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Executive Summary

THE IDENTIFICATION, DISTRIBUTION, IMPACTS, BIOLOGY
AND MANAGEMENT OF NOXIOUS RANGELAND WEEDS

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This document provides a discussion of the biology and management of exotic rangeland weeds which are a threat to native ecosystems of the western United States. Chapter 1 describes a generalized approach for managing noxious weed infested rangeland, while Chapter 2 focuses on preventing noxious weed invasion. In some cases, noxious weeds readily invade riparian areas, and because of the sensitive nature of these ecosystems Chapter 3 is devoted to riparian weed management. The following 18 chapters describe the identification, origin, history, distribution, potential invasion, impacts, biology and ecology, and management of specific noxious rangeland weeds.

TABLE OF CONTENTS

<u>Chapter</u>	<u>page</u>
1. Noxious Weed Management	2
2. Riparian Weed Management	8
3. Preventing Noxious Weed Invasion	16
4. Bull Thistle, Musk Thistle, and Scotch Thistle	23
5. Common Crupina	53
6. Dalmatian and Yellow Toadflax	60
7. Diffuse Knapweed, Tumble Knapweed	129
8. Dyer's Woad	152
9. Leafy Spurge	162
10. Mediterranean Sage	179
11. Medusahead	203
12. Oxeye Daisy	225
13. Perennial Sowthistle	235
14. Purple Loosestrife	245
15. Rush Skeletonweed	258
16. Russian Knapweed	270
17. Squarrose Knapweed	282
18. Sulphur Cinquefoil	296
19. Yellow and Orange Hawkweeds	317
20. Yellow and Purple Starthistle	335

21. The Biology and Management of Noxious Rangeland Weeds: A	
Summary	350

CHAPTER 1

NOXIOUS WEED MANAGEMENT

Roger L. Sheley*

INTRODUCTION

The magnitude and complexity of noxious 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 rangelands. Inventory and mapping is the first phase of any IWM program. The second phase includes prioritizing 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, density of the infestation, rangeland under threat of invasion, soil and ranges types, and other site factors pertinent to

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successfully managing the infested rangeland. 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. Prevention 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 weed seed free hay, feed grain, straw, or mulch,

- 2) refraining from driving vehicles and machinery through weed infestations and washing 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 them 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 without an understory of desirable species which 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 and 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 control 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 the 1) weed species, 2) 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 in the process of determining if combining treatments will provide a synergistic response in controlling weeds. Some preliminary evidence suggests most control techniques are compatible. 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 forage production over 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 drill 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.

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.

CHAPTER 2

RIPARIAN WEED MANAGEMENT

Roger L. Sheley, Barbra H. Mullin and Pete K. Fay*

INTRODUCTION

What is a riparian area?

Riparian areas are the green zones along the banks of rivers and streams and around springs, bogs, wet meadows, lakes, and ponds. They are some of the most productive ecosystems in the West, displaying a greater diversity of plant and wildlife species than adjoining lands.

What is the value of a riparian area?

Healthy riparian systems purify water as it moves through the vegetation by removing sediment. Riparian vegetation absorbs and dissipates the energy of flood waters before they cause serious damage to high value agricultural lands in lower valleys. Riparian areas reduce streambank erosion.

Many wildlife species are dependent upon the diverse habitat found in riparian areas - habitat providing food, water, cover, and

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space. Vegetation provides cover and lowers summer water temperatures favorable for fish.

What are the impacts of weeds on riparian areas?

Riparian areas are extremely valuable to the ecosystem and must be protected from invasion by noxious weeds. Invasive weed species, such as purple loosestrife, can be extremely competitive in a riparian setting. They can crowd out valuable native species, forming a solid stand of weeds. Studies have shown that weeds often do not stabilize soils as well as native bunch grasses, which can lead to soil erosion in the riparian area and loss of the stream channel.

Successful riparian weed management is difficult. It requires an integrated, well planned, and coordinated strategy based on the way the area is used. Integrated riparian weed management includes the integration of control methods to prevent new weed introductions, detection and eradication of existing infestations, the proper management of livestock and, often, revegetation.

PREVENTION AND CONTAINMENT

Limiting weed seed dispersal.

Preventing the introduction of weeds into riparian areas is critical to their management. Seeds are dispersed to riparian areas mainly by vehicles along highways adjacent to rivers. Once a single

plant becomes established, it produces thousands of seeds which are blown into moving water. Nearly all weed seeds float and are easily spread along waterways. Weed seed dispersal can be minimized by:

- 1) refraining from driving vehicles and machinery through weed infestations,
- 2) washing the undercarriage of vehicles and machinery after driving from a weed infested area to an uninfested area,
- 3) using weed seed free feed,
- 4) requesting the campers, hikers, and sportsmen take care in brushing and cleaning themselves, as well as their animals and equipment when recreating in weed infested areas,
- 5) holding livestock grazing weed infested areas for 7 to 10 days before allowing access to riparian areas.

Containing neighboring infestations.

Containment programs are generally used to restrict the encroachment of large-scale weed infestations into riparian areas. This necessarily requires an aggressive chemical control program on the advancing border of the weed infestation.

Minimize soil disturbance

Many alien weeds have evolved under abusive grazing and highly disturbed conditions. These weeds have developed many

characteristics which provide an ecological advantage over native riparian vegetation in disturbed soil. Minimizing soil disturbance by vehicles, machinery, wildlife, waterflow, and livestock is central to preventing weed establishment. Maintaining uplands in good ecological condition minimizes extremes in streamflow and soil disturbance by providing safe capture, storage and release of precipitation.

Properly manage desirable vegetation

Proper management of desirable riparian vegetation is essential to prevent weed encroachment. Competitive riparian plants, such as Nebraska sedge, are capable of limiting weed invasion as long as they are managed properly. Besides preventing weed invasion, these species bind soil that would otherwise erode. They decrease water velocity which reduces soil disturbance and subsequent weed invasion.

SYSTEMATIC SURVEYS AND SMALL-SCALE ERADICATION

Early detection of weed introductions to riparian weed management is critical because eradication of small patches may be possible. Once the infestation becomes established, eradication is unlikely. Two or 3 systematic surveys each year along waterways and adjacent roadways by personnel specifically trained to identify weeds usually provides adequate early detection.

A small-scale eradication program should be implemented once a serious weed is detected in a riparian area. The eradication program should include careful delineation of the infested area, the best control methods and approximate number of years needed for control, a revegetation plan (when desirable plants do not respond to control), and a long-term monitoring program. In many cases, it is useful to estimate the cost of the eradication program for future budgeting.

GRAZING MANAGEMENT

Proper livestock grazing is essential to maintain competitive riparian vegetation and streambank stability. Proper livestock class and stocking rates can help prevent weeds from encroaching riparian areas. Sheep tend to spend less time on riparian areas than cattle which allows land managers greater control of grazing. While cow-calf pairs tend to concentrate in riparian areas, yearlings spend more time on the uplands.

Short duration-high intensity grazing forces livestock to graze weeds as well as desirable riparian vegetation. This helps maintain a balance between plant species within the riparian plant community. Some weeds, such as leafy spurge, can be grazed by sheep or goats in riparian areas which helps shift the competitive balance to desirable species. In southwestern Montana, a rest rotation grazing system has been successful for improving riparian

vegetation. Under this grazing system, pasture use is rotated so that at least one pasture receives year-long rest from livestock grazing each year.

CHEMICAL CONTROL

Herbicides must be used with care in riparian areas in order to protect non-target vegetation and prevent water contamination. Use herbicides that are labelled for riparian areas.

Careful hand applications and spot treatments will help protect non-target vegetation. Timing of applications when run-off is unlikely, use of shorter residual herbicides with low water solubility, and application above the mean high water mark will reduce the possibility of water contamination. Prevent herbicide drift by wind onto non-target plants or nearby water.

Guidelines for selected herbicides for use in riparian areas.

2,4-D Various labels. Do not apply directly to water except under specific label directions. Some labels allow for overspray on irrigation canal ditchbanks. A Montana Special Local Need Label allows use the use of PBI/Gordon Amine 400[®] for use on purple loosestrife around water. Please refer to the labels for specific directions.

fosamine Krenite[®]. Noncropland uses. It is permissible to treat ditch banks, seasonally dry flood plains, deltas, marshes, swamps, bogs, and transitional areas between upland and lowland sites. Do not apply to open water nor while water is present in fresh water wetlands nor to areas where the herbicide is likely to move into water. Krenite[®] provides effective control of many woody and brushy species. Use care in riparian areas to protect non-target woody species.

glyphosate Rodeo[®] label only. May be applied along ditches, lake and pond banks, streams, and rivers. Do not apply within 1/2 mile of a potable water intake. Non-selective, use care around non-target vegetation.

triclopyr Garlon[®]. It is permissible to treat non-irrigation ditchbanks, seasonally dry wetlands, flood plains, deltas, marshes, swamps, bogs, and transitional areas between upland and lowland sites. Do not apply to open water or to water present in fresh water wetlands, reservoirs, rivers, streams, or creeks, below the mean high water mark.

More persistent herbicides, herbicides that readily leach, and herbicides with strict label prohibitions against contamination of water should only be used where you can be assured that they will not drift or run-off over time into nearby water of the riparian area. These herbicides include (but are not limited to): clopyralid (Stinger[®], Transline[®]), dicamba (Banvel[®]), metsulfuron (Ally[®], Escort[®]), and picloram (Tordon[®]).

BIOLOGICAL CONTROL

Ideally, natural enemies appear well suited for controlling weeds along riparian areas because they do not impact water quality. However, most biological controls stress weeds or reduce seed production, but do not KILL the plants. A main objective in riparian areas is to control weeds IMMEDIATELY to prevent rapid seed dispersal by moving water.

Some weeds, such as diffuse and spotted knapweed, have natural enemies which are effective in reducing seed production. For example, seed-gall flies have been reported to reduce knapweed seed production up to 80%. Establishing seed feeding biological control agents may limit the amount of seeds produced enough to slow the spread of weeds. Biological controls may be useful on otherwise unmanaged weed infestations. Sole reliance on biological control will have very little impact on riparian weed infestations.

MECHANICAL CONTROL

Hand pulling or grubbing can be an effective method for controlling weeds in riparian areas. This method is especially useful for controlling newly established weeds that have not produced seeds or developed an extensive root system. Grubbing each year for 10 to 15 years is required to deplete root and/or seed reserves of well established plants. Perennial plants with extensive root systems, such as leafy spurge and Canada thistle requires grubbing once or twice a month to deplete root reserves.

Mowing and cultivation is not recommended in riparian areas. In many cases, mowing does not effect root reserves and may actually increase weed seed production in wet areas by "pruning" the weeds. Cultivation can be an effective weed control method, but is usually not recommended in riparian areas because of the risk of erosion. Cultivation is usually required on 2 to 3 week intervals for at least two consecutive years for many perennial weeds.

REVEGETATION

Riparian vegetation is generally resilient because the habitat is fertile and moisture is unlimited so recovery is rapid after weeds are controlled and proper management is restored. However, residual (suppressed) understory grasses and sedges must be present for recovery. In areas without residual riparian vegetation,

revegetation may be necessary to close the plant community to re-invasion by weeds.

Most revegetation programs require spraying glyphosate (Rodeo®) early in the spring, after the majority of the weeds have emerged. Fall applications increase the risk of erosion because of the loss of stabilizing vegetation during the rainy season. Rodeo® is non-selective and kills most species, therefore spray should be applied directly to target plants. In areas where a heavy residual weed stand exists, it may be necessary to disk or plow to create a quality seedbed. After the Rodeo® application, the desired seed mixture should be drill seeded. If the site is inaccessible to equipment, broadcast seeding may be used, but is usually less effective. Broadcast seeding in riparian areas will likely require repeated attempts. Revegetation programs should be implemented on small units over a series of years to minimize risk of large-scale erosion because of poor seedling establishment.

The seed mixture used depends on the specific site. A local soil or range conservationist can recommend a good seed mixture. In general, reseeding with sedges and grasses is desirable because retreatments with 2,4-D amine, a broadleaf herbicide, may be necessary to control newly emerging weed seedlings. After 3 years, a strong grass or sedge stand should be able to limit invasion by weeds. At this time, establishing broadleaved and shrubby (willows) riparian species may be possible.

CHAPTER 3

PREVENTING NOXIOUS WEED INVASION

Roger L. Sheley*

INTRODUCTION

The most effective method for managing noxious weeds is to prevent their invasion. Developing a noxious weed prevention program requires using a combination of methods aimed at limiting weed encroachment. This publication is designed to provide the reader an initial understanding of the methods for preventing the introduction, establishment, and invasion of noxious weeds.

There are several methods of preventing noxious weeds from spreading. They are:

- * Limiting weed seed dispersal.
- * Containing neighboring weed infestations.
- * Minimizing soil disturbances.
- * Detecting and eradicating weed introductions early.
- * Establishing competitive grasses.
- * Properly managing grasses.

LIMITING WEED SEED DISPERSAL

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Noxious weed seeds are often carried along roadways in the undercarriage of vehicles. A Montana State University study showed that a vehicle driven several feet through a spotted knapweed infestation can pick up about two thousand seeds (Trunkel and Fay 1991). These seeds are then dispersed along highways. In the same study, only 10% of the weed seeds remained on the vehicle 10 miles from the infestation. Similarly, weed seeds are dispersed by machinery. It is important to remember to limit noxious weed seed dispersal by refraining from driving vehicles and machinery through weed infested areas during the seeding period. It is also important to wash the undercarriage of vehicles after driving through an area infested with a seed producing noxious weed. Be sure to control emerging weeds in the wash-up area.

Wildlife and livestock disperse seeds two ways. First, animals ingest noxious weed seeds. These ingested seeds can pass through the stomach unaffected, introducing seeds into new areas. Second, many weed seeds have appendages which assist in their attachment to animals. When the animal is moved to a weed free area these seeds fall to the ground. Little can be done to limit weed seed dispersal by wildlife. However, livestock should not graze weed infested areas during flowering and seeding, or should be transported to a holding area for about 14 days after grazing weed infested areas and before being moved to weed-free ranges.

Noxious weeds can be dispersed in feed. This is especially true on lands where recreational horseback riding and hunting is permitted, but can be a problem for rancher's as well. Using weed-seed free feed is one method of preventing the introduction of noxious weeds. The best seed-free feed is produced by grinding and pelleting forage or grain certified as weed-free (Zamora 1993).

Hikers and campers spread noxious weed seeds on their clothing. Recreationists disperse weed seeds when they pick the flowers and discard the wilted parts along trails and recreational access sites (Lacey et al. 1992). Clothing and camping equipment should be brushed and the discards placed into a hot fire before leaving an area. Prudence in limiting weed seed dispersal is critical for all recreationists.

Some noxious weeds, including diffuse and spotted knapweed, have natural enemies, such as seed-feeding gall flies, which are effective in reducing seed production. Seed-gall flies have been reported to reduce knapweed seed production up to 80% and reduce the potential for dispersal (Maddox 1982). In any noxious weed prevention program, it is important to work with university Extension Specialists to insure that biological controls are well established on neighboring infestations.

CONTAINING NEIGHBORING WEED INFESTATIONS

An integral part of any weed prevention program is to contain neighboring weed infestations. Containment practices are designed to restrict the encroachment of noxious weeds onto adjacent rangelands. The most effective method of containment is to spray borders of the infested areas with a herbicide. This approach is designed to concentrate efforts on the advancing edge of the weed infestation. Containment programs typically require a long-term commitment to herbicide application because they are not designed to modify or reduce the infestation level, only to limit its spread. Roadways and railways, where weed infestations often begin, should be under a constant prevention and containment program.

MINIMIZING SOIL DISTURBANCES

Most noxious weeds are alien to North America and have evolved under abusive grazing which causes soil disturbance and erosion. Noxious weeds have developed many characteristics which provide them an advantage over native North American plants in occupying disturbed soil. Minimizing soil disturbance by such things as vehicles, machinery, wildlife, and livestock is central to preventing noxious weed establishment.

DETECTING AND ERADICATING WEED INTRODUCTIONS EARLY

Preventing and controlling noxious weed encroachment depends on early detection. One successful methods for preventing the

invasion of weeds is to survey the area, removing any individual weed plants before they become well established. A survey plan should be developed for each management unit which includes inventory techniques (vehicle, horseback, motorcycle), area surveyed, and survey time periods. At least three surveys should be conducted on the management area each year. A spring survey should be conducted to detect weeds early enough to allow effective chemical control. The second survey should be conducted in early summer and the last survey in early fall. At each survey both new and old noxious weed introductions should be hand removed (individual plants) or sprayed with the appropriate herbicide. It is critical to prevent weed seed production. Late season chemical applications generally do not prevent seed production, and hand removal is usually necessary. Hand pulled plants should be burned. The weed infestation should be identified on a map, marked or flagged in the field, continually monitored, and controlled during subsequent surveys.

ESTABLISHING COMPETITIVE GRASSES

Another useful method for preventing the encroachment of noxious weeds is to establish competitive desirable grasses in areas susceptible to invasion. Competitive grasses can limit the establishment and growth of weed populations by using resources needed by weeds. Well established grass stands are central to

limiting weed encroachment along roadways. Specific establishment techniques depend upon the weed/grass complex and environmental characteristics of the site. In areas with a good residual (suppressed) perennial grass stand, chemical weed control (2,4-D, Banvel, Tordon 22k) may stimulate grass growth enough to allow site re-occupation.

Severe weed infestations may require revegetation. Where a heavy residual weed stand exists it may be necessary to burn in the fall to remove old stems before revegetation procedures can be implemented. In areas without a heavy residual weed stand or areas that have been burned, the soil should be chisel plowed in the fall. Plowing will create a quality seedbed, bury some weed seeds, and turn up others.

In areas dominated solely by broadleaved weeds, Tordon 22k should be applied immediately after plowing. If broadleaved and grass (cheatgrass/medusahead) weeds co-dominate, the area should be sprayed with Roundup the spring (March-April) following plowing. The round-up application should be applied as early in the spring as possible, but after the majority of the weeds emerge. Do not spray desired trees and shrubs.

In the spring, (after the round-up application, unless Tordon 22k is used), the area should be drill seeded with the proper mixture of perennial grasses. This mixture and rates vary depending on the specific range site. A local Soil or Range Conservationist

can recommend a good seed mixture. A follow-up herbicide treatment may be necessary to control weeds emerging in the seeded grass stand. After 3 years, a strong grass stand should be able to limit invasion by noxious weeds.

Other revegetation methods are also useful. Hydroseeding, plugging, or broadcasting and covering seeds with a layer of straw may be more effective on steep slopes or under various circumstances.

PROPERLY MANAGING GRASSES

On areas with a competitive grass stand, proper management insures that they remain strong and vigorous and are able to prevent noxious weed encroachment. In most cases, grasses require defoliation every 2-4 years to remove old stems which shade plants and hinder growth. Mowing, burning, and grazing are the primary methods for defoliating grasses. Grasses are generally mowed in the summer or fall. Burning is conducted in the fall or early spring before the grasses resume growth. Defoliation stimulates grass growth and enhances their competitive ability.

Proper livestock grazing is essential to maintain competitive grass plants. A grazing management plan should be developed for any management unit involved in a noxious weed prevention program. This plan should include proper stocking rates to achieve a grass utilization level of 30-40% of annual production. The plan should

include a grazing system which outlines the movement of livestock throughout the year. Grazing systems should include altering the season of use, rotating livestock to allow plants to recover before being regrazed, and promoting litter accumulation. Grazing in this manner enhances the vigor and strength of the grasses which limits weed germination and promotes early mortality of seedlings and rosettes. The grazing management plan should include a monitoring program to determine the efficacy of the grazing system in protecting grasses and limiting weed invasion. In most areas the Soil Conservation Service can provide excellent advise regarding grazing and monitoring systems.

Montana is being invaded by noxious weeds. The most economical method for managing noxious weeds is to prevent their invasion. Noxious weed dispersal must be limited, and neighboring weed infestations must be contained. Soil disturbances must be minimized, new introductions must be detected early and weeds eradicated, and proper grass establishment and management must be followed.

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CHAPTER 4

BULL THISTLE, MUSK THISTLE, AND SCOTCH THISTLE

K. George Beck*

BULL THISTLE**DESCRIPTION**

Bull thistle [*Cirsium vulgare* (Savi.) Tenore] is a member of the Asteraceae or sunflower family and thistle tribe (Zimdahl 1983). The accepted common name is bull thistle (Weed Science Society of America 1989) but bull thistle has been called spear thistle and lance-leaved thistle. Bull thistle has a short fleshy taproot and grows 2 to 5 feet tall with many spreading branches (Whitson 1991). It is green or brownish, shoots have spiny wings, and it is sparsely hairy. Leaves are more or less lance-shaped, pinnately lobed, and 3 to 6 inches long. Leaves are prickly hairy on the adaxial side (above) and very pubescent on the abaxial side (below) giving it a cottony appearance. Triangular to lance-shaped lobes are tipped with stout, needle-like spines. Flowers are 1.5 to 2 inches in diameter, 1 to 2 inches long, usually solitary, and more or less clustered at the terminal ends of shoots and branches.

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Flowers are bright purple, fragrant, and subtended by narrow involucre bracts that are spine-tipped. Achenes (hereafter called seeds) are light colored, 1/16 inch long, oblong, somewhat flattened, sometimes curved, with a long, white, hairy plume that is easily detached.

BIOLOGY AND ECOLOGY

Bull thistle normally is a biennial and can germinate in spring or fall. In Australia, it typically germinates in fall after the first substantial rain (Forcella and Wood 1986). Plants grow the first year as a rosette and develop a fleshy taproot that does not creep or spread like Canada thistle. In spring of the second year, plants resume growth, bolt (shoot elongation) to 2 to 5 feet tall. Shoots bear 10 to 200 inflorescences (hereafter called flower heads) by mid-summer (Forcella and Wood 1986). Bull thistle reproduces and spreads solely from seed.

One adult plant/m² reduced spring or summer liveweight gains of sheep by about 4.5 lb per animal (Hartley 1983). Bull thistle is believed to proliferate and thrive in pastures that are heavily grazed and subject to nitrogen fertilization (Doing et al 1969; Michael 1970). In Australia, dense bull populations exist in heavily grazed pastures but it is rare in ungrazed pastures (Forcella and Wood 1986).

Seed production per plant ranged from 1480 to 26,371 (average 12,200) in heavily grazed pastures compared to 1694 to 8849 (average 4125) in ungrazed pastures (Forcella and Wood 1986). Seedling populations in grazed pastures ranged from 276 to 570/m² (average 425/m²) compared to 26 to 508/m² (average 343/m²) in ungrazed pastures. Rosette populations in grazed pastures ranged from 0.35 to 7.7/m² (average 3.1/m²) compared to 0.07 to 2.5/m² (average 1.4/m²) in ungrazed pastures. Flowering plants in grazed pastures ranged from 0.1 to 5.3/m² (average 1.9/m²) compared to 0.13 to 2.0/m² (average 1.0/m²) in ungrazed pastures. Forcella and Wood concluded that heavily grazed pastures (stocking rate or grazing duration not defined) were at the greatest risk from bull thistle invasion. They also found that the transition from seedlings to rosettes is where the greatest bull thistle population attrition occurred. The average survival of seedlings in grazed and ungrazed pastures was 1.0 and 0.2%, respectively, over a 3 year period. Approximately 15 and 10% of seeds from grazed and ungrazed pastures, respectively, produced seedlings over 3 years and about 50% of rosettes in both pasture types survived and grew into adults over this same time.

MANAGEMENT

The key to managing bull thistle successfully is to prevent seed formation.

Chemical control

Auxin herbicides such as 2,4-D, MCPA, dicamba, and picloram will control bull thistle. The USDA found that a 1.0 lb ai/A application of these herbicides killed over 95% of bull thistle with a single application (Klingman et al 1983). Forcella and Wood (1986) reduced the number of rosettes that survived to adulthood to 10 to 12% with dicamba at 1.0 lb ai/A applied in early summer or fall. Dicamba applications in winter or spring did not influence survival of rosettes to adults. Seed production the year following treatment was reduced from all herbicide timings of application except when applied during winter. Only 19% of seedlings survived dicamba applications in fall compared to 87, 39, and 65% survival from winter, spring, or summer applications, respectively. Herbicide recommendations to control bull thistle are in Table 1.

Mechanical control

Although no information was found on mechanical control, bull thistle most likely is susceptible to hand-pulling, hoeing, or tillage operations because it is a taprooted plant. These techniques should be used in spring before bull thistle bolts to avoid the possibility of seed set. Fall also would be a good time for pulling, hoeing, or tillage because all bull thistle plants would be rosettes.

Table 1. Herbicide rates and timings to control bull thistle.

Herbicide	Rate	Remarks
	(lb ai/A)	
Dicamba	0.5 to 1.0	apply in spring or fall to rosettes
MCPA	1.0 to 1.5	apply in spring or fall to rosettes
Picloram + 2,4-D	0.13 + 1.0	apply in late spring or fall to rosettes
2,4-D	1.0 to 2.0	apply in late spring or early summer or fall to rosettes

Biological control

The seed head weevil, *Rhinocyllus conicus* (Froelich) (Coleoptera: Curculionidae), was imported from France and will attack bull thistle, although its primary target is musk thistle. The weevil was released in 1989 on bull thistle in South Africa and is reported to be spreading from its original release site (Julien 1992). The weevil failed to establish on bull thistle in British Columbia and is under evaluation in Australia.

Trichosirocalus horridus (Panzer) (Coleoptera: Curculionidae) is a European weevil that feeds on the apical meristem during the rosette growth stage and reduces flowering potential (Julien 1992). Larvae feed in the crown and adults emerge in late spring to early summer and feed on foliage. It was first released on bull thistle in New Zealand in 1984. Establishment was reported and redistribution efforts are in progress (Julien 1992).

A seed head fly, *Urophora stylata* (Fabricius)(Diptera: Tephritidae), was found in Germany and Switzerland (Julien 1992). Larvae feed on developing seeds in flower heads and seed production decreases of 65% were reported. *Urophora stylata* was first released in Canada in 1973 and established in British Columbia, Nova Scotia, and Quebec but not in Ontario. It was reported to die in sparse bull thistle stands and weed populations have not been reduced in Canada. It was first released in the United States in 1983. *Urophora stylata* established in Colorado, Maryland, and Oregon. Galls in bull thistle flower heads were first observed in Colorado in 1993 (Colorado Dept. of Agriculture, Div. of Plant Industry Annual Report 1992-1993).

Cultural control

Thistles in general invade disturbed or degraded areas where competition from desirable plants is reduced. Augmenting the desirable plant community by seeding may be necessary to succeed in long-term thistle population reductions and return the site to a productive state.

Grasses tend to be most competitive with broadleaf weeds in the western United States. In Australia, an annual ryegrass (*Lolium rigidum* Gaud.) was more competitive than subclover (*Trifolium subterraneum* L.) and researchers recommended conservation of ryegrass in pastures infested with bull thistle

(Forcella and Wood 1986). Whitson *et al* (1989) found that sequential applications of glyphosate followed by dormant seeding of perennial grasses controlled 88 to 90% of leafy spurge 4 years after treatments were initiated. No such integrated approach was found for bull thistle. However, given the observations of Forcella and Wood that bull thistle was problematic in heavily grazed pastures and rare in ungrazed pastures, there is reason to believe that suppression/control of bull thistle with herbicides followed by seeding perennial grasses in fall also may reduce bull thistle populations. Forcella and Wood (1986) suggested that cessation of grazing may improve grass vigor and competition with bull thistle and reduce its survival from seedlings to rosettes. They further suggested that cessation of grazing should be coupled to annual precipitation cycles. The length of time to stop grazing is unknown.

MUSK THISTLE

DESCRIPTION

There are three species of musk thistle in the United States; *Carduus nutans* L., *C. macrocephalus* Desf., and *C. thoermeri* Weinm and all are commonly referred to as musk thistle (McCarty *et al* 1980). Musk thistle is an Asteraceae and member of the thistle tribe (Zimdahl 1983). The accepted common name is musk thistle but

it also is called nodding thistle. Musk thistle was introduced into the United States from Europe. The earliest records for occurrence were in central Pennsylvania in 1852 (Stuckey and Forsyth 1971).

Musk thistle germinates and grows the first year as a rosette. It develops a large, fleshy, corky taproot that is hollow near the soil surface (Zimdahl 1983). In its second year, musk thistle bolts and flowering shoots grow from 2 to 6 feet tall. Leaves are dark green with a light green mid-rib and mostly white margins. Leaves are 3 to 6 inches long, alternate, clasp down the shoot, and are deeply lobed. Each lobe has five points that are tipped with a stiff, white or yellow spine. Shoots are covered with spines except that shoots subtending flowers are almost devoid of spines.

