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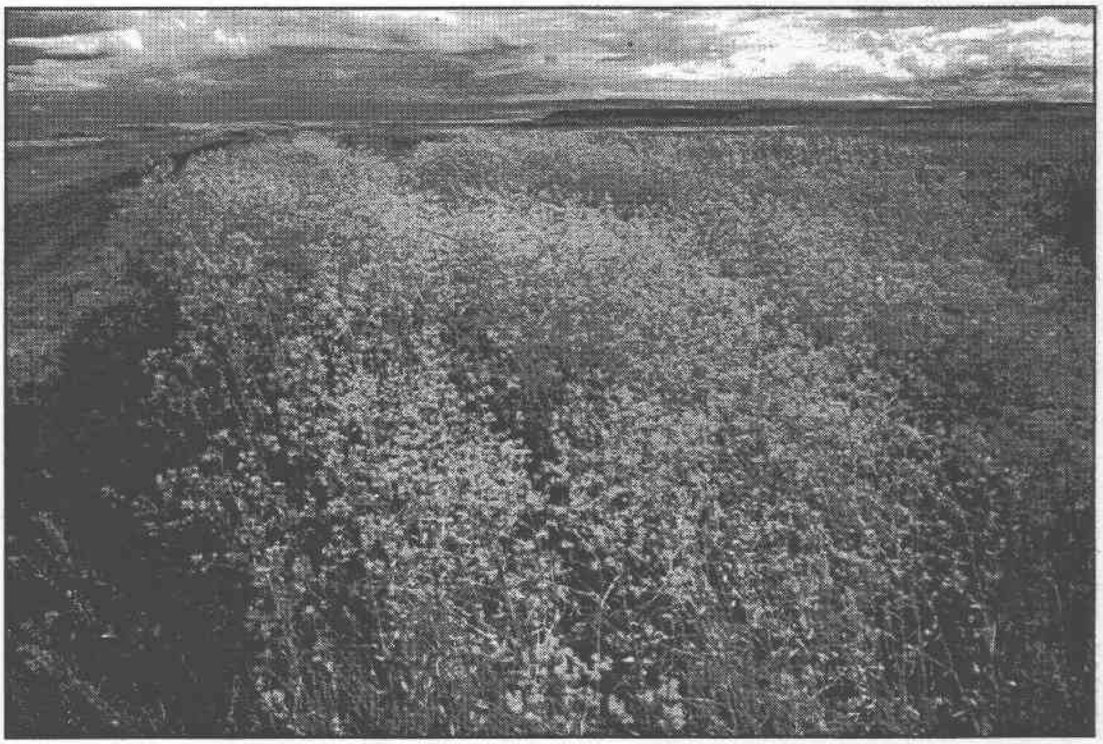
Management of Perennial Pepperweed (tall whitetop)



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Front Cover: Perennial pepperweed infestation located in Harney County, Oregon.

Photo By Leslie Richman

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ACKNOWLEDGMENTS

Many people contributed to the Perennial Pepperweed Symposium, and to these proceedings, which are an extension of the symposium. The initial idea for the symposium arose from a series of six "weed awareness" meetings held at various locations around Harney County (southeastern Oregon). The meetings were conceived and planned by the Harney County Weed Board and its advisory committee. The meetings covered economic impacts, identification, distribution, and control of rangeland weeds. At each meeting, perennial pepperweed was listed as a major concern. The suggestion of a symposium surfaced at one of the later meetings. I think the symposium was originally proposed by Leslie Richman of the Burns District Bureau of Land Management. Leslie has been actively involved in weed issues, and she took an active part in planning the symposium. Members of the Harney County Weed Board were very supportive and provided assistance whenever necessary. Individuals donated their time, but putting on a symposium and publishing a proceedings still costs money. Tammi Anderson of the Harney Soil and Water Conservation District applied for and received a grant from the Governor's Watershed Enhancement Board (GWEB) to cover the costs. Given the potential negative impacts of perennial pepperweed on watershed values, GWEB seemed like a logical supporter of the efforts. Tammi was also active in making local arrangements and getting publicity for the symposium. Many other individuals assisted in the publicity arena; getting the word out to the private landowners, refuge managers, etc., and I thank each of them for their efforts. There were about 75 attendees from at least six states.

This proceedings is a collection of the papers that were presented at the symposium. The authors did a fine job of presenting the material and the session ran longer than planned because of the many questions and the lively discussion from the audience. I thank the authors for being so prompt in sending me written (and electronic) copies of their talks. Thanks also to Roger Sheley and David Ganskopp for reviewing the initial draft of the proceedings. Carol McDonald had the substantial task of putting all the material together into one coherent document that we could send to Extension and Experiment Station Communications at Oregon State University for final editing and publication. As always, she handled the job with speed and efficiency.

INTRODUCTION

Tony Svejcar

Not too long ago, there would have been very limited interest in a symposium focused on perennial pepperweed (*Lepidium latifolium* L., also called tall whitetop). Until quite recently the interest in this species was relatively localized and it did not generate the degree of concern associated with some of the major upland weeds. All that has changed. Perennial pepperweed can totally dominate some of the most productive ecosystems of the arid West, i.e., wetlands and riparian areas. Perennial pepperweed occurs in most western states. I suspect it has the potential to invade similar habitats in Canada and Mexico, if it has not already done so.

During our preparation for the symposium, it became clear that this species was of concern to a wide cross-section of land managers; from private landowners with flood meadows and alfalfa ground to wildlife refuge managers and biologists whose primary concern was production of waterfowl. Discussions during the symposium suggested that perennial pepperweed invasion doesn't severely impact waterfowl production early in the invasion cycle. However, once it forms a closed stand, the density of stems may severely restrict waterfowl nesting. We also heard concerns about the difficulty of using chemical control on a species that inhabits wetlands.

Although perennial pepperweed has only recently made it to the limelight, this species has been with us for a long time. This point arose during communications and discussions associated with the symposium. File photos from northwestern Wyoming date some of the perennial pepperweed infestations to at least the 1940s. Residents of our county report seeing scattered individuals of this species in the 1960s. An interesting question then is: why has it taken so long for perennial pepperweed to become the problem it is today? Given its prolific growth form and seed production it seems odd that this species would not have spread and dominated habitats earlier.

Because concern over perennial pepperweed surfaced only recently, there has not been a great deal of research on this species. One of our goals for this meeting was to invite as many researchers and managers as we could that have worked with perennial pepperweed. I think the papers that follow represent the best current information available, and hope that the material will be useful to others currently struggling against this threat to both agriculture and wildlife.

INTEGRATED WEED MANAGEMENT

Roger L. Sheley

INTRODUCTION

The magnitude and complexity of pasture and rangeland weeds, combined with their cost of control, necessitates using Integrated Weed Management (IWM). IWM involves the use of several control techniques in a well-planned, coordinated, and organized program to reduce the impact of weeds on pastures and rangelands. Inventory and mapping is the first phase of any IWM program. The second phase includes prioritizing the management of weed problems, and choosing and implementing control techniques strategically for a particular weed management unit. The third phase is adopting proper range management practices as a portion of the IWM program. The IWM program must fit into an overall range management plan.

Inventory

Inventory is the first phase of all IWM programs. The goal is to determine and record the weed species present, area infested, and density of the infestation. Soil and range types, and other site factors pertinent to successfully managing the infested rangeland should also be documented. Inventories can be conducted by field surveys, aerial photography, and geographic information systems.

Planning and Implementation

Planning and implementing an IWM strategy is the second phase of a rangeland weed management program. Planning is the process by which problems and solutions are identified and prioritized, and an economic plan of action is developed to provide direction for implementing the IWM program. Implementing an IWM includes, preventing encroachment into uninfested rangeland, detecting and eradicating new introductions, containing large-scale infestations, controlling large-scale infestations using an integrated approach, and often, revegetation. The key component of any successful weed management program is sustained effort, constant evaluation, and the adoption of improved strategies.

Preventing weed encroachment. Preventing the introduction of rangeland weeds is the most practical and cost-effective method for their management. Preventative programs include such techniques as limiting weed seed dispersal, minimizing soil disturbance, and properly managing desirable vegetation. New weed introductions can be minimized by:

1) using hay, feed grain, straw, and mulch that are free of weed seeds;
2) refraining from driving vehicles and machinery through weed infestations, and cleaning the undercarriage of vehicles and machinery after driving from a weed infested area to an uninfested area;
3) allowing livestock to graze weed infested areas only when weeds are not flowering or

producing seeds, or moving livestock to a holding area for about 14 days after grazing a weed infested area, but before moving them to weed-free areas;
4) requesting that campers, hikers, and sportsmen take care in brushing and cleaning themselves and equipment when recreating in weed infested areas;
5) minimizing unnecessary soil disturbance by vehicles, machinery, waterflow, and livestock;
6) managing grasses to be vigorous and competitive with weeds.

Detecting and eradicating new introductions. Early detection and systematic eradication of weed introductions are central to IWM. Weeds encroach by establishing small satellite infestations, which are generally the spreading front of the large infestation. Eradication is employing appropriate management to totally remove the weed from the area and is achievable on a small scale. An eradication program includes delimiting the boundaries of the infestation (on-the-ground and on maps), determining the proper control procedures and the number and timing of follow-up applications. This generally requires aggressive annual applications of herbicides. Revegetation of infested areas may be required to eradicate weeds in areas that don't have an understory of desirable species that can re-occupy the site after weeds are controlled. Eradication of small patches requires continual monitoring and evaluation to ensure successful removal of the weed.

Containing large-scale infestations. Containment programs are generally used to restrict the encroachment of large-scale weed infestations. Studies have shown that containing weed infestations, which are too large to eradicate, is cost-effective because it preserves neighboring uninfested rangeland and enhances the success of future large-scale control programs. Containing a large-scale infestation requires using preventative techniques, which often includes spraying herbicides on the border of weed infestations to stop the advancing front of weed encroachment.

