RADIANT HEATER EFFECTS ON *LEONTODON TARAXACOIDES*, *HYPOCHAERIS GLABRA*, AND *PARENTUCELLIA VISCOSA* IN DUNES AND SEASONAL SWALES AT HUMBOLDT BAY NATIONAL WILDLIFE REFUGE

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ABSTRACT

Radiant Heater Effects on *Leontodon taraxacoides*, *Hypochaeris glabra*, and *Parentucellia viscosa* in Dunes and Seasonal Swales at Humboldt Bay National Wildlife Refuge

Vanessa K. Emerzian

Radiant heaters are devices used to control unwanted plant species. This study explores whether radiant heat treatments can be an effective management tool for controlling invasive plant species *Leontodon taraxacoides*, *Hypochaeris glabra*, and *Parentucellia viscosa* in dune ridge and swale environments at the Lanphere Dunes Unit, Humboldt Bay National Wildlife Refuge. Experiments were conducted in 2005 and 2006. The experiment of 2005 was designed to determine the effect radiant heating would have on *Leontodon taraxacoides* and *Hypochaeris glabra* survival. Field observations in 2005 indicated that seed set of *Leontodon taraxacoides* could be reduced by radiant heating. A fecundity experiment was designed in 2006 to quantify this reduction. A third invasive species, *Parentucellia viscosa,* was common in the plots and responded to the treatment. The effectiveness of radiant heating treatments on this species was observed and quantified.

Results of this study indicate that radiant heating does not generally kill *Leontodon taraxacoides* individuals outright, but does significantly reduce seed set when treatment occurs immediately prior to flowering. *Parentucellia viscosa* is effectively controlled by radiant heating, as individual plants are killed after treatment and do not set seed. *Hypochaeris glabra* is not generally killed by radiant heating, but the treatment seemed to have an effect on future recruitment.

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INTRODUCTION

Biological diversity has become a subject of concern in recent decades as increased evidence of an accelerated worldwide species loss appears in the scientific literature. Though loss of species is often attributed to the direct destruction of plant and animal habitats by land development, pollution and resource extraction (Wilson 1992, Cronk and Fuller 1995, Gorke 2003), arguably the most pervasive reason for species loss is the introduction of nonnative species (Blackburn and Gaston 2005).

Nonnative plants are those that appear in areas outside of their historical natural range. Cronk and Fuller (1995) pointed out that ecosystems may begin to recover after pollution, resource extraction or land development cease. However, the introduction and establishment of a nonnative species is a condition that will persist until the species is removed or dwindles in number to a point at which successful recruitment of new individuals no longer occurs. Gorke (2003) included introduction of exotic species as one of the eight primary causes of species loss. More than 40 percent of species listed as threatened or endangered under the Endangered Species Act are at risk primarily because of invasive species (Pimentel et al. 2005).

The California Floristic Province, extending from Baja California to Southern Oregon, is considered to be a habitat hot spot (Wilson 1992). The region has great species diversity, containing one-quarter of all plant species found in the United States and Canada combined. Over 2,000 of these plant species are not present in any other part of the world (Wilson 1992). While approximately 4,850 native vascular plants exist in California, the approximate 1,045 nonnative vascular plants make up nearly 20 percent of the state’s flora (Randall et al. 1998). These nonnative species compete with native species for space, water and nutrients; disturbing established patterns of ecological services and species diversity. Some nonnative species will earn the description of being “invasive” in a given habitat.

There have been numerous definitions put forth as to what constitutes a species invasion. Cronk and Fuller (1995:1) described an invasion as the unassisted spread of an organism within a habitat that produces “a significant change in terms of composition, structure or ecosystem processes.” Invasive plant species typically mature quickly from the seedling to reproductive stage. They reproduce profusely, creating large numbers of seeds some of which may lie dormant for an extended period of time in the soil’s seed bank. Their seed dispersal methods are usually those that are effective for long distance dispersal. Some have underground root or stem systems that allow them to reproduce vegetatively without producing seeds. Simple methods of pollination such as self-pollination or acceptance of generalist pollinators are advantageous as are apomixis, self-compatibility, and a lack of inbreeding depression. Many species that originate in pastures are successful invaders since they have evolved to compete with tightly packed grasses for water, nutrients and space (Baker 1986).

A successful invader can alter an ecosystem by having an impact on ecosystem properties such as soil nutrients, water flow, primary productivity, species interactions, and the disturbance regime (Walker and Smith 1997). These impacts generally occur through predation, competition, habitat alteration, disease, and genetic effects (Manchester and Bullock 2000).

One way invading plant species establish populations in new areas is by colonizing sites that have been disrupted by either natural or human-caused disturbances (Ramakrishnan and Vitousek 1989). Rejmánek (1989) suggested that in some cases, the amount of existing biomass or cover is the best indicator of potential resistance to invasion. Open space is a general factor that allows plant invasion. Plant ecologist H.G. Baker pointed out that some established ecosystems, such as light forests, riparian habitats, waterways, and sand dunes, are vulnerable to invasive plant colonization because they experience natural breaks in plant cover (1986). Where space is available, where native plants do not outcompete nonnatives for resources, and where the number of nonnative propagules introduced into the ecosystem is high, invasion is likely (Davis et al. 2000).

Whether there is a negative correlation between species diversity and ecosystem invasibility is still up for debate (Elton 1958, Levine and D'Antonio 1999). A recent study of invasions in habitat hot spots found that high native plant diversity did not discourage nonnative plant species invasion at spatial scales larger than experimental plots, such as entire sites, counties, and states (Stohlgren et al. 2003).

The subject site in this study is a coastal dune ridge and swale ecosystem. Coastal dunes make up about 40 percent of the northern California coastline, but have suffered from the effects of fragmentation due to land development, off-road vehicle recreation, and exotic species invasions (Pickart and Sawyer 1998). Seashore dune systems contain many successional stages of habitat in a relatively small space. Immediately behind the beach is the foredune which lies parallel to the shoreline. Behind the foredune is a series of dune ridges between which lie the low areas of dune swales. Windblown shifting dunes separate these nearshore dunes from the stabilized coastal forests which are the last successional stage in this ecological system (Carter 1988, Pickart and Barbour 2007).

Dune ridges and swales are highly susceptible to invasion because of their constantly shifting substrate and open space created by this movement. Some dune vegetation occurs as continuous mats, but many native dune plants are small and solitary. Unused resources in these open spaces may be the key to successful invasion (Davis et al. 2000). The deepest swales are more densely vegetated and seemingly less susceptible to the recruitment of invasive species, but the transitional areas surrounding the swales can be rife with invasives.

