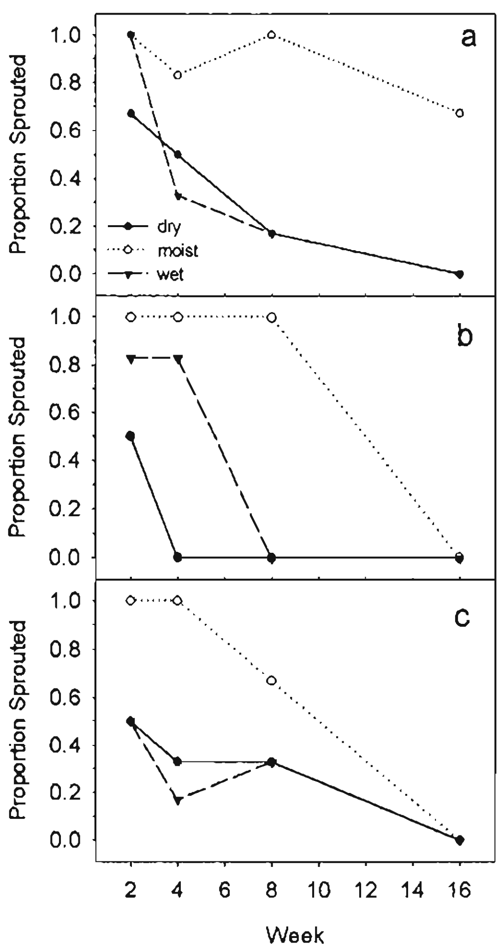

Fig. 3. Proportion of stems sprouted by week in storage and storage moisture condition for three storage temperatures. Data were arcsine, square-root transformed for analysis. Means in the figures were back transformed. a) 10 C/9 C; b) 18 C/15 C; c) 23 C /19 C.

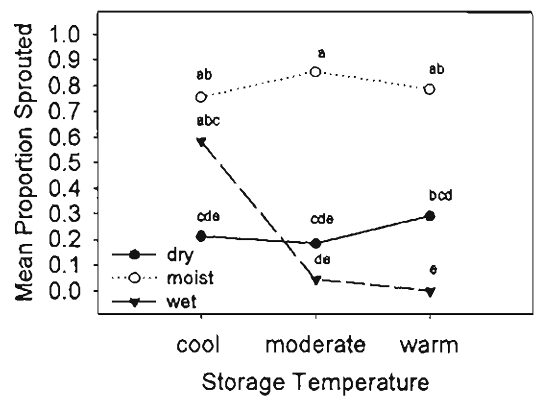

Fig. 4. Effects of storage temperature and moisture condition on sprouting from rhizomes, averaged over storage times. Means in the figures were back transformed. Means sharing the same letter are not significantly different at $\alpha = 0.01$). The letters are from an LSD test on arcsine, square root transformed data with MSE = 136.83, df = 90.

soil type experiment (planted 3 cm deep), these data suggest that a depth of as little as 10 cm limits stem sprouting. In contrast, rhizomes sprouted readily from 10 cm or 25 cm and their sprouting was not limited by reduced soil moisture.

Conclusions

Treatments were imposed that simulate the fate of *A. donax* plants following disturbance, such as flooding, or mechanical control, such as by cutting and chipping, a common practice. Sprouting of propagules after removal from the parent plant varied with propagule type and size and with treatment and duration of storage. Results suggest that control strategies can be designed to remove *A. donax* while minimizing regrowth. Mechanical chipping of stems into pieces less than 2 cm long should destroy nodes and buds and prevent sprouting. Leaving chipped pieces on the ground to desiccate should reduce viability of any remaining buds. These operations should be performed during the hottest time of the year for maximal effect. While stem sprouting can be controlled by these methods, rhizome sprouting is more prolific and stress tolerant. Further study is needed to develop control strategies for rhizomes.

Acknowledgments

Support for this research was provided by a subcontract with Jones & Stokes Associates from a primary grant by the U.S. Marine Corps at Camp Pendleton Marine Corps Base and by the University of California Division of Agriculture and Natural Resources.