Large-scale weed control. Most successful large-scale weed management programs are completed in a series of steps. Weed control areas should be divided into smaller units to make them more manageable. Weed control should be carried out unit by unit at a rate compatible with economic objectives. Initially, large-scale weed control should focus on range sites with an understory of residual grasses and the highest potential productivity. Suppressed grasses have the greatest chance of re-establishing dominance on these sites. These areas must be spot treated each year to ensure control and minimize re-invasion. In most cases, some percentage of the management unit will require that control measures be repeatedly applied until the weed seed bank and root reserves are exhausted. Next, control efforts should focus on the sites adjacent to those initially treated to minimize re-introduction of the weeds. Usually, large-scale control is most effectively applied from the outside of the weed management unit inward toward its center. Selection and application of weed control techniques in large-scale control programs depends on the specific circumstances for each portion of the management unit. Control techniques used in one area of the management unit may be inappropriate for another area. For example, sheep grazing leafy spurge in one area may provide cost-effective control, but sheep do not readily eat spotted knapweed and herbicides may be more appropriate. Similarly, the most effective herbicide for a particular weed species may not be labeled for use in an environmentally sensitive area. Selection will depend on 1) the weed species, 2) the effectiveness of the control technique,

3) availability of control agents or grazing animals, 4) use of the land, 5) length of time required for control, 6) environmental considerations, and 7) relative cost of the control techniques.

Researchers are showing that combining treatments will provide a synergistic response in controlling weeds. Experimenting with combinations of control techniques may provide better and longer term control than any singly applied treatment. For example, in areas with adequate precipitation, combining picloram with fertilizer can increase the longevity of spotted knapweed control and triple the forage production that would result under either treatment applied alone.

Revegetation. Revegetation with desirable plants may be the best long-term alternative for controlling weeds on sites without an understory of desirable species. Establishing competitive grasses can minimize the re-invasion of rangeland weeds and provide excellent forage production. In most areas, a fall herbicide application after weeds have emerged, followed by plowing or discing, and seeding, is most effective for establishing desirable species.

Proper range management

Adopting proper range management practices in conjunction with the IWM program is the third phase to successful weed management. Follow-up management determines the longevity of weed control. Proper livestock grazing is essential to maintain competitive desirable plants, which will help prevent weed re-invasion after control. A grazing plan should be developed for any management unit involved in a weed management program. The plan should include altering the season of use and stocking rates to achieve moderate grass utilization. Grazing systems should rotate livestock to allow plants to recover before being regrazed and promote litter accumulation. Range monitoring and annual evaluations should be conducted to determine the adequacy of existing management. Limited early season use is critical to any grazing system designed for weed management.

Monitoring and evaluations. Monitoring is done to determine what is happening on the range over time. Monitoring and evaluation are the keys to determining when weed and/or grazing management needs to be changed. Monitoring involves making observations, gathering data and keeping records on the range condition and trend. Monitoring must be designed to detect changes in weed and desirable plants, biological control agents, as well as soil surface conditions. Management practices (e.g. grazing utilization patterns) and factors affecting condition and trend must be monitored as well. Monitoring data must be compared to earlier years, and weed management programs must be adjusted according to the predetermined management objectives. The use of herbicides outlined in this section is only one tool that should be combined with biological or plant competition to be most effective.

INFLUENCE OF INVASION OF PERENNIAL PEPPERWEED ON SOIL PROPERTIES

Robert R. Blank and James A. Young

Problem Statement: Perennial pepperweed (*Lepidium latifolium*) is a weed native to southeastern Europe and Asia that has become widely distributed in western North America and in coastal New England. A survey conducted during the summer of 1993 revealed that perennial pepperweed is a major weed pest in wetlands in all western states except Arizona. Since that time, perennial pepperweed has encroached into Arizona. The weed is found in all but three counties in California, and in a contrasting environment, all but two counties in Nevada. Perennial pepperweed was reportedly introduced into California as a contaminant of sugar beet seed. Perennial pepperweed is also a serious weed concern in northern Europe and now characterizes virtually every landfill there. This weed is also a problem in Australia.

Perennial pepperweed has not generated a lot of interest among regulatory weed suppression agencies as it initially invaded riparian areas rather than agronomic cropland. By the time it was recognized, the infestations were so well established that eradication was considered impossible.

During the last decade, wetlands and riparian habitats have become recognized as extremely important components of ecosystems. Knowledgeable individuals have suddenly realized that perennial pepperweed has completely altered the species diversity, structure, and function of these riparian areas all over the western United States. Moreover, it has spread along irrigation structures and now is a major problem in irrigated pastures, native hay meadows that are an essential part of livestock production systems, agronomic fields, and urban landscaping.

What was done? Our main study area is north of Honey Lake, California and encompasses the Honey Lake Wildlife refuge. We compared, in similar landscapes and soils, perennial pepperweed invaded areas with non-invaded controls. Soil pits were excavated to compare the soil's visual characteristics and collect samples for laboratory analyses.

RESULTS AND DISCUSSION

The study area is on the flat post-pluvial basin of Lake Lahontan. The soils are slightly saline and sodic, generally fine-textured, with compact and hard natric subsoils. Examination of soil profiles revealed striking differences between perennial pepperweed infested areas and similar non-invaded areas (Table 1). Perennial pepperweed invaded areas have thick organic and debris-rich O horizons lacking in native hayland. Most interesting is the modification of the compact subsoil to a friable black subsoil. It appears that perennial pepperweed can, in some situations, ameliorate deleterious soil properties.

Table 1. Soil descriptions and selected attributes for perennial pepperweed infested and non-infested control.[1]

Horizon	Depth	Structure	EC	% C	C:N	Horizon	Depth	Structure	EC	% C	C:N
	cm						cm				
Infested						Non-infested					
					O1	0-+5			1.3	32.71	13.3
.A	0-5	granular	5.4	14.0	14.2	A	0-15	granular	5.8	14.24	9.2
Btn	5-18	columnar	3.4	3.48	12.9	Bty	15-28	prismatic	8.0	3.75	11.1
Bt1	18-33	prismatic	2.5	0.50	18.8	Bt	28-56	prismatic	12.0	0.42	15.1
Bt2	33-48	prismatic	2.4	0.43	111.0	BC	56-76	blocky	11.8	0.29	12.8
BC	48-68	blocky	3.6	0.42	59.7	C	76-106	blocky	22.0	0.33	10.4

[1] Soil described at the Mapes Ranch just north of Honey Lake, CA on July, 1992. Non-infested area is used as native hayland.

This ameliorative influence is supported by data collected on the Honey Lake Wildlife refuge (Table 2). In this study samples were collected, by depth, from the center of perennial pepperweed colonies that were no older than four years. The lower depth corresponds to the top of the natric subsoil. These samples were paired with adjacent non-invaded areas occupied by tall wheatgrass planted in 1989. In the top of the natric horizon, both water-soluble sodium and the sodium absorption ratio (SAR) were significantly less on perennial pepperweed invaded areas. Decreased sodium content and lowered sodium absorption ratios would lead to more favorable soil structural properties, which corroborate physical evidence from soil pedons.

The decrease in sodium in the subsoil appears to be partially offset by plant uptake and deposition at the soil surface in perennial pepperweed invaded areas (Table 2). This increase in sodium content of surface soil as well as an increase in several other solutes (Table 2) cautions that long-term invasion by perennial pepperweed may increase the osmotic potential of the soil surface, which will negatively impact seed germination and growth of salt-intolerant species.

A key in long-term control of invasive weeds such as perennial pepperweed would be to understand how it is so competitive. Perennial pepperweed is both a prolific seed producer and can rapidly expand via a creeping rhizome. Moreover, it's ability to spread and form dense monocultural stands that retard light penetration to the soil surface would be another competitive advantage. A most important aspect in perennial pepperweed competitiveness is its rapid growth rate compared to native flora. This rapid growth must occur in concert with rapid nutrient uptake, especially uptake of nitrogen. It appears that a mechanism to assure adequate nitrogen uptake of the species occurs via elevated enzyme activities in the soil (Table 3). If we can determine how perennial pepperweed modifies the soil environment to elevated nitrogen enzyme activities (root exudates, modification of soil microbial populations) we may be able to target a specific pathway to decrease nitrogen uptake of perennial pepperweed. In this scenario, more nitrogen-efficient native plants would be able to elevate their competitive profile relative to perennial pepperweed.

Table 2. Solutes in saturation extracts from intact soil cores, by depth, of perennial pepperweed invaded and adjacent non-invaded areas planted to tall wheatgrass (four replicates).[1]

	Depth 2-10 cm		Depth 22-30 cm	
Attribute	Grass	P. pepperweed	Grass	P. pepperweed
Potassium (mg kg-[1])	8.1[a]	30.3[b]	7.6[a]	23.1[b]
Calcium (mg kg-[1])	21.1[a]	68.8[b]	18.4[a]	88.3[b]
Nitrate (mg kg-[1])	13.9[a]	35.0[b]	9.3[a]	22.2[b]
Sodium (mg kg-[1])	377.0	775.0	2275.0[a]	436.0[b]
SAR	4.9[a]	2.7[b]	9.3[a]	3.0[b]

[1] Material collected on the Honey Lake Refuge, June 13, 1996. For each depth increment, significant ($P \leq 0.05$) differences between grass and perennial pepperweed microsites were deduced by ANOVA with mean separation using Duncan's test. Means followed by different letters are statistically different at $P \leq 0.05$ level.

Table 3. Soil enzyme activities, 0-20 cm, of asparaginase and urease in perennial pepperweed invaded and non-invaded control.[1]

Enzyme		Grass	Perennial pepperweed
Asparaginase activity	μmoles g^{-1} h^{-1}	0.70[a]	2.91[b]
Urease activity	μmoles g^{-1} h^{-1}	2.71[a]	5.10[b]

[1] Material collected June 13, 1996 at Honey Lake Wildlife Refuge. Significant ($P \leq 0.05$) differences between grass and perennial pepperweed microsites are deduced by ANOVA with mean separation using Duncan's test. These enzymes cleave amine groups from asparagine and urea, respectively. Means followed by different letters are statistically different at the $P \leq 0.05$ level.

PERENNIAL PEPPERWEED (*Lepidium latifolium*) ROOTING CHARACTERISTICS

Shay O. Wotring, Debra E. Palmquist, and James A. Young

Problem:

One aspect of the biology of perennial pepperweed that makes this weed especially difficult to control is the mass of creeping roots that develop in the surface soil. The rootstocks provide a bank of living tissue for re-infestation when the tops are removed mechanically or by herbicides. With mechanical tillage, the cut portions of the roots produce buds that sprout new plants. The purpose of this study was to develop a bioassay system to determine the reproductive potential of perennial pepperweed roots after mechanical or herbicidal treatments.

Purpose of Study:

Experiment Number One: To determine the influence of root diameter on the sprouting and regrowth of perennial pepperweed plants.

Experiment Number Two: To determine the influence of applications of the herbicide 2,4-D on the sprouting of perennial pepperweed root buds.