The dune swale environment is inundated by rising groundwater in winter, creating seasonal ponds that dry out during summer. Dune swales act as nutritional traps for organic matter. Swales are the first place to get cyanobacteria and algae, which increase soil nutrients, while moisture in swales enhances soil stability. These conditions provide for rapid colonization and increased growth of vascular plants as moisture and litter accumulation and decomposition foster soil development (Pickart and Barbour 2007). Consequently, dune swale soils tend to be better developed than the surrounding sand dune ridges.

Dune inhabitants must contend with nutrient-poor soils, drought, wind exposure, and smothering sand engulfment in addition to the usual ecosystem struggles of predation, competition and disease (Carter 1988). Ecosystems that are unable to successfully inhibit nonnative plant invasions, such as coastal dunes, may require human assistance to undo the human-caused disturbance of introduced plant species. Ecological restoration is a method by which this can occur.

The aim of ecological restoration is to restore lost function and (or) composition of an ecosystem, preferably to a self-sustaining state (Society for Ecological Restoration International Science and Policy Working Group 2004). Restorationists' first priority is to re-establish impaired processes. Often these projects begin with the removal of nonnative plant species, either as a means to recover processes or as an adjunct activity to accelerate recovery by increasing the space, water and nutrients available for native plants. The most common methods of control for nonnative plant species are physical, biological, and chemical (Cronk and Fuller 1995). Physical controls include shading, hand-pulling, mowing, cutting, and digging up roots. These can be very labor intensive, depending upon the target species. Another physical control is burning. This method does not require as much labor, but can have detrimental effects on surrounding native species and ecosystem. Burning can also foster growth of other nonnative plant species. The germination of at least one nonnative found at Lanphere, *Cytisus scoparius*, is promoted by fire (D'Antonio 2000).

Biological control involves using a natural enemy of the target species. Biological control is inexpensive and non-hazardous if the biological control organism remains host-specific. The disadvantages of biological controls include how long it takes to test them under controlled conditions, and the possibility that the control organism may remain a player in the ecosystem beyond the time it is needed (Cronk and Fuller 1995).

Chemical control is the application of herbicides. It is not labor intensive, but does generally require more than one application to prevent re-invasion. It can damage native plant species as well as animal species. Some herbicides can also accumulate in the soil or in leaf tissue, and may cause selection for herbicide-resistant species. One advantage to chemical control is that the presence of chemicals will diminish over time (Cronk and Fuller 1995). The control method examined in this study, radiant heating, uses high heat without flame to kill unwanted plants.

Nonnative species removal is followed by a period of preservation, re-establishment, or expansion of native plant species with the assumption that animal species will then recolonize. Ecological restoration of native plant communities is a goal at the study site, and this study examines the efficacy of a device that may help reduce the populations of particular invasive plant species found there. All botanical nomenclature follows Jepson (Hickman 1993).

STUDY SITE

The study site is located within the Lanphere Dunes Unit of the Humboldt Bay National Wildlife Refuge. The Humboldt Bay Dunes along the North and South Spits of Humboldt Bay are one of four major dune systems on the Northern California coast (Pickart and Sawyer 1998). The Lanphere Dunes Unit of the Humboldt Bay National Wildlife Refuge comprises 500 acres of coastal dunes and estuary and is managed by the U.S. Fish and Wildlife Service (Figure 1). Although a number of nonnative plant species have successfully naturalized in the Lanphere Dunes Unit, it is still the best example of an undisturbed coastal dune system remaining in the Pacific Northwest; in part due to a long history of restoration and management. Lanphere is home to over 200 species of vascular plants, including two federally listed endangered species – *Erysimum menziesii* ssp. *eurekense* (Humboldt Bay wallflower) and *Layia carnosa* (beach layia) (Pickart 2002).

The habitat types involved in this study at the Lanphere Dunes Unit include sand dune ridges, seasonal dune swales and transitional areas between ridges and swales. The semi-stable dune ridges support native species of the *Ambrosia chamissonis* herbaceous alliance (Pickart and Barbour 2007), such as *Lathyrus littoralis* (beach pea), *Abronia latifolia* (yellow sand verbena), *Eriogonum latifolium* (beach buckwheat), *Fragaria chiloensis* (beach strawberry) and *Solidago spathulata* ssp. *spathulata* (dune goldenrod).

Native herbaceous vegetation in dune swales at Lanphere includes the *Juncus breweri* (dune rush) and *Carex obnupta* (dune sedge) alliances (Pickart and Barbour