Flowers are solitary and terminal on shoots. Flowers bend or nod approximately 90 degrees to the shoot. They are 1.5 to 3.0 inches in diameter, bright purple, or rarely white. Flowers are subtended by numerous large, lance-shaped, spine-tipped bracts. Seeds are 1/8 to 3/16 inches long, shiny, striated, yellow-brown, with a white hairlike plume.

BIOLOGY AND ECOLOGY

Musk thistle typically is a biennial but it may complete its life cycle as a winter annual or occasionally as an annual (Feldman

et al 1968). Musk thistle spends approximately 90% of its life cycle as a rosette then bolt, flowers, produces seed, and dies. Seed production typically occurs within 45 to 55 days after bolting (Roeth 1979). The three species of musk thistle are commonly referred as *Carduus nutans* although McCarty et al (1980) reported that the majority of musk thistle populations are most likely *Carduus thoermeri*.

Musk thistle is dependent upon seed production for reproduction and spread (McCarty 1982). Flowering begins with the terminal (primary) bud and proceeds basipetally. The terminal flower head is solitary and the topmost branch usually develops a solitary flower head approximately the same size as the terminal one. Lower branches often develop secondary and sometimes tertiary flower heads that often are called axillary flowers. McCarty et al (1980) observed that florets on the same flower head are compatible as evidenced by the production of viable seed after self-pollination.

McCarty (1982) classified seed produced by musk thistle into four classes by weight. The different weight classes displayed characteristic germination percentages. Class I were light weight seeds that did not germinate; class II were poorly developed seeds where 2% germinated; class III and IV were fair and good seeds that germinated 38 and 96%, respectively. As flowers matured from full bloom (where all florets in a head had elongated and stigmas were

extended) to immediately before seed dissemination, total number of class IV seeds increased, i.e., that longer musk thistle plants bloomed the greater number of good seeds that were produced. It took approximately 9 weeks for all flower heads to mature. These plants averaged 54 seed heads/plant, 3580 good seeds/plant and 1270 fair seeds/plant. He calculated that 3870 seedlings potentially could be produced from the average mature musk thistle plant. Thus, the average plant produces 10,000 to 11,000 seeds only 33% of which are capable of germination and seedling establishment.

Medd and Lovett (1978) studies the light requirements of germinating musk thistle seeds and developing seedlings. They worked with the subspecies *Carduus nutans* (L.) ssp. *nutans* and found 80 and 76% germination in light within 14 days at alternating temperatures of 15/20 and 20/30 C, respectively. This coincides with typical field temperatures when musk thistle germinates in spring and fall in Australia. McCarty *et al* (1969) found no afterripening requirement for freshly harvested musk thistle seeds and reported was not a major factor controlling germination. However, Medd and Lovett (1978) found that red light was required for *Carduus nutans* (L.) *nutans* to germinate. Red light alone stimulated germination and far red light reversed its effects. Potassium nitrate solutions (2×10^{-2} M) increased germination in darkness (+ 54%), characteristic of other light sensitive species. The authors concluded that KNO_3 could occur in soil in such

concentrations in spring and cause buried seed to germinate creating a flush of musk thistle. Musk thistle germination was 1% in darkness but the addition of 6.2 to 100 mg/l of GA₃ stimulated germination similar to that in light and thus, substituted for light, also characteristic of light-sensitive species. Australian researchers (Doing et al 1969) observed that musk thistle germination was favored by daylight and found established seedlings only on bare soil. Feldman et al (1968) found that musk thistle establishment was best on poorly vegetated sites. Because abundant red light would reach bare or poorly vegetated soils and Medd and Lovett (1978) concluded their results substantiated the observations of Doing et al and Feldman et al.

Field and laboratory studies showed that musk thistle requires vernalization for floral initiation (Medd and Lovett 1978). Short days before a vernalization period reduced the length of the vernalization period necessary to initiate floral development and the need for subsequent long days after vernalization. Under 0 short days, musk thistle had to be exposed to 56 days of vernalization temperatures for 40% of the plants to flower. These plants needed 31 long days for bolting to occur and another 31 long days passed from bolting to anthesis. Under 84 short days before exposing musk thistle to vernalization temperatures, musk thistle only need 14 days of vernalization for 100% of the plants to flower. These plants required 20 long days after vernalization to

bolt and 36 additional long days passed from bolting to anthesis. The short day substitution for the vernalization requirement may explain why musk thistle displays a biennial nature for those plants germinating in spring and a winter annual nature for those that germinate in fall. Other musk thistle species (other than *Carduus nutans* ssp. *nutans*) may have different vernalization requirements and short day substitution for vernalization. There is a need to better classify taxonomically the musk thistle species that infest the United States and conduct these basic biological experiments to improve our understanding of these weeds.

Burnside *et al* (1981) found that musk thistle seeds survived in the soil a decade or more. They predicted that a period of 15 years was necessary to reduce germination of buried musk thistle seeds to 1%. They stated that land managers would have to remain vigilant in controlling musk thistle over a number of years (15?) to eradicate the weed from their land.

Inadequate soil moisture may hinder musk thistle germination and stand establishment. Musk thistle germination was reduced by 50% at approximately -1600 kPa moisture tension compared to controls (0 kPa) (McCarty *et al* 1969). Seedling growth was reduced 50% at -600 kPa moisture tension but seedlings still grew at -2000 kPa although growth was reduced 91% at this moisture tension compared to controls at 0 kPa. Medd and Lovett (1978) found 46 and 99% reductions in the germination of *Carduus nutans* ssp. *nutans* at

-400 kPa and -1000 kPa, respectively, compared to controls at 0 kPa. These data may substantiate the conclusions of Feldman *et al* (1968) where they found more musk thistle in pastures with larger amounts of litter which they believed created better soil moisture conditions for establishment and competition with desirable grasses. However, the data of McCarty *et al* (1969) and Medd and Lovett (1978) indicate that at least some musk thistle may germinate and establish under very dry soil moisture conditions.

Musk thistle seedlings may be sensitive to light competition from neighboring plants. Medd and Lovett (1978) subjected musk thistle seedlings to 10, 35, 57, and 125 W/m² photosynthetically active radiation at the plant surface (125 W/m² is approximately 30% of full sunlight). After 68 days, musk thistle seedling growth was reduced at the three lowest light intensities by 97, 68, and 35%, respectively. They concluded that enhanced competition from taller growing grasses could be exploited in spring by removing grazing animals and allowing grasses to elongate and shade musk thistle seedlings.

Musk thistle will germinate and grow under a wide range of environmental conditions. Musk thistle is found in 40 states (Dunn 1976). It infests arid areas in Nevada to relatively high moisture areas of Virginia and the east coast. Moisture stress and floral development data provide an explanation for its wide ecological amplitude.

MANAGEMENT

The key to managing musk thistle effectively is to prevent viable seed production (McCarty, M.K. 1982. Musk thistle (*Carduus thoermeri*) seed production. Weed Sci. 30:441-445).

Chemical control

Musk thistle is controlled effectively by several herbicides. Auxin herbicides such as picloram, dicamba, 2,4-D, or dicamba plus 2,4-D often are used (Table 2). Metsulfuron and chlorsulfuron also are effective. Herbicide choice and rates are influenced by growth stage, stand density and environmental conditions; e.g., drought or cold temperatures. The auxin herbicides should be applied in spring or fall when musk thistle is in the rosette growth stage. Metsulfuron or chlorsulfuron should be applied in late spring when musk thistle is in the bolting to bud growth stages.

Feldman *et al* (1968) and Roeth (1979) found that musk thistle susceptibility to auxin herbicides decreases after the weed begins to bolt. Dicamba at 0.5 lb/A, 2,4-D at 2.0 lb/A, dicamba plus 2,4-D at 0.25 + 1.0 lb/A, and picloram at 0.13 lb/A when applied to bolting musk thistle controlled 60, 43, 47, and 65% of musk thistle over a three year period (Roeth 1979). In contrast, when these herbicides were applied to musk thistle rosettes at the same rates, 90, 96, 96, and 100% of musk thistle was controlled over the same three year period.

When musk thistle was sprayed from the late bud to the late bloom growth stages with 2,4-D, dicamba, picloram, or dicamba plus 2,4-D seed production was reduced 76 to 99% compared to non-sprayed plants (McCarty and Hatting 1975). Assuming that 33% of the seed produced was Class IV, or good seed (Medd and Lovett 1978) and would germinate at 95%, seed still produced from these herbicide treatments could produce from 12 to 450 seedlings and the infestation would persist. To avoid musk thistle contributions to its soil seed reserve and to deplete the soil seed reserve over time, herbicides should be applied at a time and a rate that will eliminate viable seed production.

Musk thistle often is sprayed with herbicides after bolting because infestations are easier to locate. Chlorsulfuron at 0.75 oz/A or metsulfuron at 0.3 oz/A applied during bolting or bud growth stages eliminated viable seed production (Beck et al 1990). However, chlorsulfuron or metsulfuron applied in the rosette stage did not eliminate viable seed production. Clopyralid, dicamba, dicamba plus 2,4-D, or picloram did not eliminate viable seed production when applied at bolting, bud, or bloom growth stages.

When musk thistle is in the rosette growth stage, auxin herbicides are the best choice but after bolting begins, the sulfonyleurea herbicides should be used when chemical control is invoked. Fall is a good time to control musk thistle with herbicides because all live plants will be seedlings or rosettes.

Cool or dry weather conditions commonly associated with autumn may decrease musk thistle control from 2,4-D or dicamba. Roeth (1979) found that 2,4-D, dicamba, or dicamba plus 2,4-D did not control musk thistle under cool dry conditions as well compared to applications when weather was warmer or moisture was not limiting. He also found that picloram applied during cool, dry weather still controlled musk thistle adequately. Picloram may be a better choice for fall applications particularly if weather conditions are cool and/or dry.

Reece and Wilson applied clopyralid and clopyralid plus 2,4-D, picloram and picloram plus 2,4-D, and dicamba and dicamba plus 2,4-D in a series of applications over 3 years to a mixed stand of musk and Canada thistle (1983). The pasture area was grazed by cattle for 30 days each year after data were gathered in late spring. Perennial grass production on unfertilized plots treated with these herbicides increased 110, 314, and 212%, respectively, compared to unfertilized control plots over the 3 year period. However, grasses did not fully reoccupy the sites after herbicide treatments at the end of the 3 year study in spite of excellent weed control. These data may suggest that seeding an area after musk thistle is sprayed may be necessary to fully recover the site for productive purposes.

Table 2. Herbicides and rates to control musk thistle in pastures, rangeland, and non-crop areas.

Herbicide	Rate	Timing/remarks
	(lb ai/A)	
Picloram	0.125-0.25	spring before bolting or in fall
Dicamba	0.5-2.0	spring before bolting or in fall if good growing conditions exist
2,4-D	1.5-2.0	spring before bolting
2,4-D + dicamba	1.0+0.5	spring before bolting or in fall if good growing conditions exist
Metsulfuron	0.3 oz ai	spring from bolting to bud growth stages; add a non-ionic surfactant at 0.25% v/v
Chlorsulfuron	0.75 oz ai	<i>non-crop areas only</i> ; spring from bolting to bud growth stages; add a non-ionic surfactant at 0.25% v/v

Mechanical control

When musk thistle was mowed 2 days after terminal heads displayed anthesis, viable seed production was eliminated from mowed stalks (McCarty and Hatting 1975). Recovery of some plants ensued after mowing at each growth stage (late bud to late bloom) and seed still was produced. Although seed set was reduced 99% when mowed in late bloom, their data suggest that seven seedlings

could be produced from each mowed musk thistle plant the following year. A single mowing did not give satisfactory control because of growth stage variability in natural populations. Mowing alone may not be a viable control measure because seed invariably still will be produced.

Because musk thistle is a biennial or annual with a simple taproot and does not reproduce vegetatively, any tillage operation that severs the plant below the soil surface should provide complete control of that plant the year tillage is performed. However, it would be essential to revegetate the site with desirable plants or musk thistle will re-populate the area from its soil seed reserve.

Cultural control

Musk thistle germination and establishment is favored in open areas therefore, re-establishment of desirable vegetation usually will be necessary to complete successful weed management. However, no studies were found that combined re-seeding of perennial grasses or other vegetation with some other weed control method. This type of research needs to be conducted to develop effective musk thistle management systems.

Effective grass competition is essential to control musk thistle. Feldman *et al* (1968) compared musk thistle seedling establishment and development into rosettes under three grazing

management regimes and three pasture grass types. They compared continuous grazing, rotational grazing, and non-grazed regimes in cool-season grass pastures (intermediate wheatgrass and smooth brome) or a warm-season grass mix pasture. They seeded musk thistle into 1 m² areas in each grazing regime/grass pasture type in April or August. Musk thistle seedling establishment was best in smooth brome pastures that were non-grazed. There was a strong correlation between litter, cool-season grasses, and musk thistle establishment. Musk thistle seedling establishment was least in warm-season grass pastures that were non-grazed. Seedling transition to rosettes was greatest the year of musk thistle seeding in non-grazed, smooth brome pastures followed closely by non-grazed, intermediate wheatgrass pastures. The least survival of seedlings to rosettes was in non-grazed warm-season grass pastures. The greatest survival of musk thistle rosettes the year following seeding was in continuously grazed, warm-season grass pastures. No rosettes survived in the non-grazed pastures regardless of grass type nor in the rotationally grazed intermediate wheatgrass pastures. Fewer musk thistle rosettes survived in the rotationally grazed pastures compared to those continuously grazed; although, there was no difference for musk thistle rosette survival in the smooth brome pasture whether continuously (1 plant/m²) or rotationally (2 plants/m²) grazed. In all grass pasture types and grazing management systems, musk

thistle declined over time. The authors concluded that apparently musk thistle can invade pastures that are in good to excellent condition for grazing and grazed pastures that are carefully managed may enhance grass competition and deter musk thistle survival from seedlings to rosettes. They also stated that litter associated with cool-season grasses may harbor soil moisture and favor musk thistle seedling establishment. However, it also is apparent from their study that cool- or warm-season grass competition is an essential component of any effective musk thistle management system. This most likely is true for all weed species invading rangeland.

Biological control

Three insect species are being researched and redistributed in the United States to control musk thistle. The seed head weevil, *Rhinocyllus conicus* (Froelich)(Coleoptera: Curculionidae), is native to central and eastern Europe, western Asia, and the Mediterranean (Mellini 1951). It lives in a variety of climates including those that are extremely cold. The seed head weevil was first introduced into the United States in 1968 and since has been released in several western states. In Colorado for example, the state Department of Agriculture first received the seed head weevil in 1974 and it has spread all around the state since then and can be found at elevations from 4,500 to 10,000 feet (Div. of Plant

Industry Annual Report 1992-1993). The seed head weevil in Colorado is quite mobile and has moved several miles from various original release sites.

The seed head weevil limits seed production by musk thistle (Hodgson and Rees 1976). Females deposit eggs on flower bracts and eggs incubate for 6 to 8 days then hatch. Young larvae burrow into the flower receptacle and form cells in which they mature while consuming developing seeds. Pupation occurs in 25 to 30 days and adults develop 8 to 14 days later. Adults remain within the cells several more weeks before leaving the plant. Adults overwinter in soil, under rocks, duff, and wood (Zwolfer 1967). The weevil may have one or two generations per year (Hoffman 1954; Mellini 1951; Scherf 1964).

The seed head weevil attacks terminal and early developing lateral flower heads much more than later developing flower heads (Kok and Surles 1975). It will use *Carduus*, *Cirsium*, *Silybum*, and *Onopordum* genera as hosts but prefers the *Carduus nutans* 'group' (Rees 1991). Rees reported in the Gallatin Valley of Montana that *Rhinocyllus conicus* used *Carduus macrocephalus* and *C. thoermeri* equally well. There were no differences between the two weed species for the number of weevils per flower head or weevil survival. Typically, 7 to 16% of the larvae from eggs deposited on bracts will infest that flower head. Unless the weed is moisture stressed or the flower head is damaged, survival of larvae in the

head usually exceeds 98%. The viability of undamaged seeds from head infested with the seed head weevil also is reduced. Rees (1991) reported a 24% reduction in the viability of undamaged seeds when four to five weevil larvae infested musk thistle flower heads. Viability of undamaged seed was reduced to less than 2% when flower heads had nine or more larvae present. However, viable seed reduction is variable. Surles and Kok (1978) observed a 10 and 75% reduction in viable seed in the terminal and first lateral flower heads in 1973 and 1974, respectively. Viable seed production was reduced 35 and 36% in all heads in 1973 and 1974, respectively. They found that 70% of terminal heads were infested with weevils with an average of 6.8 pupation chambers per flower head; and 28% of axillary flower heads were infested with weevils at an average of 2.6 pupation chambers per head. Mean germination of seeds from axillary heads infested with weevils was 28% higher than seed from axillary heads from plants where no flower heads were infested with weevils. They suggested that axillary flower heads on musk thistle plants with flower heads (terminal, lateral, and axillary) infested with seed head weevils became stronger nutrient sinks and developed larger, more viable seeds. McCarty and Lamp (1982) also found that later developing flower heads produced greater quantities of viable seed compared to earlier developing flower heads that were infested with weevils again suggesting that later developing flowers became stronger nutrient sinks. Viable seed reduction was variable in

their study where weevils reduced viable seed production by 28 and 78% in 1978 and 1979, respectively. Data from Surles and Kok (1978) and McCarty and Lamp (1982) suggests that increased viable seed production in later developing axillary heads may be a compensatory response of the weed due to predation of earlier developing flower heads. Seed destruction by the weevil is not 100% and viable seed will be produced from plants infested with *Rhinocyllus conicus* and infestations may perpetuate, albeit at least in some instances, at a reduced population.

Trichosirocalus horridus (Panzer) (Coleoptera: Curculionidae) is a European weevil first introduced into the United States in 1974. This weevil has one generation per year and larvae feed on apical meristems of musk thistle rosettes and developing shoots reducing plant vigor and flowering potential (Rees 1991). Surviving plants produce fewer flower heads which produce fewer seeds. The increased number of smaller flower heads may provide more niches for *Rhinocyllus conicus*. *T. horridus* was reported to be established in Virginia, Kansas, Missouri, and Wyoming, although it has been released in other states (Colorado Dept. of Ag, Div. of Plant Industry Annual Report 1992-1993). In Colorado for example, *T. horridus* was first received for redistribution in 1983 and is well established. During the summer of 1993, approximately 31,000 weevils were collected and redistributed to 65 locations in 31 counties. As with the musk thistle seed head weevil, *T. horridus*

appears well-adapted to Colorado and is spreading quickly and establishing itself throughout the state.

A relatively new insect, *Cheilosa corydon* (Harris) (Diptera: Syrphidae) was first released in the United States in 1990 to control musk thistle. Eggs are deposited in young leaves and shoots near the center of the plant. Larvae burrow into shoots and move up and down causing shoots to break or dry prematurely (Rees 1991). Plant water and nutrient transport are impaired, flowering and seed production are reduced, and secondary invasion by soil microbes occurs through lesions in roots caused by feeding larvae. By summer, the third instar larvae burrow into roots where they remain until fall precipitation begins.

Chemical, mechanical, and biological control data may suggest that the threshold for viable seed production by musk thistle is zero to achieve long-term population reductions. Zero seed production by musk thistle may not be a realistic goal. This underscores the importance of desirable plant competition in any musk thistle management strategy to deter the establishment of musk thistle seedlings and transition to the rosette growth stage. As with bull thistle, the transition from seedling to the rosette growth stage in musk thistle may be the most precarious stage in its life cycle. Data from Feldman *et al* (1968; Roeth 1979) may substantiate this hypothesis however, research to specifically address this hypothesis should be conducted.

SCOTCH THISTLE

DESCRIPTION

The primary species of Scotch thistle in the United States is *Onopordum acanthium* L. A second species may be found in some locations. In Colorado for example, *O. tauricum* is found in the southern section of the state along the foothills of the Sangre De Cristo mountains from Pueblo to Walsenburg. Both are members of the Asteraceae, or sunflower family, thistle tribe. The accepted common name is Scotch thistle (Weed Science of America 1989) but it also has been called cotton thistle, downy thistle, silver thistle, Queen Mary's thistle, and asses' thistle.

Scotch thistle is native to Europe and Asia where it is common in central Asia, southern Europe, and Asia Minor. Scotch thistle was introduced into the eastern United States in the late 1800's (Bentham and Hooker 1904; Botanical Institute im. V.L. Kamarou of the Academy of Science of the U.S.S.R. 1952; Gray 1889).

Onopordum acanthium leaves are large, green, spiny, and covered with fine dense hairs on both sides giving the leaf a grayish-green appearance (Whitson et al 1991; Zimdahl 1983). *Onopordum tauricum* leaves are similar except that they are glabrous and bright green. First year rosettes are 10 to 12 inches or more in diameter. Leaves may be two feet long and one foot wide.

Leaves have a distinct, white mid-rib. Leaves of young plants are oblong while leaves of older plants are more rectangular. Scotch has a fleshy taproot. Flowering shoots may grow eight feet tall or more. Shoots are pubescent (*O. tauricum* are glabrous) and have a distinct winged appearance. Prominent triangular lobes occur on leaf margins and winged margins of shoots. Lobes end with a prominent, sharp, green to white spines. Flower heads are numerous and are terminal on primary and axillary shoots. Flowers are one to two inches in diameter, pale purple to red, flat on top, and subtended by a series of imbricated bracts, each tipped with a spine. Seeds are about 3/16 inch long, oblong to obovate, four-angled, deep brown to black, and distinctly wrinkled. Seeds are tipped with a pappus that is bristle-like but not feathery.

BIOLOGY AND ECOLOGY

Scotch thistle typically grows as a biennial although, historical literature indicates that it may grow as an annual as well. Young and Evans (1969) found Scotch thistle to grow as an annual, biennial, or short-lived perennial depending upon the environmental conditions in which it was growing. They believed this variation gave it a competitive advantage. Its life cycle was not bound by strict photoperiod or temperature requirements. They also found seed production to be independent of plant density. Over two years, flowering plant density ranged from 0.1 to 2.1

plants/ft² and the number of flowering heads per plant ranged from 70 to 310. Seed production per flowering head ranged from 110 to 140 and 8 to 14% of Scotch thistle seeds were non-dormant when freshly harvested.

Scotch thistle seeds contain a water soluble germination inhibitor (Yound and Evans 1972). The location of the inhibitor was not determined and could have been in the seed coat or in the embryo. Light quality influenced germination of freshly harvested seeds. Seeds exposed to continuous light from incandescent bulbs (rich in red light) did not germinate. Germination increased 1% when a light/dark cycle of 8 hours light and 16 hours of dark was imposed with the same light source. Germination inhibition under incandescent bulbs also was improved by 18% when GA₃ was included in the medium. Potassium nitrate plus GA₃ increased germination to 38% under incandescent light. The addition of GA₃ to seeds germinated in the dark did not increased germination. However, prewashing seeds in water and germinating in the dark with GA₃ in the medium improved germination by 50%. Washing alone improved seed germination in the dark from 14 to 38%. Germination in fluorescent light under an 8/16 light/dark cycle was 48% and was improved to 70% when seeds were prewashed. Scotch thistle seeds recovered from soil were not sensitive to photoperiod but did respond similarly to light quality compared to freshly harvested seeds. Young and Evans concluded that two systems were operative

in regulating Scotch thistle dormancy and germination; phytochrome (light quality) and the presence of a water soluble inhibitor. Approximately 85 to 90% of Scotch thistle seeds display innate dormancy upon maturity which assures a soil seed reserve and perpetuation of the population. No information was found on soil seed longevity.

MANAGEMENT

Scotch thistle reproduces and spreads solely from seed and the key to its management is to prevent seed formation.

Cultural control

As with bull and musk thistle, a management system that improves the desirable plant vegetation may be the most effective way of reducing Scotch thistle infestations. No data were found for Scotch thistle management systems that included competitive grass seedings however, given that Scotch thistle tends to invade degraded habitats, seeding infested areas after other control measures are invoked may provide long-term weed population reductions.

Chemical control

Young and Evans (1969) evaluated picloram, dicamba, 2,4-D, picloram plus 2,4-D, and amitrole applied in spring to control

Scotch thistle rosettes. The best control was from picloram at 0.03 to 2.0 lb/A and all weeds were killed when treatments were applied in the rosette growth stage. Scotch thistle was controlled for 2 years from the picloram treatments. Dicamba at 4.0 lb/A killed all Scotch thistle plants but controlled 70% of Scotch thistle when applied at 2.0 lb/A. Scotch thistle reinvaded the dicamba treated plots 1 year after treatments were applied. Weeds survived all the 2,4-D treatments and picloram plus 2,4-D was no better than picloram alone. Research in Idaho (Belles et al 1980) showed that 2,4-D (2.0 lb/A), picloram (0.25 and 0.5 lb/A), dicamba (2.0 lb/A), dicamba plus 2,4-D (0.5 + 1.5 lb/A), and picloram plus 2,4-D (0.13 + 0.25 lb/A) reduced seed formation 80 to 100% 4 months after herbicides were applied. Only picloram and picloram plus 2,4-D treatments controlled 87% or more Scotch thistle 1 year after herbicides were applied.

Mechanical control

No data were found on mechanical operations to control Scotch thistle. It may be susceptible to tillage because it has a simple taproot and rarely is a problem in agronomic fields adjacent to infestations possibly from tillage operations associated from raising a crop. However, tillage typically is not practical under most rangeland situations. No data were found on mowing to control Scotch thistle and research using this method seems warranted.

Biological control: The musk thistle seed head weevil, *Rhinocyllus conicus*, will attack *Onopordum* species but apparently not to the same degree as with musk thistle. *Rhinocyllus conicus* was first released in Oregon in 1973 to control Scotch thistle (Julien 1992). No data on seed reduction was found.

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CHAPTER 5

Common Crupina

Donald C. Thill*

IDENTIFICATION

Common crupina (*Crupina vulgaris* Cass.) is a member of the Asteraceae (Sunflower) family and the Cynareae (Thistle) tribe. This tribe also contains several other troublesome rangeland weeds including yellow starthistle (*Centaurea solstitialis* L.), diffuse knapweed (*C. diffusa* Lam.) and spotted knapweed (*C. maculosa* Lam.).

Seedlings first appear aboveground as two oblong, fleshy cotyledons 1/2 to 1 inch in length. The prominent midvein of the cotyledons is usually purple or red. The midvein and the large, fleshy cotyledons distinguish common crupina from associated species. Rosette leaves develop above the cotyledons and progress from entire (smooth margins) to lobed to finely dissected as the plant grows. Rosette leaves can be up to 3 inches in length. The finely divided, lace-like leaflets are produced alternately along the elongating stem. Older leaves develop short, stiff spines that are prickly to the touch.

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Each plant usually has one main flowering stem, 1/2 to 3 feet tall, that can branch near the top into five to 15 branches under good growing conditions. One or more flower heads appear at the end of each branch. Under poor growing conditions, or where crupina plants are very crowded, each plant produces only one to three branches with flower heads.

Flowers are lavender to purple in flower heads that are 1/2 inch long. Seeds are 1/8 to 1/4 inch long, cone shaped and taper to blunt point. A dense circle of 1/4-inch-long barbed hairs surrounds the wide end of the seed. Seeds are black or silvery beige.

ORIGIN, HISTORY AND DISTRIBUTION

Common crupina is a native to the Mediterranean region of Europe. It is weedy in Russia, where it is a pest of semi-arid pastures. Common crupina was first identified in the U.S. in 1969 by P. F. Stickney. He reported that this species appeared to dominate a 45-acre area of rangeland along State Highway 13, 6 miles east by northeast of Grangeville, Idaho. Since then, it has been found in California, Oregon, and Washington. Common crupina currently infests over 50,000 acres in these four states.

How common crupina was first introduced into the United States is unknown. Localized and long-distance dissemination of common crupina seed is believed to be associated with moving water, upland

game birds, wildlife and domestic livestock. Because seeds of common crupina are large, they do not disseminate great distances in wind. Seeds can be transported from one pasture to another attached to the hooves and hair of wildlife and domestic animals. Viable seeds will pass through the digestive tract of cattle, deer, horses and Chinese pheasants, but not sheep.

POTENTIAL FOR INVASION

Common crupina occurs in a wide range of habitats. The primary Pacific Northwest habitat is southern slopes in steep canyon grasslands. The weed infests sites where downy brome, wheatgrasses, fescues, lupines and arrowleaf balsamroot occur. Forested areas also can support this weed. Ponderosa pine and Douglas-fir are associated with common crupina as are oceanspray, smooth sumac and poison ivy. Common crupina has been reported rarely in annually tilled cropland but occurs along field edges and in improved pasture, hayfields, grass seed fields and Conservation Reserve Program (CRP) plantings. The weed frequently infests gravel pits, roadsides, railroad embankments, and other right-of-ways.

Common crupina appears to be adapted to a wide range of soil and climatic conditions and is capable of establishing solid stands that can reduce the forage productivity and livestock carrying

capacity of rangelands. Common crupina potentially could invade rangelands throughout Idaho and adjacent western states.