Experimental Procedures:

Experiment Number One: Perennial pepperweed roots were collected in the field and divided into diameter classes from 0.5 to 4.0 cm. Each root section was 2.5 cm long. The root sections were planted in flats of soil in the greenhouse in randomized complete block experimental design. Emergence and shoot growth was measured daily. Two, 1-way Randomized Complete Block Analyses of Variance were performed (one for % sprouting, and one for sprout length). Treatments consisted of the root diameter classes and blocks were the flats in the greenhouse containing roots of varying diameter sizes.

Experiment Number Two: Perennial pepperweed roots were collected from replicated field experiments that had received 2 lb/ac of an amine of 2,4-D ([2,4-dichlorophenoxy]acetic acid) at the flower bud stage of growth the previous summer. The stems were cut in 2.5 cm sections. Roots were collected from untreated control plots from the same experimental design. The roots were planted in flats containing soil and kept moist in the greenhouse.

Results

Experiment Number One. The sections of perennial pepperweed roots sprouted profusely.

Table 1. Perennial pepperweed root sprouting in relation to root diameter. Summer 1993, USDA-ARS, Reno, NV.

Root diameter Classes cm	Sprouting Length (%)	Sprout cm
0.05 - 0.75	89	4.8
1.00 - 1.25	33	10.0
1.50 - 1.75	68	5.7
2.00 - 2.75	68	19.1
3.00 - 4.00	56	14.2

Despite considerable differences among the means for both percentage sprouting and shoot growth, there were no significant differences ($P \geq 0.5$). The important point is all diameter classes of perennial pepperweed roots produced abundant shoots.

Experiment Number Two: There was a significant ($P \geq 0.05$) difference in sprouting between the control and 2,4-D treated perennial pepperweed roots, even accounting for the significant relationship between the covariate of initial root weight and number of sprouts. Only 5 percent of the treated roots sprouted, while 50 percent of the control roots sprouted. Unfortunately, we know from experience with field plots that the 5 percent sprouting is sufficient to result in complete recolonization of the treated plots by the end of the first growing season following herbicide treatment.

Discussion

In other experiments we determined that even when perennial pepperweed roots were cut much shorter than the 2.5 cm segments used in this experiment, proficient sprouting occurred. Using normal tillage treatments (disk harrow) it is not possible to cut the majority of the roots to the 2.5 cm size, much less into smaller segments. Several times in this experiment it was noted that 2.5 cm segments produced more than one sprout. Several times in the experiment it was noted that 2.5 cm segments produced more than one sprout. The shoots produced by these perennial pepperweed segments, which were planted in early summer in the greenhouse, produced flowers and seed in late summer.

The results of the herbicide-treated root experiment indicates that considerable quantities of 2,4-D was being translocated to the roots. Unfortunately, it did not prevent sprouting of sufficient root buds, whereby the control became ineffective at the end of the second growing season. Obviously, the influence of repeated treatments with 2,4-D, either in the same season (early flowering and fall) or in subsequent years, needs to be studied. It is also important to know *which* roots sprout after 2,4-D applications. Is it a specific portion of the roots of all plants, or a portion of the roots of specific plants? If it is the roots of specific plants that sprout, repeated treatments with 2,4-D may select for herbicide resistance.

Potential for Biological Control of Perennial Pepperweed (*Lepidium latifolium* L.)

J.L. Birdsall, P.C. Quimby, Jr., T.J. Svejcar, and J.A. Young

INTRODUCTION

Perennial pepperweed (*Lepidium latifolium* L.) in the Brassicaceae family ("crucifers") is a herbaceous perennial weed that reproduces by seed and stoloniferous rhizomes. This species is native to southern Europe and western Asia, but now inhabits Mexico, Canada, and many parts of the United States including the Atlantic Coast and all of the far western states except Arizona (Whitson et al. 1992, Young et al. 1995). Perennial pepperweed readily spreads along river systems where plants infest riparian and wetland areas (Young et al. 1995). This weed also establishes in waste places, ditches, irrigated land, roadsides, croplands, and fields.

Several features of perennial pepperweed make this species very difficult to control with conventional measures. Mechanical control of perennial pepperweed is limited as new plants easily sprout from root buds contained on small sections of the creeping roots (Young et al. 1995). Grazing is inhibited as a control measure because of the persistence of semi-woody stems. Before grazing can be used in the early spring to suppress this weed, the old stems must first be reduced by mowing, brush beating, or burning. Grazing may also be impractical as a control measure if perennial pepperweed proves to be poisonous to livestock. Most cases of suspected
poisoning occurred under confined conditions where horses were fed hay containing perennial pepperweed (Young et al. 1995).

Perennial pepperweed may be similar to whitetop [*Cardaria draba* (L.) Desv.] in plant response to herbicides. Whitetop is difficult to control chemically due to the short period of maximum carbon allocation to below ground tissue, the large proportion of below ground tissue, and the wide variation in phenology among plants at any given time (Miller et al. 1994). While phenoxy herbicides easily kill the tops of perennial pepperweed, the root and crown buds rapidly sprout and require repeated treatments (Young et al. 1995). The sulfonylurea herbicides have shown some promise for control. Dupont recommends controlling perennial pepperweed with 0.75 oz of Escort® (metsulfuron) or 1 oz of Telar® (chlorsulfuron). While Escort® has no grazing restrictions at rates up to 1.67 oz/acre, Telar® is not registered for range or pasture lands. Both Escort® and Telar® are terrestrial herbicides. In situations where perennial pepperweed infests waterways, the applicability of these herbicides may be limited (Cantlon 1995, Young et al. 1995). Additional factors hamper the usefulness of herbicides for controlling perennial pepperweed. The persistent semi-woody stems of perennial pepperweed interfere with chemical application (Young et al. 1995). Perennial pepperweed often infests remote, inaccessible areas of low economic value where chemical control is neither practical nor cost-effective. In addition, herbicides can kill competing vegetation, including natives and threatened, endangered, and sensitive species. The subsequent lack of competition might allow perennial pepperweed or another weed to readily reestablish.

Because perennial pepperweed has been difficult to control with conventional measures, interest is increasing for developing a biological control program for perennial pepperweed. This paper will address the potential for such a program.

Biological Control

To date, no biological control programs have been established to control a cruciferous plant, although the Brassicaceae family contains about 350 genera and 3,000 species, several of which are serious weeds. The lack of biological control programs may stem from the number of important cultivated and ornamental plants in this family such as canola, mustard, cabbage, and kale, which are now cosmopolitan because of agricultural activities (Lipa 1974). However, as the crops are generally annuals and perennial pepperweed is a perennial, suitable biological control agents might be identified that attack only the persistent vegetative structures of the weed. This strategy might confer some protection to the annual crops. Additional protection would be conferred if biological control agents could be found that were specific to perennial pepperweed or to the genus *Lepidium*.

The genus *Lepidium* is one of the largest genera of the Brassicaceae (Mummenhoff 1994). Worldwide there are between 130 to 175 species (Lipa 1974, Young et al. 1995). Over 20 *Lepidium* species are present in western North America (Britton and Brown 1970). However, none of the native or introduced species found in western North America are very similar in size and growth habit to perennial pepperweed, (Young et al. 1995) which may help in the search for host specific biological control agents. In anticipation of the environmental assessment process required for approval of biological control agents, we examined the threatened, endangered, and sensitive species within the *Lepidium* genus in the United States and Canada. There is one federally endangered *Lepidium* species in the United States, one additional species proposed for federal listing, nine additional species the U.S. Fish and Wildlife service is concerned about, one additional species listed by the U.S. Forest Service as sensitive, three additional species listed by a state natural heritage program, and one additional species listed in Canada (Table 1).

Classical biological control has traditionally involved using exotic insects as control agents, although exotic plant pathogens have been used in some cases (Quimby and Birdsall 1995). Perennial pepperweed is widely distributed in southern Europe and western Asia. There are numerous countries that can be explored for potential classical biological control agents including Austria, Albania, Armenia, Belgium, Bulgaria, Czechoslovakia, Denmark, Finland, France, Germany, Great Britain, Greece, Holland, Hungary, India and Himalayas, Iran, Ireland, Italy, Kurdistan, Lebanon, Norway, Poland, Portugal, Romania, Russia, Spain, Sweden, Switzerland, Tibet, Turkey, and Yugoslavia (Bobrov et al. 1970, Holm et al. 1979). A study has already been undertaken to explore the insect fauna on cruciferous plants in Poland (Lipa 1974). Several general feeding insect species were reported on perennial pepperweed and eight other *Lepidium* species including *L. campestre*, *L. densiflorum*, *L. graminifolium*, *L. neglectum*, *L. perfoliatum*, *L. ruderale*, *L. sativum*, and *L. virginicum*. While no insects specific to perennial pepperweed were found, the potential for finding host specific species has not been exhausted.

Augmentative biological control using plant pathogens might also be possible with perennial pepperweed. Augmentative biological control involves manipulating natural enemies that are already present in a location and has traditionally involved the use of fungal plant pathogens that are often applied in somewhat the same manner as chemical herbicides (Quimby and Birdsall 1995). Several species of fungi have been identified that might be appropriate for augmentative biological control of perennial pepperweed. Jim Young noted a white rust occurring on many of the perennial pepperweed plants in the Honey Lake Valley area in Nevada during the 1995 summer season. The rust is believed to be *Albugo candida* (Pers.) Kuntze, which has been reported from other *Lepidium* and crucifer species (Farr et al. 1989). Under apparently ideal conditions, the rust was able to prevent seed production but did not kill the plants. Over 20 other fungi, including *Sclerotinia sclerotiorum*, have been reported on *Lepidium* species in the United States (Farr et al. 1989). In addition, the fungi *Alternaria alternata* and *Albugo lepidii* have been reported on *L. sativum* (Melkania 1980, Rao 1979). *Alternaria alternata* and *Sclerotinia sclerotiorum* have been investigated as potential biological control agents of other weedy species (Miller et al. 1989, Stierle et al. 1988).

Often, achieving successful management of troublesome weeds requires integrated management that includes biological controls as well as chemical and other techniques. When some fungal plant pathogens have been used in conjunction with certain chemical herbicides, insecticides, fungicides, or plant growth regulators, positive effects have occurred that increase pathogen effectiveness. These positive effects include weakened host defenses, improved colonization by the pathogen, and reduced rates of chemicals required for weed control (Quimby and Birdsall 1995). To successfully control perennial pepperweed, opportunities should be investigated for combining augmented fungi and/or bacteria with low doses of herbicides registered for riparian zones.