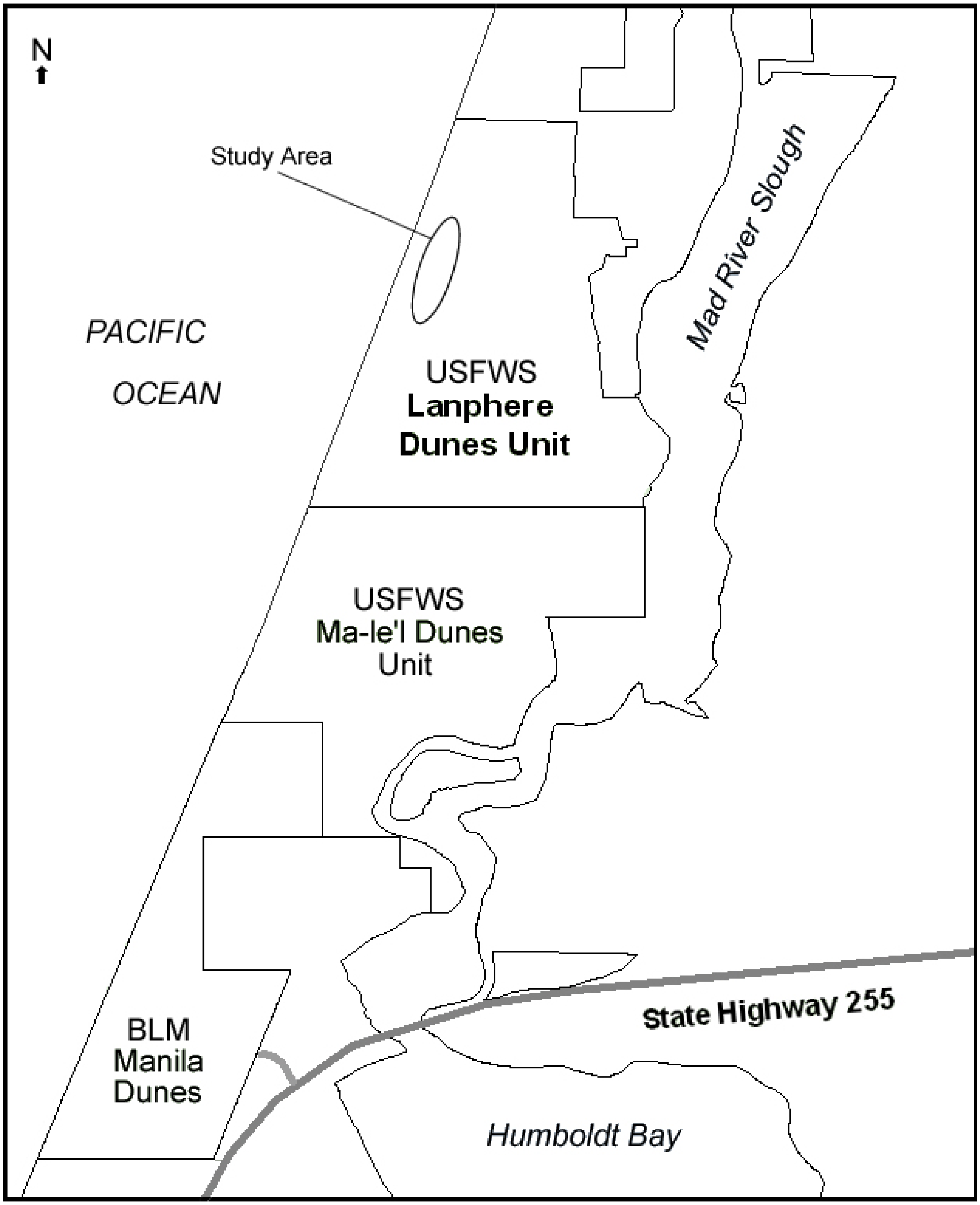

Figure 1. Location of study area at Lanphere Dunes Unit of Humboldt Bay National Wildlife Refuge, North of Humboldt Bay, Arcata, California.

2007). Associated species include *Juncus falcatus* var. *falcatus* (sickleleaf rush), *Juncus bufonius* var. *bufonius* (toad rush) and *Scirpus cernuus* (low club rush).

Between the dune ridges and swales are transitional areas. Native species found in the transitional areas include *Lotus purshianus* var. *purshianus* (birdsfoot trefoil), *Lotus micranthus* (small-flowered birdsfoot trefoil), *Epilobium ciliatum* ssp. *watsonii* (hairy willow-herb), and several *Gnaphalium* (cudweed) species. The three invasive species examined in this study (*Leontodon taraxacoides*, *Hypochaeris glabra*, *Parentucellia viscosa*) all grow in the dune transitional areas. *Hypochaeris glabra* is also found in the dune ridges, as is *Leontondon taraxacoides* to a lesser extent. Both *Leontodon taraxacoides* and *Parentucellia viscosa* can be found in the seasonal swales.

Leontodon taraxacoides (hairy hawkbit) is native to Europe and found in grasslands, sand dunes and pond borders (Morton 1985, Grimoldi et al. 1999). It is biennial to perennial and has unbranched stems. Available literature indicates that it has a taproot (Grimoldi et al. 1999), but it was observed to have a more fibrous root system at the Lanphere Dunes Unit (Figure 2). Flowering typically begins at the end of spring and ends at the beginning of autumn, and the flowers are self-compatible (Grimoldi et al. 1999). It produces two types of seeds. The central seeds have a well-developed pappus for wind dispersal. The peripheral seeds possess virtually no pappus and probably germinate in place to maintain established populations.

Hypochaeris glabra (smooth cats-ear) is also native to Europe. It flowers from May to June (University of California Davis Natural Reserve System 2003) and is an

Figure 2. *Leontodon taraxacoides* (left) with fibrous root system and *Hypochaeris glabra* (right) with taproot at Lanphere Dunes Unit.

annual that recruits new seedlings successfully in disturbed areas (Fischer et al. 1992). It has a tap root and branched stems, which make it easy to distinguish from *Leontodon taraxacoides* at a distance during the summer when both are flowering. Both *Leontodon taraxacoides* and *Hypochaeris glabra* have basal leaves that are entire or shallowly lobed. The specific epithet *glabra* implies that the leaves are glabrous (without hair), however this species was observed to have hair on occasion at the Lanphere Dunes Unit. To distinguish a hairy *Hypochaeris glabra* from *Leontodon taraxacoides* when they are not flowering, one can use a hand lens to examine the hairs. The hairs on *Hypochaeris glabra* are tapered, whereas the hairs on *Leontodon taraxacoides* are split in two at the end. The seeds produced by both *Leontodon taraxacoides* and *Hypochaeris glabra* are small and wind-dispersed. These are traits most commonly found in propagules of pioneer species of primary successions (Fenner 1987).

A third invasive species was common in experimental plots; *Parentucellia viscosa* (yellow glandweed), a member of Scrophulariaceae. It is a pasture weed native to Europe and introduced to the United States (Baker 1986). It is an annual hemiparasite that grows well in damp, grassy locations. A study in Western Australia lists 27 species that were shown to be parasitized by *Parentucellia viscosa*. Seven of these species are also found at Lanphere; one of which is *Hypochaeris glabra* (Pate and Bell 2000). Previous research at the Lanphere Dunes has shown that *Parentucellia viscosa* is hosted primarily by *Lotus purshianus*, although it is not truly host specific (Pickart and Wear 2000).

Ecosystems generally have several built-in barriers to invasion by nonnative species. These include competition with well-established native species, losses to predation and disease, a lack of pollinators or other necessary facilitators, and deleterious low densities which make it difficult to find a mate (Crawley 1987). At Lanphere Dunes, none of these barriers appear to exist to any effective degree for the studied organisms. There is limited competition for space and moisture. Though some insect predation of *Leontodon taraxacoides* was observed during this study, the impact appeared negligible.

Management plans have been developed to control several invasive plant species on dune ridges at Lanphere, but few studies have been conducted in the swales. Invasives *Hypochaeris glabra* and *Leontodon taraxacoides* are widely distributed at Lanphere, and management is needed to reduce their numbers. *Parentucellia viscosa* distribution is limited to localized invasions, but identification of an effective control method is a potentially valuable contribution.