POTENTIAL IMPACT

Common crupina readily invades disturbed sites, such as overgrazed rangelands, and is capable of producing heavy infestations that reduce forage and livestock productivity. The nutritional value of common crupina is similar to that of downy brome but it is palatable to livestock only through the rosette stage of development. Short, stiff spines develop on stems and leaves 1 to 2 weeks after bolting begins. As a result, livestock will no longer graze the plant. Field observations and a horse-feeding trial indicate that common crupina is not toxic to livestock. Stands of common crupina also may displace native, rare and endangered plant species.

ECOLOGY AND BIOLOGY

Common crupina seeds usually germinate in the fall but spring germination is reported frequently. Mature seed germination is 86 percent or greater at day/night temperatures ranging from 84° to 77°F day to 59° to 39°F night when soil moisture is ample. Some seed germination can germinate over a wide temperature range. The first above-ground structures are the two entire, fleshy, oblong cotyledonary leaves. Common crupina overwinters as a rosette.

Under Idaho's climatic conditions, floral stems are initiated in early-spring and begin to bolt in April. Flowers are visible about 4 to 6 weeks after bolting begins.

Flowering is indeterminate. It usually begins in early June and will continue as long as soil moisture is sufficient. Each plant can have as many as 40 flowering heads capable of producing from 1 to as many as 5 seeds. In University of Idaho tests, 96 percent of the collected seeds were viable.

MANAGEMENT

Mechanical

Hand pulling, hoeing or other tillage is frequently the best treatment in and adjacent to homesites, gardens, urban areas and some sensitive crops or where infestations consist of only a few plants and can be inspected frequently. Inspect the infested site every 2 to 4 weeks each spring and summer to find and remove all common crupina plants before they flower.

Herbicides

Control of common crupina in most currently infested sites depends mainly on use of herbicides. Read product labels to verify use is legal and to comply with safety requirements. Before you use a herbicide that does not name common crupina on its label, be

sure that the label shows that the herbicide is legally approved for use on the site for which it is intended.

The following herbicide treatments are tolerated by grasses. Most include picloram because it is the most effective, long-lasting treatment due in part to its long life in soils. ***Picloram is a restricted-use herbicide; you must possess an applicator's license to purchase or apply it.*** Do not apply picloram in highly sensitive areas, such as near homesites, waterways and sensitive crops. Banvel and 2,4-D can be used more safely near waterways. The rates of all chemicals are expressed as active ingredient per acre (ai/acre) because not all products contain the same concentration of herbicide.

Picloram (0.25 pound ai/acre) – This treatment works best if applied in fall or early spring when plants are in the seedling, rosette or early bolting stages. Make aerial applications when shrubs in the area are without leaves; otherwise, use a handgun to get the herbicide under the shrubs. This treatment controls common crupina even when applied during light rainfall (less than 0.05 inch per day).

Picloram (0.5 pound ai/acre) – This is the best treatment when only one application per year can be made. This picloram rate controls common crupina for 2 years, longer than other listed treatments. This rate is not recommended for use on all sites

because it may injure susceptible perennial vegetation. Light rain does not hinder effectiveness.

Picloram + 2,4-D amine (0.25 [or 0.5] + 1.0 pound ai/acre) – Picloram plus 2,4-D amine effectively controls bolting plants and decreases viable seed production in flowering plants. Picloram alone often only retards growth of older plants while permitting seed production. Use the higher rate of picloram when using hand sprayers. Some shrubs and perennial herbs are affected by this treatment. Check the herbicide labels. Precipitation within 6 hours after application decreases control because some herbicide washes off the leaves.

Dicamba (0.5 or 0.75 pound ai/acre) – Apply dicamba by handgun or wand sprayer in sensitive areas such as near homesites, waterways and sensitive crops. Warm, dry weather during and after application is needed for good control, especially at the lower application rate. Because weather conditions are variable in early spring, delaying treatment until May and using the higher rate usually will yield better results. Delaying treatment until May, however, can increase the likelihood of injury to nontarget vegetation.

Dicamba + 2,4-D (0.5 + 1.0 pound ai/acre or 0.75 + 1.9 pound ai/acre) – Dicamba plus 2,4-D is a good treatment near streams and other sensitive areas and where common crupina is bolting or flowering. The low rate is effective on small bolting plants if

warm, dry weather follows the application and is less injurious to perennial herbs and shrubs. The high rate quickly stops seed production on flowering plants but injures perennial herbs and shrubs.

Revegetation

Common crupina readily invades depleted grasslands, and infestations in pasture or rangeland are much more severe where the competing perennial vegetation is sparse. These sites usually need revegetation to recover after treatment of common crupina infestations and to enhance control measures. A dense stand of perennial grass also resists invasion by other weed species.

Revegetate with perennial grasses. Historically, the plant communities infested with common crupina were perennial grasslands. Replanting with grasses will return the area to a more natural state. Furthermore, established perennial grasses tolerate the herbicides used to destroy common crupina, while broadleaf herbaceous plants typically are susceptible.

Plant grass in fall or late winter before broadcast herbicide application. Best results can be expected from a February or March seeding. Several grass species are well adapted to most of the habitats in which common crupina lives. Species adapted to the Pacific Northwest include Oahe intermediate wheatgrass (*Thinopyrum intermedium* subsp. *intermedium*), Luna pubescent wheatgrass

(*Thinopyrum intermedium* subsp. *barbulatum*), Nordan standard crested wheatgrass (*Agropyron desertorum*) and tall oatgrass (*Arrhenatherum elatius*).

Broadcast seeding generally has met with limited success, and several years are required to establish a stand. Slow stand establishment allows annual weedy grasses to increase and suppress the new seeding. Revegetation is most successful with standard seedbed preparation and grass seeding into the soil. Where the soil is productive and annual grasses are controlled, nitrogen fertilization can help maximize stand establishment, return on investment, and long-term crupina control. Ask your county extension agricultural agent or other consultant for fertilizer recommendations.

CHAPTER 6

DALMATIAN AND YELLOW TOADFLAX

Sherry Lajeunesse*

ABSTRACT

Dalmatian and yellow toadflax are introduced deep-rooted herbaceous perennials that reproduce by seed and by underground root stalks. The toadflaxes are easily distinguished from other range weeds by the distinctive shape of the bright yellow and orange flowers. Flowers are similar to the domestic snapdragon; distinguish toadflax species from these ornamental species by the presence of a long spur, or tail, at the end of the toadflax blossom and by the perennial nature of the noxious weeds. Ornamental snapdragons are used as annuals. Leaf shape helps distinguish between the different species of toadflax. Although Dalmatian and yellow toadflax do not occupy the large acreages that some of the noxious weeds do, both can be serious localized problems, displacing forages and native vegetation in a wide range of habitat types and climatic zones. Both are unpredictable and difficult to control. Effects of herbicide applications are inconsistent. Biological control agents have had impact on yellow toadflax but little effect on Dalmatian toadflax.

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Additional species of insects have been released in Canada and appear to have effect on both weed species.

DALMATIAN TOADFLAX

Two species of Dalmatian toadflax are found in the United States and Canada; broad-leaved Dalmatian toadflax, Linaria dalmatica (L.) Mill., and narrow-leaved Dalmatian toadflax, Linaria genistifolia (L.) Mill., Scrophulariaceae, the figwort family (Hartl 1974; Davies 1978). Both species are closely related; sometimes species in the genus Linaria are difficult to distinguish, partly because of hybridization and partly because of variation. Broad-leaved is the most widely distributed of the two.

BROAD-LEAVED DALMATIAN TOADFLAX, Linaria dalmatica (L.) Mill

IDENTIFICATION

Seedling Stage

Plants originating from seed have cotyledons that are three to seven mm long and somewhat pointed at the tip. The first true leaves are slightly larger than the cotyledons, about 3/16 by 1 3/8 inch (0.5 by 3.5 cm), and are lanceolate or ovate-lanceolate. Successive leaves become progressively wider and more heart-shaped (Robocker 1974).

Plants arising from root buds (vegetative shoots) do not have cotyledons and leaf shape is ovate-lanceolate or lanceolate.

Juvenile Stage

When plants four to six inches (10-15 cm) tall, upper leaves become more characteristically heart-shaped and the whitish or blue-green color and waxy coating become more distinct. After four to six true leaves have formed, the plant begins to send up additional upright stems and vertical and lateral roots have begun to develop; both types have root buds which can produce new and independent plants. Flowers and seed can be produced during the first season. (Robocker 1974).

Adult Stage

Stems and Leaves

Stems are robust and woody at the base and grow two to three feet (four to nine dm) or taller. Although the stems can persist for one or two years, the plants are herbaceous, producing no permanent woody material. Leaves are smooth margined, one to three inches (2.5 to 8 cm) long and 3/8 to 3/4 inch (one to two cm) wide or wider. Both leaves and stems are waxy and have a whitish or bluish cast. The leaves are usually heart-shaped but can vary from broad, ovate shape, to ovate-lanceolate, or even lanceolate, especially on lower portions of the plant. The bases of the leaves

tend to wrap around the stem and upper leaves are conspicuously broad at the base. Leaves alternate on the stem, but can appear to be opposite each other due to crowding (Reed and Hughes 1970; Robocker 1974; Cronquist et al. 1984).

Flowers and Seeds

Blossoms are bright yellow with an orange center, and a spur on the end that is approximately as long as the rest of the flower combined. The blossoms are two-lipped, 3/4 to 1 1/2 inches (two to four cm) long and grow at the bases of upper leaves.

Seeds are dark, small and irregularly angled, about 1/16 inch (one to two mm) in diameter, with slight, irregular, papery wings. Seeds are contained in a two-celled capsule, about 140-250 seeds each. Single plants can produce up to one-half million seeds (Reed and Hughes 1970; Robocker 1970; Cronquist 1984; Whitson 1991).

Roots

The root system of Dalmatian toadflax reaches depths of four to ten feet (approx. one to three m) or more. Vegetative root buds are found on both vertical and lateral roots and can produce shoots that become independent plants. Root buds have been found as deep as six feet (1.8 meters) (Robocker, 1974). Lateral roots are normally found in the upper two to eight inches (5 to 20 cm) of the soil profile and can extend ten feet (three m) or more from the

parent plant (Lange 1958; Reed and Hughes 1970; Robocker 1974; Cronquist 1984).

ORIGIN, HISTORY, AND DISTRIBUTION

Dalmatian toadflax is native to the Mediterranean regions of Europe and western Asia, from the Bosnia/Serbia region (Yugoslavia) to northern Iran (Alex 1962).

In Europe the plant has been cultivated as a ornamental for nearly four centuries, and was brought to the west coast of North America as an ornamental about 1874 (Alex 1962).

Currently, Dalmatian toadflax has been reported in all western states and western Canada. Heaviest infestations are in the northwestern states and California (Alex 1962; Forcella and Harvey 1981), British Columbia, and Alberta. The weed is found in widely scattered locations in most of the north-central and northeastern states (Lajeunesse, et al.). Many infestations originated as introductions as ornamentals which then escaped cultivation.

POTENTIAL FOR INVASION

There are many factors that affect establishment and success of plants, making it difficult to accurately predict where conditions will be favorable for establishment of any one species; we simply don't understand enough about the complex interactions involved. At this time, the best we can do is predict areas of

potential invasion based on the successful establishment of the species in similar habitats.

This is especially true of the toadflaxes because of the high degree of variability within the species. This means that individual populations can develop site-specific adaptations and adaptive responses to disturbances. In one area toadflax might not be found in a particular habitat type, yet in another area it could thrive in those same conditions. This makes prediction of susceptible areas difficult. Only some broad generalizations can be presented at this time.

We do know that it is highly competitive where summer moisture is limited. It is often found in well drained, relatively coarse-textured soils varying from coarse gravels to sandy loams, but is also sometimes found in heavier soils. Areas of low interspecific competition, sparseley vegetated soils and drier, open areas on rangeland seem susceptible to invasion in some cases. Sites include roadsides, near dwellings, vacant lots, cemeteries, gravel pits, fields, waste areas, spreading to valleys and sagebrush flats, overgrazed pastures, and other disturbed sites. It is also found on hillsides, particularly south- and south-east facing, and sometimes on steep slopes. The species shows tolerance to low temperatures and is commonly found in soils ranging in pH from 6.5 to 8.5 (Lange 1958; Alex 1962; Reed and Hughes 1970; Robocker 1974; Parker and Peabody 1983).

Some of the plant communities with which Dalmatian toadflax has been associated:

Annual grasses: downy brome, Bromus tectorum L. and Japanese brome, B. japonicus Thunb.

Bunchgrasses: needle-and-thread, Stipa comata Trin. & Rupr., Junegrass, Koeleria cristata (L.) Pers., crested wheatgrass, Agropyron crustatum (Fisch.) ex Link Schult., bluebunch wheatgrass, A. spicatum (Pursh) Scribn. & Smith, Idaho fescue, Festuca idahoensis Elmer.

Sod-forming: intermediate wheatgrass, A. intermedium (Host.) Beauv., western wheatgrass, A. smithii Rydb., Kentucky bluegrass, Poa pratensis L., Canada bluegrass, P. compressa L.

Broadleaf winter annuals (Robocker 1974).

Ponderosa pine (Lange 1958).

Perhaps mountain mahogany, Cercocarpus spp. (Rosaceae) (Beck, pers. com. 1994)

However, it is an unpredictable, variable weed, and association patterns are not clearly defined.

IMPACTS

Ecological & Environmental

Densities in infested areas are often high enough that biodiversity is decreased within stands. Native plants and improved forages and the animal life associated with them are displaced. Mature toadflax plants are particularly competitive with winter annuals and shallow-rooted perennials and with their own seedlings. It is believed this is primarily due to the effectiveness of mature plants in competing for limited soil moisture.

Some wildlife will browse toadflax casually, and seed is used by some species of birds and rodents. It provides cover and habitat for these smaller animals. Cattle casually browse flowering shoots (Harris & Carder, 1971), and sheep will utilize the plant as a major food source (Barnett, pers. com. 1992; James, pers. com. 1994). It is not known to be heavily used by any native species although deer have been observed to browse on the plants (Robocker 1970). Loss of forage for big game species, especially in winter range occurs in habitats where toadflax is adapted. Effects on soil organisms are not known.

Soil erosion, surface runoff, and sediment yield can be increased on sites where sod-forming or bunchgrass communities are replaced by toadflax. However, habitats colonized by this weed are often so harsh and sparsely vegetated that toadflax can actually help stabilize soil in those habitat types.

Economic Impact

Reduction in cattle carrying capacity due to forage displacement, reduction in appraised value of rangeland, impact on real estate values, and direct management costs are four significant economic effects of toadflax infestations.

Data specific to Dalmatian toadflax are scarce, but economic impact of toadflax resulting from reduced cattle carrying capacity can be estimated by placing a value on forage. For example, a forage value of \$10/ha can be used for land rated at one animal unit month (AUM) when the value of the AUM is \$10. A 65% reduction in forage due to displacement by Dalmatian toadflax would reduce the stocking rate by 65% to 0.35 AUM/ha and the value to \$3.50. Estimate economic impact by multiplying the number of ha affected by the reduction. For example, 25 ha x \$6.50 (the reduction) = \$162.50 for the 25 ha area. Information is available in Lacey and Olsen (1991) and in other sources for estimating effects of noxious weeds on land values and evaluating economic impact.

Data on direct management costs specific for toadflax are also scarce. Costs will depend on wages, equipment and materials used, management methods used, degree of infestation and other factors. For more information on calculating costs associated with noxious weed management, refer to Chapter 9. Management costs in 1992 on one ranch for 431 ha of which 30% were severely infested with Dalmatian toadflax (25-100% vegetative cover) averaged \$99/ha.

Reduction in cattle carrying capacity and reduction in the appraised value of the ranch's land increased the figure even more.

Occasional cases of mild poisoning have been reported for cattle (Mitich 1993) but the toadflaxes are usually avoided and cases are rare; economic impact due to this factor are probably negligible. There is some uncertainty regarding potential toxicity to livestock; all members of the genus Linaria have been reported as toxic (Polunin 1969) and indeed do contain glucosides, alkaloids, and other mildly toxic substances. However, neither Dalmatian nor yellow toadflax was reported by Kingsbury (1964) as poisonous to animals. Sheep will utilize Dalmatian toadflax heavily, showing good weight gain and no ill effects (Barnett, pers. com. 1992; Scott, pers. com., 1994) and in Europe cattle will eat dried yellow toadflax plants (in Kraus 1909). Yellow toadflax has also been used as a medicinal plant in Europe for cattle that "won't ruminate" (Marzell 1972).

Sociological Impact

Sociological impact of noxious weeds depends in large part on the perceptions of the individual and on the degree of economic impact experienced by that individual. General statements that apply to all noxious weeds apply to toadflax as well: individuals faced with forage loss or decreased property values often view control activities and state and county expenditures on management

favorably. Conversely, persons without these considerations can view control activities, herbicide applications, and public expenditures negatively, or have no opinion at all. Controversy over the application of herbicides and other control methods can be heated, even to the extent of physical confrontations.

Toadflax is less likely than many noxious weeds to be considered aesthetically displeasing due to the ornamental qualities associated with the plant.

The on-the-ground work of weed control can be monotonous, strenuous physical labor. It can be difficult to find individuals willing to do the work. For owners and managers, and even laborers, the knowledge that the work will have to be repeated in one, two, or three years, for many years, can impart a sense of futility; the knowledge that if that work is not done, forage loss, displacement of native or desirable plant species, etc. can impart a sense of frustration.

BIOLOGY AND ECOLOGY

Early top growth regeneration in spring from root reserves and activity during all seasons of adequate moisture and temperature, in a wide variety of habitats gives the toadflaxes a competitive edge which is characteristic of successful invaders. Established Dalmatian toadflax is especially competitive for moisture, nutrients and light.

Native Habitat

Open, sunny, sandy, gravelly, or rocky, places. Elevations from nearly sea level to more than 9,000 feet, in habitats such as uncultivated fields and vineyards, mountain meadows, ridges of sand hills, and limestone mountains, grassy slopes, steep slopes, including north-facing ones. Latitudinal range in its wild state in native habitat is ca. 35 degrees N. to ca. 47 degrees N. (In North America latitudinal range exceeds that range in both southwardly and northwardly directions: ca. 33° N. to ca. 56° N.) (Alex 1962). In its native habitat, no characteristic plant communities, either beneficial or pest species, have been determined.

Toadflax species evolved under moderate to intense grazing pressure, primarily by domestic livestock e.g. sheep and goats, and cattle to a lesser extent. Grazing pressure exerted by wild herbivores, such as deer, is not known. Because much of the land is arable in the region of origin, many populations have evolved with periodic disturbances primarily due to the activities of man, such as herbicide applications, farming operations, and other soil disturbances.

Life Cycle

Seedling Emergence and Top Growth Regeneration

In the Pacific northwest, emergence of seedlings in both spring and autumn is usually seen first on south or southeast 40% slopes; soils on these sites warm first in the spring and remain warm later in the fall. Emergence of seedlings on level ground occurs two to three weeks later. In eastern Washington spring emergence of seedlings on south, south-east facing slopes usually begins the first or second week in March and lasts until the first or second week in April (Robocker 1970). Specific degree day information is not yet available. Spring emergence of seedlings is primarily temperature-dependent because soil moisture is usually sufficient; fall seedling emergence is dependent on both soil moisture and temperature and is more erratic (Robocker 1970). In eastern Washington vegetative shoots generated from root stock usually emerge in spring several days after seedling emergence (Robocker 1974).

Seedling and Shoot Growth

Survival of seedlings after emergence often depends on spring and early summer precipitation or lack of competition from other plants, particularly perennials (Robocker 1970). Seedlings are easily outcompeted by plants in closed communities, and in particular by well adapted perennials. They are also out-competed by downy brome when soil moisture is limited. Shoots generated from root stock are highly efficient in scavenging soil moisture;

consequently, soil moisture is seldom a limiting factor in spring vegetative regrowth. This enables vegetative shoots to be highly competitive and to commonly displace existing plant communities.

Vertical roots of first-year plants can reach depths of 20 inches (50 cm) or more, with lateral roots that are usually one to four inches (two to ten cm) deep. Rather weak floral stems, and some seed, can be produced during the first year.

In early autumn prostrate stems are often produced by young plants, depending on available moisture. Leaves of these stems are ovate, and the stems often form a mat-like rosette, surviving into the following spring. They are apparently involved in storage of carbohydrates in first-year plants, and to a lesser degree in mature plants (Robocker 1974).

Floral Stems

The strong, upright floral stems of the mature plant are apparently produced only after a winter's dormancy and exposure to temperatures between 50°F-68°F (10°C-20°C). The lack of abundant seed production by plants which do not receive the required low temperatures may be a factor in the geographical distribution of Dalmatian toadflax. Because of the relatively short life of a plant, the ultimate survival of stands probably depends on floral stem and seed production. Floral stem development is usually associated with prostrate stems from the previous autumn, with

floral stems developing directly beneath the living prostrate stems on the primary root (Robocker 1974).

Flowering normally begins in June and continues until September or October (Lange 1958). Flowering can occur earlier in warm seasons in warmer habitats. Plants are self-incompatible, pollination is primarily by bumblebees and halictid bees.

Seed Characteristics

Seeds are produced for about three months, beginning in late June or early July, peaking between June and early September. In one study, about 97% of seeds produced were produced in the first five weeks of production (Lange 1958). Seed production can begin on lower portions of the plant while upper portions are still in various stages of bloom (Parker and Peabody 1983).

Dispersal

Seed dispersal begins as early as July and continues into winter. Dried floral stalks with seed capsules can remain standing for two years, retaining some of the seeds inside capsules but dispersing most during the first year.

Although wind has been considered a major means of seed dispersal (Lange 1958; Alex 1962; Robocker 1970; Robocker 1974; others) studies done for seed of yellow toadflax (Nadeau

and King 1991) showed that 80-90% of seed produced fell within 2.5 feet (0.5 m) of the plant and very few seed fell farther than five feet (1.5 m) from the plant. It is possible that Dalmatian toadflax seeds also fall within short distances of the parent plant: seed size of both yellow and Dalmatian toadflax is 0.04-0.08 inch (1-2 mm), and although there is a high degree of variation in toadflax seed weight (Robocker 1970), average seed weight for both species is also similar; 0.00216 grain (0.00014 gm) for yellow (Salisbury 1961) and slightly heavier for Dalmatian at 0.00221 grain (0.000143 gm) (Robocker 1970). Yellow toadflax seeds have a well-developed papery wing; Dalmatian toadflax seeds are angular with a small, irregular wing. Because of the similar weights and because of the less-developed wing of Dalmatian toadflax, it is possible that distance of seed dissemination by wind is similar to, or less than that for yellow toadflax. This would indicate that windblown seeds are not a major means of seed dispersal for either species. A condition under which wind has been observed to disseminate seed occurs when seeds fall from upright dried floral stems onto crusted snow and are blown across the surface (Lowe 1992, pers. comm.; Saner 1994).

Cattle browsing on toadflax are known to transport viable seed. Deer also browse toadflax and may also be involved in

transport of seed, as well as birds and other wildlife. Movement of seeds can also occur in surface runoff, especially if populations are found on heavier soils (Robocker 1970).

Germination

Some seed germination occurs in the fall, but most occurs the following spring, with peaks in April and May and lowest rates in November. Laboratory studies showed germination percentages of up to 75% for seeds that were from one to four years old. Seeds which do not germinate can remain dormant for at least ten years (Robocker 1970).

Root Characteristics

Seedling roots can reach depths of 20 inches (five dm) or more nine weeks after seed germination. For the first several weeks, seedling roots are not good competitors for soil moisture and are easily outcompeted by both annuals and perennials; after that initial period, they are extremely effective competitors. Seedlings typically develop a primary vertical root, which is not completely dominant, and a prominent lateral root that is 1-4 inches (2-10 cm) beneath the soil surface. Vertical and lateral roots of both seedlings and mature plants have vegetative buds.

Primary branching of mature roots usually occurs in the top foot (three dm) of soil, with many fine lateral roots extending

from these branches. Under good conditions, the prominent lateral root produces secondary crown sites. A secondary branch root system usually develops at the site of a new crown, which can become an independent plant the second year.

Longevity

Dalmatian toadflax is a short-lived perennial, with individual plants living an average of three to five years. With the exception of prostrate stems, most top growth dies back in the fall and is regenerated from the root system each spring (Robocker 1974). As plants age, they begin to die out from the center, forming a ring (Lowe 1992, pers. com.). Death of a plant usually occurs in the fall and is signaled by the absence of fall growth of prostrate stems. Individual patches can persist for 13 years or more under favorable conditions.

Dalmatian toadflax stands frequently disappear for several years, then re-establish, from either buried seeds or perhaps from vegetative root buds. It is not known if root buds of Dalmatian toadflax exhibit true dormancy. Age of the stand, persistence, and cyclic appearance seem to be due to variables such as soil type, competing vegetation, and climate or microclimate (Robocker 1974).

Population Characteristics and Ecological Factors that Determine Success and Management of the Weed

Variability

The high variability of toadflax is reflected in many aspects of its biology and ecology, including persistence patterns, taxonomic variation, adaptation to a wide range of habitat types, and inconsistent responses to management efforts, including biological control. The ability to reproduce both sexually from seed and asexually from root buds increases variability and allows the plant to adapt to and reproduce under a wide range of environmental conditions. The weed can establish in a wide variety of geographic locations, can adapt to site-specific disturbances such as herbicide application, and is unpredictable. This indicates a variety of control strategies will be needed.

Hybrids between yellow toadflax and Dalmatian toadflax can be produced in the laboratory and natural occurrence of this hybrid should be considered (in Saner 1994).

Persistence Patterns

Robocker (1974) noted four population patterns, and mentioned the possibility of many gradations or variations beyond those he had seen.

1. Stands of long duration; possibly due to particularly favorable conditions, e.g. underlying aquifers, periodic soil disturbances that enable stand perpetuation by seedling establishment, or other conditions.
2. Cyclic establishment; disappearance, and re-establishment on a fairly regular cycle, e.g. three-year cycles, with little or no expansion of stand size attributable to lateral root development. Mature plants have a two year life span, for example, and the third year, seedlings again become established and the cycle is repeated. Periodic soil disturbances may again play a role.
3. Cyclic patterns similar to that just mentioned, but in areas in which native vegetation has mostly died out and/or been invaded by downy brome. In this pattern, competition from the perennials grasses or downy brome continues and the period between consecutive stands of toadflax is generally longer than the life of a stand.
4. Sites where the soil surface is a thin layer of organic matter and herbaceous vegetation is sparse, such as areas where grass cover is depleted, or in open stands of ponderosa pine. Lateral roots are sometimes only 0.5 or one inch (one or two cm) below the surface, extending only a few inches or cm a year with new crowns giving rise to only one or two floral stems. This appears to be

the principal means of propagation in these stands. The shallow lateral roots and secondary crowns are more vulnerable to drought than plants with original primary stem and root systems.

Ultimate survival of a stand probably depends on seed production because of the relatively short life of the plant (Robocker 1974).

Rate of Increase in Patch Size

A patch originating from one seedling can reach a diameter of three feet (approx. one m) in a year. In subsequent years, borders of the patch can extend about one foot (three dm) per year due to vegetative growth. Rates of patch expansion vary due to environmental factors, seedling establishment, and variability within the species.

Degree Day Requirements and Phenological Events

Degree day (DD) requirements for Dalmatian toadflax are not available at this time, but site-specific DD information can be easily generated. See Chapter 3(?) for information on generating your own DD information. Degree Day information can be correlated with field observations to better predict when events such as seedling emergence will occur. This can be useful information for

timing of control strategies, such as herbicide application to manage seedlings before vegetative reproduction begins.

Wilting coefficient

Monitoring soil moisture can be an additional management tool. The point at which seedlings do not recover from drought stress was determined to be 3.4% (soil moisture) in gravelly loam soil. Wilting coefficient of downy brome is significantly lower, approximately 2.7%, allowing this annual grass weed to deplete soil moisture and outcompete Dalmatian toadflax seedlings on sites where soil moisture is a limiting factor (Robocker 1974).

Germination Temperature

Average soil temperature at which germination occurs was determined to be 10°C at a depth of one inch (2.5 cm). Soil temperature measurements can be taken in regional sites to correlate them with degree days, for use in integrated weed management programs.

Maximum Germination Depth

Maximum soil depth from which Dalmatian toadflax seedlings will emerge was determined to be 1.25 inches (three cm) in sand (Robocker 1970), and one inch (2.5 cm) in clay and loamy sand (Alex

1959, Ph. D dissertation, in Robocker 1970). However, most seedlings emerge from the top 1/4 to 3/8 inch (0.5-1.0 cm) of soil.

Specific Activities and Disturbances that Influence Spread

* Inattention and inability to identify the weed are probably as responsible for spread as any other factor. As with most noxious weeds, Dalmatian toadflax is easier to control when patches are small; identify and control new infestations.