The U.S. Department of Agriculture - Agricultural Research Service (USDA-ARS) is considering developing a biological control program for perennial pepperweed and two other cruciferous weeds: dyers woad (*Isatis tinctoria* L.) and whitetop or heart-podded hoary cress [*Cardaria draba* (L.) Desv. = *Lepidium draba*]. At present, we recommend that biological control efforts begin with development of a host specificity test plant list for Brassicaceae targets, and with foreign exploration and quarantine work aimed at identifying potential biological control agents for perennial pepperweed, whitetop, and dyers woad. An evaluation of the economic and environmental losses caused by these weeds might also be beneficial in generating support for a control program.

CONCLUSION

At present, prevention is the best policy for managing perennial pepperweed. Transporting equipment and hay from infested areas is apparently a major means of new introduction. Equipment should be thoroughly cleaned before transport. Hay and seed sources should be checked to ensure that there is no perennial pepperweed contamination. New infestations should be controlled promptly to prevent further spread. However, because prevention is not always possible and perennial pepperweed is a serious weed threat, this species deserves to be examined as a target for biological control, particularly since conventional control measures have been largely unsuccessful or impractical. Both the classical and augmentative biological control approaches have potential for controlling this weed and warrant further examination. The existence of closely related threatened, endangered, and sensitive species and related crop and ornamental species will pose challenges for a biological control program, but do not necessarily negate biological control as an option to be included in integrated management systems. As with other weeds, successful control of perennial pepperweed will undoubtably require an integrated management system where biological controls are used in conjunction with other available techniques.

Table 1. Threatened, endangered, and sensitive *Lepidium* species in the United States and Canada[1].

1994 Federal Threatened and Endangered List

1. *Lepidium barnebyanum*, Barneby ridgecress = peppercress, UT, Endangered[2]

1996 Federal List of Plant Species Under Review for Listing

1. *Lepidium arbuscula*, Anaunau, HI, Proposed as Endangered

1993 Federal List of Plant Species Under Review for Listing[3]

1. *Lepidium arbuscula*, Anaunau, HI, Category 2[4]
2. *Lepidium bidentatum* var. *remyi*, Remy's Anaunau, HI, Category 2 but possibly extirpated in wild
3. *Lepidium davisii*, Davis' peppergrass, ID & OR, Category 2
4. *Lepidium flavum* var. *felipense*, Borrego Valley peppergrass, CA, Category 2
5. *Lepidium jaredii* ssp. *album*, Panoche peppergrass, CA, Category 2
6. *Lepidium jaredii* ssp. *jaredii*, Jared's peppergrass, CA, Category 2
7. *Lepidium montanum* var. *papilliferum*, ID, Category 2
8. *Lepidium montanum* var. *stellae*, kodachrome peppergrass, UT, Already proposed to be listed as endangered
9. *Lepidium ostleri*, UT, Category 2
10. *Lepidium serra*, Anaunau, HI, Category 2

Forest Service Sensitive Plant Lists

Region 4:

1. *Lepidium montanum* var. *neeseae*, Neeses' peppergrass, Dixie Natl. Forest, Sensitive
2. *Lepidium papilliferum*, Slick-spot peppergrass, Caribou Natl. Forest, Sensitive

State Natural Heritage Program Lists

California:

1. *Lepidium flavum* var. *felipense*, Borrego Valley peppergrass
2. *Lepidium jaredii* ssp. *album*, Panoche peppergrass

3. *Lepidium jaredii* ssp. jaredii, Jared's peppergrass
4. *Lepidium latipes* var. *heckardii*, Heckard's peppergrass
5. *Lepidium virginicum* var. *robinsonii*, Robinson's peppergrass

Hawaii:
1. *Lepidium arbuscula*, Anaunau
2. *Lepidium bidentatum*
3. *Lepidium bidentatum* var. *o-waihiense*, Anaunau
4. *Lepidium bidentatum* var. *remyi*, Remy's Anaunau
5. *Lepidium serra*, Anaunau

Idaho:
1. *Lepidium davisii*, Davis' peppergrass

Nevada:
1. *Lepidium montanum* var. *nevadense*, Pueblo Valley peppergrass

Oregon:
1. *Lepidium davisii*, Davis' peppergrass, List 1: Threatened with extinction or presumed extinct throughout range.

Utah:
1. *Lepidium barnebyanum*, Barneby ridgecress = peppercress, Endangered
2. *Lepidium ostleri*, Federal Category 2

Washington:
1. *Lepidium oxycarpum*, Sharp-fruited peppergrass, Sensitive

Wyoming:
1. *Lepidium montanum* var. *alyssoides*, List 2: Moderately rare globally, regionally, or in WY

Canadian Lists

British Columbia:
1. *Lepidium densiflorum* var. *pubicarpum*, Red List: Candidates for endangered or threatened status, extirpated taxa, and globally rare taxa
2. *Lepidium virginicum*, Yellow list: May become vulnerable in near future

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[1] Forest Service regions, U.S. states, and Canadian provinces not appearing in the table had no listed *Lepidium* species.
[2] When available, information is provided on scientific name, common name, historic range, and listing status.
[3] In 1996, the U.S. Fish and Wildlife Service completed an exhaustive review of the 1993 candidate species to ensure that they truly warranted issuance of a proposed listing and to reevaluate the relative listing priority of each species. Listing of Category 2 species was discontinued because sufficient information to justify issuance of a proposed rule was lacking. While the Fish and Wildlife Service does not regard Category 2 species as candidates for listing and no longer lists these taxa, the Service remains concerned about these species and acknowledges the need for further biological and field study of these species.
[4] In 1993, Category 2 taxa were described as taxa for which information in the possession of the U.S. Fish and Wildlife Service indicates that proposing to list as endangered or threatened is

possibly appropriate, but for which sufficient data on biological vulnerability and threat are not currently available to support proposed rules. The Service hoped that the notice would encourage necessary research on vulnerability, taxonomy, and/or threats for these taxa.

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PERENNIAL PEPPERWEED IN IDAHO

K. Taylor Cox

INTRODUCTION

Perennial pepperweed (*Lepidium latifolium*) was probably first introduced in Idaho in the 1950's. The heaviest infestations are in southwest Idaho, near rivers, canals, and in other areas with high water tables. There are also small infestations in southern and eastern Idaho (Figure 1). Perennial pepperweed is often found along canals and ditches, but is not considered a problem in cropland, due to intense weed control activities there, and the effectiveness of select herbicides in controlling it. The greatest concentrations are in waste areas of low economic value, where weed control activities are not common. It can also be a pest in pastures if not controlled.

A survey of county weed control superintendents indicates that perennial pepperweed is, for the most part, not spreading rapidly. One superintendent mentioned, however, that it does appear to be getting more dense. Table 1 is a summary of acreage estimates reported by county weed superintendents from 1991 to 1995. In many counties, an aggressive control program could eradicate or severely restrict the weed within one to five years. Some of these counties are in fact undertaking such a program.

Although treatments vary among the counties, the most common herbicide used to control perennial pepperweed in Idaho is metsulfuron methyl (*Escort*). The rate varies from .75 to 1.5 ounces per acre, and is reported to be quite effective. An adjuvant is commonly added to the mixture. One weed superintendent reports that, while 2,4-D or dicamba alone will not effectively control perennial pepperweed, a mixture of the two (such as *Weedmaster*) appears to do the job. During the latter part of May 1996, this individual used a mixture of .5 ounces of *Escort* and 1 quart *Weedmaster*, formulated specifically to spray an area heavily infested with pepperweed. About a month later, there appeared to be near 100 percent control. In another county, *Escort* was applied to perennial pepperweed at the county fairgrounds two years ago. Only one plant is growing there this year.

In one county, imazapyr (*Arsenal*) has been used quite successfully in limited situations. One area sprayed with *Arsenal* four years ago had virtually no regrowth of perennial pepperweed. There were similar results in another area that was sprayed three years ago. However, because of its non-selectivity, it should only be used in areas where rapid establishment of desirable vegetation is possible.

Other herbicides that have been tried with varying success are chlorsulfuron (*Telar*), picloram (*Tordon*), 2,4-D LV, and dicamba (*Vanquish*). Telar has proven to be very effective in Idaho, but has a more restrictive labeling than does *Escort*.

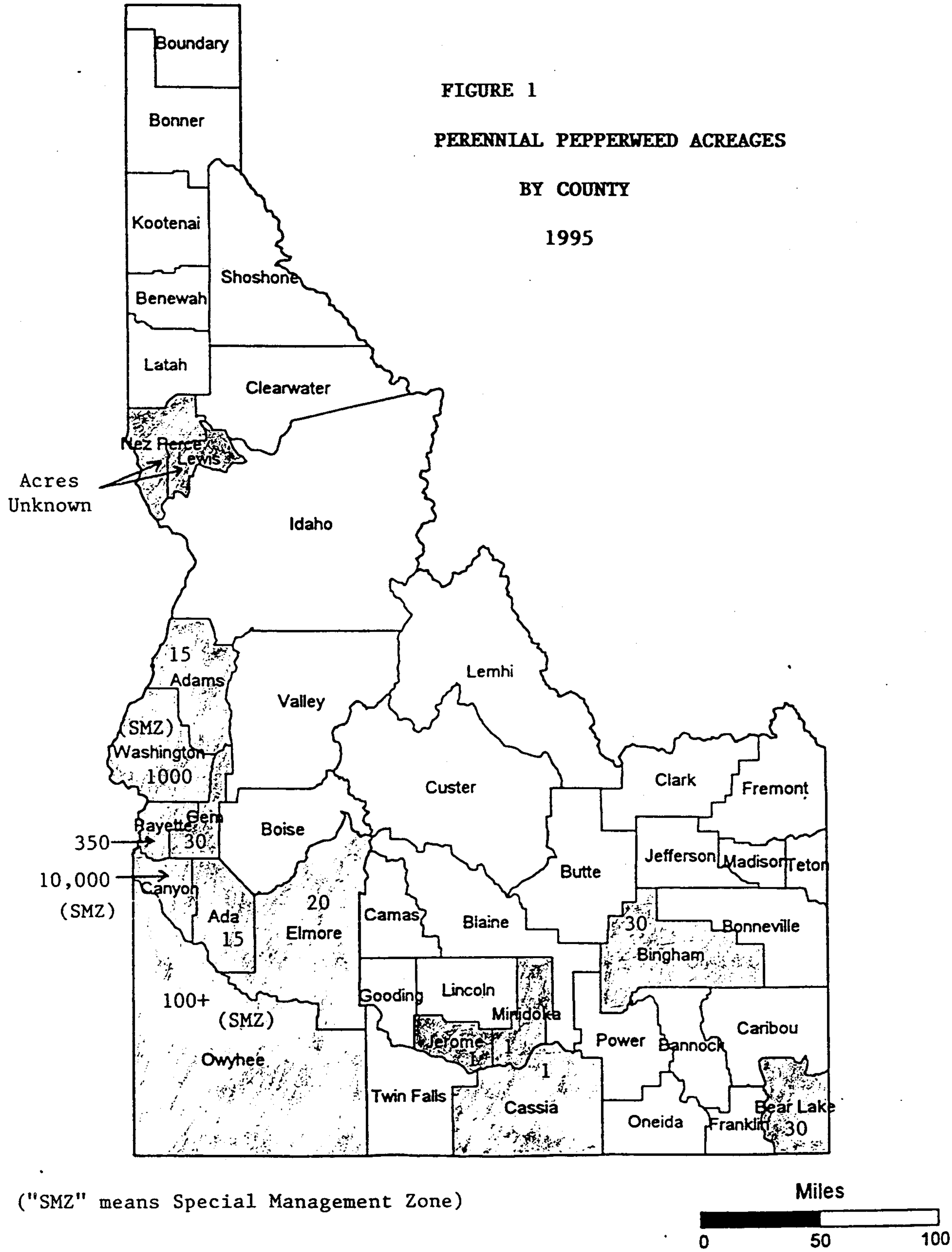
Idaho

FIGURE 1

PERENNIAL PEPPERWEED ACREAGES

BY COUNTY

1995



("SMZ" means Special Management Zone)