MATERIALS AND METHODS

The initial research during summer 2005 was designed to explore how radiant heat treatments would affect survival of two plant species of Asteraceae that are invasive at Lanphere Dunes: *Leontodon taraxacoides* and *Hypochaeris glabra*. *Leontodon taraxacoides* is predominantly found in the swales, and *Hypochaeris glabra* is predominantly found on the dune ridges. A second experiment was designed in 2006 to determine whether or not radiant heat treatments could effectively reduce seed set of *Leontodon taraxacoides*. Throughout this paper, the primary plant inflorescences of these composite species will be referred to as “flowering heads,” after fruit maturation they will be referred to as “seedheads,” and the individual achenes as “seeds.”

Radiant heaters were used as the method of control in this study. They are used in an effort to control weeds in a relatively clean and focused manner. The heaters utilized in this study were Eco-Weeder Lady models manufactured by Swiss company Messerli Sessa. They are lightweight and portable, being the approximate size and weight of a common household line trimmer (Figure 3). They required one-pound propane tanks for fuel which provided enough energy for seven to eight hours of treatment. They can be an ideal tool for use in the control of weedy plant species in remote locations accessible only by foot. The radiant heater directs high temperatures onto plants which boils the moisture within plant cells. This causes the plant to wilt, and photosynthesis stops. It is used as a safer, more environmentally friendly way to control weeds than open flame treatments or herbicides. The initial treatment requires only a few seconds per plant, but additional treatments are likely to be needed (Favreau, 2003).

Figure 3. Radiant heater used in study.

Survival Experiment

Thirty-one plot locations were chosen in ridge, swale, and ridge-swale transition environments. Nine plots were in ridges, ten plots were in swales, and twelve plots were in transitional areas. At each location, three to four subplots were created that measured 2 by 2 meters - a Control subplot in the middle, at one end a Spot Treat subplot in which only *Hypochaeris glabra* and *Leontodon taraxacoides* were treated with the radiant heater, and at the other end a Plot Treat subplot in which the entire area was treated with the radiant heater (Figure 4). A coin toss determined which end subplot would receive which type of radiant heat treatment. At seventeen ridge and transitional plot sites, a fourth subplot of Hand-Pull treatment was added to the end of the plot, adjacent to either the Plot Treat or Spot Treat subplot. Hand-Pull treatments were not possible in swales. The dense swale soil combined with the fibrous root system of *Leontodon taraxacoides* made hand-pulling impractical.

Vegetation surveys were conducted at all subplots in May, 2005, to determine species composition and cover. A one-meter square sampling frame was used to assist in the ocular estimation of cover. Categories were included for litter, bare sand, and non-vascular species (mosses/lichens) in addition to all the individual vascular plant species. Each subplot was digitally photographed prior to and after treatment.

Radiant heat treatments were conducted from May 27 to June 3, 2005. Some individual plants of both *Leontodon taraxacoides* and *Hypochaeris glabra* recovered

Spot Treat	Control	Plot Treat	Hand-Pull

Figure 4. Example of plot configuration in survival experiment. Each subplot measured 2 meters by 2 meters.

from the treatment. Re-growth at the center of wilted *Leontodon taraxacoides* leaves occurred as quickly as two days after the first radiant heat treatment. For this reason, a second treatment was administered from June 13 to June 20, 2005. This second treatment was applied to individuals of the target species only. After the second treatment, in June, 2005, another assessment of *Parentucellia viscosa* cover was made.

Observations of *Leontodon taraxacoides* recovery in heat-treated subplots six weeks after the second treatment indicated that an additional experiment was needed to determine how *Leontodon taraxacoides* seed production was affected by radiant heat treatment. Therefore, a second study to examine fecundity was designed to begin in May of 2006 and extend until the end of the *Leontodon taraxacoides* 2006 flowering season.

In May and June of 2006, monitoring for plant species composition and cover was again conducted at the survival experiment plots using the same method utilized for initial monitoring. A Kruskal-Wallis one-way analysis of variance on ranks was used to determine whether there was a significant difference in cover of *Leontodon taraxacoides*, *Hypochaeris glabra*, and *Parentucellia viscosa* among treatment types from 2005 to 2006. A Kruskal-Wallis one-way ANOVA on ranks was also used to compare *Parentucellia viscosa* before and after treatment cover values recorded in May and June of 2005. The Kruskal-Wallis test was used because the data did not meet assumptions of normality. It compares average ranks instead of means.

Fecundity Experiment

This experiment focused on treating *Leontodon taraxacoides* individuals in transitional and swale regions. Thirty-one plots were created in areas where *Leontodon taraxacoides* was found at ground cover rates of at least 26 percent with consistent distribution within the plot site. The accompanying plant species varied from location to location, but generally included the natives *Lotus purshianus*, *Carex obnupta*, and various rushes. The plots measured two meters by one meter and were divided into two one-meter square subplots: one treatment and one control. A coin toss determined which subplot received the treatment. Each subplot was monitored for species composition and cover, and each was digitally photographed prior to and after treatment.

Leontodon taraxacoides cover was recorded, as well as the percentage cover of other identifiable vegetation to genus or species, including invasive *Parentucellia viscosa*. A one-meter square sampling frame was used to assist in the ocular estimation of cover. The first of two radiant heat treatments was applied to *Leontodon taraxacoides* individuals on May 30, 2006. In the survival study, the timing between the two heat treatments of subplots ranged from 12 to 18 days. The average number of days was 15.7, so the second treatment of the fecundity experiment was applied 15 days after initial treatment, on June 14.

Beginning on June 4, the number of *Leontodon taraxacoides* flowering heads observed was recorded for each subplot. Once fruits matured, seedheads were collected from both control and treatment subplots until seeding stopped. Continued monitoring of plots and collection of *Leontodon taraxacoides* seedheads was conducted every two to three days throughout the summer and fall and concluded in December, 2006. During the study, subterranean mammal burrowing was observed in three plots at the end of July and beginning of August. In two of these plots, more than 25 percent of a subplot was disturbed. This disturbance prohibited normal growth, flowering, and seeding of *Leontodon taraxacoides* throughout the season. The data gathered from these two plots were not included in statistical analyses.