* Disturbance of natural plant communities, especially shallow-rooted perennials and winter annuals; both are displaced by toadflax. Disturbances include construction activity, cultivation in farming operations and home landscapes, along roadsides, vacant lots, gravel pits, railroad-rights-of-way, shelter belts, subdivisions, etc. (Lange 1958; Alex 1962; Robocker 1970; Robocker 1974.)

* Minimum and no-till farming methods could enable yellow toadflax to invade or re-invade areas where regular tillage has kept populations at acceptable levels (McClay 1992) and the same situation might apply to Dalmatian toadflax.

* Spring grazing of infested pasture and rangeland; proper timing is imperative to maintain competitiveness of desired

forages as much as possible. Movement of livestock from infested areas can result in movement of viable Dalmatian toadflax seed.

* Transport of plant and seed stock by human activities e.g. crop or revegetation seed contamination, seed transport on tires and undercarriages of farming implements and recreational vehicles, movement of gravel and topsoil, and other construction materials from infested sites to areas where the weed has not established.

* Revegetation efforts that fail to use species that are well-adapted and competitive could result in an advantage for toadflax because of the disturbances created.

Potential for Invading Excellent or "Pristine" Rangeland

Although Gates and Robocker (1960) reported complete failure of Dalmatian toadflax seedlings to establish in the non-cultivated sites used in their study, it has also been reported to successfully invade undisturbed permanent, established grassland (Lange 1958; Alex 1962; Beck, pers. com. 1994). It should be assumed that natural soil disturbances and openings in ground cover occur even in "excellent or pristine" rangelands, creating sites

where toadflax can establish if they occur in habitats where toadflax can grow.

MANAGEMENT

Proactive Weed Management:

1. **Education**
2. **Prevention**

It seems our nature to be **reactive** rather than **proactive**; in no case is this more true than for noxious weed management. And in no case can proactive management pay bigger dividends. An aggressive prevention program incurs costs for education, surveillance, and small-scale eradication. The traditional reactive weed management program can cost thousands, even hundreds of thousands of dollars each year, with large expenditures in man hours of tedious labor. Reactive control efforts are seldom completely successful. As alien plant species continue to find their way from continent to continent, an aggressive, proactive weed management program will pay ever larger dividends.

Education

The first step in proactive weed management is education, which you are doing now. Stay current about new developments and new exotic species that may arrive in your region; be able to

identify them. Educational efforts should be extended to include any personnel you supervise. For additional sources of assistance contact the state Extension Service at your land grant university and your State Department of Agriculture.

Preventing Invasion

The second step of proactive management is prevention:

Sources of Weed Seed Contaminant

Because seeds are the initial colonizer for most new infestations of Dalmatian toadflax, keeping contaminated materials or equipment off of the property or management unit or out of uninfested areas can be very cost-effective.

Potential sources: Transport of plant and seed stock by human activities e.g. contaminated crop seed or seed for revegetation- purchase certified weed seed-free; seed transport on tires and undercarriages of farming implements and recreational vehicles. (Vehicles can pick up weed seeds in parking areas, road turnouts, stock yards, equipment yards, among other sites- control weeds religiously in these areas.); movement of gravel and topsoil, and other construction materials from infested sites to areas where the weed has not established; contaminated hay or feed- purchase certified weed seed-free. Inquire about local weed problems when purchasing livestock feed such as hay or alfalfa- you may wish to

purchase feed grown in areas that do not have toadflax infestations.

Competitive Cover

Attempt to maintain competitive, closed communities of desirable species. Dalmatian toadflax seedlings have difficulty in establishing in non-cultivated areas in competition with well-adapted species (Gates and Robocker 1960). Implement grazing management practices which promote competitive stands of desirable species. Limit spring grazing in infested areas so that desirable species can remain competitive during the crucial period when soil moisture is present. Even on range in excellent condition, however, watch for early infestations that can occur.

Re-seeding and Revegetation

For re-seeding and revegetation projects, regional Soil Conservation Service Plant Centers can make recommendations for locally adapted, competitive species. Re-seed after any activities that result in soil disturbances; monitor those areas periodically for toadflax establishment. Fertilizer applications can sometimes be feasible in increasing competitiveness of dryland grasses. For specific information, see Revegetation section on p. XX.

Livestock Containment

Before moving livestock that have been grazing in infested areas to uninfested pastures or ranges, hold in containment for several days to allow viable seeds to be passed through the digestive tract (six days for cattle and 11 days for sheep and goats). These times are based on containment time required for livestock grazing in leafy spurge-infested areas; times specific for toadflax have not been determined. Containment areas should be monitored periodically to check for toadflax seedlings. Pulling by hand or spot application of an herbicide can help prevent establishment of these plants.

Riding and Pack Animals

Feed that is free of weed seeds should be used for livestock taken into wilderness or other pristine areas as riding or packing animals. Certified feeds are available.

Seed Formation

Prevent toadflax seed production whenever feasible to slow natural dispersal to uninfested areas.

Containment and control

Develop a Management Plan

Use chapters One through Nine in this manual to develop a management plan. Include regular re-mapping as part of the plan.

Assistance

County and state weed personnel, including Extension Service, are valuable resources when planning and implementing a management program.

General Considerations

Four important aspects of toadflax biology influence management strategies:

1. Toadflax is very competitive once established,
2. It produces large numbers of seeds,
3. It has an extensive root system with vegetative buds, and
4. It is adaptable to a wide variety of soil types and moisture conditions.

No single method will be adaptable enough to control all infestations. Consequently, an integrated combination of methods is needed.

METHODS OF CONTROL

When areas are exposed by removal of toadflax plants, seed the open areas with a competitive species to prevent re-establishment of weeds.

Mechanical and Physical Controls

Grubbing or Pulling by Hand

These methods can be effective for small infestations, especially in sandy soils and when soils contain moisture. Pulling each year for five to six years is needed to deplete the root system of root reserves. The site must be visited for 10 to 15 years to remove seedlings produced from seeds (C. Lacey 1992, Pers. Com.). Many plants produced from vegetative root buds arise from the lateral roots, which are normally found two to eight inches deep and can extend 12 feet (nearly four m) from the parent plant.

Mowing

Mowing is not recommended since it does not affect root reserves or buried seeds, nor is it feasible on rocky or steep slopes. Although it prevents season seed production, and can prevent establishment of new infestations from seed, flowers must be eliminated every year for many years if this strategy is used because of the extensive root reserves. Hand removal of the flowering tops from the plants is a marginal strategy even for very small infestations.

Cultivation

Cultivation, where feasible, will control toadflax. Sweep-type cultivators appear to work best, and cultivation should start early in June and be repeated every 7 to 10 days. Eradication requires at least two years of cultivation, with four to five cultivations the second year (Parker and Peabody 1983). Once cultivation is begun, it must be done regularly until the populations are reduced to a manageable level to avoid possible increases in density due to regeneration from root fragments, as may occur with yellow toadflax (Nadeau et al. 1992).

Cultural Controls

Cultural control can be defined as the manipulation of the environment or plant community to manage weeds.

Competitive Plant Communities

The importance of maintaining a vigorous, competitive plant community cannot be overemphasized. Competitive plants reduce the chance of toadflax seedling establishment since toadflax seedlings are very poor competitors for soil moisture. Conversely, mature Dalmatian toadflax plants are extremely effective competitors for moisture and suppress growth of other vegetation mainly by competition for water. Even in competitive plant communities watch

for new infestations that may establish in small, naturally-occurring disturbances.

Spring Grazing

Overgrazing in the spring by livestock can be detrimental to desirable species, and increases the competitive advantage of toadflax especially in spring when soil moisture is plentiful. Timing of grazing can help reduce seedling establishment, but will not be as effective in restricting expansion of established stands by vegetative spread because of the deeper, more competitive root system of toadflax.

Burning

Burning is not usually effective because the soil temperatures reached are not sufficient to kill root buds or buried seeds. In some cases burning can increase the competitiveness of the toadflax by removing desirable plants. Removal of top growth could also stimulate production of vegetative shoots. However, scorching of floral stalks using propane burners can help prevent seed production.

Biological Controls

Foliage Feeders

To date only one foliage-feeding insect species, the defoliating moth, Calophasia lunula Hufnagel, has been released against Dalmatian and yellow toadflax. C. lunula is well established on yellow toadflax in Ontario, Canada, and defoliates up to 20 percent of the leaves from the plant (Harris 1988). Other populations of this moth have been found on yellow toadflax at two sites in northern Idaho. Establishment of C. lunula on Dalmatian toadflax has been reported (McDermott, et al. 1990), but establishment and distribution is thought to be restricted due to temperature requirements. Defoliation by this insect does not appear to have much impact on toadflax plants due to the extensive root system. However, in conjunction with biocontrol agents that attack other portions of the plant, its impact might be increased.

Seedhead Feeders

Three insect species accidentally introduced to North America attack yellow toadflax, and to a lesser degree, Dalmatian toadflax. These include: an ovary-feeding beetle, Brachypterolus pulicarius (L.); and two seed capsule-feeding weevils, Gymnaetron antirrhini (Paykull) and Gymnaetron netum (Germar). B. pulicarius and G. antirrhini are widely distributed in the western U.S. and Canada. Both species are effective in reducing seed production in yellow toadflax. In contrast, G. netum has a more limited distribution

and apparently has little impact on yellow toadflax (Smith 1959; Darwent et al. 1975; Harris 1988; McClay 1992).

While B. pulicarius reportedly will feed on Dalmatian toadflax, its impact on seed production has not been documented. The two weevil species show a preference for yellow toadflax, but will also feed on narrow-leaf Dalmatian toadflax, L. genistifolia (Smith 1959). Their impact on narrow-leaf Dalmatian toadflax is not known.

Stem Borers

Host specificity testing was completed several years ago in Switzerland for a stem-boring weevil, Mecinus janthinus Germar (Col: Curculionidae). The weevil shows promise in the laboratory and in preliminary field trials. It has been released in Canada and permission to release is being sought in the United States (Jeanneret and Schroeder 1992).

Root Borers

A root-boring moth, Eteobalea intermediella (Treitschke), has been released in British Columbia, Alberta, and Saskatchewan and appears to have established on both Dalmatian and yellow toadflax (Saner and Moeller-Schroeder 1994). Pending approval in the United States, these insects will be reared and released.

The addition of stem- and root-feeding insects should improve the chances for biological control of Dalmatian toadflax in North America.

Continuing Biocontrol Efforts Using Insects and Pathogens

Several insect species are currently being tested in both North America and Europe for potential as biocontrol agents. To date, no pathogens have tested as biocontrol agents, although several have been recorded on yellow toadflax in field observations. Efforts are continuing to locate potential candidates.

Grazing - Sheep

Preliminary results of field trials in Montana show that sheep can be used to help manage Dalmatian toadflax. In these preliminary studies 1,000 ewes and lambs were placed in a hilly rangeland area of moderate to heavy infestations with densities of 25-100% vegetative coverage by Dalmatian toadflax. Approximately 35-45% of the toadflax foliage was stripped, including the terminal 15-25 cm of plant stems. Although initially the sheep just nibbled at the plants, in two to three weeks they were utilizing Dalmatian toadflax regularly, even though other forages were present. In these preliminary studies the sheep did well and showed good weight gain. It is possible that sheep will provide a method for

suppressing stands of toadflax and limiting seed production (Barnett 1992 pers. com.; James 1994, pers. com.). Controlled studies are now under way.

Chemical Controls

Effectiveness of herbicides used for toadflax control is highly variable. In south central Montana, 98 percent control of Dalmatian toadflax was obtained for three years with picloram (Tordon™ 22K) applied in the fall at a rate of two quarts (1 lb. a.i.) per acre. Application in the spring resulted in 85 percent control. In Colorado, only fair control of yellow toadflax was obtained for one year, after using one gallon of picloram per acre. However, excellent control (97%) of Dalmatian toadflax was observed two years after application with just one quart of picloram per acre applied in the fall (Sebastian and Beck 1989; Sebastian et al. 1990).

In other research, picloram has not been as effective. Soil type may be an important factor determining the success of this herbicide, since leaching of the herbicide below the plant root zone is more likely on sites with sandy soils or on soils low in organic matter. Picloram, at this high rate of application, will kill many broadleaf species and could injure desirable plant species. Since picloram is degraded by sunlight, it works best when rainfall is received soon after application. Under dry

conditions, picloram is not moved into the soil and significant losses can occur in sunlight in three or four weeks.

In other research, excellent control was observed one year after application of dicamba (Banvel™) at a rate of one gallon (4 lb. a.i.) per acre prebloom. A tank mix of picloram plus 2,4-D (0.5 lb. and 1.0 lb. a.i./acre) applied prebloom or in the fall provided 90 to 100 percent control (Sebastian and Beck 1989; Sebastian et al. 1990).

However, while this research was highly promising many commercial treatments have not been effective. Even when herbicide treatment was successful, permanent long-term control was not achieved since reinvasion occurred; therefore, it will be necessary to retreat an infestation every three to four years for as long as twelve years to achieve eradication.

In fall, three to eight cm of green growth indicates roots are taking in energy for winter; this can sometimes be a good time to apply herbicides (Lowe 92) or other control methods for Dalmatian toadflax. The waxy leaf surface probably serves as a protective barrier which hinders herbicide uptake in some cases.

When stands exhibit persistence patterns in which lateral roots are very close to the soil surface, herbicides can move through the soil beyond the root zone where they are no longer available, especially in coarse soils with little organic matter (Lowe 1992, pers. comm.). Herbicides will not affect dormant seeds

in the soil, nor will they affect any vegetative structures that exhibit dormancy. It is not known if vegetative buds of the toadflaxes exhibit dormancy.

When implementing weed control in mixed communities that include the toadflaxes, higher rates are often needed because toadflax seems to expand after plants such as spotted knapweed are taken out (Duncan 1992, pers. com.). Releases of toadflax after control of St. Johnswort, Hypericum perforatum, have also noted (Lange 1958).

Implementing an initial management program

1. Develop a Weed Management Plan using the guidelines and resources listed in the first chapters of this manual. Assistance in developing the plan is readily available.
2. Attempt to maintain competitive, closed communities of desirable species by using range management recommendations and grazing management programs appropriate for your area. Limit spring grazing in infested areas so that desirable species can remain competitive during the crucial period when soil moisture is present.

Be aware that infestations can establish even in rangeland that is considered to be in "excellent" or "pristine" condition; be prepared to identify and

eradicate new infestations while they are small, preferably before seed is produced. Mark these new sites as you find them, and make returning to eradicate them top priority. Locating new infestations should not be left to chance- actively watch for and search out new infestations. This will be a continuing effort, but will save much effort and expense in the long run.

3. Prevent toadflax seed production whenever possible.
 - a. Grubbing and pulling where feasible, can provide effective control of toadflax if conducted annually for 10 to 15 years.
 - c. Apply low rates of picloram prebloom to prevent seed production. Alternatively, use propane weed burners to scorch floral stalks.

Because Dalmatian toadflax allocates equal reproductive effort to seed production and vegetative propagation, and seed viability and germination rates are fairly high, this may imply that management efforts for Dalmatian toadflax should emphasize equally the prevention of seed formation and vegetative control. In contrast, yellow toadflax allocates heavily to vegetative reproduction, seed viability and germination rates are lower, making emphasis on vegetative control more effective. For both

- species, prevent movement of seed into uninfested areas, as seed are the primary source of new infestations.
4. Make spot applications of picloram at high rates to control small infestations.
 5. In areas where toadflax has been controlled, reseed any open ground with desirable species to prevent invasion by other weed species or re-establishment of toadflax from seed.
 6. Introduce biological control agents as they become available.

Follow-up Programs

Monitor and re-map annually to track progress and test effectiveness of management strategies. This can also help you determine the economic feasibility of your program. Adjust or adopt different strategies if these follow-up efforts indicate weak or ineffective methods in the program.

Check sites where small infestations have been eradicated for signs of re-establishment from buried seed or vegetative buds.

Develop Degree Day models for infested sites; the information can be valuable in the critical timing of seedling control. Monitoring soil moisture can provide additional information useful in control efforts, especially as the wilting coefficient threshold for the weed is reached. For assistance in developing these tools, refer to Chapter 3 (?).

Long-term Control Strategies

Keep contaminated materials and equipment out of uninfested areas. Attempt to develop a grazing management program that will mimic pressures from herbivores similar to the pressures under which toadflax evolved. Keep current on new information as it develops, incorporating new methods and ideas as appropriate.

Revegetation of Weed-Dominated Rangeland

After toadflax suppression, seeding of competitive grasses seems to be most effective in the Great Plains-Intermountain West regions, rather than attempting to establish legumes, grasses, and forbs at the same time. The initial competitiveness of the grasses appears more effective in crowding out germinating seedlings from buried seed. Although data is scarce, a logical sequence might be to 1) suppress the weed population, 2) plant grasses, and 3) after two to five years introduce forbs if the grasses have established adequately and the weeds are a part of the plant community rather than dominating it. In the Intermountain West, fall is a good time for seeding; dormant seeding seems to provide the greatest opportunity for establishment (G. Beck pers. com.). Forage agronomists and SCS Plant Materials Specialists can help with revegetation species selection and seeding information.

When selecting plant species to be used for revegetation, attempt to select species that will be highly competitive early on, to minimize seedling establishment, and additional species that

have root systems that are competitive at the depth of the lateral roots of yellow toadflax, yet complimentary to the species used to minimize seedling establishment. Consider also incorporating deep-rooted species that can compete at the deep level where tap roots of yellow toadflax grow, again attempting to select species that will complement the other plants to be used. These deep-rooted species should be planted after initial seedlings have established. Try to develop a plant community in which the individual species compliment each other both above ground and below ground. Efficiency in scavenging water will be one important selection criteria, and early and late season growth will be another. Native species may or may not be good choices, depending on site-specific factors and land use goals. You may wish to consult with the Soil Conservation Service Plant Materials Specialist in your region for help in developing such a project. Forage agronomists at the land grant university in your state can also help with species selection and project development.

Consider herbicide applications that are carefully timed to the biologies of the plant community you are attempting to establish and the biology of yellow toadflax; there may be windows in time when the herbicide will have minimal effect on the revegetation species yet affect the toadflax at a particularly vulnerable time. Fertilizer applications, when feasible, can also be timed with the same goals in mind. Weed specialists may need to

consult with SCS Plant Materials Specialists to help you develop such a schedule, if one is possible for the plant community you wish to establish. For general information on revegetation, refer to Chapter 7.

Sustainable, Long-term Management - Potential for Integrating Strategies

Because so little data exists on the effectiveness and the economics of toadflax control on rangeland, determining the sustainability of efforts will require the annual process of re-mapping and evaluation. It is only with this information that the site-specific management efforts required for this highly variable weed can be evaluated and adjusted to determine the most economical and effective combination of strategies. Sustainability will probably vary with site conditions, characteristics of the specific population, and willingness to adjust and readjust strategies. Persistent implementation of those strategies will be required.

Some of the more important strategies to include in an integrated program will be minimizing seed production, seedling control in infested areas using selective herbicides or other methods, maintaining appropriate stocking rates for the range conditions, and timing of grazing.

Patience and persistence

For any perennial weed management program to succeed, efforts must be sustained with patience for a long period of time, coupled with constant vigilance. There is truth to the statement 'perennial weeds require perennial solutions.'

NARROW-LEAVED DALMATIAN TOADFLAX, Linaria genistifolia (L.) Mill

Current distribution of Narrow-leaved Dalmatian toadflax is restricted to several locations in western Oregon, northwestern Washington, and rarely in British Columbia. The mature plant is quite similar in appearance to Broad-leaved, except for the somewhat narrower leaves and smaller flowers. The information for Broad-leaved Dalmatian toadflax can be applied to this species also, because of similarities in biologies of the two species and also because little information specific to narrow-leaved Dalmatian toadflax is available. The species was probably an accidental introduction into North America because it is not usually considered an ornamental. Area of origin is the same for both species, but in the native Eurasian habitat narrow-leaved is more widely distributed than wide-leaved Dalmatian toadflax, possibly indicating potential to become widely distributed in North America also (Smith 1959; Harris 1988).

YELLOW TOADFLAX

YELLOW TOADFLAX - Linaria vulgaris Mill., Scrophulariaceae (Figwort family). **Additional common names:** common toadflax, butter-and-eggs, wild snapdragon, ramsted, flaxweed, Jacob's ladder, others.

This herbaceous perennial was originally introduced as an ornamental and is still marketed, under the common names of "butter and eggs" or "Jacob's ladder". Infestations still originate from escaped ornamentals.

IDENTIFICATION**Seedling Stage**

Seedlings have cotyledons that are 0.1 to 0.3 inch (3-7 mm) long and rather pointed at the tip. First true leaves are linear and pointed at both ends. Vegetative shoots arising from root buds are similar, but without cotyledons. First true leaves of vegetative shoots are slightly longer, 0.25 to 0.5 inch (5-12 mm) long.

Juvenile Stage

Young plants are fine-textured but otherwise resembling more mature plants. Branching of stems begins when plants are approximately 16-24 inches (4-6 dm) tall.

Adult Stage

Stems and Leaves

Yellow toadflax stems are usually one to three feet (three to eight dm) high, are somewhat woody at the base and smooth toward the top, sparingly branched. Leaves are narrow, linear, and somewhat pointed at both ends, one to two inches (2.5-5.0 cm) long or longer, and 0.1 to 0.25 inch (three to six mm) wide, alternating on the stem but can appear to be opposite of each other when crowded. Stems and leaves are pale green.

Flowers and Seeds

The flowers are similar to those of Dalmatian toadflax and are two to three cm long. The blossoms occur at first in clusters (racemes) near the ends of the stems, becoming more elongately spaced as the season progresses.

Seeds are about 1.0 mm in diameter, dark, and flattened, surrounded with a papery wing. Diameter including wing, is 1.4-2.1 mm. Seed capsules are two-lobed and 8-12 mm long and usually contain 10-40 seeds (Arnold 1982), with numbers being highly variable. Number of seeds produced per plant have been estimated at 15,000-30,000 (McClay 1992), although determining what consists of an individual plant is difficult because of the reproductive characteristics of roots.

Roots

Yellow toadflax has an extensive, well developed root system. The transition from stem to root is 2-5 cm below the soil surface (Saner 1994). The root system consists of underground stems (rhizomes), a vertical primary tap root, and a system of lateral roots, one of which becomes dominant. Both vertical and lateral roots have vegetative buds that can develop into shoots which can later become independent plants. Vertical roots can penetrate into the soil three feet (a meter) or more, while lateral roots can be several yards (meters) long, and grow in the top two to eight inches (5-20 cm) of soil.

ORIGIN, HISTORY, AND DISTRIBUTION

Yellow toadflax originated in the steppes of south-eastern Europe and south-western asia (Meusel et al 1978).

Although the plant has been used for centuries as a folk remedy and fabric dye, it was introduced into New England in the late 1600's as an ornamental (Fernald 1905; Rousseau 1968). By the 1950's it had spread westward throughout North America (Saner 1991).

Invasion throughout North America was partly by transport and use as an ornamental, as a contaminant of crop seed and livestock feed, with ballast of ships, and along transportation corridors such as roads and railroads, as well as by natural means.

It is most common throughout the north-eastern United States and south-eastern Canada, and localized in other parts of the continent, particularly the western Canadian provinces.

POTENTIAL FOR INVASION

In its native region, yellow toadflax is distributed over a wide geographic region, in many habitat types, indicating adaptation to a wide range of growing conditions. This is also reflected in its wide distribution in North America. Because of high genetic variability of the species (see Biology and Ecology section), it will probably continue spreading as it adapts to new niches and sites, or simply is transported into new areas.

Habitats

Climate

Wet or dark conditions appear to limit yellow toadflax (Zilke 1954; Saner 1994), although it is often found on well-drained gravelly or rocky river banks. It occurs from sea level to 2800 m (Cronquist et al. 1984), and approximately 55° - 65° N. latitude, coinciding with Dawson (Yukon), Churchill (Manitoba), and Schefferville (Labrador) (Saner 1994).

Soils

Sandy, gravelly soils are typical, but the weed is found in other types as well. Roadsides, dry fields, grainfields, waste areas, gravel pits, pastures and rangeland, vacant lots, and railroad yards (Reed and Hughes 1970; Frankton and Mulligan 1970; Lorenzi and Jeffrey 1987) are sites typically colonized by yellow toadflax.

Characteristic Plant Communities

Lists of plant communities associated with yellow toadflax have been compiled, but none which are characteristic can be identified. It occurs in plant communities that are typical for disturbed open habitats (Arnold 1982). This lack of association with particular plant communities makes it more difficult to predict potential areas of invasion.

IMPACTS

Ecological & Environmental

As a competitive, exotic invader, native plant communities, and wildlife in some cases, are displaced, resulting in decreased biodiversity in areas of moderate to high density. Most of the general impacts discussed in Chapter 2 apply to toadflax as well.

Economic Impact

Yellow toadflax is a weed in cultivated crops, serious in some areas, and is believed to become more prominent in reduced-tillage farming operations. This problem is increased because of resistance to many herbicides (Ontario Ministry of Agriculture and Food 1993). It also displaces desirable rangeland plants, causing loss of forage for domestic livestock. It is reported to be mildly poisonous to cattle due to secondary compounds such as alkaloids and glycosides (Parker and Peabody 1983; Saner 1994), but some uncertainty exists as to effects; see section in Dalmatian toadflax, p. xx. Reported cases of poisonings are rare, probably due to avoidance of the plant by livestock, making economic impact minimal.

The root system provides an overwintering site in New York state for cucumber mosaic virus and broad bean wilt virus, serious pests of cultivated crops (Rist and Lorbeer 1989).

As in the case of Dalmatian toadflax, actual costs associated with yellow toadflax infestations are not readily available. In Alberta, a 1987 survey showed an estimated 28,000 ha infested with the weed, 20% in rangeland and non-agricultural land and 30% in annual crops and forages, at a cost of treatment by municipalities and counties of more than \$360,000 per year (McClay 1987), costs of about \$13 per ha per year. Standard procedures are used for estimating economic impact of yellow toadflax on rangeland. Refer to Dalmatian toadflax section.

Sociological Impact

Similar to that for Dalmatian toadflax; see page XX.

BIOLOGY AND ECOLOGY

Early top growth regeneration in spring from root reserves and its activity during all seasons of adequate moisture and favorable temperatures in a wide variety of habitats gives yellow toadflax a competitive edge which is characteristic of successful invaders. Established yellow toadflax is especially competitive for moisture, nutrients and light.

Native Habitat

Sites susceptible to invasion appear to be similar in both the native habitat and in North America and include woodland clearings, clearcuts, and vinyards, in addition to the sites listed in the Habitat section above (Saner 1994). In Eurasia, it does not appear as invasive in non-arable sites as it is in North America, perhaps due in part to differences in grazing pressures.

In central Europe, it often occurs in dry to moderately humid sandy loam soils that are moderate to rich in nutrients and minerals. In eastern Europe it is reported to be common in calcareous soils (Salisbury 1961) and able to tolerate heavy metals. In Europe, as in North America, no characteristic plant community can be identified for yellow toadflax. (In Saner 1994.)

Toadflax species evolved under moderate to intense grazing pressure, primarily by domestic livestock e.g. sheep, goats, and cattle to a lesser extent. Grazing pressure exerted by wild herbivores, such as deer, is not known. Because much of the land is arable in the area of origin, the plants have evolved with periodic disturbances primarily due to the activities of man, such as herbicide applications and farming operations.

Life Cycle

Seedling Emergence and Top Growth Regeneration

Seedling emergence has been reported in early to mid-May in Alberta (Nadeau and King 1991), but probably begins earlier, in warmer regions of the U.S. The majority of seedling emergence occurs in spring, tapering off as the season progresses, then a second, smaller flush occurs in the fall. Most energy of seedlings is devoted to stem growth.

Top growth regeneration in spring occurs when buds on the tap roots produce vegetative shoots; emergence of vegetative shoots occurs in early to mid-April in Canada, when soil temperatures reach 42-50°F (5-10°C) (Saner 1994), and possibly in mid- to late March in warmer regions of the U.S. Dalmatian toadflax shoots emerge several days after seedling emergence, but it is not known if the same sequence occurs in yellow toadflax. In contrast to seedlings, vegetative shoots growing from root buds, especially

root fragments, expend more energy on root production. It is not known if intact roots show the same allocation of energy; the faster vegetative spread of plants arising from root systems, as compared to spread from plants arising from seed, seem to indicate this is true of intact roots also.

Seedling and Shoot Growth

Seedlings can begin to produce their own vegetative shoots from root buds two to three weeks after germination (Zilke 1954; Nadeau and King 1991), which indicates early control of seedlings can slow vegetative expansion. A single seedling can produce a patch over three feet (one meter) in diameter in the first year (Zilke 1954). Because of continuous recombination of genetic material seedlings from seed (genets) may have an adaptive advantage for exploiting new or changing environments, when compared to plants produced vegetatively. The high degree of variability in the species makes this especially true.