TABLE 1. PERENNIAL PEPPERWEED ACREAGES (ANNUAL REPORTS, 1991-95)

	Ada	Adams	Bear Lake	Bingham
1991	15	.5	5	200
1992	25	1	5	200
1993	60	1	5	200
1994	10	5	4	100
1995	15	15	30	50

	Canyon	Cassia	Elmore	Gem
1991	.5	--	2	3
1992	10,000	.3	2	??
1993	30,000	--	1+	40
1994	10,000	2	15	40
1995	10,000	1	20	30

	Jefferson	Jerome	Minidoka	Owyhee
1991	100	5,000	--	400+
1992	??	5,000	--	100+
1993	--	4,000	--	100+
1994	??	1	.5	100+
1995	??	--	.5	100+

	Payette	Washington
1991	100	300
1992	110	500
1993	350	1,000
1994	350	1,000
1995	350	1,000

NOTE:

There are also reported to be infestations in Nez Perce and Lewis Counties, but there are currently no acreage estimates.

Herbicidal Control of Perennial Pepperweed (*Lepidium latifolium*) in Nevada

James A. Young, Debra E. Palmquist, and Robert R. Blank

INTRODUCTION

Perennial pepperweed has invaded so many different types of habitats that it is necessary to target the specific situation and/or environment where control measures are proposed. The information presented here concerns the herbicidal control of perennial pepperweed in native hay meadows in the intermountain area. These are unimproved meadows with wild flooding irrigation systems. Typically, one cutting of hay is obtained and crop aftermath is grazed in the fall. In Nevada, it appears that virtually all of these meadows are or will be infested with perennial pepperweed. On many of these meadows, biomass actually increases with perennial pepperweed invasion, but total digestible nutrients, and especially digestible protein, drops. Cattle preference for the regrowth or old growth of perennial pepperweed is very low. Perennial pepperweed clogs irrigation ditches and colonizes earthen irrigation structures in these meadows.

In the spring these meadows are often substantially flooded on normal to wet years. The meadows provide prime waterfowl nesting areas. The invasion of perennial pepperweed changes the nesting characteristics of the meadows and these changes are apparently detrimental.

Traditional Control

In areas where perennial pepperweed has been a problem for some time, such as the Susan River Valley of Lassen County, California, ranchers have attempted to control this pest in hay meadows with annual applications of 2,4-D ([2,4,-dichlorophenoxy] acetic acid). They formally used 4 lb/ac of a l.v.e (low volatile ester) formulation applied at the bud stage (usually early to mid June). Since new label restrictions have appeared for 2,4-D this has been reduced to 2 lb/ac applied with 50 gallons per acre of carrier (water). Ranchers who worked very hard at this type of herbicide application, year after year, have had some success in suppressing perennial pepperweed. The cost is about $12.00 to $15.00 per acre, annually, plus application cost. This type of application requires treating the fence corners and rough areas that are not usually mowed as well as the main meadows. If an area is missed with the herbicide application, it will be totally dominated by perennial pepperweed at the end of the growing season that same year.

There are restrictions on the application of l.v.e. esters of 2,4-D around water. Read the label and check with local regulatory agencies. For some amine forms of 2,4-D, the application restrictions around water are more liberal. We have not seen a lot of difference in control obtained between l.v.e. and amine forms of 2,4-D.

More Modern Herbicides

The herbicide chlorsulfuron (2-chloro-N-[{4-methoxy-6-methyl-1,3,5-triazin-2-yl}-

aminocaryl] benzenesulonamide) has proven very effective for control of perennial pepperweed. This is a selective herbicide that does not kill grasses and grass-like plants commonly found in native hay meadows. It does kill broadleaf species. It has a label for such applications in non-crop areas in many western states. Be sure and check for label restrictions in your area and for restrictions concerning your specific application situation.

Chlorsulfuron has both soil and foliar activity. In timing of application experiments, we obtained the highest level of control with applications at the bud stage. However, excellent control can be obtained with early spring or late fall applications. Essentially, foliar up-take of the herbicide is not necessary for control of perennial pepperweed with this herbicide. This provides several management opportunities for perennial pepperweed control in native hay meadows. The herbicide can be applied in late summer on re-growth patches of perennial pepperweed. The mass of perennial pepperweed herbage has been removed by then by the haying operation. The meadows are usually dry after haying so water contamination is not an issue. If the perennial pepperweed infestation is not continuous, re-growth patches are obvious, so the area requiring treatment is easily delineated.

You need to check with pesticide regulatory agencies for your area and make sure that your meadow situation matches label requirements. Remember that chlorsulfuron has soil activity and can be taken up by roots. Do not apply this material under trees or shrubs.

Chlorsulfuron is applied at a rate of 1.5 oz per acre for perennial pepperweed control. It is expensive, with the cost of materials being about $30.00 per acre. The advantage over 2,4-D is it gives complete control for several seasons and does not require annual application.

CONTROL OF PERENNIAL PEPPERWEED IN WYOMING

John L. Baker

I have worked for Fremont County Weed and Pest since 1975. At that time perennial pepperweed was widespread in the Crowheart area, mostly along the Wind River in Western Fremont County on the Wind River Indian Reservation. A second center of infestation was on the Big Horn River Northeast of Riverton. While this is in the same drainage, the two infestations were not connected and appeared to have originated independently. Records and photos in our files date these infestations to at least the 1940s. The lands infested were mostly wet saline bottom lands along the river. In the Crowheart area, it was common in poorly managed irrigated pasture and hay land. In general, these lands saw limited use for livestock grazing and the impact of the weed was minor. It appeared that these infestations were not expanding and the weed was restricted to these saline sites.

In 1990, we mapped perennial pepperweed on the reservation for the Bureau of Indian Affairs (BIA). That effort disclosed that it was spreading rapidly along irrigation canals in the Crowheart area and was nearly continuous throughout the river bottoms from 20 miles west of Crowheart, to Boysen Reservoir, which is northeast of Riverton. That is about 100 miles of river. We were able to overlay the maps with a soils map for a portion of the infested area. This indicated, that while the weed was spreading, most of the infestation was still confined to high pH, saline soils. The pH ranged as high as 9.2, with the weed growing right to the edge of white alkali patches. We also noted many of the small patches in crop lands where the soil is good. It does not appear to depend on saline conditions; it is just tolerant of them. The completed maps were turned-over to the BIA at the completion of the contract. They were sent off to be digitized for the BIA's GIS, but have been lost. Thus, the objective data on growth of the weed in Fremont County will have to wait for another mapping project. Mapping efforts in Sweetwater County reveal similar site information and that the area infested with the weed has doubled over 20 years in spite of an aggressive spray program.

During the 1990 project for the BIA, observations were made of natural enemies. In the Crowheart area, late season perennial pepperweed becomes the object of attention for ants around the base. It was discovered that the ants were tending a root feeding aphid. Sometimes the ants excavated the soil away from the roots to a depth of 6 inches, leaving the plants loose in the ground. In the Riverton area, perennial pepperweed is attacked by a flea beetle. The two insects were collected, but I am not sure that identification was ever made. There was a high incidence of a white mold, which was identified as common to cole crops. Regardless of natural enemies observed, there was no associated plant injury.