References

Boose, A. B. and J. S. Holt. 1999. Environmental effects on asexual reproduction in *Arundo donax*. Weed Research 39: 117-127.

Fischer, B. B., A. H. Lange, J. McCaskill, B. Crampton, and B. Talbraham. 1978. Grower's Weed Identification Handbook. No. 4030. Div. Agric. Sci., Univ. Calif., Berkeley, CA. Frandsen, P. 1994. Team Arundo: an interagency success story. Proceedings California Weed Science Society 46: 157-161.

Snedecor, G. W. and W. G. Cochran. 1967. Statistical Methods, 6th Ed.. Iowa State University Press, Ames, Iowa.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics: A Biometrical Approach, 2nd Ed.. McGraw-Hill Publishing Company, New York, New York.

MSTATC. 1992. MSTATC Version 2.0. Michigan State University, East Lansing, Michigan.

SAS. 1996. SAS Version 6.12. SAS Institute, Cary, North Carolina.

Table 1. The mean proportion of propagules sprouted, by treatment, for the significant effects of water, propagule type, and the interaction of water and propagule type from the soil type experiment. There was no significant effect of soil type on the ability of the propagules to sprout.

Factor	Level	Mean proportion sprouted[1]
Propagule type	rhizome	0.996 a
	stem	0.587 b
Water	wet	0.978 a
	dry	0.671 b
Propagule type x water	rhizome, wet	1.000 a
	rhizome, dry	0.986 a
	stem, wet	0.915 a
	stem, dry	0.205 b

[1]Means are the back transformed arcsine, square-root proportions. Within each factor, the means followed by the same letter are not significantly different at the a=0.01 level. The error term for the LSD was the MSE (102.6) from the ANOVA, with 84 degrees of freedom. For the factors propagule type and water, n=6. For the propagule type by water interaction, n=3.

Cape Ivy (*Delairea odorata*) Distribution in California and Oregon

Ramona Robison[1], Eva Grotkopp[1] and Rosie Yacoub[2]
[1] Univ. of California, Davis Plant Biology Graduate Group
[2] California Dept. of Food and Agriculture, Integrated Pest Control Branch, Noxious Weed Information Project

Introduction

Cape ivy (*Delairea odorata* synonym *Senecio mikanioides*) (Family Asteraceae) is an invasive exotic weed in California's coastal habitats. It's a bright green perennial vine with alternate leaves and yellow flowers. Cape ivy is native to South Africa and is uncommon there, occurring in only a few locations. However, in southern Europe, Hawaii, New Zealand, Tasmania and Australia, as well as in western North America, Cape ivy is an invasive weed. The reported range in North America is from Oregon south through California and into Baja California. In these areas it forms dense mats in both sun and shade, smothering native vegetation.

The Cape ivy distribution information collected for this study is intended to help land managers and volunteer groups develop large-scale control strategies for the species. Future studies will include Geographic Information System (GIS) analysis of the location information to detemine if any distribution patterns exist. A statewide map is included in two parts in this article.

Methods

The CalEPPC Cape Ivy Working Group began collecting distribution data in 1995. In May 1995, Eva Grotkopp and Alfred Kuo mapped Cape ivy's distribution in southern coastal California, from Monterey to San Diego. The streams and hillsides along Highway 1 and areas near Highway 101 were examined. Additionally, other appropriate habitats (lakes, campgrounds, parks, etc.) within 25 miles ofHighway 1 were visited. All populations reported by CalEPPC members, California Native Plant Society (CNPS) members, park rangers, and other concerned citizens were visited and described. California Automobile Association maps were used for base maps as they provided good detail of roads, streams, parks, and other geographical features. The boundaries of the populations were estimated and drawn on the maps.