A plant section eight inches long (five dm), part root and part shoot, can produce a patch three to six feet (one to two m) in diameter in one year in cultivated land, with 75 to 694 shoots in barley and fallow land, respectively, with barley appearing to inhibit vegetative shoot production to some extent (Nadeau 1991). This indicates the need for intensive management when toadflax is present in these areas. Population growth and expansion appears to

be achieved mainly by vegetative reproduction (Nadeau et al. 1992).

When vegetative shoots are 16-24 inches (4-6 dm) tall, branching begins, which signals the beginning of flower bud formation.

Floral Characteristics

Flowering begins in May and continues until October, and is variable. Seed capsules can begin opening on lower portions of the stem while flower buds are still forming on upper portions (Parker and Peabody 1983); this extended period of flowering and seed production enables the plant to withstand periods of adverse growing conditions. Yellow toadflax is self-incompatible and insect pollinated (Arnold 1982).

Floral stems die at freezing, but the woodier stems, including some with seed capsules, may remain standing through the winter, allowing seeds to drop through the winter months.

Seed Characteristics

Dispersal. Capsules on dried floral stems that remain standing through the winter can drop seeds onto snow surfaces, where they are sometimes blown by wind (Saner 1994). Wind appears less important as a dispersal factor in the absence of snow because although the seeds are winged, over 80% fall

within a 2.5 foot (0.5 m) radius of the parent plant, and very few fall farther than 4.5 feet (1.5 m) (Nadeau and King 1991). Dispersal by water is possible because seeds are oily and can float for extended periods (Lewis 1954). Migration along water courses has been observed (Zilke 1954). Farm operations and other human activities are also thought to be important modes of dispersal. Birds, rodents, and ants may also transport seeds. It is not known if livestock and wildlife are factors in dispersal.

Germination. Most seeds germinate in about the top inch (2-3 cm) of soil (Nadeau and King 1991). Germination rates are highly variable, often below 10%. Seed viability is often low also, 40-50% in one study (Nadeau and King 1991), which, along with seed dormancy, could partly explain the low germination rate. Two seed types are common, black and grey, with black usually exhibiting higher viability and heavier weight. Grey seeds are often incompletely filled and are more often infected by Alternaria and Cladosporium fungi than the black seeds. Some grey seeds are viable, and both black and grey seeds can be produced after periods of restricted resource availability, such as drought. Seed weight and viability are variable, apparently dependent on availability of resources. During periods of sufficient available resources, higher

proportions of heavier, black (viable) seeds may be produced. Site-specific variation is also a factor (Clements and Cavers 1990). Lower seed weight may be correlated with lower viability (McClay 1992).

Dormancy. Most seeds produced are dormant (Lewis 1954; Zilke 1954; Nadeau and King 1991) and can remain dormant up to ten years (Carder 1963) or more.

Although both seeds and root sections appear to be equally capable of initiating new infestations, seed dormancy and low viability results in low seedling establishment. Therefore, vegetative propagation, rather than seed germination, is thought to be primarily responsible for the increase in size of established populations. However, seeds may be more important in colonization of new sites (Nadeau et al. 1992).

Roots

A seedling can begin vegetative reproduction two to three weeks after germination, giving rise to its own daughter shoots (Zilke 1954; Nadeau et al. 1992).

Vertical tap roots of established plants have fewer reproductive buds and are more perennial in nature than the lateral roots, surviving for the life of the plant. Lateral roots have

been divided into two categories, perennial and annual. The perennial roots, also called "long roots", bear adventitious buds. The "short roots" die in early winter, to be replaced the following spring (Charlton 1960). Individual roots can live up to four years (Bakshi and Coupland 1960). It is not known if the vegetative buds of yellow toadflax can exhibit true dormancy, as can the root buds of some species.

Longevity

Individual plants live up to four years, but it is difficult to determine which parts are individual plants due to the vegetative reproduction characteristics. Theoretically, a stand may persist indefinitely.

Individual and Population Characteristics and Ecological Factors that Determine the Success of the Weed and Management Practices

Yellow toadflax has many of the characteristics typical of successful invasive plants: early vegetative reproduction, perennial, deep root system, extended period of seed production, high degree of genetic variability, and rapid increase in patch size, among other traits. These characteristics enable the species to colonize, adapt, and spread in a wide variety of habitat types. It will grow well in fertile, moist habitats, but is most

competitive and persistent in less favorable habitats, a successful survival strategy.

The morphology of the root system prevents grazing animals from dislodging or destroying the plants, and enables them to withstand some cultivation methods. Root segments as short as 0.5 inch (one cm) can reproduce vegetatively. After tillage operations, it is common for segments several inches (dm) long to produce vegetative shoots (Nadeau et al. 1992). The species can persist and spread locally even in the absence of seed production as in the case of subarctic populations that are unable to produce seed (Staniforth and Scott 1991).

Because many of the lateral roots are close to the soil surface, Kutschera (1960) stated yellow toadflax can be susceptible to root competition. However, like Dalmatian toadflax, it is an efficient competitor for soil moisture and when soil moisture and perhaps other conditions are limiting factors it can retain the competitive advantage in spite of the shallow root system.

Bud formation is inhibited by soil disturbance to some extent. During vegetative reproduction, little starch is accumulated in the root system (Bakshi and Coupland 1960).

Persistence Patterns

No specific patterns have been noted.

Rate of Increase in Patch Size

After seedling establishment, increase in patch size due to vegetative propagation is rapid the first year, and steady in subsequent years. In Canada patches originating from a first-year seedling were reported to have a diameter of nearly 6.5 feet (two m) and average increases in the diameter of established patches of nearly four feet (1.2 m) (Zilke 1954), with shoot densities an average of 300 per m² in barley seedings and 700 shoots per m² in fallow ground (Nadeau et al. 1992). A symbiotic mycorrhizal relationship been reported (Pendleton and Smith 1983), which could facilitate rate of growth.

Variability

With increased variability comes increased ability to adapt to and colonize a variety of sites and withstand a wider variety of environmental conditions, factors which are very important to the success of a noxious weed. Localized populations (phenotypes or genotypes) can develop that respond differently to management methods, biological control agents, herbicides, environmental conditions, etc. A high degree of variability is seen in all populations of yellow toadflax, manifested by variations in morphology, the size and fertility of pollen grains, and frequent irregular meiotic divisions. Variation is both genotypic and phenotypic, manifested in many aspects of the biology of the plant.

An additional source of genetic variation occurs in some regions of the northeast where yellow toadflax forms a hybrid with another exotic Linaria species, Linaria repens, striped toadflax. This hybrid is partially fertile or fertile, is weakly self-compatible, and has cyanogenic properties. The backcross is morphologically nearly identical to yellow toadflax, and remains cyanogenic. Hybrids between yellow toadflax and Dalmatian toadflax can be produced in the laboratory and natural occurrence of this hybrid should be considered (in Saner 1994).

Wilting Coefficient

The wilting coefficient of yellow toadflax seedlings is not known. It is possible it is similar to that of Dalmatian toadflax (see page XX).

Degree Day Requirements and Phenological Events

Information on degree day requirements and the thresholds for phenological events such as the onset of bloom is not available. It is known, however, that the phenology is highly variable, dependent on environmental conditions (Saner 1994). General phenological information is presented throughout the text. Degree day information can be developed on site and correlated with phenological events of importance, such as seedling emergence.

Germination and Growth Temperature

Growth of vegetative shoots in spring begins when soil temperatures reach 42-50°F (5-10°C) (Saner 1994).

Maximum Germination Depth

Most seed germinates at depths of 0.75-1.25 inches (2-3 cm). Maximum depth is not noted.

Dispersal

Dispersal to new sites and habitats is primarily via human activities and to a lesser extent by natural factors such as water, wind and wildlife. It has not been documented whether domestic livestock browse upon yellow toadflax flowering stems, transporting viable seed as is sometimes the case with Dalmatian toadflax. Rootstock containing vegetative buds is seldom transported naturally, although it is possible that farming implements and topsoil that is moved could contain root fragments. Root fragments as short as 0.6 inch (1.5 cm) can produce vegetative shoots (Nadeau et al. 1992).

Specific Activities and Disturbances that Influence Spread

Inattention and inability to identify the weed are probably as responsible for spread as any other factor. As with most noxious weeds, yellow toad flax is easier to control when patches are

small. For additional comments on spread, see section for Dalmatian toadflax, page XX.

Minimum and no-till farming methods could enable yellow toadflax to invade or re-invade areas where regular tillage has kept populations at acceptable levels (McClay 1992).

Potential for Invading Excellent or "Pristine" Rangeland

Although seedlings are easily outcompeted by vigorous, well adapted groundcover, even in excellent condition rangeland small openings or natural disturbances inevitably occur. Yellow toadflax definitely has the ability to colonize these "microsites" and once established it is competitive due to effective vegetative reproduction. Dormant seeds which are transported into these areas can take advantage of opportunities that can arise over time. Neither "excellent" nor "pristine" rangelands have remained uninfested.

MANAGEMENT

Proactive Weed Management

1. Education
2. Prevention

It seems our nature to be **reactive** rather than **proactive**; in no case is this more true than for noxious weed management. And in

no case can proactive management pay bigger dividends than for noxious weed management. An aggressive prevention program incurs costs for education, surveillance, and small-scale eradication. The traditional reactive weed management program can cost thousands, even hundreds of thousands of dollars each year, with large expenditures in man hours of tedious labor. Reactive control efforts are seldom completely successful. As alien plant species continue to find their way from continent to continent, an aggressive, proactive weed management program will pay ever larger dividends.

Education

The first step in proactive weed management is education, which you are doing now. Educational efforts should be extended to include any personnel you supervise. For additional sources of assistance contact the state Extension Service at your land grant university and your State Department of Agriculture.

Prevention

The second step is prevention:

Sources of Weed Seed Contaminant

Because seeds are the initial colonizer for yellow toadflax, keeping contaminated materials or equipment off of the property or

management unit or out of uninfested areas can be very cost-effective. Strategies for preventing invasion by yellow toadflax and potential sources of seed contaminant are similar to those for Dalmatian toadflax: refer to the preventative section on page XX.

Competitive Cover

Maintaining good cover of competitive, well adapted species can be helpful in preventing establishment of new infestations from seed. Although yellow toadflax has the ability to invade pristine areas and rangeland in excellent condition, seeds have a low rate of viability and seedlings are not considered highly competitive until several weeks after germination. Once vegetative growth begins, competitive cover of desirable range species will probably do little to slow expansion of the site.

Re-seeding and Revegetation

Re-seeding and revegetation should be considered essential when any weed populations are removed, leaving open areas susceptible to colonization. For specific recommendations, see section on Dalmatian toadflax, p.XX.

Livestock Containment

It has not been documented whether livestock will browse yellow toadflax as they do Dalmatian toadflax; until this

information is available it is probably advisable to contain livestock which have been ranging in infested areas in corrals or small pastures until viable seed have had time to pass through the digestive tract before moving them to areas that are weed-free. See recommendations in section on Dalmatian toadflax, p. XX.

Riding and Pack Animals

Feed that is free of weed seeds should be fed to livestock used as riding or packing animals taken into uninfested areas, wilderness, or other pristine areas. Certified weed-free feeds are available.

Seed Formation

Prevent toadflax seed production whenever feasible to slow natural dispersal to uninfested areas. Seed viability is low for this species, but it is still the major source of new infestations.

Containment and control

Develop a Management Plan

See section on Dalmatian toadflax, p. XX.

Assistance

See section on Dalmatian toadflax, p. XX.

General Considerations

See section on Dalmatian toadflax, p. XX.

Reseeding

See section on Dalmatian toadflax, p. XX.

METHODS OF CONTROL**Mechanical and Physical Controls***Grubbing or Pulling by Hand*

Can be effective for some of the shallower horizontal roots in lighter soils; shoots also emerge from portions of the root system deeper in the soil, especially the tap root (Saner 1994), and pulling or grubbing will not affect these roots. Attempt this method only on smaller infestations, when soils are moist. Because established infestations of yellow toadflax increase in size mainly by vegetative spread, physical removal, especially around perimeters, can be more effective in limiting spread than for species that reproduce primarily by seed.

Mowing

See section in Dalmatian toadflax, p. XX.

Cultivation

See section in Dalmatian toadflax, p. XX. Additionally, tillage for yellow toadflax should be consistent once undertaken as a management method; irregular tillage can spread infestations because small portions of root pieces can produce new shoots which rapidly establish a stand that can reach a diameter of more than three feet (one m) in a single season (Nadeau et al. 1992). This should be a consideration in fallow, no-till, and low-till operations in arable lands infested with yellow toadflax. Care must be taken not to transport root pieces on machinery to clean fields. Segments as short as 0.6 inch (1.5 cm) are capable of producing vegetative shoots.

Cultural Control

Cultural control can be defined as the manipulation of the environment or plant community to manage weeds.

Competitive Plant Cover

See preceding section on Preventing Invasion by yellow toadflax, "Competitive Cover", p.XX.

Spring Grazing

See section on Dalmatian toadflax, p. XX.

Burning

See section on Dalmatian toadflax, p. XX. Additionally, burning yellow toadflax could result in increased vegetative shoot production. In order to deplete root reserves, burning must be repeated as new shoots emerge to avoid replenishment of root reserves. Ability of yellow toadflax to produce root buds is, for all practical purposes, unlimited; control by removal of topgrowth is difficult.

Biological Control

See section on Dalmatian toadflax, p.XX.

Grazing - Sheep

Information on use by sheep is not available.

Chemical Control

See section on Dalmatian toadflax, p.XX.

Follow-up Programs

See section on Dalmatian toadflax, p.XX.

Long-term Control Strategies

See section on Dalmatian toadflax, p.XX.

Revegetation of Weed-Dominated Rangeland

Revegetation efforts in areas dominated with yellow toadflax will be similar to efforts for Dalmatian toadflax but species selected for the revegetation could be different because of differences in the root systems and in seed viability. See section on Dalmatian toadflax, p.XX and Chapter 7 for more complete information about revegetation programs.

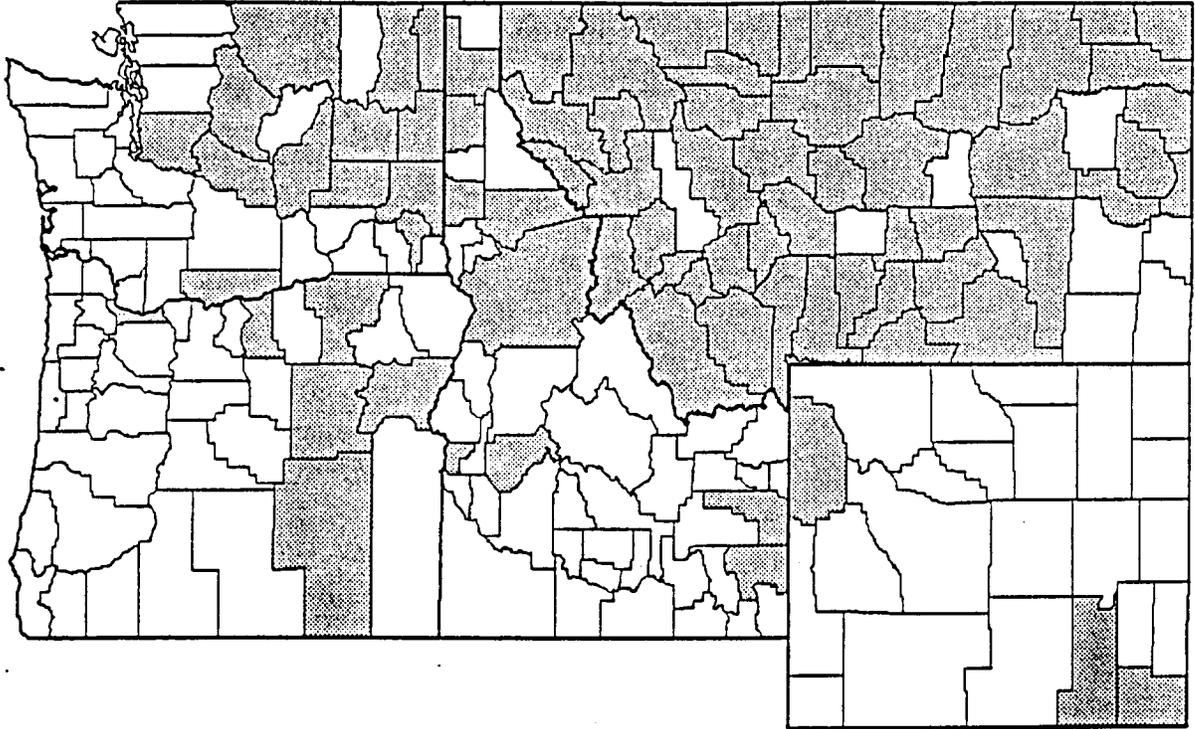
Sustainable, Long-term Management - Potential for Integrating Strategies

See section on Dalmatian toadflax, p.XX.

PATIENCE AND PERSISTENCE

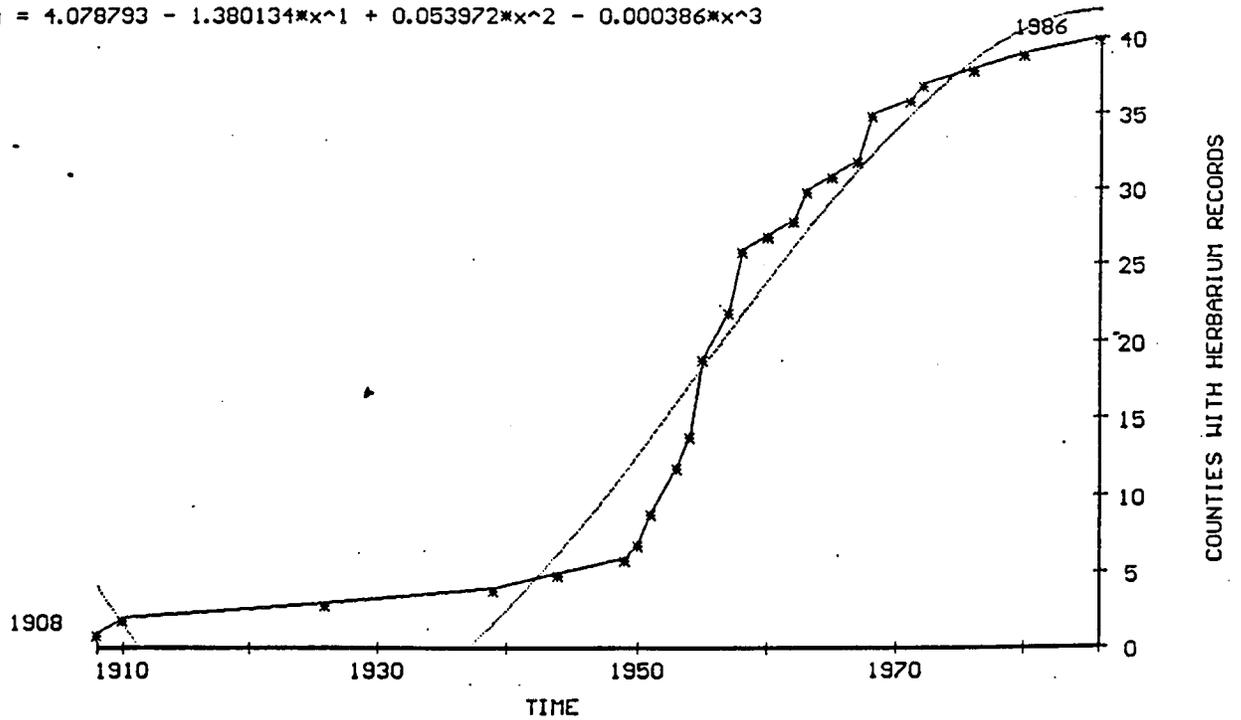
For any perennial weed management program to succeed, efforts must be sustained with patience for a long period of time, coupled with constant vigilance. There is truth to the statement 'perennial weeds require perennial solutions.'

Counties reporting the exotic *Linaria dalmatica* (dalmatian toadflax), 1875-1993.

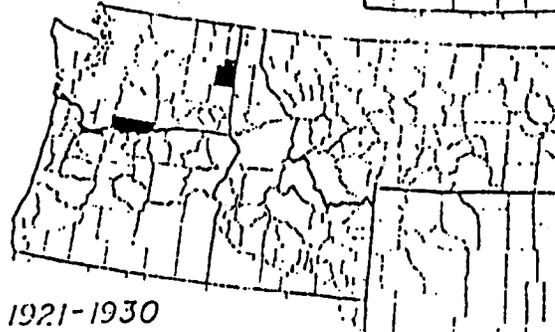
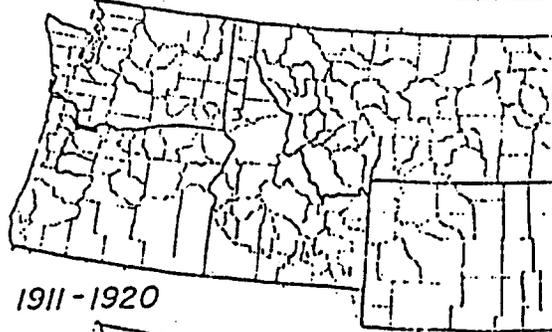
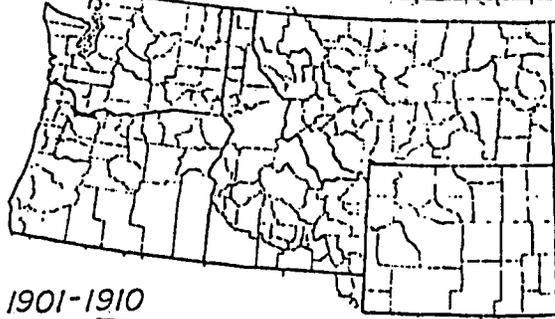
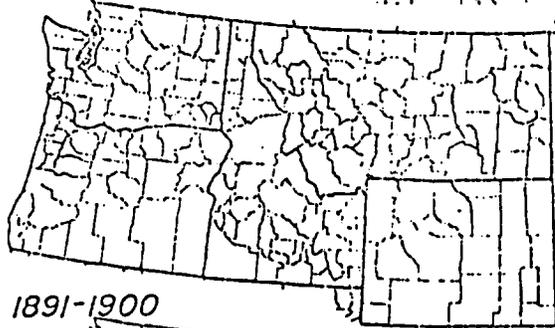
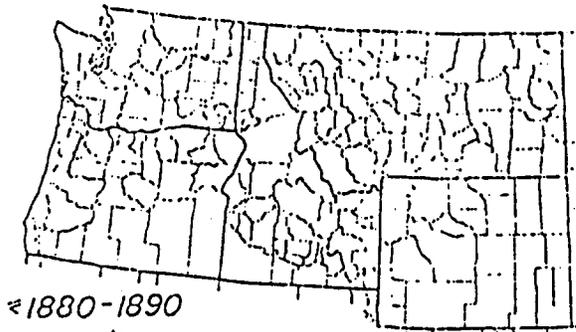


Linaria dalmatica INCREASE IN NORTHWEST STATES

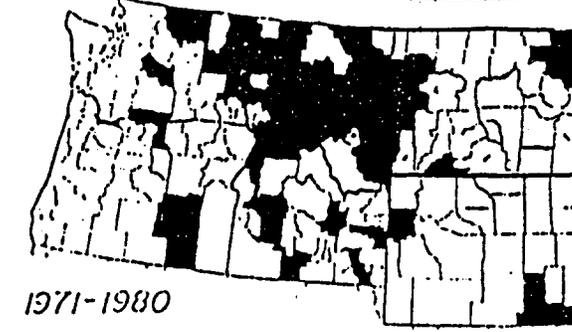
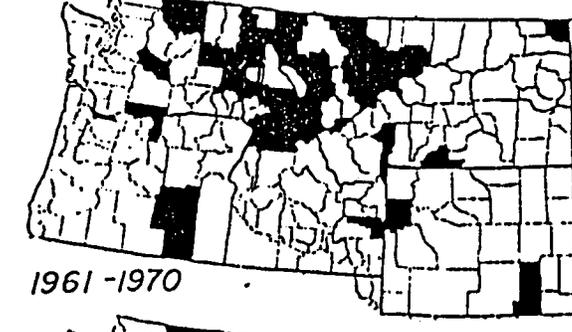
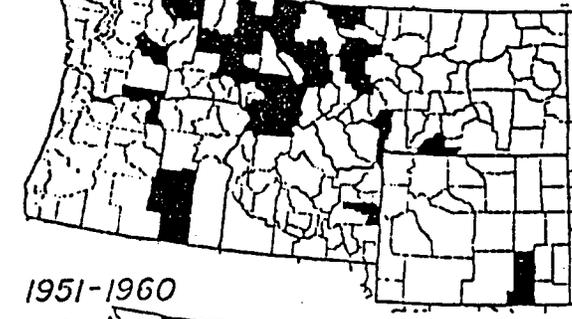
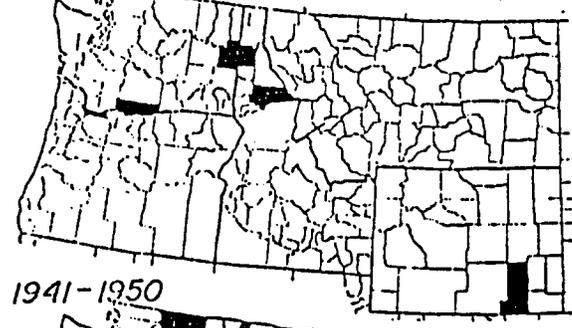
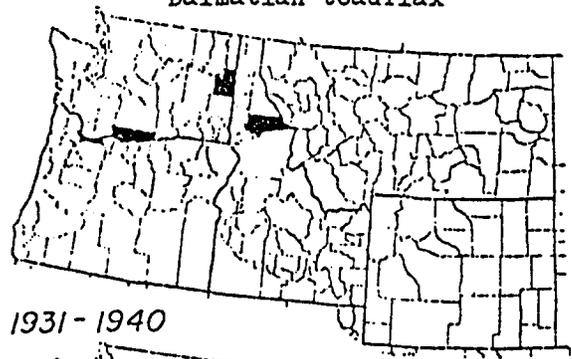
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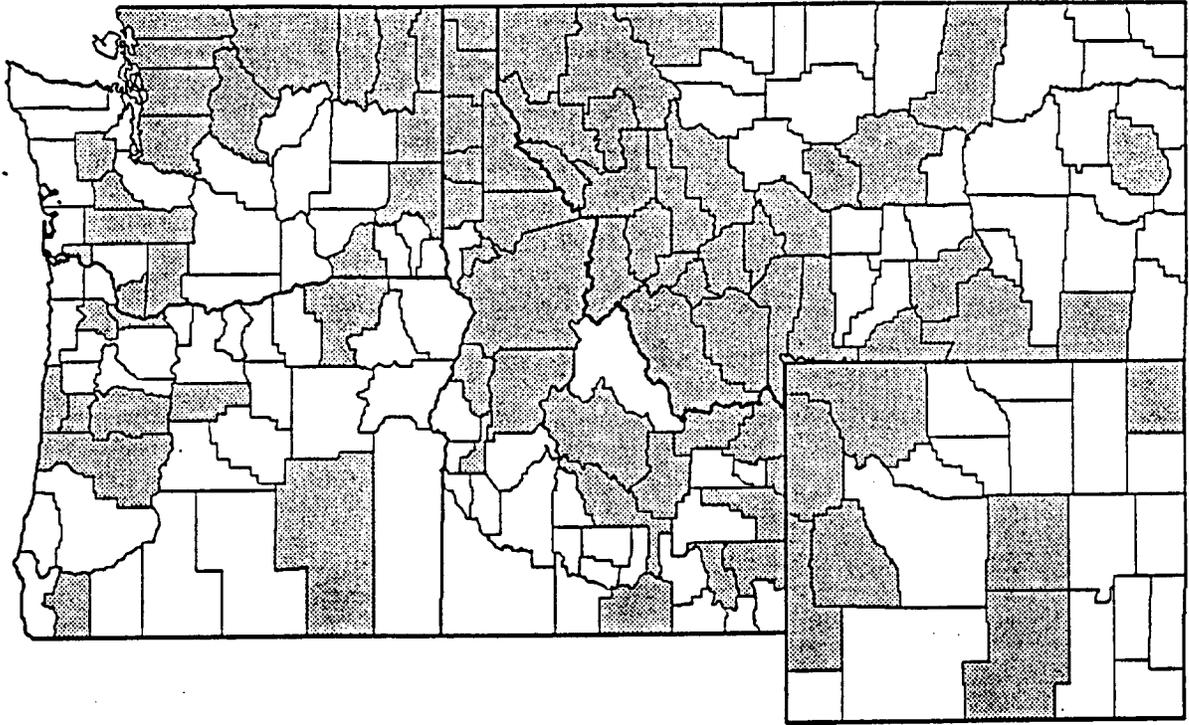
Linaria dalmatica