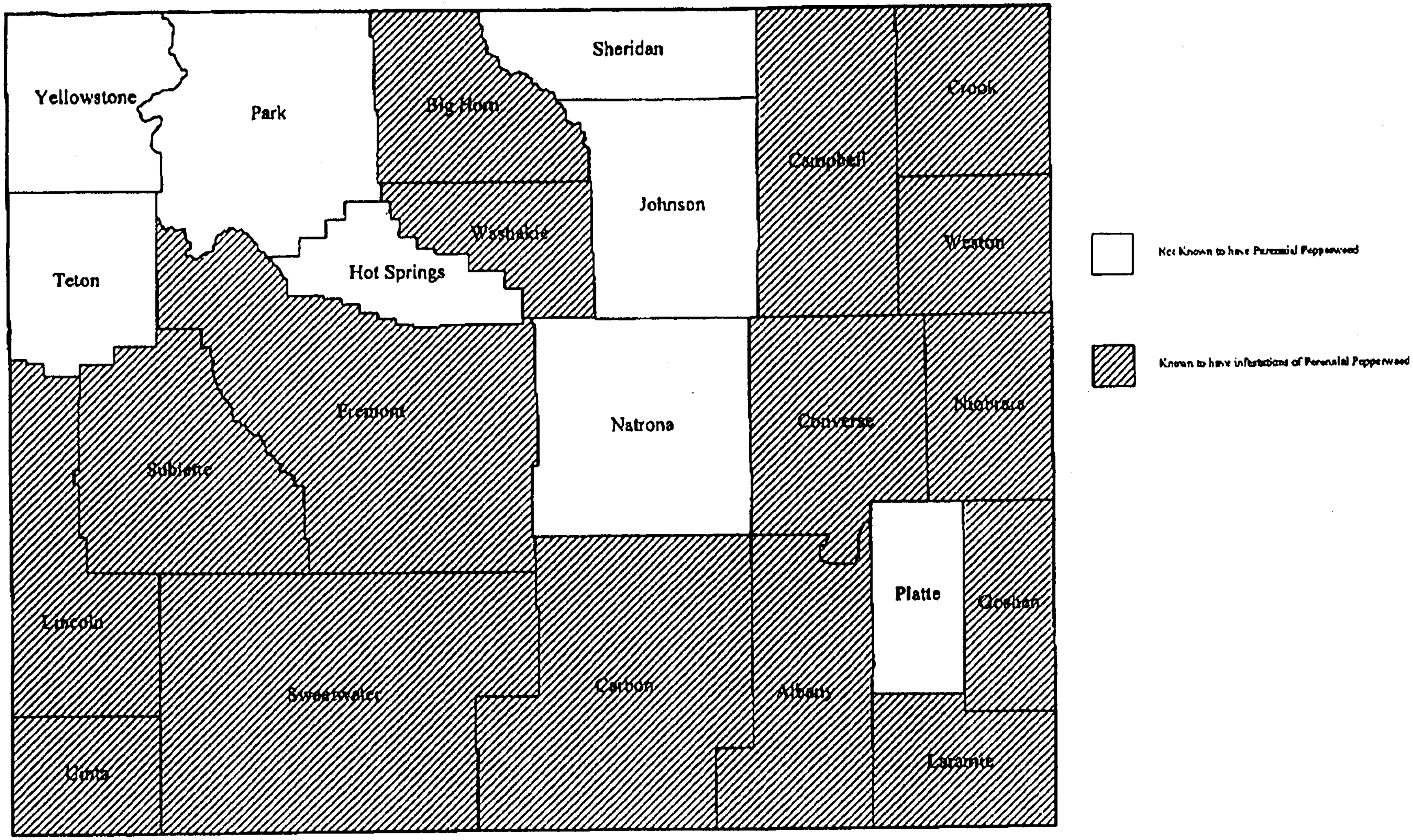
Control efforts for many years with chemicals were only mildly successful. Test plots were maintained for many years examining various products and combinations. The least expensive approach for irrigated hay land was 2,4-D *LV Ester*, applied in spring and fall. Hundreds of acres were treated twice a year in Sweetwater County. The regular use of broadleaf herbicides to control the perennial pepperweed eliminates any legume from the hay, reducing hay quality and yield. *Banvel* provided no stand reduction at rates as high as 8 pounds active ingredient per acre. *Tordon* gave no control except when applied late in the fall. October treatments on apparently dead plants resulted in 60 percent stand reductions the following year at rates of .5 lbs ai/ acre or more. With both *Banvel* and *Tordon* there was significant injury to trees and brush, limiting the usefulness of both herbicides. As a result, a lot of perennial pepperweed goes untreated. Recent introduction of *Telar* and *Escort* has provided us with useful herbicides. Treatments of .75 to 1 oz of either product per acre usually results in long-term control with stand reductions of 90 percent or more. Many sites treated 4 or 5 years ago are still clean. The impact of either of these two herbicides is significant and long-lasting. A single treatment with *Escort* cost about the same as two treatments with 2, 4-D, but the 2, 4-D treatment will have to be repeated every year as it provides limited stand reduction.

Pastures with perennial pepperweed rapidly become useless to cows and horses. Spread and stand density of the weed increases under grazing, while haying infested fields seems to prevent it from developing into a monoculture. Sheep readily eat pepperweed and even heavily infested pastures appear weed free. Once the sheep are removed the weed comes back. In one pasture there was no significant stand reduction the following year when sheep grazed pepperweed off to the ground for the entire growing season. Digging up a few roots reveals large tuberous rhizomes developing a few inches below the surface. The stored energy reserves must be considerable.

While we are aware of the obstacles faced by biological control, it still seems prudent to investigate the possibilities. Financial support for that work could be found among county weed districts and the state of Wyoming. Thus, Dr. Chuck Quimby's interest in biological control of the weedy mustards is most welcome. A subcommittee of the state biological control steering committee is being organized from the southwestern counties of the state to help focus our efforts on perennial pepperweed.

I am enclosing a map of the counties in Wyoming reporting pepperweed. The total is now 16 of 23 counties. Twenty years ago only four counties reported the weed. Depending on who is counting, and how they do it, there are between twenty and fifty thousand acres infested.

Presence/Absence



Map by Kiana Rogers August 9, 1996 Cooperative Agricultural Pest Survey (CAPS) Dept. of Plant, Soil and Insect Sciences University of Wyoming

Use of Integrated Pest Management to Restore Meadows Infested with Perennial Pepperweed at Malheur National Wildlife Refuge

Kevin M. Kilbride, Fred L. Paveglio, David A. Pyke, Margaret S. Laws, and Joel, H. David

INTRODUCTION

Perennial pepperweed (*Lepidium latifolium*), and exotic species herein referred to as pepperweed, is a cool-season perennial that is widely distributed throughout western North American. Pepperweed is frequently found in riparian habitats from high-altitude meadows to alkaline sinks in desert valleys and coastal marshes (Weber 1989). After establishment in riparian areas, pepperweed typically spreads to meadows and pastures, where it forms dense monotypic stands (Tosso et al. 1986). Vegetation displaced by pepperweed provides important habitat and forage for wildlife. On the Malheur National Wildlife Refuge (MNWR), pepperweed has displaced 5 and 10 percent of the meadow and grass/shrub uplands, respectively, that are critical habitats for nesting aquatic and neotropical birds (U.S. Fish Wildl. Serv., unpubl. data). Because hay from infested pastures is not marketable, pepperweed jeopardizes the haying program on the MNWR , which also provides short and medium grasses for sandhill cranes (*Grus canadensis*), shorebirds, and waterfowl.

The goal of our study is to restore native vegetation in MNWR meadows infested with pepperweed using integrated pest management (IPM) techniques (herbicides, disking, fire, and combinations thereof). A second part of this study to be initiated during fall 1996 will determine whether seeding or transplanting of native species will be necessary to restore native plant communities in areas where pepperweed is controlled. Because little information exists regarding the efficacies of control methods, the objectives of our study are to determine pepperweed control and response of native vegetation associated with IPM techniques at MNWR.

Study Area

MNWR is locationed 51 km southeast of Burns, Oregon. The 75,087-ha refuge is characterized by the following habitat types: grass/shrub uplands (34 percent), wetlands (33 percent; ponds sloughs, and seasonal wetlands), alkali lake beds (17 percent), meadows (14 percent), croplands (1 percent), and riparian (<1 percent). Mean monthly temperature and precipitation range from -10 (January) to 30° C (August), and 0.2 (August) to 1.1 cm (March), respectively.

The Malheur-Harney Lake Basin, which encompasses MNWR, is an important area for wildlife, particularly migrating and nesting aquatic birds. Large numbers of waterfowl, geese, trundra swans (*Cygnus columbianus*), and sandhill cranes use the Basin during fall and spring migrations. Peregrine falcons (*Falco rusticolus*) and bald eagles (*Haliaeetus luecocephalus*) use the Basin during spring migrations. Malheur Lake is a major production area in the Pacific flyway for redheads (*Aythya americana*) and canvasbacks (*A. valisineria*) as well as colonial waterbirds and shorebirds. Uplands characterized by basin big sagebrush (*Artemisia tridentata*), basin wildrye (*Leymus cinerus*), black greasewood (*Sarcobates vermiculatus*), and saltgrass (*Distichlis spicata*) provide habitat for upland-nesting waterfowl as well as passarines. Meadows with perennial grasses such as creeping wildrye (*L. triticoides*), bottle brush squirreltail (*Sitanion hystrix*), basin wildrye, Nevada bluegrass (*Poa nevadensis*), and saltgrass provide nesting cover for waterfowl, shorebirds, and wetland-obligate passarines, as well as foraging areas for Canada geese and sandhill cranes.

METHODS

Within three meadows (Big Sage [BS], Oliver Springs [OS], and Skunk Farm [SF] at MNWR, nine 0.24-ha (66 x 36 m) plots were established and randomly assigned to one of the following experimental groups during 1995: Telar®, Escort®, disk, Telar®-disk, Escort®-disk, fire, Telar®-fire, Escort®-fire, and control (untreated). Study plots were predominantly pepperweed interspersed with trace amounts of creeping wildrye, squirreltail, basin wildrye, saltgrass, cheatgrass (*Bromus tectorum*), and forbs (e.g., flix-weed [*Descurainia sophia*]) as well as rushes (*Juncus* spp.) and sedges (*Carex* spp.) in lower (wet) areas.

For all herbicide treatments, Telar® (84g/ha [3 ounce/acre]) or Escort® (28 g/ha [1 ounce/acre]) were mixed with Sylgard® 309 (silicon based nonionic surfactant at 0.24 liters per 379 liters [0.5 pints per 100 gallons] of spray solution [0.063 percent solution]) and applied by a tractor-mounted broadcast sprayer on days with windspeeds $\leq$8 km/hr, and no precipitation 24 hrs before or after treatment. All herbicide treatments were applied either during bud development before flowering (OS and SF; June 13 and 15) or at the start of flowering (BS; July 5). The disk treatment application consisted of early (July 11) followed by late summer (August 23) diskings with a 4.3-m disk (91.4 cm blades) to produce a smooth soil surface for germination of the soil seed bank. Early summer (June 13 to July 5) application of Escort® and Telar® followed by late summer (August 23) disking was used for both herbicide-disk treatments. For both herbicide-fire treatments, herbicides were sprayed in early summer (June 13 to July 5) and then vegetation was cut to a height of 10 cm with a tractor-propelled brush mower 1 week before burning (October 17) to increase fire heat at the soil surface for pepperweed control. For fire only treatments, plots were similarly mowed 1 week before the fall burn (October 17). All burns were accomplished with back fires ignited by drip torches.

Fire behavior and vegetative response to treatments were assessed from within a central core area (0.18-ha; 60 x 30 m) within each plot. Core areas were used to minimize the effect of unevenly treated edges of plots.

Pre- and post-burn herbaceous fuels were measured by collecting all material in 10 sampling frames (1 m^2) randomly located throughout the core area of each plot treated with fire. Fuels collected in these plots were partitioned into the following categories: live grass/forb, dead grass/forb, live pepperweed, and dead pepperweed. In the laboratory, fuel samples were weighed (g), oven dried to constant weight for 48 hrs at 70° C, and then weighed again to determine moisture content and dry weight (DW). Fuel consumption by fire for each plot was calculated as the difference between the average biomass of all fuel types pre- and post-burn.