In 1999, Ramona Robison continued the distribution mapping work begun in 1995. She focused on the areas not covered in 1995 field surveys, namely coastal counties north of Monterey and the San Francisco Bay Area. Through knowledgeable individuals in CalEPPC and CNPS, she identified local experts and asked them to provide maps of known Cape ivy locations in their area. This method was chosen because many Cape ivy populations on private property were not accessible or may be so small they could easily be missed in a drive-by survey. In addition to collecting maps from experts, we met with knowledgeable individuals in the field and collected data using a hand-held GPS (Global Positioning System) (Trimble GeoExplorer) with an overall accuracy of 1 to 3 meters. In areas not familiar to experts, she drove major roads and checked stream crossings for Cape ivy populations.

All spatial data were brought into a GIS (Geographic Information System). MapInfo Professional 5.0 was used to create maps, store and edit the data. Much of the data was drawn on paper maps and then was digitized onto 1:100,000 scale maps. The GPS data were exported from Pathfinder to a MapInfo format, and ArcView shape files provided by Golden Gate National Recreation Area (GGNRA) were converted to MapInfo format and included in the GIS.

Discussion

The Cape ivy distribution information collected for this study is intended to help land managers and volunteer groups develop large-scale control strategies for the species. Hopefully the maps will serve as a clearing house of information which will encourage additional research. As is evident in the state-wide map, the Cape ivy infestation in California is extensive, covering much of coastal California in both urban and rural areas. The discussion below summarizes the general trends in the distribution data.

Del Norte and Humboldt County, as well as Curry County, Oregon, contained relatively few Cape ivy populations. In many locations on the north coast, notably in Arcata, all of the reported locations were either completely dead or were just beginning to re-sprout in late September, 1999, perhaps due to heavy frosts in the winter of 1998 – 1999. The southern part of Humboldt County was not surveyed extensively, and it's likely that more populations are located in the streams and around historic settlements there.

Coastal Mendocino and Sonoma counties contained a number of Cape ivy infestations. The infestations seemed to be correlated with human settlements, though they are also in streams and other wildland locations between settlements. Cities with large infestations included Fort Bragg, Mendocino, Gualala and Bodega Bay.

The San Francisco Bay Area was also heavily infested with Cape ivy. The infestations ranged from coastal to interior Marin County and occurred in Sonoma County as far inland as Petaluma. GGNRA was heavily infested. Most open spaces in San Francisco County supported Cape ivy, including Golden Gate Park, the Presidio and Mt. Sutro. The furthest inland location reported in Contra Costa County was in Little Pine Creek on Mount Diablo. In the eastern portion of the Bay Area the infestations were not as large as those observed in San Francisco and coastal San Mateo County.

South of San Francisco in interior San Mateo County, San Bruno Mountain supported large Cape ivy populations. Two locations with detailed Cape ivy distribution information available were San Francisquito Creek in Palo Alto and


Curry County, Oregon
Del Norte
Humboldt
Mendocino
Sonoma
Contra Costa
Alameda
Santa Clara
Monterey

San Pablo Creek in Pacifica. In coastal San Mateo County, from Pacifica south to the border of Santa Cruz County, we observed Cape ivy in almost every drainage. Further south, in Santa Cruz, Aptos, Monterey and Carmel, as well as along the Pajaro River, experts reported large Cape ivy populations.

In Southern California, Cape ivy infestations are also heaviest in coastal urban areas such as San Luis Obispo, Santa Barbara, and San Diego. The futhest inland population known from Southern California was located in Los Angeles County in the San Dimas Experimental Forest. Two locations are known fiom the Channel Islands, one on Santa Cruz Island and the other on Santa Rosa Island.

The Cape ivy distribution information we compiled is preliminary, and input and corrections are strongly encouraged. Please contact Ramona Robison via e-mail at rarobison@ucdavis.edu with additional information or corrections.

Acknowledements

We would first like to thank the California Dept. of Food and Agriculture's Noxious Weed Information Project for providing the technical assistance necessary to complete the mapping project. Steve Schoenig provided the vision to help see the project through, and Rosie Yacoub, Pat Akers, Aaron Queheillalt, John Gendron and Carri Benefield provided much needed technical assistance. Robin Wall and Tina Costelia also provided help with field data collection during 1999 field surveys.