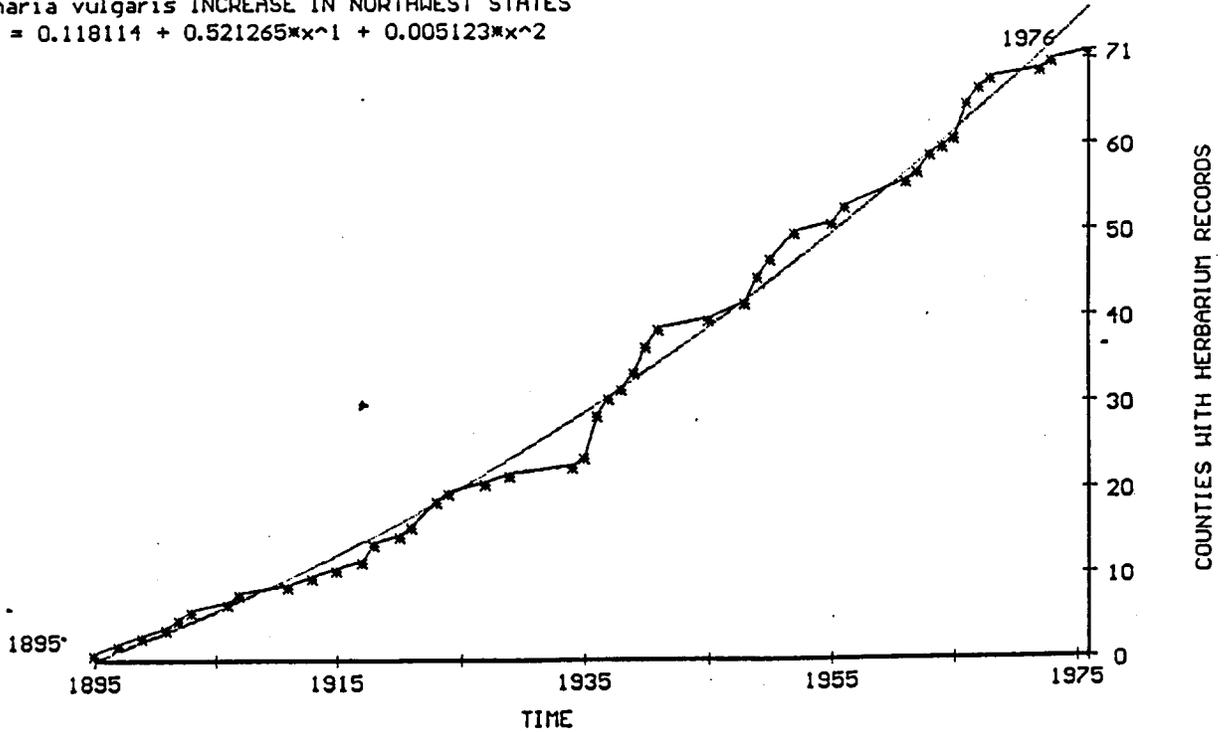
Dalmatian toadflax



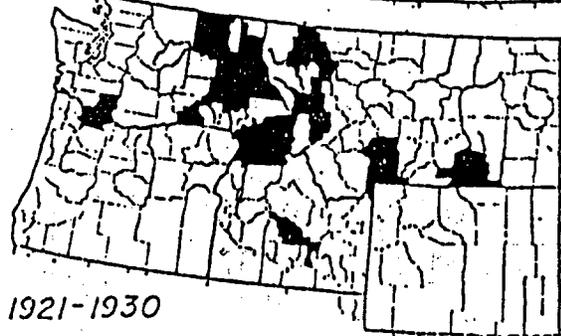
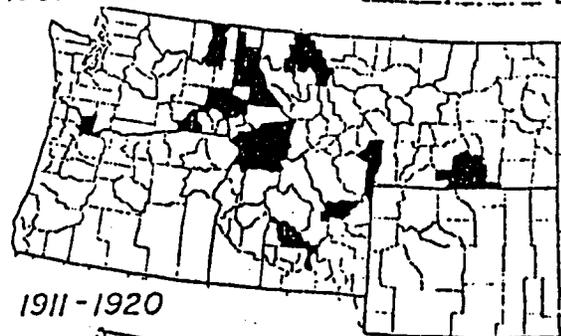
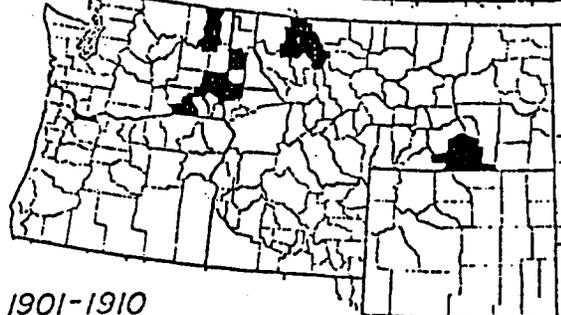
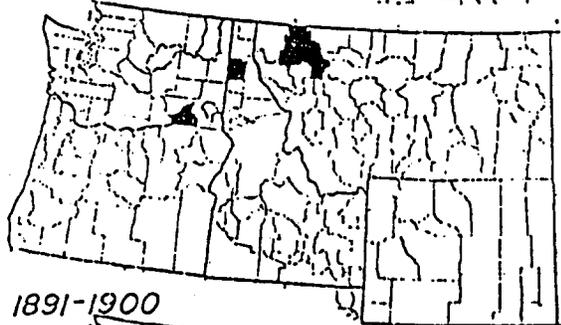
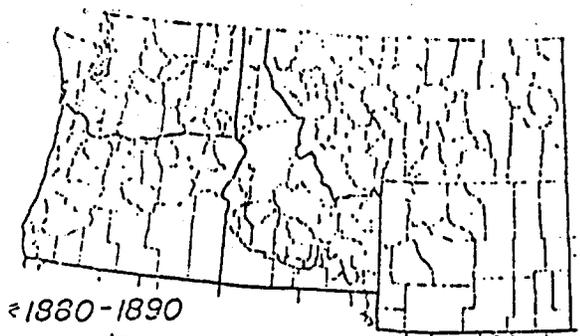
Counties reporting the exotic *Linaria vulgaris* (yellow toadflax), 1875-1994.



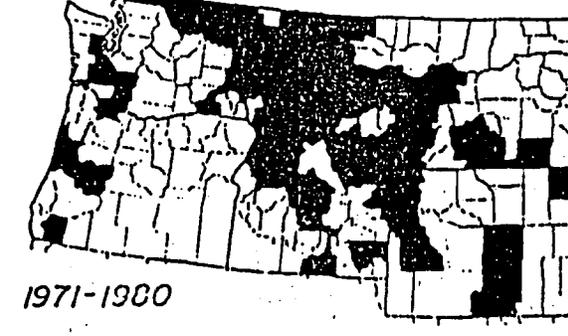
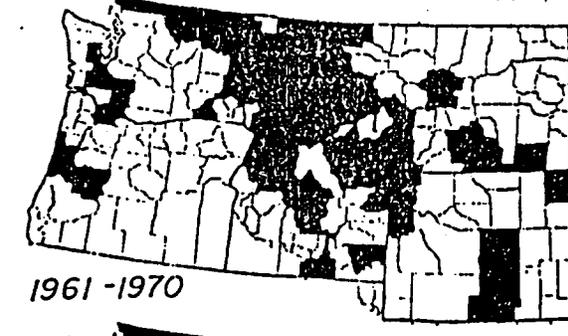
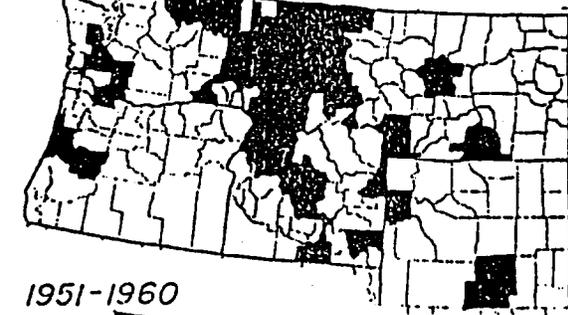
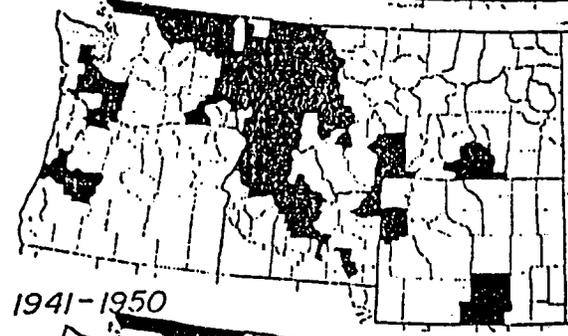
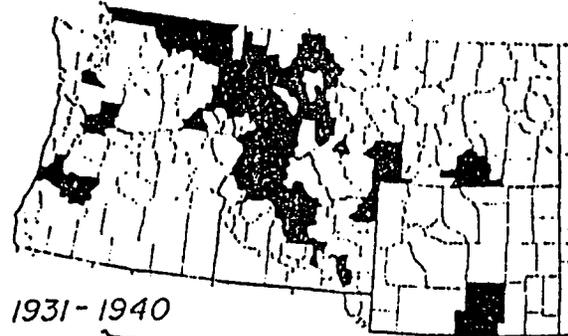
Linaria vulgaris INCREASE IN NORTHWEST STATES
 $y = 0.118114 + 0.521265x^1 + 0.005123x^2$



Linaria vulgaris



Yellow toadflax



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CHAPTER 7

DIFFUSE KNAPWEED, TUMBLE KNAPWEED

Ben F. Roché, Jr.*

Diffuse knapweed (*Centaurea diffusa* LAM.) is normally a biennial, but may live for several years as a rosette before flowering or continue to grow after producing seed to flower again as a short-lived perennial. It grows 1 to 3 feet tall from a deep taproot. Upright stems have numerous spreading branches, which give the plant a ball-shaped appearance and tumble-weed mobility when broken off.

In the basal rosette, leaves, borne on short stalks, are deeply divided into lobes on both sides of the leaf's midrib. Stem leaves are stalkless, becoming smaller and less divided higher up the stem; smallest leaves on the upper stems appear bractlike.

Urn-shaped flower heads are $\frac{3}{16}$ to $\frac{1}{4}$ inch in diameter and $\frac{5}{16}$ to $\frac{7}{16}$ inch long, excluding spines and flowers. Heads are solitary or borne in a cluster of two or three at the ends of the branches.

Bracts surrounding the flower heads are yellowish green with a buff or brown margin. Each bract is edged with a fringe of spines ending with a longer spreading spine (about $\frac{1}{8}$ inch long)

* Washington State University

at the tip. Some diffuse bracts are as "spotted" as spotted knapweed (*C. maculosa*) bracts, especially on heads with lavender or purple flowers, but the longer terminal spine is characteristic of diffuse knapweed.

Most plants have white flowers, but rose-purple and lavender flowered plants are not uncommon. Flowering occurs from June to September, or later if moisture and mild temperature permit.

Seeds are buff to dark brown, about 1/8 inch long, having a plume of bristle-like hairs that varies from scalelike to 1/8 the length of the seed (Roché and Roché 1993).

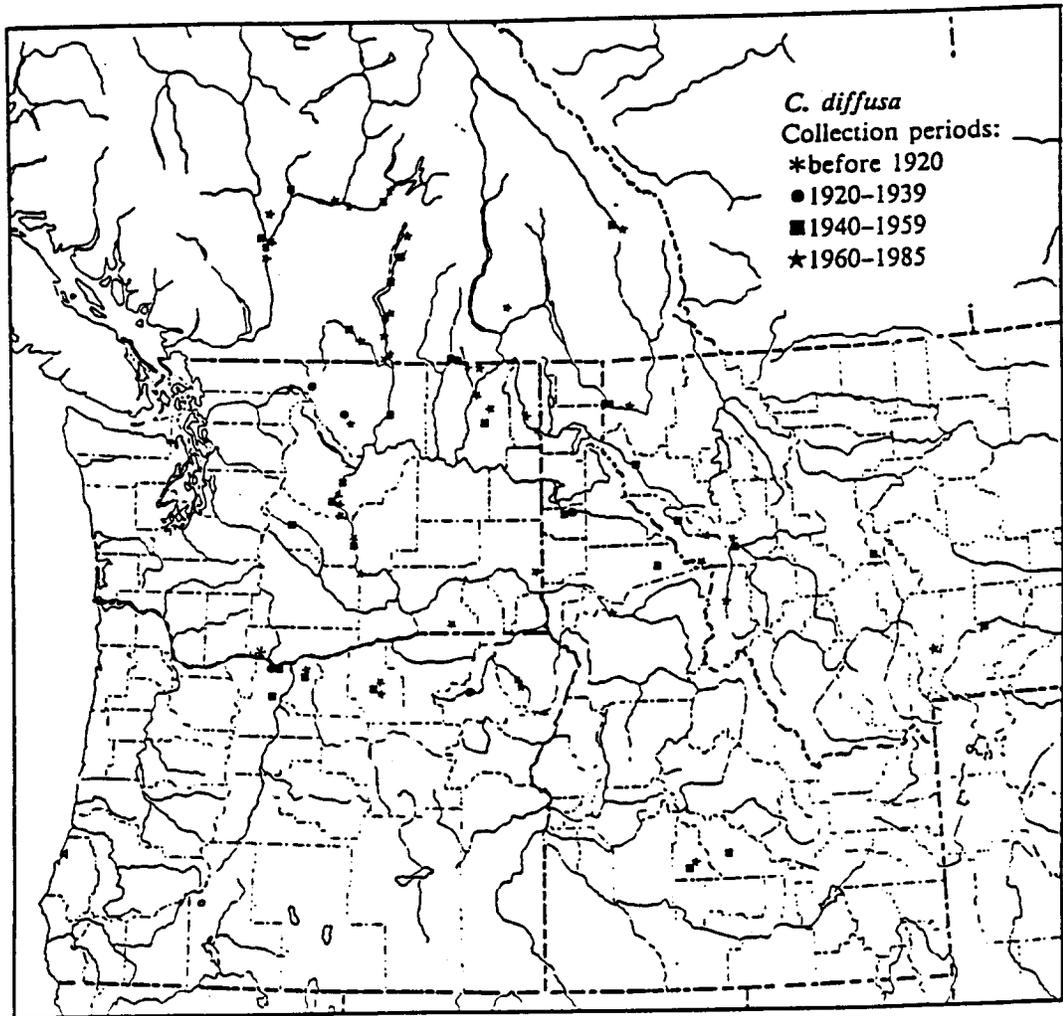
The knapweeds, that is the *Centaurea* species called knapweeds, are believed to have evolved in the eastern Mediterranean region (Greece, Turkey, and Iraq) following the retreat of the last major glaciation, some 10,000 years ago (Small 1919). It is also believed that as the glaciers retreated, watering the plains, the knapweeds moved into the glacially disturbed area. Hence the knapweeds were provided the opportunity to sort themselves so as to fit the many types of disturbed sites created (Prodan 1930). This all preceded the decision by man, about 7,000 years ago to settle in the same general area, develop the first planned cropping systems, and to domesticate grazing animals (Lowdermilk 1953). The two scenarios, one by a genus of potential weeds and the other by man creating disturbances provided the *Centaurea* species ample opportunity to become preadapted to similar disturbances in similar

environments in our region. We have investigated these invaders and propose that the primary differences are in the infested site (ecologic amplitude) and the type, desirability and vigor of the residual vegetation.

Diffuse knapweed (*Centaurea diffusa*) is native to Eurasia, being common in Romania, Yugoslavia, northern Italy, the eastern shore of the Mediterranean, Turkey, Greece, Bulgaria, Asia Minor, Syria, and Russia, especially in the Ukraine and the Crimea (Popova 1960). The earliest record of diffuse knapweed in western North America is from an alfalfa field at Bingen, Washington, in 1907 (Howell 1959). It was collected by Wilhelm N. Suksdorf whose family farmed near Bingen (Roché and Talbott 1986). It may have been introduced with Turkestan alfalfa seed from the Caspian sea region (Harris and Myers 1976). Maddox (1979) implicates alfalfa seed from Asia Minor-Turkmenistan or hybrid alfalfa seed from Germany as sources.

Diffuse knapweed at The Dalles, Wasco County, Oregon, 1931, is identified in the literature as the first naturalized colony in the United States (Howell 1934). However, Renney (1959) reported that diffuse knapweed infestations apparently occurred in British Columbia before 1930 as it was found at Lytton and Pritchard at that time. The 1930s appear to be the decade of rapid movement of diffuse knapweed to widely scattered locations along roadsides and railroads in British Columbia, Washington, Oregon, and Idaho (Roché

and Talbott 1986).



It was collected in Okanogan County in 1937, Stevens and Chelan counties in 1950, and Grant and Kittitas counties in 1952 (Roché and Talbott 1986). In 1967 it was reported in 12 eastern Washington counties, and considered a serious range weed problem in Chelan, Ferry, Kittitas, Klickitat, Okanogan, Spokane, and Stevens counties (Roché 1967). It was established along a railroad fillslope in Walla Walla County in 1965 (Dillon 1967) and along the Grande Ronde River in Asotin County by 1976 (Roger Holland, Chief Joseph Wildlife Area, pers. comm.). The problem escalated in the 1970s as diffuse knapweed moved from initial introduction sites along travel corridors onto adjacent pasture and rangeland. This was the response predicted by Cade (1968) when he wrote that the "very first plant or seed of a bad weed is . . .the slow motion equivalent of the tiny flame that could eventually burn the house down." The spread of diffuse knapweed has been like a wildfire: sending out fingers along roads, spot infestations in disturbed sites, and the eventual coalescing of the spots.

Acreages of major vegetation types susceptible to diffuse knapweed invasion in eastern Washington are summarized from Appendix Tables 18-ae and 19 in the Washington State Grazing Land Assessment (Washington Rangeland Committee and Washington Conservation Commission 1984):

<u>Eastern Washington steppe sites</u>	<u>Acres</u>
Loamy site-sagebrush/bunchgrass	3,408,000
shallow site-sagebrush/bunchgrass	1,640,000
Sandy and sandy loam site complex, bitterbrush/needle and thread grass/bluebunch wheatgrass	861,000
Bottomland bluebunch wheatgrass	67,000
site- bunchgrass/basin wildrye/bluegrass	5,967,000
subtotal	
<u>Eastern Washington timber range sites</u>	
Ponderosa pine/bluebunch wheatgrass	2,258,000
Douglas-fir/pinegrass	4,233,000
subtotal	6,491,000
Total	12,467,000

Using the compound interest method of Lacey (1983), the rate of spread of diffuse knapweed and a date for reaching its potential limits can be estimated. Assuming that there was one acre of diffuse knapweed when it was first collected in 1907, and that the estimate of 427,800 acres in 1986 is reasonably accurate, the equation for the rate of spread to date is the following:

$$427,900 = 1 (1+ i)^{79}$$

Solving for "i", the rate of spread during the past 79 years in eastern Washington is 17.8%. Assuming that rate of increase continues and the potential acreage for diffuse knapweed is 12.5 million acres, the equation for estimating the number of years to reach that level:

$$12,500,000 = 427,800 (1.178)^n$$

Solving for "n", diffuse knapweed would infest 12.5 million acres in 21 years, or in the year 2007. The growth curve of a population is usually S-shaped (Lacey 1983). A hypothetical population is currently in the phase of geometric increase (Figure 1). This is a generalization for the 20 county area as a whole. Lower elevation ranges in Okanogan, Ferry, and Stevens counties may be approaching the upper level. The population may be just initiating growth in Asotin, Garfield, Columbia, and Walla Walla counties.

The 1993 survey, receiving a 50% response from eastern Washington counties, provided an estimate of 820,388 acres of this weed. If 1986 figures are increased at the historic rate of 17.8%, the predicted acreage is 1,586,365. That's about twice the estimate of half the counties—not bad! However, among those reporting, a wide range of acreage shifts occurs:

County	1986	1993
Yakima	51,891	40,000
Ferry	51,591	51,000
Douglas	7,667	8,645
Kittitas	33,316	320,000

Two simple hypotheses for those variables follow:

1. Yakima and Ferry counties have active, well organized weed programs that were absent in Douglas and Kittitas counties for most of this survey period.
2. Kittitas County has many acres of bitterbrush/bunchgrass or ponderosa pine/bitterbrush/bunchgrass range in or adjacent to the valley. Our 1984-1986 survey suggested that of the 26 habitat types supporting diffuse knapweed, those supporting bitterbrush were the best suited and, hence, the most likely to be invaded by diffuse knapweed.

The 10 western Washington counties responding to the 1993 survey reported a total of 108 acres of diffuse knapweed. However, several Washington Department of Transportation District Supervisors report it as common on roadsides. It is particularly common on roads that cross the mountains from eastern Washington in areas that have been subjected to the U.S. Forest Service spray

injunction. It's unlikely that diffuse knapweed will duplicate its eastside aggressiveness under westside conditions, with the possible exceptions of dry meadows and pastures in poor condition (Roché 1994).

Approximately 3.1 million acres in the western United States are infested with diffuse knapweed. The amount reported by state includes 30,000 acres in Colorado, 1.4 million acres in Idaho, 10,000 acres in Montana, 1.2 million acres in Oregon, 1000 acres in South Dakota, 25 acres in Utah, 427,000 in Washington, and 5,000 acres in Wyoming (Lacey 1989). It also grows in Nevada and California.

Acreage estimates are subjected to extremes in subjectivity. The ground rules (we assume that there are ground rules) vary. Area reported varies from actual area occupied to total area exposed to the invader. Note the discrepancies in this paper: Lacey (1989) reported 1.4 million acres in Idaho and 1.2 million in Oregon. Callihan and Sanders (1994) suggest that the 100,000 acres in Blaine County plus the 487 acres reported by other counties is an estimate of Idaho's acreage of diffuse knapweed. Issacson's map (1993) shows 252 townships invaded. That's 5.8 million acres infested—not occupied.

In Oregon, the weed board has classified diffuse knapweed as a "B" weed. This listing attaches no special priority to control of this weed over the other 44 weeds similarly listed. One exception

is that the Department of Agriculture (ODA) actively distributes and monitors six bioagents now available for this species. The ODA also controls diffuse knapweed on joint programs with (an)other organization(s). Detecting and pulling diffuse knapweed on the Mt. Hood National Forest is one example. Diffuse knapweed has increased in range from 53 townships known to be infested in 1982, to 252 in 1992 (Figure 2) (Issacson 1993).

Although northern Idaho has the largest infestations of most *Centaurea* species, diffuse knapweed is an exception. Blaine County has the largest infestation of diffuse knapweed at approximately 50,000 acres—reportedly reduced from 100,000 acres since 1983. All other counties reporting had a total of only 487 acres. This weed is present in most of Idaho's counties. While believed best adapted to the sagebrush ecosystem of southern Idaho, it may prove equally well adapted to the drier, treeless canyon slopes of northern Idaho rivers, e.g., the St. Maries (Callihan and Sanders 1994).

Diffuse knapweed is normally a biennial, but may behave as an annual or a short-lived perennial (Watson and Renney 1974). In replicated spaced plantings under garden conditions, 10% of 400 plants flowered the first year, and only 3 plants died following flowering. Twenty-two percent of another 100 plants were still growing in the fourth year of mowing to 2-inch height each month of the growing season of April through October (Roché and Roché 1990).

Diffuse knapweed is ideally suited to spread by vehicles and

by tumbling in the wind. It evolved to spread by the wind blowing the ball-shaped plants in the same manner as tumble mustard (*Sisymbrium altissimum*). The seeds, held in urn-shaped heads which do not open widely, are lost gradually, giving the plant the advantage of far distant distribution. This technique adapts extremely well to hitchhiking on the frames of vehicles and colonizing the bare shoulders of roads. Plants are also carried in rivers and irrigation systems.

Diffuse knapweed can produce viable seeds even if the parent plant is cut the same day that the florets emerge from the bud (Table 1). Although diffuse knapweed requires pollination to produce seed, energy remaining in the cut plants is adequate for seeds to develop. Diffuse knapweed mowed early in the flowering period will produce few viable seeds. If an abundant seed bank already exists, a few additional seeds are insignificant. In contrast, a few seeds produced by newly established plants in isolated locations may be enough to maintain and expand the weed population. Also, diffuse knapweed mowed in the early flowering stage will usually regrow and produce abundant late season seeds. More importantly the heads that produce these late season seeds will likely be out-of-synch with those biocontrol organisms expected to parasitize "normal season" seed heads.

Pulling or cutting diffuse knapweed is a frequently recommended environmentally favorable control measure. While labor

intense it is effective, provided that enough of the taproot is removed to discourage sprouting. In our studies those plants that had been cut just below the crown (as though all of the green had been removed) regrew 38% of the time. While only 4% of those that had the rosette removed along with 2 to 4 inches of the taproot survived.

Table 1. Viability of seed produced by mowed diffuse knapweed, by number of days from flower pollination to mowing.

No. of days	Filled seeds per head Mean	Germination filled seeds %
0	1.5	32
2	1.2	0
3	2.7	34
5	3.3	14
7	3.4	24
9	3.2	57
10	3.4	43
11	7.4	48
12	4.0	75
14	3.8	58
15	7.4	77
16	4.0	81
19	8.0	61
20	3.6	80
22	6.8	52
26	1.9	83
28	3.0	76
32	2.2	77
34	3.7	67

37	9.5	84
38	2.5	75
40	3.3	81

Of the *Centaurea* species studied, diffuse knapweed has the widest ecologic amplitude in eastern Washington: elevational range was sea level to 5000+ feet, all aspects 0-360●, all slope positions, flat to over 60%, a wide spectrum of soil properties, average annual precipitation ranged from 6 to 35 inches and 26 habitat types were recorded. However, its zone of maximum competitiveness is in the shrub steppe, with superior invasiveness in the bitterbrush/bunchgrass communities (*Purshia tridentata*/*Agropyron spicatum* with or without *Stipa comata*). Diffuse knapweed is less competitive on shallow soils (less than - 15-inch depth) and coarse textured soils (sand, loamy coarse sand). In Washington, diffuse knapweed does not grow in dense shade or on poorly drained soils (Talbot 1987).

In eastern Washington there are three major areas of diffuse knapweed dominance:

- a. In the north central area the important habitat types include bitterbrush, with or without an overstory of ponderosa pine (*Pinus ponderosa*).
- b. In the northeastern area the important habitat types are the cleared and often abandoned ponderosa pine or

Douglas-fir shrub lands (*Pseudotsuga menziesii*/*Symphoricarpos albus* or *Physocarpus malvaceus*). Much of this was, prior to invasion by diffuse knapweed, dominated by Kentucky bluegrass (*Poa pratensis*).

- c. The west central area includes the middle and lower elevations of the east slope of the Cascades. The habitat types range from ponderosa pine and bunchgrass (with or without a shrub union) into the big sagebrush (*Artemisia tridentata*)/bunchgrass types.

The answer to the question of whether or not invasion by diffuse knapweed depends on overgrazing isn't simple. It was reported (Fletcher and Renney 1963) that diffuse knapweed was allelopathic. That toxic substances were produced by the plants and the assumption was made that the environment or at least the microenvironment was made poisonous to other plants hence the rapid spread and dominance by the weed. Tucker (1990) made a joke of the claim in a cleverly written piece entitled "The Myths of Knapweed." However, it was Kelsey and Bedunah (1989) that provided evidences that, although a chemical (cnicin) could be isolated from the aerial tissues of knapweed species that would, at a range of concentrations, reduce the development of the seedlings of selected species, the source material (knapweed foliage) when applied at three times normal litter production provided no appreciable

reduction in grass growth. Nevertheless, it is likely that these knapweeds are our best symptom of range degradation. They fill the niches created by disturbances and in some instances, due to differences among and between species and their varying abilities to compete, are able to dominate the site. The results are decreased forage produced, increased surface runoff and reduced rain-use efficiency. That's desertification!

". . .the sustained decline and/or destruction of biological productivity of arid and semi-arid lands caused by manmade stresses, sometimes in conjunction with natural extreme events" (Sabadell etal 1982).

THE FORAGE CONNECTION

Forage is defined as: "All browse and herbaceous foods that are available to grazing animals" (Kothman 1974). The knapweeds and starthistles are considered poor forage, i.e., less desirable, less palatable and without food value. The first two of the above listed descriptives are rated or ranked according to what else is available. Neither desirability nor palatability is as important to a foraging animal as is availability. Food value also varies with availability but relative to the use of knapweeds it is keyed on developmental stages of the plant as well as the season. Let's accept that knapweeds, at least diffuse, spotted and yellow

starthistle are naturalized and begin a realistic appraisal.