Collected seedheads were counted and then stored in a freezer throughout the flowering season. When flowering stopped in December individual seedheads were randomly selected and examined for the number of seeds produced in each to determine mean seeds per seedhead in the treated versus control subplots. The number of seedheads examined was determined by taking a random sample size of at least 7 percent from each subplot, with an absolute minimum of 10 individuals examined per subplot. Eleven of the treated subplots required the 10 individual minimum. In those cases the percentage examined ranged from 9 to 20 percent. One-sample paired t-tests were used to compare seedhead and seed production in the treatment versus control subplots.

Monitoring was repeated in July of 2006 for *Parentucellia viscosa* to determine cover. These figures were compared by Kruskal-Wallis one-way ANOVA on ranks to the original *Parentucellia viscosa* cover for significance of treatment effect.

RESULTS

Survival Experiment

Within several weeks of treatment of entire subplots (Plot Treat) in 2005, there were indications that control of *Parentucellia viscosa* is possible with radiant heat treatments (Table 1). In plot locations where *Parentucellia viscosa* blanketed the area, there were almost no remaining individuals in the subplots that had been entirely treated and fewer in the subplots that had been spot-treated than in the control (Figure 5). A Kruskal-Wallis one-way analysis of variance on ranks showed a significant difference ($P < 0.000001$) in cover change of *Parentucellia viscosa* between the control and treated subplots several weeks after treatment. This trend was again observed in *Parentucellia viscosa* cover recorded during the fecundity experiment of 2006 (Table 1) with similar statistical findings ($P < 0.000001$).

In 2006, one year after treatment, there were losses of *Hypochaeris glabra* observed in all subplot types, but the mean cover losses were greater in heat-treated subplots than in hand-pull and control subplots (Table 2). *Leontodon taraxacoides* also experienced losses of cover in all subplot types with higher losses in the heat-treated subplots than in the hand-pull and control subplots (Table 2). One year after treatment, mean *Parentucellia viscosa* cover loss was observed only in the subplot in which the entire area had been treated (Table 2). Though these figures may imply that the treatments had an effect on survival, a Kruskal-Wallis one-way ANOVA on ranks found no difference of statistical significance among the four treatment types. The same statistical test did detect a difference between the years for *Hypochaeris glabra* (Table 3).

Table 1. Mean percent cover with standard error of *Parentucellia viscosa* illustrating cover change several weeks after treatments in 2005 and 2006.

	May 2005	June 2005	Increase or Decrease
Parentucellia viscosa			
Control	0.82(±0.34)	3.69(±1.52)	+349%
Plot Treat	0.69(±0.34)	0.11(±0.08)	-84%
Spot Treat	0.84(±0.27)	0.66(±0.34)	-21%
Hand-Pull	0.38(±0.20)	0.24(±0.15)	-38%

	May 2006	July 2006	Increase or Decrease
Parentucellia viscosa			
Control	1.03(±0.20)	8.19(±1.66)	+694%
Treated	1.06(±0.28)	0.47(±0.17)	-56%

Figure 5. Area of heavy *Parentucellia viscosa* growth several weeks after radiant heat treatment. Plot Treat subplot is outlined.

Table 2. Mean percent cover with standard error of *Hypochaeris glabra*, *Leontodon taraxacoides*, and *Parentucellia viscosa* illustrating change in cover from 2005 (before treatment) to 2006 (one year after treatment).

	2005	2006	Increase or Decrease
Hypochaeris glabra			
Control	3.73(±0.74)	2.23(±0.72)	-40%
Plot Treat	4.90(±1.06)	1.89(±0.53)	-62%
Spot Treat	4.10(±0.94)	1.44(±0.41)	-65%
Hand-Pull	3.50(±0.68)	2.00(±0.57)	-43%
Leontodon taraxacoides			
Control	14.65(±2.06)	12.90(±1.72)	-12%
Plot Treat	14.50(±2.08)	10.26(±1.35)	-29%
Spot Treat	13.39(±1.83)	9.47(±1.26)	-29%
Hand-Pull	7.09(±1.87)	5.56(±1.60)	-22%
Parentucellia viscosa			
Control	0.82(±0.34)	1.95(±0.82)	+137%
Plot Treat	0.69(±0.34)	0.60(±0.17)	-14%
Spot Treat	0.84(±0.27)	1.69(±0.65)	+102%
Hand-Pull	0.38(±0.20)	0.47(±0.19)	+23%

Table 3. Kruskal-Wallis one-way ANOVA on ranks results for *Hypochaeris glabra*, *Leontodon taraxacoides*, and *Parentucellia viscosa* comparing variation in cover change among the four subplot types from 2005 to 2006. N=31 in Control, Plot Treat, and Spot Treat subplots. N=17 in Hand Pull subplots.

Difference among treatments	P-value
Hypochaeris glabra	0.614722
Leontodon taraxacoides	0.144744
Parentucellia viscosa	0.988993
Difference between years	
Hypochaeris glabra	<0.000001
Leontodon taraxacoides	0.072618
Parentucellia viscosa	0.585081

Fecundity Experiment

Leontodon taraxacoides is known to flower and set seed from late spring to early autumn (Grimoldi et al. 1999), but at the study site flowering and collection of seedheads continued through to mid-December. By the end of the season, individuals in the treatment subplots had produced significantly fewer seedheads (mean = 187 ±18.43 SE) than those in the control subplots (mean = 477 ±35.65 SE) ($P < 0.000001$). Mean seedhead production in treatment subplots was 39.2 percent of that in control subplots.

The mean number of seedheads produced in the deeper swale control subplots 493 (±48.90 SE), was similar to the mean number of seedheads produced in the transitional control subplots 472 (±44.85 SE). However, mean seedhead production in corresponding treated subplots differed by environment type with 271 (±23.67 SE) produced in the treated swale subplots versus 160 (±20.13 SE) in the treated transitional subplots; indicating that higher soil moisture aids plant recovery after treatment.

There was also a noticeable variation in size of seedheads. Seedheads produced in control subplots appeared to be larger on average than those produced in treatment subplots. A count was done to determine the average number of seeds produced in each type of seedhead. From a 7 percent sample the control subplot seedheads produced significantly more seeds (mean = 51 ±1.01 SE) than treated subplot seedheads (mean = 36 ±0.89 SE) ($P < 0.000001$).

DISCUSSION

Survival Experiment

The survival experiment was designed to determine what, if any, effect radiant heating would have on *Leontodon taraxacoides* and *Hypochaeris glabra*. As has been observed in an earlier radiant heater experiment (Bach et al. 2004) deep-rooted species such as *Leontodon taraxacoides* and *Hypochaeris glabra* may appear to be wilted and dead a day or two after treatment, but can begin to recover from treatment within a week. Repeated treatments improve radiant heater efficacy.