A list of those who contributed their time and expertise follows, and we apologize to anyone who was mistakenly omitted.

Maria Alvarez, Ileene Anderson, Greg Archbald, Joe Balciunas, Noah Booker, Carla Bossard, David Boyd, Cindy Burrascano, David Chipping, Kim Cooper, Joe DiTomaso, Tom Dudley, Barbara Ertter, Pete Holloran, Lori Hubbart, Tim Hyland, Jodi Isaacs, Jim Johnson, Mike Kelly, Alfred Kuo, Gordon Leppig, Gary Lester, Don Mayall, Bertha McKinley, Fred McPherson, Ken Moore, Louisa Morris, Renee Pasqinielli, Mike Pitcairn, John Randall, Mary Rhyne, Diona Roja, Tamara Sasaki, Susan Schwartz, Jake Sigg, Veva Stansell, Mike Vasey, and Peter Warner.

Noxious Weed Education Program

Barbara Mullin,
Montana Dept. of Agriculture, Helena, MT

In 1996, interested Montana citizens began a series of meetings to plan for a coordinated statewide education and awareness campaign on weeds in the State of Montana. From these meetings the group identified seven educational messages that they felt were important to present to eight specific target audiences.

These messages include:

- An explanation of what a noxious weed is and identification of plants and infestations;
- How people are affected by noxious weeds;
- How the environment is affected by noxious weeds;
- Why the general public needs to support all aspects of noxious weed efforts;
- What the general public (and each target audience) can do;
- Successful weed management programs in Montana; and
- There are many ways to manage weeds.

The target audiences include: the public at large, both urban and rural; youth; environmental groups; government; realtor, developers, and small landowners; recreation, sportsman, and tourists; utilities and transportation; and producers

Subcommittee groups are working on specific programs for different target audiences. Some projects completed or in progress are development of a realtor slide presentation kit; bumper sticker contests for youth; weed impacts brochures and displays for garden centers, extension offices, and other areas; public service announcements featuring Montana's Governor and targeting the hunting sportsman; offhighway-vehicle training programs; and development of training materials.

Carbohydrate Use of *Arundo donax* Under Light-limiting Conditions.

Joseph G. Decruyenaere and Jodie S. Holt, University of California, Riverside.

Arundo donax is a serious pest of riparian areas throughout Southern California. The perennating organ of *A. donax* is the rhizome, which is rich in starch and can readily subsidize new shoot growth in situations where control of *A. donax* is attempted. The cost to the rhizome of producing new shoots without benefit of photosynthesis has not been previously investigated. *A . donax* rhizomes (average mass approximately 220 g) were planted under various regimes of shoot suppression, with and without benefit of photosynthesis, to gauge the extent to which carbohydrate reserves can maintain viability of the plant. Shoot suppression was accomplished by means of weed blocking fabric of 33, 67 and 100 cm diameter. Plants were grown under these conditions for 100 days or until new shoots appeared at the edge of the suppression zone, whichever came first. The resulting carbohydrate content of rhizomes as well as photosynthesizing and non-photosynthesizing shoots and leaves was determined.

A significant difference in carbohydrate usage was found to correlate with intensity of shoot suppression in rhizome samples. Significant differences in photosynthesizing tissues were not found.

Development and Management of Artichoke Thistle, *Cynara carduncculus*

Virginia A. White, Jodie S. Holt, and Amanda B. Boose,
University of California, Riverside.

Artichoke thistle, *Cynara cardunculus*, is an invasive perennial weed occurring on thousands of acres of California grassland. Effective management of this weed and restoration of invaded land will require biological information such as phenology, growth rate, and length of time until the plant is functionally perennial.

A phenology experiment was conducted to observe emergence, growth, and development of *C. cardunculus* over 18 months. In an irrigated field at the UCR Experiment Station, seeds were planted each month for one year in a randomized complete block design. The number of days required to reach specified phenological stages (emergence, 2 - 10 leaves, bolting, 1 - 10 flowers, and seed set) was recorded.