To determine pepperweed control and the vegetative response associated with IPM techniques, the core area within each plot was sampled during late May/early June 1995 (pre-treatment) and in 1996 (1-year post treatment). Each plot was divided in half within which four transects (30-m) were randomly located in each half of the core area. Pepperweed density (plant/m^2) and basal cover (%) of live plant species, bare ground, and residual plant material were determined with 0.35m^2 (1.0 x 0.35 m) rectangular and 50-point (4 cm between points; Bonham 1989) frames, respectively, placed at five equal (6 m) intervals along each transect. Because transects were considered samples, pepperweed density and cover values were averages of values from the five frames along each transect.

RESULTS AND DISCUSSION

A lack of adequate fuels (forbs and grasses) available at OS and SF resulted in unsuccessful burns at these meadows. Approximately 50 percent more pre-burn biomass (fuel) was present at BS compared with OS and SF (69, 48, and 46 g/m^2 DW, respectively). Moreover, BS had a greater proportion of its pre-burn biomass associated with live grass/forb (55 percent) compared with OS (8 percent) and SF (15 percent). In contrast, BS had a smaller proportion of its pre-burn biomass associated with live and dead pepperweed (15 percent) compared with OS (62 percent) and SF (56 percent). Plots with fire treatments at all meadows had approximately the same proportion of pre-burn biomass for dead grasses and forbs (30 percent). At BS, fuels consumed by burns were 94, 92, and 82 percent for Telar®-fire, Escort®-fire, and fire treatments, respectively.

After one post-treatment year, Telar® and Escort® alone and in combination with disking or fire reduced pepperweed densities by >90 percent. For the herbicide only treatments, Telar® reduced pepperweed densities 100 percent in all three meadows; whereas Escort® control ranged from 90 (BS) to 100 percent (OS). Similarly, the Telar®-disk treatment had better control compared with Escort®-disk; pepperweed densities were reduced 100 percent for Telar®-disk at all three meadows compared with 98 (SK) to 99 percent (BS and OS) for Escort®-disk. For the herbicide-fire treatments at BS, the Telar®- and Escort®-fire plots had 100 and 97 percent reductions in pepperweed densities, respectively. In contrast with treatments involving herbicides that consistently controlled pepperweed, the disk treatment only slightly decreased (32 [SF] to 46 percent [BS]) or increased (2 percent [OS]) pepperweed densities after one post-treatment year.

After one post-treatment year, Telar® and Escort® alone and in combination with fire generally reduced cover of forbs and increased cover of grasses. Although forb cover at BS increased for Telar® (=46 percent) and Escort® (=27 percent) plots, it decreased (>91 percent) for these herbicide treatments at OS and SK. In contrast, grass cover increased for Telar® (=86 [OS] to =191 percent [BS]) and Escort® (=34 [SF] to =229 percent [OS]) treatments. Similarly, grass cover increased for fire alone (=22 percent) and in combination with Telar® (=91 percent) and Escort® (=145 percent) at BS. Although forb cover increased for the Telar®-fire plot (=317 percent), it decreased for fire only (-13 percent) and Escort®-fire (-43 percent) treatments.

Plots for Telar® and Escort® alone (all three meadows) and in combination with fire (BS only) were predominantly covered with creeping wildrye, as well as rushes and sedges in lower areas; however, the creeping wildrye on the Telar®- and Escort®-fire treatments was at least twice as tall compared with Telar® and Escort® plots. The vigorous stands of creeping wildrye on the Telar®- and Escort®-fire plots likely resulted from release of nutrients and/or stimulation of rhizome buds associated with burns. Although creeping wildrye was prevalent on the fire plot, its stand was not as vigorous as those for herbicide-fire treatments and resembled those for the Telar® and Escort® plots at BS.

Disking alone and in combination with herbicides reduced cover of forbs and grasses after one post-treatment year. For disk only plots, forb and grass cover decreased 46 (SF) to 97 percent (OS) and 13 (SF) to 100 percent (BS), respectively. Forb and grass cover decreases were larger for Telar®-disk treatments compared with disk plots where declines after one post-treatment year ranged from 94 (BS) to 100 percent (OS) and 60 (SF) to 100 percent (BS), respectively. Forb and grass cover also decreased for Escort®-disk treatments, where declines ranged from 71 (OS) to 100% (BS) and 49 (OS) to 100% (BS), respectively. Telar®- and Escort®-disk plots at all three meadows were characterized by bare ground with patches of cheatgrass and Canada thistle (*Cirsium arvense*), except those at BS with almost no vegetation. Alkaline soils as indicated by salt deposits, likely prevented plant establishment after treatments for these BS plots.

PRELIMINARY CONCLUSIONS

After one post-treatment year, Telar® and Escort® treatments alone and in combination with disking or fire reduced pepperweed densities, where all Telar® treatments appeared to result in slightly better control. Reductions in forb cover for Telar® and Escort® treatments likely were in response to herbicide applications. Herbicide-disk treatments reduced cover of native forbs and grasses and resulted in the establishment of undesirable, exotic species (cheatgrass and Canada thistle). Telar®- and Escort®-fire plots had more vigorous stands of native grasses, mostly creeping wildrye, compared with herbicide, only treatments at BS. Burns could not be conducted for OS and SF plots because adequate amounts of grasses and forbs were not present to carry a fire.

At this time, we cannot definitively determine which treatment will offer the best control and/or be the most cost effective method to restore pepperweed-infested habitats on MNWR. An additional 1 to 2 years of data collection will be needed to determine whether a longer period between control efforts is associated with Telar® as opposed to Escort® treatments in order to justify its higher cost ($151.34/ha [$0.72/g x 210.2 g/ha]) compared with Escort® ($51.87/ha [$0.74/g x 70.1 g/ha]). Field tests with two application rates for Telar® (28/ha [label minimum] and 84 g/ha [label maximum]) and one Escort® rate (28/ha) conducted at MNWR by Ron Crockett (Monsanto Agricultural Company) will provide additional insight regarding cost-effective measures to control pepperweed.

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Managing Perennial Pepperweed in Uintah County, Utah

Chad R. Reid, G. Allen Rasmussen, and Steven Dewey

Introduction

Perennial pepperweed (*Lepidium latifolium* L.) is a native of southern Europe and western Asia and has become dominant on some wetlands in the intermountain west. It has been declared a noxious weed in a number of western states. Original importations were thought to be in contaminated sugarbeet (*Bela vulgare* L.) seed. Spread of this weed is usually by water carrying seed from upstream areas. Once established, perennial pepperweed rapidly spreads by rhizomes, especially in moist soils. The plant can grow to heights greater than 1 m and readily suppresses surrounding herbaceous vegetation. Research on management of perennial pepperweed is limited, with most of the work being done on cropland.

The first report of perennial pepperweed in Uintah County known by the authors was at the Ouray National Wildlife Refuge in 1972 (Neil Folks, personnel communication). It was of little more than botanical interest at that time. In 1983 extremely high flows on the Green River (50,000 CFS near Jensen, Utah) caused extensive flooding of low areas along the river. After these high flows, landowners started reporting perennial pepperweed in pastures and hay fields. In 1989 the county weed supervisor initiated a spray program for perennial pepperweed. Several landowners cooperated with the county to spray approximately 600 acres with 2,4-D amine applied by airplane at the rate of 3 quarts per acre. Perennial pepperweed was in full bloom. Results were disappointing with estimates of control in the 10 to 20 percent range. After this, landowners were very skeptical about control of perennial pepperweed.

Perennial pepperweed is linked to other problems in Uintah County. Land areas along the Green River include some of the most productive mosquito habitat in North America. This habitat is capable of producing up to 10 million mosquitos per acre per brood. This also creates considerable human health concerns as surveillance sentinel flocks of chickens in Uintah County frequently seroconvert for mosquito-borne Western Equine Encephalitis and Saint Louis Encephalitis. Perennial pepperweed directly interferes with mosquito control in the area because of changes in the vegetation canopy in the invaded areas. Vegetation in these areas would normally consist of salt grass (*Distichlis stricta*), alkali sacaton (*Sporobolus airoides*), and poverty sumpweed (*Iva axillaris*) all of which are low growing plants. When these areas become dominated by perennial pepperweed the canopy height and density make effective application of insecticides difficult for mosquito control. Repeated applications of organophosphate insecticides for the past 20 years to control mosquitoes have resulted in mosquito populations with a developed resistance to these insecticides. Newly developed insecticides such as Bti (*Bacillus thuringiensis israelensis*) require much shorter application intervals and must be applied directly to the water to control the aquatic larvae. The dense canopy of perennial pepperweed severely impacts these applications by intercepting the chemical before it contacts the water (Steven V. Romney, personal communication).

The problem of perennial pepperweed along the Green River has been further intensified by the Recovery Program for Endangered Fishes of the Upper Colorado. There are currently four species of fish listed as endangered in the Green River. The Colorado squawfish *(Ptychocheilus lucis*), the humpback chub (*Gila cypha*), the bonytail chub (*Gila elegans*) and the razorback sucker *(Xyrauchen texanus*). The last three species mentioned are thought to require backwaters for spawning and young fish grow-out areas. In order to increase the number and size of these areas the U.S. Fish and Wildlife Service is proposing to flood areas adjacent to the river channel on a regular basis. Flooding these areas produces a large number of mosquitos and appears to further the spread of perennial pepperweed.

These factors and poor results of past herbicide treatments lead to the initiation of a study by Chad Reid, USU Extension Agent, Allen Rasmussen, USU Range Management Specialist and Steven Dewey, USU Extension Weed Specialist, to evaluate control methods for perennial pepperweed. On riverine areas, few control methods have been developed, though herbicides have shown the greatest potential. A review of the available literature showed the only treatment reported to be effective was 2,4-D amine (2,4 diclorophenoxy acetic acid) at a rate of 2 quarts per acre applied twice a year for 3 to 6 years and then repeated when necessary (Hackett and Post 1986). However, this strategy has still not provided long-term control on riverine systems in Utah. The purpose of this study was to evaluate the efficacy of new herbicides on perennial pepperweed populations in wetlands in two locations in Uintah County, Utah.