Hypochaeris glabra was already flowering and fruiting in dune ridge plots by the time the vegetation survey began on May 20, 2005. *Hypochaeris glabra* leaves appeared to wilt from the radiant heat treatment, but any seedheads that had not yet opened did so and dispersed their seeds the day following treatment. The life cycle was still completed, though at a slightly accelerated pace. Several days after treatment, the *Hypochaeris glabra* plants began to re-grow their leaves (Figure 6). Some individuals also re-grew stems and produced additional flowering heads and seedheads. *Hypochaeris glabra* plants were observed to have a deep tap root, and it seemed that the reserves of these tap roots were sufficient to re-grow damaged portions of the plant.

Though the *Hypochaeris glabra* mean cover decrease was greater in the radiant heat-treated subplots than in the control and hand-pulled subplots, differences were not strong enough to be detected by statistical analysis. However, the change in cover from 2005 to 2006 irrespective of treatment was detectable. These decreases in *Hypochaeris glabra* cover could have been the result of an anomalous weather pattern.

Figure 6. *Hypochaeris glabra* and *Leontodon taraxacoides* re-growth following radiant heat treatment.

The winter of 2005-2006 produced a significant amount of rainfall in the study area. Total rainfall recorded at the closest rain gauge for this period was 60 inches while the preceding 30-year average rainfall was 42 inches (United States Department of Agriculture Forest Service Redwood Sciences Laboratory 2007). Rainfall in 2005-2006 was nearly 150 percent of normal. Flooding was extensive at Lanphere. Over twenty inches of rain fell from February through April. Many swales and transitional areas between the ridges and swales remained submerged at the beginning of the flowering season. This may have played a role in noticeable changes in species composition in the low-lying plots in 2006. In some plots several dune ridge species and areas of bare sand were found to be replaced by transitional and swale species. These plots were more densely vegetated than in the prior year. In other low-lying plots, many species were eliminated entirely, leaving sparse cover by just a few species.

Though *Hypochaeris glabra* was a target species for the radiant heat treatment, the disappearances documented here are not solely a result of the treatment. This is evident by the loss of cover in the control subplots. *Hypochaeris glabra* appears to have been reduced by flooding alone. The presence of standing water in low-lying plots late in the spring season may have prevented proper germination of seeds.

Radiant heat treatments in this experiment did not produce an effect that was statistically significantly different from the control, but the effects could be biologically significant. Being an annual, the mean cover numbers of 2006 reflect the recruitment rate of new individuals. The light, wind-dispersed seeds of *Hypochaeris glabra* need plant material or litter to catch them and keep them in place for eventual burial and germination in the windy dune environment. It could be that the reduction of plant litter resulting from the radiant heat treatment is what contributed to a lower germination rate in the heat-treated subplots.

Hypochaeris glabra was wilted by the radiant heat treatment and could potentially be treated prior to flowering to achieve a seed set reduction similar to that found in *Leontodon taraxacoides*. However, the ease with which *Hypochaeris glabra* can be manually pulled makes the radiant heat treatment a more time-consuming process than manual removal if the primary goal is to decrease the number of seeds released into the dunes.

Leontodon taraxacoides, in the wetter swale environment, seemed to have a later bloom time. Most *Leontodon taraxacoides* individuals had not yet produced flowering stems at the time of the first treatment from May 27 to June 3, 2005. Like *Hypochaeris glabra*, *Leontodon taraxacoides* individuals were capable of regrowth. By the second treatment, which was conducted from June 13 to June 20, 2005, *Leontodon taraxacoides* recovery and leaf re-growth was observed in 40 to 90 percent of established individuals in the heat-treated subplots.

In 2006 *Leontodon taraxacoides* mean cover in radiant heat-treated subplots showed losses that were more than twice the amount observed in control subplots, but these changes were not found to be statistically significant among treatments or by year. As in the case of *Hypochaeris glabra*, losses in the control subplots appear to have been the result of flooding, and some losses in treated subplots must have also been the result of flooding. A study on the effects of flooding on *Leontodon taraxacoides* found that under the condition of total submergence for 25 consecutive days, 50 percent of all individuals died. After submergence for 40 consecutive days, 100 percent of *Leontodon taraxacoides* individuals died (Grimoldi et al. 1999). Therefore, it is possible that many of the individuals observed in low-lying areas in 2006 were new germinants. Again, the effects of radiant heat treatments were confused by flooding and no difference of statistical significance could be found between radiant heat treatments and controls, but the lower rate of survival in the radiant heat-treated subplots could be biologically significant. From a land management point of view, these reductions might be enough to warrant using this device on *Leontodon taraxacoides*.

Immediate results observed within the 2005 and 2006 flowering seasons indicated that *Parentucellia viscosa* was effectively eliminated when exposed to radiant heat treatments, however past research at Lanphere Dunes confirms a persistent seedbank for this species (Pickart and Wear 2000) indicating that repeated treatment would be needed. In 2006, one year after treatment, *Parentucellia viscosa* was observed to have expanded its mean cover in all subplot types except for those in which the entire subplot area was treated; but this difference was also statistically insignificant. Because only *Hypochaeris glabra* and *Leontodon taraxacoides* were removed from the hand-pulled subplots, changes observed in these subplots for *Parentucellia viscosa* can be attributed to the effect of removal of potential host species *Hypochaeris glabra* and *Leontodon taraxacoides* or to accidental trampling.

The use of radiant heaters as a treatment for the targeted species was not intended as a single use approach, but to examine this method as one of many potential tools that could be used in a plant community-based integrated weed control/restoration plan. When conducting radiant heat treatments on a species, it will be important to treat the other invasives in the area so they will not spread into the newly created niche and replace what has been removed.

One limitation of this study was the extensive raining and flooding in the winter of 2005-2006. This could have overshadowed changes that may have been detected in the absence of flood effects. Species that had reached maturity and reproductive stages by the end of May in 2005 were not at this point until mid to late June in 2006. Additionally, there were losses of higher dune ridge species from the transitional areas, one of which was the target species *Hypochaeris glabra*. The higher dune ridge plots did not experience as significant a change in species composition and cover from 2005 to 2006. However, the rainfall anomaly provided a valuable record of the rapidity of species turnover in these habitats in response to environmental fluctuations.