A clipping experiment was conducted to determine when plants become functionally perennial. At predetermined phenological stages, all aboveground plant matter was removed and the number of days until resprouting was recorded.

In the phenology experiment, rate of rosette formation and reproductive maturity were greatly affected by month of planting. In the clipping experiment, every treatment resprouted but the number of days necessary to resprout was affected by the stage at which the plant was clipped. Furthermore, even plants clipped at the cotyledon stage resprouted, indicating that plants become functionally perennial soon after emergence. These findings suggest that management of C. cardunculus should focus on prevention of seed production.

Weed Management Areas in California

Steve Schoenig
Integrated Pest Control Branch, Calif. Dept. of Food and Agriculture, 8acramento

Sacramento Weed Management Areas (WMAs) are local organizations that bring together landowners and managers (private, city, county, State, and Federal) in a county, multi-county, or other geographical area for the purpose of coordinating and combining action and expertise in combating common invasive weed species. The WMA functions under the authority of a mutually developed memorandum of understanding (MOU) and is subject to statutory and regulatory weed control requirements. A WMA may be voluntarily governed by a chairperson or a steering committee. To date, groups in California have been initiated by either the leadership of the County Agricultural Commissioneris Office or a Federal Agency employee. WMAs are unique because they attempt to address agricultural (regulatory) weeds and *wildland* weeds under one local umbrella of organization. It is hoped that participation will extend from all agencies and private organizations. WMAs have printed weed identification /control brochures, organized weed education events, written and obtained grants, coordinated demonstration plots, instituted joint eradication and mapping projects, as well as many other creative and effective outreach and weed management projects.

How Landscape Changes Occurred in California

Andy Dyer, University of California, Davis

The California landscape has been dramatically and irrevocably changed by the addition of over a thousand new species in the span of only 230 years. The process of invasion invariably has been associated with some form of human disturbance either to the vegetation or to the soil. While disturbance is a natural process in most ecosystems, humans tend to change the intensity or the frequency of disturbance. The most dramatic example has been agricultural conversion. Many species, particularly annual grasses, have co-evolutionary histories with herbivory, soil disturbance, and agricultural practices. These three forms of disturbance are characteristic of human modified landscapes and invasive species are often pre-adapted by association with human activities.

The invasion and conversion of ecosystems results in shifts in ecosystem characteristics and functions. Annual grasslands have higher plant densities, modified patterns of resource availability, and have become more intense competitive environments for one or more resources. These changes put many native species at a competitive disadvantage in their home environment. As the abundance and distribution of native species is reduced, niche space is opened, and opportunities for future invasion are created. Thus, the process of invasion can become cyclic as new species modify the landscape and prevent native species re-establishment.

Mechanism(s) Responsible for Enhancing the Effeetiveness of Glyphosate in Controlling Perennial Pepperweed

Mark J. Renz and Joseph M. DiTomaso,
University of California, Davis

Glyphosate only temporarily suppresses perennial pepperweed (*Lepidium latifolium* L.) growth and provides limited long-term control. However. a glyphosate treatment at 3.33 kg/ha to foliage that has returned to the flower bud stage after an early season mowing drastically improves long-term control of perennial pepperweed (89% after 1 year). Current research is attempting to determine the mechanism(s) responsible for enhanced control. Potential mechanisms are 1) increased glyphosate deposition. 2) increased glyphosate absorption and 3) increased glyphosate translocation into belowground perennial organs.

Mowing has been shown to alter the aboveground morphology of the shoots, changing leaf angles and size as well as reducing density and height of plants at the flower bud stage. These changes in the canopy structure of perennial pepperweed infestations could increase glyphosate deposition compared to unmowed plants. Recovering foliage also appear to have less cuticular wax on the leaves, thus glyphosate absorption could be enhanced.