MATERIALS AND METHODS

Ten treatments were evaluated including nine herbicide treatments and a control. Herbicide treatments included: Escort (metsulfuron) at three rates (1/3, 1/2, 3/4 oz. product/acre); 2,4-D amine (2 qts. product/acre); 2,4-D amine (2 qts. product/acre) + plus three rates of Escort (1/3, 1/2, 3/4 oz. product/acre); and two rates of Landmaster (2,4-D + glyphosate) (26 oz. product/acre, 54 oz. product/acre). Treatments were applied to perennial pepperweed during the bud stage of development on May 25, 1994. Fall treatments using the same herbicides were applied but showed minimal effect so the results will not be discussed further. Herbicides were applied using a CO_2 backpack sprayer with a hand-held 6-nozzle boom (20-inch nozzle spacing), delivering 12.4 gallons per acre at 35 psi. A non-ionic surfactant (X-77) was added to treatments containing Escort. Herbicides, application rates, and timing were determined from a pilot study. Mechanical top removal was included in the pilot study. However, since it provided no control, it was not included in this study.

This study was conducted on two sites and arranged in a randomized complete block design, with three replications. Plots were 10 x 30 feet. The first site was an Utaline loam soil on an old terrace of the Green River. This is a desert loam (shadscale range site) but is now an artificial wetland because of adjacent irrigated cropland. The other site was on wet meadow adjacent to the Green River that is flooded periodically in the spring and receives agricultural tail-water. The soil on this site is a Pogoneab clay loam and described as a wet saline stream bank (coyote willow range site). Plots were evaluated by visual inspection on September 7, 1994. Two independent observers recorded estimates of percent control, and these estimates were then averaged. In addition, biomass was estimated by clipping two 0.25 m^2 quadrates on September 14, 1994 in each plot. Biomass was recorded using air dry weights. ANOVA was used for data analysis. Treatment means were separated using Duncan's MRT.

RESULTS

Perennial pepperweed biomass reduction and visual control ratings were significantly ($P<.05$) different between the Utaline loam and Pogoneab clay loam sites. Biomass values were not significantly different among herbicide treatments on the Utaline loam site (Table 1). However, visual control ratings for herbicide treatments during the first growing season after application were significantly ($P<.05$) different from each other on this site. Biomass and visual control ratings were significantly different among herbicide treatments ($P<.05$) on the Pogoneab clay loam site.

Escort at 3/4 oz. per acre plus 1 qt of 2,4-D showed the greatest reduction in biomass on site one. Escort at 1/3 oz. per acre was most effective in controlling pepperweed on site two. The low rate of Landmaster was least effective on both sites. Biomass production on plots treated with the high rate of Landmaster was not different from the Escort treatments. The Utaline loam site had a lower soil water holding capacity and was subjected to drought stress associated with irrigation on the adjacent farm ground not being started until late summer. This added stress appeared to increase the efficacy of most herbicide treatments. Higher rates of Escort and Escort combined with 2,4-D did not significantly ($P>.05$) increase control based on first-year evaluations. Data from this study and a pilot study (Table 2) indicate that low rates of Escort are the most economical way to treat perennial pepperweed. While higher rates of Landmaster gave equal control, Roundup had a negative effect on desirable grasses in the plots. Also, data from the pilot study indicated that treatments with 2,4-D or Glyphosphate (Rodeo) showed less control during the second growing season.

SUMMARY

Low rates of Escort (1/2 to 3/4 oz. per acre) will give excellent control the first year of application and good control the following year. Further research is needed looking at longer-term control of perennial pepperweed including competition with desirable species. Efforts in Uintah County include herbicide application to restrict perennial pepperweed to the Green River drainage and the evaluation of competitive grass species such as Newhy RS Hybid Wheatgrass (*Agropyron repens* X *Agropyron spicatum*) to prevent re-invasion.

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Table 1 Percent visual control and biomass of perennial pepperweed at two locations near Jensen, UT, 1994.

Treat.	Herbicide	Rate	% Visual Control		Biomass (lbs/acre)	
			Site 1	Site 2	Site 1	Site 2
1	Escort	1/3 oz. per acre	99 [d]	82 [d]	71 [a]	71 [a]
2	Escort	1/2 oz. per acre	90 [bc]	91 [e]	142 [a]	107 [a]
3	Escort	3/4 oz. per acre	93 [c]	87 [e]	178 [a]	427 [ab]
4	Escort+ 2,4-D (amine)	1/3 oz. + 1qt. per acre	93 [c]	85 [e]	14 [a]	320 [ab]
5	Escort+ 2,4-D (amine)	1/2 oz. + 1qt. per acre	92 [c]	91 [e]	249 [a]	427 [ab]
6	Escort+ 2,4-D (amine)	3/4 oz. + 1qt. per acre	98 [d]	89 [e]	28 [a]	356 [ab]
7	2,4-D (amine)	1qt. per acre	95 [cd]	64 [c]	142 [a]	676 [b]
8	Landmaster	26 oz. per acre	85 [b]	48 [b]	641 [a]	1282 [c]
9	Landmaster	54 oz. per acre	92 [c]	73 [cd]	107 [a]	320 [a]
10	Check (untreated)		0 [a]	0 [a]	2777 [b]	2065 [d]

All rates listed as amount of product per acre
Site 1 = Utaline Loam
Site 2 = Pogoneab Clay Loam

Table 2. Results by year of selected pilot-study treatments near Jensen, UT, for 1994 and 1995.

Treatment	Herbicide	Rate	% Visual Control	
			Year 1	Year 2
1	Escort	3/4 oz. per acre	97 [c]	76 [c]
2	Escort + 2,4-D (amine)	1/2 + 1qt. per acre	99 [c]	78 [c]
3	2,4-D (amine)	2 qts. per acre	95 [c]	70 [c]
4	Rodeo	2 qts. per acre	75 [b]	13 [b]
5	Check (untreated)		0 [a]	0 [a]

All rates listed as amount of product per acre

PROCEEDINGS SUMMARY AND SUGGESTIONS FOR FUTURE WORK

Tony Svejcar

The overview of Integrated Weed Management provided a nice framework for the rest of the papers in this symposium. If we are to have any success limiting the spread of perennial pepperweed, it will be necessary to use all the available tools and information. It will be necessary to take preventative steps, and control populations where they currently exist. Given the costs of control and the limited resources, there must be some strategic planning to ensure that money is spent where it will do the most good.

Many of us know from experience that perennial pepperweed is a very prolific plant and develops a dense mat of creeping rootstalks (rhizomes). Research from the Agricultural Research Service (ARS) group in Reno, Nevada, showed that perennial pepperweed rootstalks would sprout even when cut into one-inch segments. The sprouting ability explains why tillage treatments are not effective at controlling this species. The research from Reno also demonstrated that rootstalks from 2,4-D treated plants sprouted at a lower rate than those from untreated plants. However, the rate of sprouting in the 2,4-D treated plants was still sufficient for perennial pepperweed to completely recolonize a site after spraying. This result helps explain why 2,4-D spraying tends to provide only temporary control.

Biological control has potential in cases where a weed has become widespread, and/or where control efforts have been only marginally successful. The theory behind biological control is that many plants are kept in check in their native setting by natural enemies (usually insects or diseases), but when the plants are introduced into other regions, the enemies may be absent. If an effective enemy can be found in the plants native setting it may be possible to introduce that species to help keep the weed in check. The idea seems simple, however, in practice there are a number of major obstacles. The genus to which perennial pepperweed belongs also contains a number of threatened and endangered species, as well as important cultivated and ornamental crops. Any potential biological control agent will have to be proven harmless to other members of the genus. As mentioned in the chapter on this subject, biological control should be viewed as part of an Integrated Weed Management approach and is generally not a solution by itself.

The last five papers in the proceedings summarized the experiences of researchers and managers from five different states. The emphasis was primarily on herbicide control, and there were similarities in the results. It appears that once an area is infested with perennial pepperweed 2,4-D will provide only short-term control. In one paper it was suggested that two applications of 2,4-D per year, for three to six years are required to eliminate perennial pepperweed from a site. It is possible that 2,4-D will be useful in controlling small introductions, but even that is not certain. There was consistent success with the sulfuronal herbicides, Telar® and Escort®. In fact, the success of these two herbicides was almost universal. These herbicides became available relatively recently and some fine-tuning of their use may be expected. There are still questions about the minimum rates necessary to control perennial pepperweed. With the cost of these herbicides, rate becomes a very important economic consideration. The research from Utah indicates that as little as 1/3 ounce per acre can be effective on some sites. It appears that 3/4 to

1 ounce per acre is the rate most commonly used. The sulfuronal herbicides exhibit both foliar and soil activity, which greatly expands the application-window compared to 2,4-D. As with all herbicides, please read the label to determine if any specific restrictions apply to your area.

There is a great deal of interest in controlling the spread of perennial pepperweed. This species threatens to, or has already invaded many of our most productive habitats. It is clear that no simple cure to the perennial pepperweed problem is likely. A combination of prevention and control techniques in well-coordinated Integrated Weed Management plans will be necessary to successfully halt the spread of perennial pepperweed. Because of the complexity of introducing biological control agents, that is one tool that will likely not be available in the near future. However, the sulfuronal herbicides provide an effective option not previously available. I would like to again emphasize the importance of developing an overall plan at whatever level you are working, i.e., ranch, drainage, county, or region. Limiting the spread and controlling small introductions will always be more environmentally and economically effective than waiting until a large-scale weed infestation has occurred.

Suggestions for Future Work

There has been little research on perennial pepperweed compared to many other important weed species. That may be because of the relative recentness of the concern over this species. There are many suggestions that could be made for future work. I will mention only a few.

A number of practical questions need to be answered:

1. What is the most economical application rate for the sulfuronal herbicides and at what intervals will treatment be necessary?

2. Is it possible to design haying treatments that will limit the production of viable perennial pepperweed seed?

3. How does the rumen influence seed viability, and how quickly do pepperweed seeds pass through the rumen?

4. What effect does defoliation at different growth stages have on perennial pepperweed? We know short-term mowing treatments are ineffective, but could long-term grazing treatments have potential for success?

5. Are there potential biocontrol agents that might be tested? This area will require both practical and basic biology research to be successful.

There are also some basic biology questions that might assist in designing perennial pepperweed control strategies:

1. How quickly does a seedling become an established patch? What is the basic

growth pattern of this species?

2. What happens at the leading-edge of an infestation? Does this species expand by seed and then use its creeping rootstalks to gain dominance?

3. When is the plant actively sending sugars below ground to grow more roots? An understanding of the physiology and population biology often yields clues to effective design strategies.

Weed management is an area where coordination among researchers, managers, policy-makers (federal, state, and local), and the general public is essential. We hope this symposium serves as a useful means of information transfer among the various groups. However, the exchange of information will need to continue if we are to develop well-coordinated plans that are so essential in controlling a widely distributed weed.