Another limitation is that this study records only a brief snapshot of time. Continued monitoring of plots such as these over a number of years would reveal more information regarding the changes in vegetation taking place at Lanphere Dunes. For instance, changes in the ratio of nonnative to native plant species cover could be ascertained.

Fecundity Experiment

The fecundity experiment was designed to determine whether or not radiant heat treatments could effectively reduce seed set of *Leontodon taraxacoides*. Rejmánek (1989) stated that, among other factors, a successful invasion will be dependent upon the number of nonnative propagules introduced into the ecosystem annually and the length of time this importation continues. This is a phenomenon dubbed “propagule pressure” in the literature (Levin 2006). By these criteria, *Leontodon taraxacoides* has been successful at colonization at Lanphere. A reduction of propagule pressure can curb that success.

After treatment, flowering head numbers in the control subplots steadily increased while treatment flowering head numbers remained low. Treatment subplots did not begin to flower in earnest until two weeks after the second treatment. From that point on the flowering in treatment subplots also steadily increased (Figure 7). The two bouts of radiant heat treatments appear to have delayed the onset of flowering by approximately three weeks. The first plots to flower were those that were drier and more sparsely vegetated. The last to flower were in a deeper swale region. The wettest swale plots were the last to flower in both control and treatment subplots. Just as flowering was delayed by the radiant heat treatments, so was seedhead maturation (Figure 8).

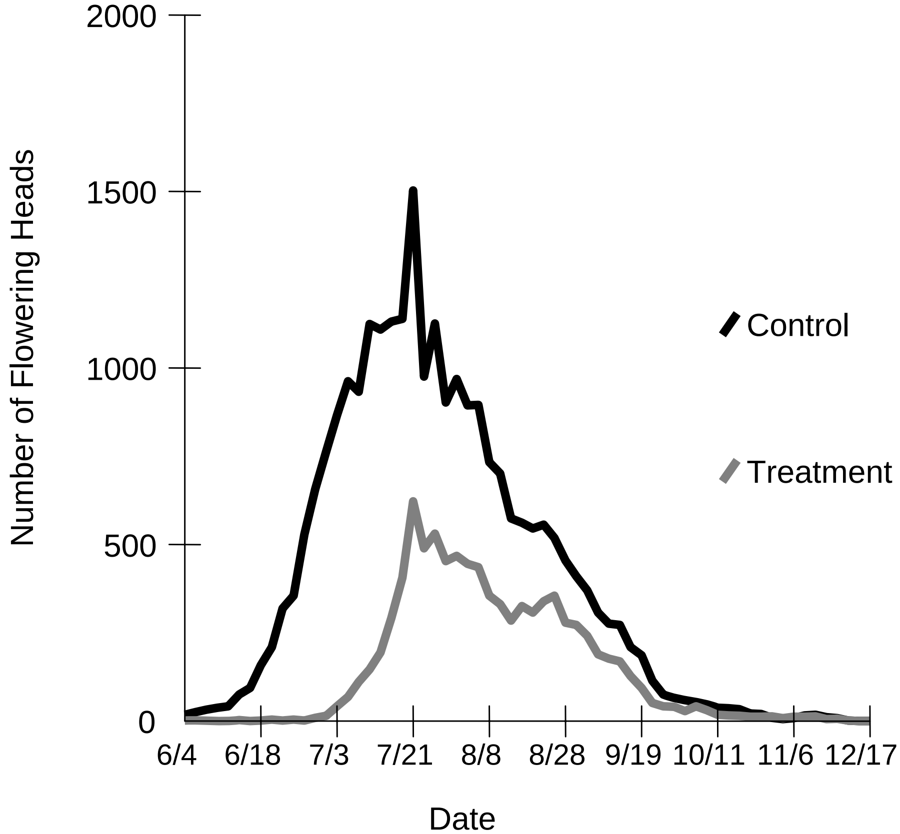

Figure 7. Number of flowering heads observed in control and treatment subplots during the 2006 growing season. Treatment appears to have delayed onset of flowering head production by approximately three weeks.

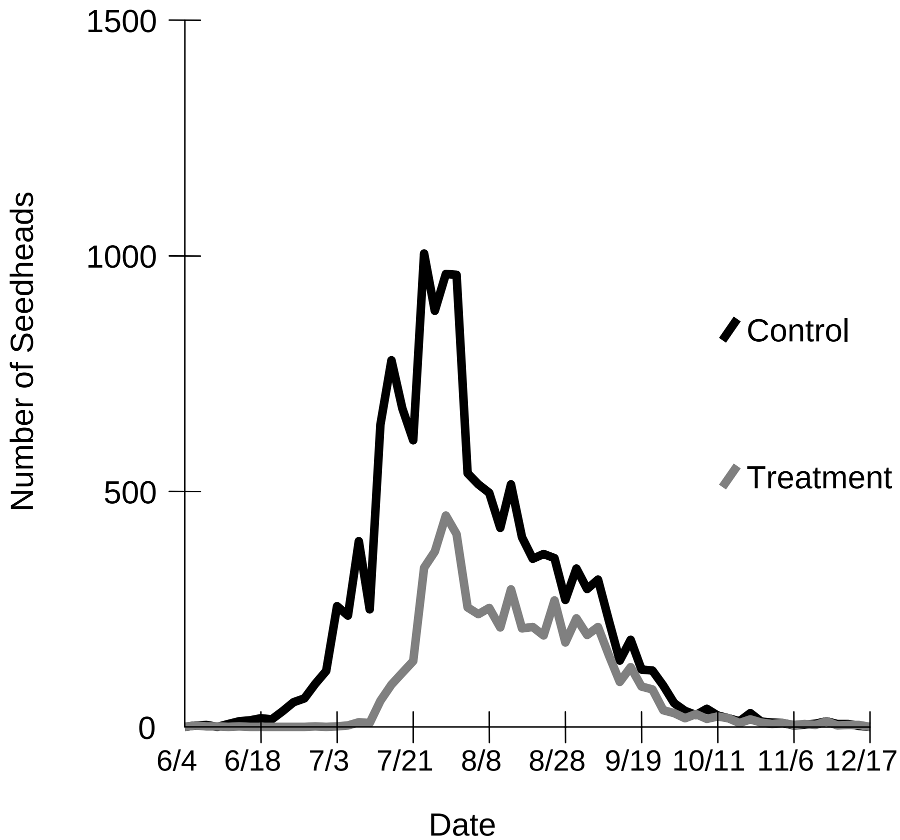

Figure 8. Number of seedheads collected from control and treatment subplots during the 2006 growing season. Treatment appears to have delayed onset of seedhead maturation by approximately three weeks.