Miller (1990) reported that diffuse and spotted knapweeds were important food sources for mule deer, whitetailed deer and California bighorn sheep in the West Kootenays of British Columbia. Prior to snowfall the sheep diet was 80% grass, 18% forbs and 2% shrubs. As the snow receded in January and February knapweed rosettes comprised 80% of the diet, while grass contributed 18%. Nutritional analyses from the Robson/Syrina Park area (Miller 1990) are presented in Figure 3.

Analyses made in Washington are comparable at the rosette stage (Table 2.)

Table 2. Percent crude protein at stages of growth.

	Diffuse %	Spotted %	Yellow Starthistle %
Rosette	18.03	16.85	12.83
Bolting	11.14	10.34	
Bud	8.14	5.16	5.78
Flower	8.19	7.16	7.36
Seed Ripe ¹	7.45	2.91	4.46

¹ Diffuse seeds remain in the head (while upright) whereas the other two species lose the seeds at maturity.

Methods of utilizing knapweeds or starthistles and managing livestock to contain or control weeds are being continually reviewed. In Montana trials, sheep have readily grazed spotted knapweed and rotational sheep grazing has reduced flower stem

production (Wallander et al. 1992). In California, the effects of grazing yellow starthistle by sheep or cattle are being evaluated (Thomsen et al 1989). As noted above, timing relative to the stage of development of the weed is critical. Wallander et al. (1992) report that:

"Although sheep do not completely avoid the grasses, we minimized grazing on Idaho fescue by grazing the pastures first in mid-June when the spotted knapweed was bolting and the Idaho fescue was going dormant. We timed the September grazing to occur before fall growth of the cool season grasses."

Thomsen et al. (1989) made similar recommendations:

"We found that proper timing of grazing is critical to suppressing yellow starthistle, and that the first grazing should be timed to the bolting, pre-spiny stage. Subsequent grazings are generally required; local conditions (the moisture regime) determine the number. Timing was more important than class of animal although differences in acceptance of yellow starthistle was evident among livestock classes."

The more commonly accepted form of biocontrol (i.e., insects and pathogens) continues to be expanded. Piper (1993) reported that 9 biocontrol agents have been introduced in the western United States for diffuse knapweed control. They are:

flies	<i>Urophora affinis</i> and <i>U. quadrifasciata</i>
beetles	<i>Sphenoptera jugoslavica</i>
moths	<i>Pelochrista medullana</i> and <i>Pterolonche inspersa</i>
weevils	<i>Bangasternus fausti</i> , <i>Larinus minutus</i> , and <i>L. obtusus</i>

Biocontrol insects have significantly reduced the population of some weeds (e.g., tansy ragwort or St. Johnswort), but to date don't seem to have slowed diffuse knapweed. On the other hand, we are looking at a relatively short time span, *Urophora* was introduced in 1972 and *Sphenoptera* in 1976, and it has been made clear to the student of weed control that time will be a factor as will the addition of complimentary biocontrol agents (Story 1984).

In the meantime, manage the untilled areas so as to maintain a vigorous, competitive stand of desirable vegetation, pull and burn the initial invaders, refer to herbicidal recommendations for an acceptable solution to established populations and remember that diffuse knapweed can be utilized. Weeds are best defined as those species having a negative value in a given management system. This

recognizes the necessity for a definable value system and accepts the premise that all resources are or should be subject to predetermined managerial objectives.

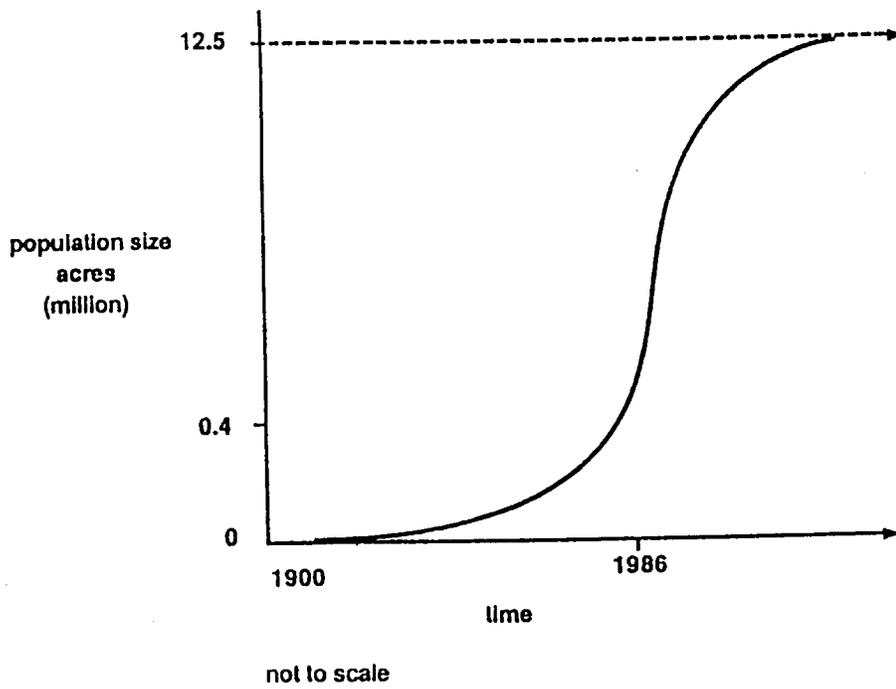


Figure 1. Diffuse knapweed potential population growth curve.

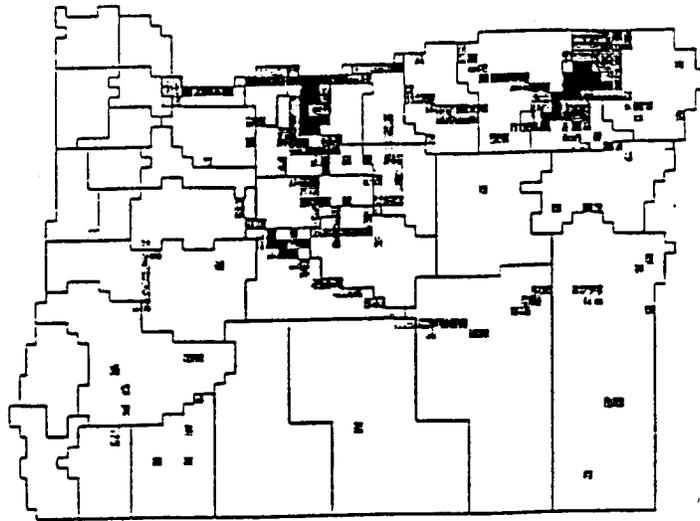


Figure 2. Distribution of diffuse knapweed has increased from 53 townships (black squares) in 1982 to 252 townships in 1992 (dotted squares).

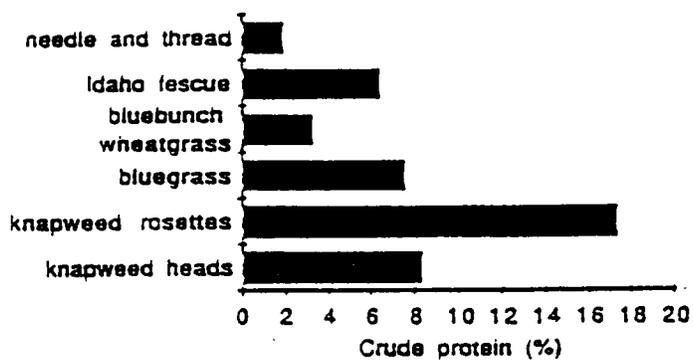


Figure 3. Forage values in mid-December.

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CHAPTER 8

DYER'S WOAD

John O. Evans and Steven A. Dewey*

INTRODUCTION

Loathed by land managers and loved by photographers admiring nature's bounteous floral display, *Isatis tinctoria* (dyer's woad) is no exception to the rule that many noxious weeds were at one time introduced as wonder plants. Even before the Christian era, dyer's woad was believed to have medicinal benefits and later it was cultivated as a dye crop. Ancient warriors painted themselves with dyer's woad dye prior to going into battle in an effort to look more ferocious. Dyer's woad was introduced from Europe and cultivated in the eastern United States as a textile dye crop but escaped to become a troublesome plant on range and cropland west of the Missouri River. Currently, its rapid invasion of western range and forest land is of extreme concern to public land policy makers throughout the intermountain west, although it doesn't appear as a threatening weed in the eastern states where it was initially grown.

IDENTIFICATION

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Dyer's woad is a blue-green mustard (Brassicaceae) plant with numerous bright yellow flowers in an umbrella-shaped inflorescence which makes it easy to identify. It normally grows 1 to 3 feet tall, but may reach over 4 feet. Typically, it has a 3 to 5 foot long taproot and some lateral roots in the upper foot of soil. Rosette leaves, attached by a stalk, are widest near the tip and have soft fine hairs. Stem leaves are alternate, lance-shaped and clasp the stem with short basal lobes. Stem leaves lack hairs and their margins are mostly entire. All leaves have a cream colored midrib on the upper surface from the base to the leaf tip, a key identifying feature. The flower stems are branched in the upper part of the plant and stiffen into an umbrella-like structure at maturity.

ORIGIN, HISTORY AND DISTRIBUTION

A native of southeastern Russian, dyer's woad has spread or been taken to many countries; currently, it exists on six continents. It grows wild in China, Tibet, and Afghanistan. It probably came to North America from Europe by eastern United States colonists either as a textile dye crop or as a crop seed contaminant and later as a contaminant in alfalfa seed imported to California from Ireland. Today, dyer's woad persists as a weed in eight western states and threatens to invade others, particularly those with large amounts of rangeland and pastures. Dyer's woad

exists mainly on rangeland but it also invades alfalfa and small grain fields, orchards, pastures, wasteland and waterways.

POTENTIAL INVASION

Dyer's woad poses a real threat to rangelands, forests, and pastures of the intermountain west due to its ability to dominate plant communities where dense dyer's woad infestations exist. Dyer's woad competition begins early in the growing season, probably due to its accelerated growth rate from rosettes to flowering plants. In one experiment , dyer's woad stem growth rate averaged 10 cm per week in April and May. This provides a canopy over other slower growing plants which reduces light and lessens the amount of growth they display.

Dyer's woad poses a rangeland threat because it thrives on limited water, nutrient and soil resources. Apparently, one reason for dyer's woad's success rests with its root structure and design. Some have suggested that dyer's woad is similar to sagebrush in this regard. A deep taproot extends into the soil and uses the deeper water and nutrient reserves, while a shallower set of lateral roots take advantage of spring moisture and surface nutrients.

The fruits of this weed probably contain allelopathic substances but as yet the chemicals have not been fully characterized. Experiments were conducted in Nevada to determine

allelopathic effects of dyer's woad on itself and on other species. Dyer's woad fruits were soaked in water for varying intervals and the water was used to irrigate germinating seeds of several crops and weeds. The water extract inhibited germination of dyer's woad and numerous other species. Dyer's woad seeds separated from the fruits do not express seed dormancy and readily germinate under a variety of conditions, but they do not readily germinate when they remain in the fruit pods. The inhibitors in the pods may prolong dyer's woad germination over time and may correlate with precipitation patterns that leach inhibitors from fruits and allow seed germination over extended periods of time.

Prolific seed production enables dyer's woad to spread at a rapid rate. One infestation south of Dillon, MT, increased from two acres to more than 100 acres in just two years. It is estimated that dyer's woad is spreading at an annual rate of 14% on BLM rangelands in the northwest and reducing grazing capacity by an average of 38%. The number of infested hectares on National Forest lands in the Intermountain Region increased more than 35 fold from 1969 to 1985.

IMPACTS

In 1981 it was estimated that dyer's woad reduced crop and rangeland production in Utah by two million dollars. The dyer's woad infestation has doubled in the last decade and certainly

causes several million dollars loss at the present time, causing widespread concern among land managers. Dyer's woad can be controlled more easily in cropland compared with rangeland and forests. Dyer's woad control in forest and ranges is limited by lack of available control alternatives, undesirable impacts of machinery and chemicals on associated desirable forage, inaccessible terrain, and questionable economic returns on control investments.

Many mustard weeds do poorly in the absence of disturbance, but dyer's woad is capable of encroaching upon and increasing its density in well vegetated range sites that have not been grazed or disturbed for decades. A healthy, dense stand of grass and other perennials deter the spread of dyer's woad but do not prevent invasion.

BIOLOGY AND ECOLOGY

The plant has small bright yellow flowers with 4 petals and 4 sepals. Petals are about 1/8 inch wide and only slightly longer. Flowers are clustered in racemes on upper parts of branched stems. At peak flowering, dense stands of dyer's woad appear bright yellow with a hint of chartreuse green. Each flower produces a teardrop-shaped winged silicle (fruit) that hangs from a small stalk. Fruits are 1/2 to 3/4 inch long and 1/4 inch wide, black or purplish brown at maturity. The fruit is strongly flattened with

a wing around a thickened center where the single seed is held. Seeds are brownish-yellow and cylinder-shaped. The seed-containing fruits separate intact from the plant, unlike most mustards whose fruits split to release the seeds.

Dyer's woad behaves as a winter annual, biennial, or short-lived perennial. In the intermountain area, it typically germinates in the fall, remains as a rosette of basal leaves during the following summer and winter, flowers in April and May of the second year and seed ripens in June and July. Studies have shown that about 1% of fall-germinated plants flowered the first spring, half of the 35% of the plants that survived the second winter, flowered the second spring and 12% did not flower until the third spring. Winter chilling is necessary for rosettes to bolt and flower. Seeds develop about 8 weeks after the time that stems start to elongate in the spring. Often about 20 stalks begin to develop from each rosette, but fewer than 8 mature. Plants may produce 350 to 500 seeds each but selected plants have been known to produce over ten thousand seeds in one year.

Dyer's woad spreads to uninfested sites only by seed. Seed dispersal studies revealed that 95% of the winged seeds fell within 22 inches of the parent plant. The greatest distance that seeds were wind blown from their source was 8 feet. Wind and rain were important in fruit detachment as well as the direction seeds moved from the parent. Some fruits remain on the plants until

winter when winged fruits may blow much greater distances over the surface of crusted snow. Vehicles, flowing water, animals, feed, bedding and crop seed are important in long distance dispersal. Dyer's woad seeds themselves are not dormant, but are enclosed in fruits which contain a germination inhibitor. This water soluble inhibitor leaches out over time and does not appear to provide long-term seed survival in the soil. Anecdotal reports of dyer's woad reappearing after tillage of grasslands suggest that seed may stay viable in the soil for many years, but this has not been verified under controlled conditions. A fruit pedicel can serve as a hook-type apparatus which attaches to vectors such as animals or people. Long-range seed dispersal is often facilitated by moving water such as canals, streams, and rivers.

MANAGEMENT

Prevention and early detection are paramount in managing dyer's woad invasion. One of the most important methods of prevention or control is hand rogueing; the process of removing individual plants in the field. The easily identified distinct yellow dyer's woad blossoms are readily recognized by individuals such as boy scouts, high school students, and hourly employees, lacking special training in plant identification, that can clear large land tracts. The fleshy taproot must be removed below the crown of the plant or regrowth will occur. Rogueing is very

effective in hard to reach spots such as fencelines, canal banks, wooded areas and may be the only practical control method in difficult terrain or in forests and sites with associated sensitive plants. Do not let dyer's woad plants go to seed! Breaking or cutting off the tops does not kill dyer's woad but will encourage it to develop new stems and produce seed later in the season. Plan to hand-rogue dyer's woad 2 to 3 times each year for several seasons.

In fields where dyer's woad infestations are more severe, cultivation and herbicides can be used to advantage. Annual crops and rowcrops are cultivated often enough that tillage itself should eliminate dyer's woad, occasionally an additional tillage may be required particularly if cropland is fallowed to conserve moisture. Dyer's woad must pass through a cold temperature period in order to produce seed. Spring cultivation destroys the vernalized rosettes and effectively stops seed production provided escapes are appropriately dealt with. Dyer's woad seedlings sometimes appear after spring cultivation but cannot mature until the next season following cold exposure. To remove the competitive effects of immature dyer's woad seedlings in small grain and forage grass fields, selective herbicides such as 2,4-D, metsulfuron, and dicamba can be employed.

Dyer's woad is often a problem in perennial crops such as alfalfa, particularly the fields grown without irrigation. Dyer's

woad can easily spread to new areas in hay bales transported over great distances in the western states. Animals that consume dyer's woad contaminated alfalfa hay can further aid the dissemination process to even more remote areas. Domestic animals and wildlife will deposit dyer's woad seed to rangelands where its effects are more severe and more difficult to manage than in alfalfa fields. Hexazinone, metribuzin and 2,4-DB are herbicides that are effective in controlling dyer's woad in alfalfa fields. Hay stands need to be properly managed in order for herbicides to satisfactorily control dyer's woad. Thin stands of alfalfa or fields that display stressed crop plants should be taken out of hay and rotated to other crops rather than trying to force herbicidal weed control.

There are three major strategies used to control dyer's woad in rangeland and forests: rogueing, herbicide application and biocontrol. Rogueing or hand removal of individual weeds is probably one of the simplest, yet most essential, methods of dyer's woad control. Rogueing is most effective in areas surrounding major infestations and in areas where the weed has been introduced far from any major infestation. To be effective, it is generally necessary to wait until the woad bolts and flowers before attempting the rogueing operation. The distinctive yellow flowers make it easy to identify and locate all of the plants in an area. Once the plants have been identified, they can be removed by pulling or digging them with a hoe or shovel. The important thing

to remember is that there are only 4 to 6 weeks from flowering time until the seeds are mature. It is essential that plants be removed as soon as possible after flowering to prevent the possibility of some slipping by and going to seed.

The importance of hand roguing cannot be overstressed, especially in those areas which have a light infestation of dyer's woad. Land managers and others should constantly be on the alert for dyer's woad and as they make surveys in May and June, remove any small, isolated patches of the weed.

Excellent control of dyer's woad can be obtained by spraying with 2,4-D in rosette stages. As the plant enters early bud and blossom stages, 2,4-D often does not kill it quick enough to prevent seed production. Combining 2,4-D with other herbicides shows more promise to immediately stop dyer's woad growth and seed production. The use of 2,4-D should be confined to those areas where adjacent properties will not be damaged by spray drift.

Dyer's woad typically enters an area by moving along highways, railroads, or canals. Apparently dyer's woad seed can be spread by vehicles or railcars where it is dropped onto suitable sites. As the seeds germinate, new plants readily grow and produce seed and spread to neighboring fields or are picked up once again by passing vehicles and thus continue the cycle. Because roadsides and railways are such effective avenues of seed dispersal, it is extremely critical that any woad growing in these areas be

destroyed or removed. It is especially important not to allow the plants to produce seed.

One of the most exciting discoveries with regard to stopping the advance of dyer's woad is the impact that a native rust pathogen, *Puccinia thlaspeos*, has on this noxious weed. Fruit and seed production are completely prevented on almost all infected plants. Studies are underway to determine optimum conditions for the pathogen and whether rust spores can be hand disseminated to remote dyer's woad locations. Recent surveys reveal that the rust is naturally spreading to new dyer's woad infestations and significantly slowing the growth and reproduction of many dyer's woad plants.

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CHAPTER 9

LEAFY SPURGE

R. G. Lym*

INTRODUCTION

Leafy spurge grows on a wide variety of terrain from flood plains to river banks, grasslands, ridges, and mountain slopes (Hanson and Rudd, 1933). It is primarily found in untilled non-cropland habitats such as abandoned cropland, pastures, rangeland, woodland, roadsides, and waste areas (Selleck et. al., 1962; Dunn, 1979 and 1985). The plant grows in diverse environments from dry to subhumid and from subtropic to subartic. It occurs on many topographic positions from the flat bottom of glacial lakes to the slopes of sand dunes and glacial moraines. After leafy spurge is introduced into an area, there does not seem to be any topographic limits to its invasion of new areas.

Leafy spurge tends to occupy sites having high sand content, at least as the site for initial infestation (Bakke, 1936). Leafy spurge often is the dominant species in bottomland positions, with less on the topslope, summit, and shoulder slope, respectively. The favored site associations seem more related to moisture and fertility conditions favorable for plant growth than to edaphic

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factors.

Wild and domestic animals, birds, (Selleck et al., 1962) and insects are agents (Pemberton, 1988) of dispersal. Birds as primary disseminators of leafy spurge seed have been suggested because of frequent feeding on seed and frequent occurrence of new patches under trees and fences. Viable seeds have been found in the droppings of some birds, such as sharptail grouse. Mourning doves (*Zenaida macroura*) may spread seed especially when ground-nesting, but less than one intact leafy spurge seed/g was found in fecal materials (Blockstein et al., 1987). Seeds probably move with mud on animal feet or hair. Some leafy spurge seeds can occur in sheep manure, and probably can occur in the manure of other animals. Seeds also move on machinery and in hay.

Latex is present throughout the plant (Bakke, 1936). Injury to any part of the plant will result in immediate flow of the white, sticky latex to seal the wound.

Leafy spurge contains a toxic substance that, when taken internally, is an irritant, emetic and purgative. It causes scours and weakness in cattle and may result in death (Selleck, 1962). The toxin has produced inflammation and loss of hair on the feet of horses from freshly mowed stubble during haying (Kingsbury, 1964) and has caused mortality of sheep in Alberta (Johnston and Peake, 1960). Animals will eat the dried plant in hay, but livestock, particularly cattle, avoid eating growing plants. Sheep and goats

are less affected by the toxic principle in the latex and will graze young plants. Thus, sheep and goats have been used in management programs for leafy spurge control.

There is indirect evidence that leafy spurge has allelopathic properties, i.e., the weed releases chemicals that inhibit the growth of other plants in the same area. For example, the small number of forbs in patches of leafy spurge, even when bare ground is visible between shoots, suggests that this species exerts inhibitory effects on other plants (Selleck, 1972; Steenhagen and Zimdahl, 1978). However, specific chemicals have not been identified to verify the occurrence of allelopathy.

Alfalfa (*Medicago sativa* L.) and leafy spurge occurred together in only 8% of over 700 areas sampled during three surveys (Stack and Statler, 1989). A parasitic rust fungus, *Uromyces striatus* Schroet., infects both leafy spurge and alfalfa as alternating hosts. It was hypothesized that nonconcurrency of alfalfa and leafy spurge may be due to naturally occurring biocontrol.

About 95% of leafy spurge infestations within a 374 ha native prairie area were associated with soil disturbances such as vehicle tracks or road construction and fireguards which removed native plant cover and exposed mineral soil (Belcher and Wilson, 1989). After leafy spurge invasion, plant diversity declined from 11 species outside the infestation to three species at the center.

The only species that were positively correlated with leafy spurge were smooth brome and Kentucky bluegrass (*Poa pratensis* L.), both of Eurasian origin. This correlation may have occurred because Eurasian agricultural species readily invade disturbed soil.

Soil disturbance by humans promotes the establishment of leafy spurge. Over 45 times more seeds established on bare soil than in undisturbed vegetation (Best et al., 1980). In non-cultivated areas leafy spurge patches increased in radius by 0.3 to 0.9 m/yr, with a median of 0.612 m (Selleck et al., 1962). Spread is potentially much greater in cultivated habitats because of reduced competition and movement of root fragments (Hanson and Rudd, 1933). Many plant population models have been developed to predict the rate of expansion for leafy spurge patches (Bowes and Thomas, 1978; Maxwell et al., 1988). These models include many environmental and physiological variables that simulate leafy spurge communities. However, these models are difficult to use in applied situations.

Stroh et al. (1990) have proposed a simple formula to estimate leafy spurge patch expansion. The formula is based on a review of the literature and research on native grasslands in the upper Great Plains.

Leafy Spurge Patch Expansion Formula

$$X = \pi * [(Y-4) * 0.61m]^2$$

$$Z = X * (100 \text{ stems/m}^2)$$

where Y = years

M = meters

X = area of patch in m²

Z = total stems in patch

The formula is based on the premise that more than 4 yr are required before a seedling will start to spread vegetatively. Thus a single leafy spurge seedling could infest 0.5 ha in 80 yr. However, the actual rate of increase would be faster since the formula does not generate information on new patches formed from seed dispersal.

ECONOMIC IMPACT

The influence of leafy spurge on long-term land value is difficult to assess (Messersmith and Lym, 1990). However, short-term return can be estimated by measuring changes in forage production and use by livestock following leafy spurge control (Lym and Kirby, 1987; Lym and Messersmith, 1990).

Leafy spurge reduces the livestock carrying capacity 50 to 75% (Lym and Kirby, 1987). In North Dakota, cattle used 20 and 2% of the forage available in zero- and low- (<20% cover) density leafy spurge infestations by mid-season. Moderate- and high-density infestations were avoided until early fall when the milky latex in

leafy spurge disappeared. Leafy spurge canopy cover of 10% or less and shoot control of 90% or more was necessary to achieve 50% forage use by cattle in Montana (Hein and Miller, 1992).

Moderate and high leafy spurge densities reduced long-term herbage production approximately 16.5 to 33% in North Dakota on land that was 50 to 100% infested, respectively (Lym and Messersmith, 1990). A ranching enterprise would lose approximately 17.5% from cattle refusing to graze herbage in moderate to heavy leafy spurge infestations and an additional 17.5% from lost annual production (Lym and Kirby, 1987). Besides production losses, control costs to manage infested sites and potential for increased infestation each year must be included in assessing the economic impact of leafy spurge.

Thompson et al. (1990) estimated both the direct and secondary effects of reduced livestock carrying capacity due to leafy spurge in North Dakota in 1990. They found the reduction in carrying capacity is best approximated by the equation:

$$C.C. = 100 - 1.25 (P.I.)$$

P.I. = Percent land area covered by leafy spurge.

Thus, a leafy spurge infestation covering 80% of the land area would reduce the carrying capacity to zero from a practical management standpoint. They estimated direct reduction of 577,000

animal unit months or \$8.6 million annually, similar to the earlier report (Messersmith and Lym, 1985). The decreased production due to the lost carrying capacity was \$14.4 million (Thompson et al., 1990). The secondary impacts were estimated at \$25 million in lost personal income. Substantial impacts were also shown for the retail trade sector (\$19.3 million) and the agriculture-crop sector (\$10.7 million). The total estimated annual loss was \$75 million. They further estimated \$195 million annual loss due to decreases in forage and livestock production, wildland and wild-life associated recreation, and soil and water conservation.

Leafy spurge does have some economic value. Commercial honey producers utilize leafy spurge as an early-season food source (Messersmith et al., 1985). The plant flowers prior to the prime honey producing months. Also, leafy spurge honey does not granulate quickly in cold weather, so it makes good honey to feed bee colonies in the winter.

CONTROL

Leafy spurge is difficult to eradicate, but topgrowth control and a gradual decrease in the underground root system is possible with a persistent management program. Nearly all experimental herbicides have been tested on leafy spurge since the introduction of 2,4-D [(2,4-dichlorophenoxy)acetic acid] in the 1940s (Alley et al., 1984; Lym and Messersmith, 1985). Most of these herbicides

have little or no activity on leafy spurge.

Herbicides commonly used to control leafy spurge include 2,4-D, dicamba (3,6-dichloro-2-methoxybenzoic acid), glyphosate [*N*-(phosphonomethyl)glycine], and picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) (Lym and Messersmith, 1985). Picloram, dicamba, and 2,4-D are selective herbicides that control broadleaf weeds while glyphosate is nonselective and controls both grass and broadleaf weeds. Dichlobenil (2,6-dichlorobenzonitrile) suppresses leafy spurge growth only and can be used under trees (Lym and Messersmith, 1982) and fosamine [ethyl hydrogen (aminocarbonyl) phosphonate] can be used adjacent to water (Lym and Messersmith, 1988).

Long-term control of leafy spurge is extremely difficult to achieve. The most cost-effective control method depends on the size and location of the infested area. Small patches of leafy spurge can be eliminated with a persistent herbicide program, however, large areas will require continued control measures. A combination of chemical and cultural treatments such as cultivation, cropping and grazing may be necessary to stop the spread of leafy spurge (Alley et. al., 1984; Dersheid et. al., 1985; Sedivec and Maine, 1993).

The key to controlling leafy spurge is early detection and treatment of the initial invading plant. A persistent management program is needed to control topgrowth and to gradually deplete the

nutrient reserve in the root system.

Picloram and 2,4-D are the most frequently used herbicides for leafy spurge control. Picloram reduces leafy spurge density the most effectively but 2,4-D controls the leafy spurge foliage at the lowest cost. Both herbicides are poorly absorbed (generally less than 30%) and 5% or less of the absorbed chemical is translocated to the roots (Lym and Moxness, 1989). Herbicides that control leafy spurge most effectively must be applied at relatively high rates, have a long soil residual, and/or cannot be applied in environmentally sensitive areas.

The most widely used treatment for both leafy spurge control and improved forage production is picloram plus 2,4-D at 0.28 plus 1.1 kg ae/ha (Lym and Messersmith, 1990). About 93,000 ha in North Dakota are treated with picloram plus 2,4-D annually to control leafy spurge. Over \$2 million are spent annually in the Northern Great Plains for leafy spurge control alone, and the weed infestation continues to increase.