Initial data indicate that mowing does not increase basipetal translocation rates, however glyphosate applications to previously mowed areas are made later in the season. At this period translocation rates into belowground perennial organs are highest, causing a greater accumulation of absorbed glyphosate in these structures. Coordination of glyphosate applications with maximal basipetal translocation rates and maximum glyphosate deposition onto the foliage is hypothesized to be the main factors responsible for enhanced control.

These potential mechanisms are currently being evaluated in field and greenhouse studies to determine their role in the observed enhanced control. Results will help optimize this control strategy and help to develop other control strategies for the management of perennial pepperweed.

The Role of Molecular Systematics & Phylogeography in Biological Control

John Gaskin, Missouri Botanical Gardens

Invasion of habitats by non-native organisms is considered the second largest threat to biodiversity worldwide. Many invasive taxa can be controlled by mechanical or chemical means. When these approaches are not feasible, biological control may be an option for some alien species that are not closely related to native taxa or crops.

Development of a successful biological control program, which may require over a decade of research. relies heavily on finding extremely host-specific agents from the invasive species native habitat. This requires detailed information on the invasive's geographic origins. In most cases. an accurate history of the invasion, or careful morphological comparisons between the invasive and the specimens from the species native range can be used to infer the invasive's origin. However, for some taxa, history of the invasion is unavailable, and morphological data are inconclusive. Even worse, multiple species of a genus may have become invasive, as has happened in Tamarix (saltcedar). Identification of geographic origins for morphologically difficult genera with multiple invasions are particularly difficult due to the following reasons:

1. Confusion over the identity of invading species and their correspondin,o native ranges.
2. Hybridization events may have occurred between naturalized species in the genus that were disjunct prior to introduction, possibly altering the phenotypic characters that stiln ulate host-specific biological control agents.

Even once the invasives are identified, there may be significant genetic variation across a species with a widespread native range. Biocontrol agents selected from the wrong floristic area of a widespread species may not be as effective.

Modern molecular phylogenetic techniques provide a means of testing hypotheses of taxonomic identity and relationships that were previously based on morphology. Recent advances in phylogeographic methods (which study the geographic distribution of genealogical lineages) offer unparalleled opportunities to locate precise origins of introduced species. There are many molecular techniques available for estimating origins, searching for hybridization events, and analyzing population structure, such as allozymes, RAPDS, restriction sites, DNA sequence data, etc. Phylogenetic studies that are based on ordered data such as DNA sequences or mapped restriction sites, (in which relationships among allelic variants are known) can estimate the genealogies (or family trees) of the genes studied. This is analogous to tracking your roots in the Old World by just looking at physical similarities between you and Old World populations, or actually using a family tree to find where you came from. The latter choice has better odds of being accurate.

So how can this be, done on a morphologically difficult genus containing multiple invasive taxa? Vouchered DNA samples from the invasion and from the native ranges of suspect species are used to create a phylogeny of the group. Comparison of the range of DNA sequences for a gene fragment from the invasive specimens with that of different suspect species can then elucidate the taxa or taxon that comprise the invasion. Post-introduction hybrid events (which would be extremely recent on an evolutionary scale) can be revealed if an invasive specimen contains a chloroplast sequence belonging exclusively to the native genotype of one species, and a nuclear sequence belonging exclusively to the native genotype of a different species (phylogenetic incongruence), or if an invasive or naturalized specimen contains nuclear haplotypes (the two nuclear copies of a gene found in each organism) corresponding exclusively to the native genotypes of two different species (nuclear heterozygosity).

To pinpoint invasive population origins, highly variable DNA sequences are used to construct a haplotype tree. If there are only a few invasive haplotypes represented across a wide geographic range in the Old World, or many invasive haplotypes derived from multiple introduction events corresponding to various origins, the outlook for more specific control agents is doubtful. Alternatively, if the invasion contains just a few haplotypes that correspond to a restricted geographic origin, the biocontrol search can be narrowed, saving valuable research tilne and offering the chance of finding extremely hostspecific agents.