Seedhead reduction in treatment subplots ranged from 31 to 84 percent of seedheads produced in control subplots. Possible reasons for the wide range, aside from treatment effect, include differing soil moisture levels in different locations, the effects of surrounding vegetation types, the timing of flowering and seeding of *Leontodon taraxacoides*, the variability of temperature emitted by the radiant heater, and insect predation. It appeared that a treated subplot would produce a higher proportion of seedheads if it was in a wetter, deeper transitional or swale environment. If soil moisture affects the timing of flowering and seeding as well as the recovery of radiant heat-treated individuals, timing of radiant heat treatments could be a crucial factor in terms of efficacy.

Though the radiant heat treatments of 2006 did not eliminate the *Leontodon taraxacoides* individuals, less biomass was allocated to reproduction in treated individuals than in controls. This same tendency was observed when *Leontodon taraxacoides* was exposed to varying levels of flooding (Grimoldi et al. 1999). In both cases, resources that would have been used for reproductive purposes were diverted to recovery of photosynthesizing leaves to help ensure survival. The overall impact was production of fewer seeds and seedheads, thereby reducing propagule pressure. And though a relatively large number of seeds were still produced in treatment subplots, the percentage of seeds that germinate in nature can be very low (Bazzaz 1986). Consistent reduction of seed set with radiant heating may make great strides in managing and even reducing cover of *Leontodon taraxacoides*.

One potential limitation of this study has to do with the variability of temperature emitted by the radiant heater. The gas valve is either closed or open to some degree. Therefore, the results of treatment can be somewhat inconsistent, especially when the gas tank is nearly empty. During this study, one gas tank change was made. It was done during the second round of treatments by two plots that produced a higher percentage of seedheads when compared to neighboring plots in the immediate vicinity. It seems possible that the intensity of heat applied was waning at that time.

Another limitation was that insect predation was not anticipated and planned for. When possible, insect predation was recorded. These were cases in which *Leontodon taraxacoides* flowering heads were observed to have been partially eaten. The partially eaten flowering heads were collected, but not included in the day's tally of flowering heads observed. Fenner et al. (2002) examined the correlation between flowering head size and infestation of seed-eating insect larvae. They found that the average rate of infestation on *Leontodon taraxacoides* capitula was 2 percent. The recorded predation in this study was closer to 1 percent, but only flowers that were partially eaten were counted. If a flowering head had been eaten down to the stem, it would have been indistinguishable from stems that had been cut as a result of seedhead collection.

CONCLUSIONS AND RECOMMENDATIONS

Radiant heating, the method used in this study, is a relatively new method of weed control. Through this study some advantages have been identified. Radiant heating can be targeted on a small space, sparing the surrounding native vegetation. The device itself is lightweight and can be carried long distances to remote locations for treatment. The cost is minimal once the initial investment is made for the device as it runs on one-pound tanks of propane. A one-pound tank can last for almost eight hours. One disadvantage is that the method is time intensive. During the 2006 treatments, I noted how many square meter subplots I was able to treat in an hour. The number of subplots treated in an hour was twelve. There was some time that elapsed during the travel from plot to plot and the outlining of the treatment area with a border, however this type of treatment does take more time than an herbicide application or open flame treatment.

Radiant heating appears to be effective as a method of control for some invasive species at Lanphere Dunes. The degree of this effectiveness varies from species to species. When examining overall cover of the invasive species targeted in this study, the spot treatment did as well as the treatment in which the entire subplot was treated. Since it requires less time and fewer materials, I recommend spot treatment on targeted invasive species for Lanphere Dunes unless litter reduction is also desired. Invasives nearest the targeted area should also be treated to avoid the spread of unheated invasives into the treatment area. It may be possible to combine this method with other treatments for optimal results, but further experimentation is needed.

This method of control can reduce the seed set of *Leontodon taraxacoides* in dune ridge and swale environments at Humboldt Bay when the timing of treatments immediately precedes flowering. The optimal number of treatments per flowering season and timing of said treatments may be determined by future studies. Though radiant heat treatments are labor and time intensive for a large area in need of treatment, such as Lanphere Dunes, it may be safer for the surrounding flora and fauna than herbicides and open flame treatments. Additional studies are proceeding to determine whether native vascular and nonvascular flora or fauna are negatively affected by radiant heating to a significant degree. A future study may also be done to determine the level of viability of seeds produced by treated *Leontodon taraxacoides* individuals.

I would not recommend radiant heating as a control method for *Hypochaeris glabra*. The tap root of *Hypochaeris glabra* and its tendency to recruit in looser soils make even time and labor intensive hand-pulling a quicker and easier method of control than radiant heating. Further study could determine whether radiant heat treatments reduce *Hypochaeris glabra* seed set, but given the ease with which it can be manually removed, that appears to be a more effective option. *Hypochaeris glabra* begins flowering earlier in the spring than *Leontodon taraxacoides*. My recommendation for the timing of *Hypochaeris glabra* is to begin removal just prior to the blooming of flowers.

Radiant heating has a dramatic effect on survival of *Parentucellia viscosa*. My recommendation for the timing of treatment would be as soon after seedling emergence as possible. Seedlings are small, treatment is quick at this stage, and the plants do not recover to reach the flowering and fruiting stages. Repeated applications would be needed until the seedbank is depleted, and future studies may determine the longevity and feasibility of this method.

This study has generated several questions for future studies. Would additional treatments have a bigger impact on control of the deep-rooted species? How should treatment timing vary when considering moisture levels in the soil and surrounding vegetation? What is the germination rate of seeds from treated individuals as opposed to seeds from untreated individuals? Are seeds that have already developed affected by exposure to the radiant heater? Is there a time limit on the viability of *Leontodon taraxacoides* seeds? Can *Parentucellia viscosa* be killed with only one radiant heat treatment? Future studies may also include active restoration of native species. There is evidence that restoration of native plant species can constrain invasion, though species differ in their effectiveness in this service (Bakker and Wilson 2004).

An important thing to consider when using a radiant heater for control of nonnative plant species is that life history traits vary from species to species. The mechanisms of survival and reproduction of each plant species will in large part determine when and how often treatment will need to occur. With attention to this level of detail, radiant heating can be an effective invasive plant management tool.

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