Picloram plus 2,4-D at 0.28 plus 1.1 kg/ha costs \$35/ha and needs to be applied annually for 3 to 5 yr to obtain approximately 90% control (Lym and Messersmith, 1987). This treatment plus application would cost landowners and government agencies over \$20 million annually if the total infested acreage were treated. Leafy spurge control with herbicides is not always practical due to the high cost of treating large areas of infestation especially because

the economic return is low on range and untilled land where it most frequently occurs. Also, the weed frequently occurs in environmentally sensitive areas where herbicide use is prohibited. Thus, control with biological agents offers the best solution for control on a large scale and in the diverse environments where leafy spurge grows.

A major program for leafy spurge biocontrol was initiated across the United States in the 1980s. Since then, seven insects for biological control of leafy spurge have been released in North Dakota (Carlson and Mundal, 1990). The spurge hawkmoth (*Hyles euphorbiae* L.), a foliar feeder, generally has not survived and when it does, provides control too late in the growing season to be very useful (Messersmith and Lym, 1990). Four root-feeding flea beetles, *Aphthona cyparissiae* Koch, *A. flava* Guill, *A. czwalinae* Weise, and *A. nigriscutis* Foudras, and a gall midge, *Spurgesa esulae* Gagné, have established and reproduced well at several research sites in the state and region. A stem-boring beetle, *Oberea erythrocephala* Shrank, has been released at two locations in North Dakota and has established but not in sufficient numbers to allow integrated research.

The *Aphthona* spp. have had the most effect on leafy spurge because the larvae feed on the root system, the population has increased rapidly since introduction, and the insect is easily captured for transport to additional locations. *A. nigriscutis* has

been the most successful biological control agent and has been redistributed to all 52 North Dakota counties 5 yr after its introduction into the state.

Although *Aphthona* spp. are well established at many sites, leafy spurge control by *Aphthona* spp. has been slow, because populations must be high enough so several larvae feed on each root and the insects do not move rapidly from the center of establishment. Some flea beetle release sites have been sprayed with herbicides because the farmer, rancher, or county weed control officer were impatient after a couple of years waiting for leafy spurge to disappear.

Dramatic increases in biological control agent population and subsequent leafy spurge control have been observed in the field when herbicides were combined with biocontrol insects¹. For example, a release of 250 adult *A. nigriscutis* near Minot, North Dakota in 1989 increased to over 1 million by 1993. The Minot insectary site had been sprayed accidentally with picloram plus 2,4-D in both 1991 and 1992. The leafy spurge density was reduced by 80% in a 2 ha area and 500,000 insects were redistributed to other infested areas. This was the largest increase in insect population (>4000-fold) and decrease in leafy spurge density in any of the 27 release sites in the state. A similar incident at the North Dakota Army National Guard Camp Grafton training location resulted in near complete leafy spurge control when an *A. nigriscutis* population was

accidentally sprayed in the fall. The observations from these incidents support the hypothesis that insect and herbicide treatments can be integrated to enhance leafy spurge control and have lead to the preliminary research of combining herbicides with biological agents.

Some perennial grass species can effectively compete and provide leafy spurge control. Several grass species in a leafy spurge infested area have been evaluated for establishment and productive capabilities under a tilled or non-tilled program (Whitson et. al., 1990). Established grasses included: Luna pubescent wheatgrass (*Agropyron trichophorum*), Ephraim crested wheatgrass [*Agropyron cristatum* (L.) Goertn.], mountain rye (*Secale montanum*), Sherman big bluegrass (*Poa ampula*), RS1 hybrid wheatgrass (*Agropyron repens* x *A. spicatum*), Lincoln smooth bromegrass (*Bromus inermis* Leyss.), Oahe intermediate wheatgrass (*Agropyron intermedium*), Secar bluebunch wheatgrass [*Agropyron spicatum* (Pursch) Scribn.], Rosana western wheatgrass (*Agropyron smithii* Rydb.), Bozoisky Russian wildrye (*Elymus cinereus*) and Critana thickspike wheatgrass (*Agropyron dasystachyum*).

Four yr after seeding, areas tilled before seeding and then established to Russian wildrye, pubescent wheatgrass, big bluegrass, and intermediate wheatgrass maintained greater than 90% leafy spurge control, with dry matter yields of 1411, 2281, 3297, and 3490 kg/ha, respectively (Whitson et. al., 1990). In no-tilled

areas, big bluegrass and pubescent wheatgrass maintained leafy spurge control with dry matter yields of 2330 and 1168 kg/ha, respectively.

Table 19.1 Leafy spurge control, forage production, and estimated net return from several herbicide treatments in eastern and western North Dakota, during a 5-yr management program.

Original treatment date and herbicide	Rate	Retreat- ment applied	Cost	Control ^a Aug. 1988	Total Yield		Total net return
					Forage	Leafy spurge	
	(kg/ha)	(Year)	(\$/ha)	(%)	----- (kg/ha)	-----	(\$/ha)
Spring 1984					Eastern North Dakota		
2,4-D ^b	2.2	85-88	75	30	10,780	4170	356
Picloram + 2,4-D ^b	0.28+1.1	85-88	175	70	11,480	2210	284
Picloram ^c	2.2	1988	405	100	12,770	1760	105
Dicamba ^c	9	85-87	1010	90	12,180	2230	-523
Fall 1983							
2,4-D ^b	2.2	84-87	75	0	8,320	7390	258
Picloram + 2,4-D ^b	0.28+1.1	84-87	175	20	10,890	3830	261
Picloram ^c	2.2	1985	405	90	12,310	330	87
Dicamba ^c	9	1986	505	70	12,080	860	-20
Control	---	---	0	0	10,480	8630	
LSD (0.05)				15	1,600	850	60
Spring 1984					Western North Dakota		
2,4-D ^b	2.2	85-88	75	40	4,780	590	116
Picloram + 2,4-D ^b	0.28+1.1	85-88	175	90	7,070	180	108
Picloram ^c	2.2	86,87	610	100	6,920	140	-333
Dicamba ^c	9	85-87	1010	100	5,670	390	-783
Fall 1983							
2,4-D ^b	2.2	84-87	75	10	5,520	1550	146
Picloram + 2,4-D ^b	0.28+1.1	84-87	175	20	5,110	1420	29
Picloram ^c	2.2	1986	405	70	6,690	50	-137
Dicamba ^c	9	85,86	755	60	6,280	120	-504
Control	---	---	0	0	4,610	3230	
LSD (0.05)				20	850	450	35

^aControl 12 months after last treatment.

^bAnnual retreatment.

^cRetreated when control declined to less than 70%.

Table 19.2 Longevity of leafy spurge control.

Original	Years without treatment		
		1	2
Control			
	3		
95 or more	85	70	<20
80	60	<20	0
70	<30	0	0
60	20	0	0

Values given in % control; compiled from Lym and Messersmith (3, 11).

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CHAPTER 10

MEDITERRANEAN SAGECindy Talbott Roché and Linda M. Wilson¹**IDENTIFICATION**

Mediterranean sage (*Salvia aethiopis* L.; $2n=22$ (Singh 1984)) is a member of the mint family (Lamiaceae). It has erect, sturdy, squarish stems up to 3 feet tall, opposite leaves and a stout taproot. Plants are densely woolly with white hairs, especially when young. As they age, the upper sides of the leaves lose some of the felty covering of hairs, revealing prominent veins and a wrinkled surface.

Seedlings have two oval cotyledons with notched tips. The first true leaves develop a distinctive mat of tangled white hairs. Juvenile plants form a basal rosette that remains close to the ground. Rosette leaves are indented or shallowly toothed and have a stalk 1 1/2 to 3 1/2 inches long. Second year rosettes are very leafy, almost succulent, and are usually 7 to 10 inches in diameter, although they can grow to 4 feet across. Dense, silvery-white hairs make leaves appear light to gray green. In the juvenile stage, Mediterranean sage could be confused with common mullein which also forms rosettes of felty leaves. However,

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mullein leaves tend toward yellow green, in contrast to the gray or blue green cast of Mediterranean sage leaves. Mullein leaves lack petioles and are not toothed along the margin. In addition, Mediterranean sage emits a pungent sage-like odor when crushed.

Mature plants have upright stems with clasping leaves that become progressively smaller up the stem. The uppermost leaves are reduced to-purple-tinged bracts having a long tapering point. The branched panicle that resembles a candelabra bears numerous flowers in woolly clusters. Four to six white flowers are clustered in whorls, each subtended by silvery-haired bracts with pointed tips. Each flower is about 1/2 inch long, shaped like a mint flower, with the upper lip resembling a hooked beak. The pale yellow lower lip divides into three lobes, having a center lobe smaller than the outer lobes. Each flower produces four seeds. Seeds are about 1/8 inch in diameter, somewhat egg-shaped, but rounded on the back and over the top and slightly flattened to an indistinct central ridge on the front face toward the basal scar. Darker brown veins form an irregular pattern on the smooth brown surface.

References containing additional photographs, line drawings or descriptions of Mediterranean sage include Dennis (1980), Gaines and Swan (1972), Hawkes et al. (1985), Hitchcock and Cronquist (1973), Polunin (1987), Robbins et al. (1970), Roché (1991) and Whitson et al. (1991).

ORIGIN, HISTORY AND DISTRIBUTION

Mediterranean sage is native to southern and southeastern Europe, as far north in central Europe as Czechoslovakia and to 51° North Latitude in south central Russia, including Crimea, and east through Turkey into Iran (Davis 1975, Tutin et al. 1972).

Probably introduced in the United States in alfalfa seed (Dennis 1980), Mediterranean sage has also been planted as a garden flower (Bailey 1935). The earliest record of Mediterranean sage in the United States is from roadsides in Susanville, California (Lassen County) in July 1892 (Howell 1941) where it "figuratively stood still by the edge of the road for about 60 years" until widely transported by new highway construction (Bellue 1950). Mediterranean sage was present in Plumas County, California, by 1919 (Howell 1941, Bellue 1950). The expansion of Mediterranean sage in Modoc County was described by Bellue (1950) as mostly along the North Fork of the Pit River about half way between Alturas and the lower end of Goose Lake, with scattered plants adjacent to the North Fork and the highway in the vicinity of Surprise Station and Joseph Creek, along the Southern Pacific right of way just south of Davis Creek, a trace almost at the Oregon border near Pine Creek, then a wide skip to a few plants along Highway 299 near Stone Coal Mountain and another isolated patch near Ambrose. White (1955) reported that the 32 different locations of Mediterranean sage in Modoc County were under control. The distribution in California

currently includes Siskiyou, Modoc, Lassen and Plumas counties (Barbe 1990) for an estimated 7,000 acres (Andres et al. in press).

In Oregon, Mediterranean sage was present in Lake County by the 1920's and had established in Klamath County by 1949 (Bellue 1950). At that time, the largest infestation of Mediterranean sage in Lake County was about 5 miles wide extending 25 miles north of Lakeview, with scattered small infestations to the north, south and east. Additional, widely separated but larger acreages between Lakeview and Klamath Falls contributed to the overall infestation of about 42,240 acres (Bellue 1950). By 1954 the estimated size of the infestation had grown to over 100,000 acres (White 1955). The largest infestations still occupy southern Lake County, with smaller scattered populations in Baker, Grant, Harney, Klamath, Malheur and Wheeler counties, with an estimate of the overall infested area being 1,300,000 acres (Andres et al. in press). In Oregon, major populations are found in the sagebrush steppe of central southeastern counties. Vegetation types include both Wyoming and big sagebrush with bluebunch wheatgrass, Thurber needlegrass and Idaho fescue, juniper/sagebrush/bunchgrass and ponderosa pine/bitterbrush or bunchgrass. Mediterranean sage has been seen growing in a greasewood or shadscale type only on slopes and it has not invaded the shallow, saline/alkaline sites of internally drained basins. Mediterranean sage grows on moderate (14-16") or deeper soils with good drainage. Mediterranean sage

invades disturbed or degraded sites more rapidly and may attain understory dominance in sagebrush/cheatgrass communities, but invasion also occurs in good to excellent condition sites where rosettes establish between the grass bunches (Bob Bolton, BLM, Lakeview, pers. comm.).

The earliest collection from Idaho is from Payette (Payette County) in 1967 (Herbarium, Weed Diagnostics Lab., Univ. Idaho). In 1976 it was collected in the vicinity of Lucille, Idaho County, along the Salmon River and on dry hillsides (Herbarium specimens, Univ. Idaho and Wash. State Univ.). Currently, Mediterranean sage is widespread in Idaho County, with smaller populations reported from near Council in Adams County (Gordon Keetch, Extension Agricultural Agent, pers. comm.) and near Orofino in Clearwater County (L. M. Wilson, pers. obs.). The infestation in Idaho County was estimated at 4,000 acres (Carl Crabtree, pers. comm.). In Idaho, Mediterranean sage grows in the Canyon Grasslands and extends up into the adjacent ponderosa pine woodlands. The Canyon Grasslands are severely disturbed habitats due to prolonged and severe livestock grazing. The canyon area in the northern Intermountain West are steep, stony, grasslands which are easily eroded. Overgrazing and soil erosion due to trampling have resulted in the native vegetation being displaced by predominantly exotic annual grasses, such as *Bromus* spp., and weedy forbs.

Mediterranean sage has flourished in these habitats. It also grows in riparian areas and dry pastures.

The first record for Washington is a collection from pasture land and flood plain areas of the Touchet River in Columbia County in 1951 (Gaines and Swan 1972, Marion Ownbey Herbarium, Wash. State Univ.). Infestations in Washington have been contained in Columbia County, comprising an estimated 400 acres (Fred Gritman, pers. comm.). A previous report in Klickitat County (Roché 1991) was apparently in error. In Washington, Mediterranean sage grows in openings in ponderosa pine associated with snowberry, ninebark and bluebunch wheatgrass and in *Crataegus douglasii* floodplains currently dominated by Kentucky bluegrass. Some of the ponderosa pine habitat has had the overstory removed, some is grazed by cattle and some is relatively undisturbed. All of the floodplain and riparian areas are grazed and highly disturbed (Roland Schirman, Columbia County Extension, pers. comm.).

Mediterranean sage was first reported in Colorado in 1947 in a pasture near Longmont (W. A. Weber, Univ. Colorado Herbarium, pers. comm.). It remained a small stable colony near Boulder, Colorado, for many years, but began spreading rapidly in the late 1980's along the Foothills Highway north of Boulder (Weber 1990). It now infests an area of approximately 4 square miles north of Boulder (W. A. Weber, pers. comm.).

In Arizona, Mediterranean sage was reported in 1951 on the South Rim of the Grand Canyon (Coconino County), Prescott, Yarnell and Peoples Valley (Yavapai County), with rapid expansion on overgrazed rangeland in the Peoples Valley in the previous 12 years (Kearney and Peebles 1951). Since then it has been collected on Lake Mary Road near Flagstaff and at Lee's Ferry on the Colorado River (Coconino County) (Tina Ayers, Herbarium Curator, Northern Arizona University, pers. comm.).

Mediterranean sage has not been found in Montana (MSU Herbarium, Harold Stepper, Montana Dept. Agric., pers. comm.), Utah (BYU Herbarium and G. A. Rasmussen, Utah Extension Range Spec., pers. comm.), Wyoming (Tom Whitson, pers. comm.) or Nevada (Jeff Knight, Nevada Dept. Agric., pers. comm.).

POTENTIAL INVASION

Based on current infestations, the steppe, shrub steppe and Ponderosa pine zones in west-central Idaho and eastern Oregon and Washington are susceptible to invasion by Mediterranean sage. This large region of steppe and shrub steppe communities include big sagebrush/bluebunch wheatgrass (*Artemisia tridentata/Agropyron spicatum*), and the Canyon Grasslands of bluebunch wheatgrass/Sandberg bluegrass (*Agropyron spicatum/Poa sandbergii*) bordering the Snake, Salmon and Columbia rivers, extending through the *Agropyron/Festuca* zone into the Ponderosa pine/shrub types

surrounding the Blue Mountains (Franklin and Dyrness 1984, Daubenmire 1970, Tisdale 1985, Ferguson et al. 1987). Andres et al. (in press) suggested that much of the Salmon and Snake River watersheds, the Great Basin, and northern California are susceptible to attack by Mediterranean sage. The prediction that Mediterranean sage can potentially spread throughout much of the west is based upon the climatic similarities between this region and the native range of Mediterranean sage which appears to span Mediterranean and Continental climates (Polunin 1987, Davis 1965).

BIOLOGY AND ECOLOGY

Mediterranean sage is classed as a typical steppe hemicryptophyte, a member of the Pontian and Pannonian flora (Bogavac 1972). In Serbia, it is associated with *Marrubium peregrinum*, *Hordeum murinum*, *Centaurea solstitialis*, *Carduus crispus*, *Euphorbia cyparissias*, *Delphinium consolida*, and *Andropogon ischaemum* (Bogavac 1972).

In its native range, Mediterranean sage is usually found associated with successional habitats, never reaching densities to consider it a problem (Bogavac and Mitic-Muzina 1971). These include ruderal habitats with dry soils, such as roadside cutbanks, pastures, abandoned fields, and other areas of disturbance. In Serbia and Macedonia, Mediterranean sage is most frequently found on alluvial deposits of sand and clay, on limestone and in

chernozemic soils (Bogavac 1972). These sites are generally soils unsuitable for agriculture (Bogavac 1972). It is rarely found as a dominant member of the vegetation community, or associated extensively with weedy vegetation. Only occasionally is it found in crop land (Bogavac 1972).

Mediterranean sage is an aromatic biennial, reproducing only by seed. Seeds germinate in the spring or fall, depending on moisture, and develop into leafy, prostrate rosettes the first growing season. Young seedlings quickly establish a taproot. One study of seedling root growth in Asotin County, Washington, showed that roots averaged 28.7 cm (n=19) in length after the first month of growth (March 31-April 26), while length of the first true leaves during the same time averaged 1.7 cm (L. Wilson, unpublished data). Plants overwinter the first year as rosettes, shedding most of their leaves which become mulch for the overwintering crown. Rosettes appear to need vernalization in order to flower, a characteristic typical of temperate plants with a biennial life cycle. Plants resume growth in the spring, produce new leaves, and may or may not flower the second year. Plants bolt by late May, and reach full height around the middle of June. Flowering begins in early June and peaks around early July. By late July, mature plants begin to senesce. Plants produce between 50 and 100,000 seeds (White 1955). Seeds mature in the flowers and are not dispersed until September or October.

Like many other biennials, Mediterranean sage does not adhere to a strict two year life cycle. Rosettes may persist in the vegetative stage for two or more years. Wilson (1992) reported that only 54% of second year rosettes at two sites in northern Idaho flowered. All other rosettes remained in the vegetative stage. It has recently been suggested (Werner 1975, Klinkhamer and DeJong 1987, Thompson and Stout 1991) that timing of flowering in biennial plants is largely dependent on the size, not age, of the rosette. Rosettes, including those up to two years in age, which do not flower go dormant during the period of summer drought. Summer drought forces rosettes to drop their leaves and stop growing. Growth resumes with the onset of fall rains. Thus, rosettes often undergo two periods of dormancy in a single year, summer and winter.

Mediterranean sage is a tumbleweed. The stalk of a mature plant has a stout, robust, candelabra-like shape that becomes stiff, brittle, and lightweight as it dries. A natural abscission line on the stem 10-15 cm above the soil surface allows the dry plant tops to easily break from the stem base and get blown around by the wind. Seeds are shed as the plants tumble. Thus, the predominant means of long-distance seed dispersal in Mediterranean sage is through wind dissemination via the tumbling action of plants. However, in the canyon grasslands of west central Idaho, dry plants have been seen caught up in strong wind currents, thereby being

dispersed long distances. Plants are typically seen in the autumn caught in fence rows, or lodged in thickets or along creek bottoms.

Seed dispersal studies on Mediterranean sage have not been conducted, thus it is not known what proportion of seeds is dispersed and what is deposited around the adult plants. However, seedling recruitment within an established population can be high, particularly in a moist year, for example, in 1993. During drought years, seeds may not germinate and remain in the soil. Longevity of seeds the soil seed bank is unknown. Between 1990-1992, populations of Mediterranean sage in northern Idaho and Oregon had a severe reduction in population density. Reasons for this decline were likely a combination of drought-induced mortality and winterkill of young rosettes.

There appears to be a seed maturation period before which the seeds will not germinate. Seeds collected from plants in late July and August did not germinate in the laboratory until late September. Under natural conditions, this correlates with the timing of seed dispersal and the autumn rainy season.

Due to the means of dissemination, seeds are deposited on the soil surface or in the surface layer of the soil. They lack structural adaptations to bury themselves into the soil. Seeds of Mediterranean sage have a mucilaginous coating to overcome the risk of desiccation when germinating. When they get wet, they imbibe water and almost immediately (within 20 minutes) develop a layer of

mucilage around the entire seed. The mucilage protects the seeds from desiccation somewhat like a covering of soil (Young et al. 1970, Young and Evans 1973).

Plant chemistry has been extensively studied in the Lamiaceae. Mediterranean sage is closely related to the common culinary sage, *S. officinalis*, and has been shown to have a wide variety of secondary plant metabolites (Ulubelen and Uygur 1976, Rodriguez et al. 1984). Volatile oils, predominantly terpenes, are exuded as aromatics from the epidermal hairs (Lovett and Weerakoon 1983) and from the roots (Rodriguez et al. 1984). In Serbia, Mediterranean sage is considered a medicinal herb; the leaves are used as a wound dressing (Bogavac 1972). It has been suggested that secondary metabolites contribute to the allelopathic properties of several *Salvia* species (Lovett and Weerakoon 1983). However, it is not known whether allelopathy is a factor mediating the population ecology of Mediterranean sage in the western US. These chemicals and the plant's dense pubescence are believed to deter attack by many phytophagous insects (Strong et al. 1984). A lack of natural enemies may contribute to the success of Mediterranean sage in North America. Mediterranean sage has not been reported as toxic to livestock (Andres 1966), nor does it have forage value for grazing animals (Bogavac and Mitic-Muzina 1971). There are two benefits that may be attributable to the weed's chemistry, i.e.,

the weed is not known to harbor any insect or disease pests (Andres *et al.* in press).

There are a number of morphological characters exhibited by Mediterranean sage that are typical of xerophytic plants, and make it well suited to warm, dry environments. These include hairiness, a wrinkled leaf surface, a thick cuticle, mucilaginous seeds, and an adaptation to summer dormancy.

New infestations of Mediterranean sage can start from the long distance seed dispersal. The start of new infestations long distance and to more remote areas than established infestations has been attributed to wind dispersal of seeds.

Once established, Mediterranean sage is able to spread into non-disturbed land but is not normally found in pristine habitats. Disturbances such as livestock grazing and trampling appear to increase spread of the weed.

MANAGEMENT

Containment and control of Mediterranean sage in the US has been achieved with a number of methods. Containment includes prevention of seed movement and eradicating small scattered infestations. In addition to tumbleweed seed dispersal, seeds may move with contaminated soil, hay, agricultural equipment, livestock, wildlife (including birds) and vehicles. In eradication of scattered or outlier infestations, individual plants may be dug out with a

shovel. Cutting the taproot 2 to 3 inches below the crown when plants are starting to bolt prevents most resprouting (Roché 1991). Cultural methods such as tillage are effective for pastures and abandoned fields where equipment access is feasible. Mowing can prevent seed production if repeated several times during the growing season, as plants will continue to bolt after cutting. Rosettes are too low to be cut and mowing may spread seeds by cutting flowering tops if done too late in the season. Several herbicides effectively control Mediterranean sage, particularly when applied with a surfactant to plants in the rosette stage. Aerial applications are an option for steep, rugged or inaccessible rangeland infestations. Selective herbicides are especially useful in containment programs for roadsides and other rights-of-ways. Specific recommendations vary by region; consult the State Extension Weed Specialist. These methods must be repeated for years to deplete seed reserves, requiring persistence and continuity in a weed control program. Management of the grazing resources to favor the forage species in competition with the weed is necessary for long term success.

Biological control of Mediterranean sage using natural enemies shows considerable promise as an effective long-term weed reduction strategy. A biological control program for Mediterranean sage was initiated in the US in 1974 with the introduction of the small root-feeding weevil, *Phrydiuchus tau* Warner. The weevil,

introduced from Turkey, was released in Oregon and Idaho. It has spread to all known Mediterranean sage populations in Idaho, Oregon and California.

The weevil has been shown to have a significant impact on the plants. Weevil larvae feed inside the root crown, destroying vegetative buds and meristematic tissue (Wilson and McCaffrey 1993). In some instances, flowering is either prevented or delayed because of damage caused to the root crown (Wilson and McCaffrey 1993). The impact of the weevil is believed to have reduced the density of Mediterranean sage populations in Oregon (E. Coombs, pers. comm.) and Idaho County, Idaho (C. Crabtree, pers. comm.). Long-term studies could determine the impact of the natural enemy on Mediterranean sage populations, especially the interactions between the introduced insect and abiotic factors, and the role of competition from other plants in the community.

Map of Zones of Potential Invasion

From Franklin + Dyrness

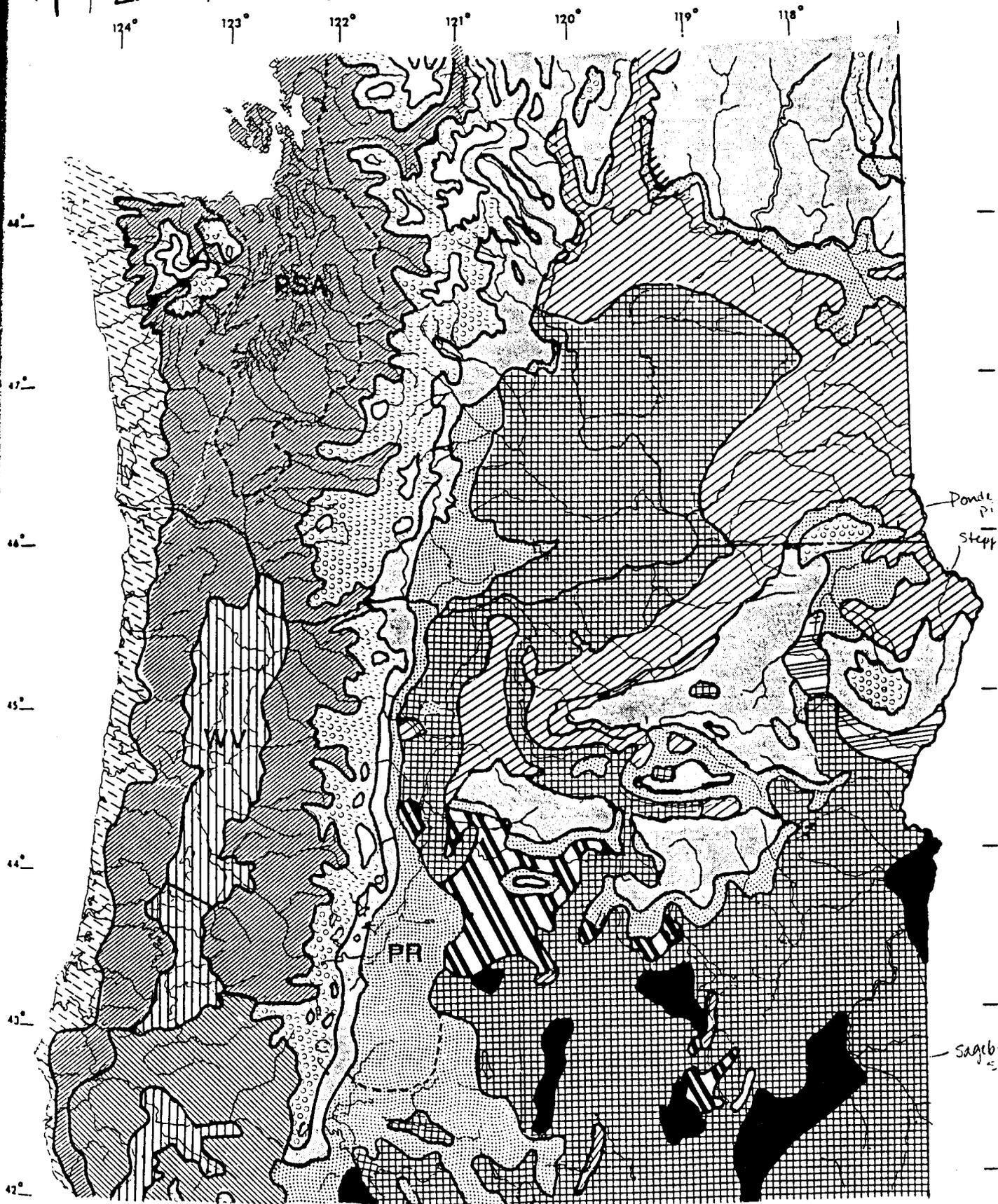
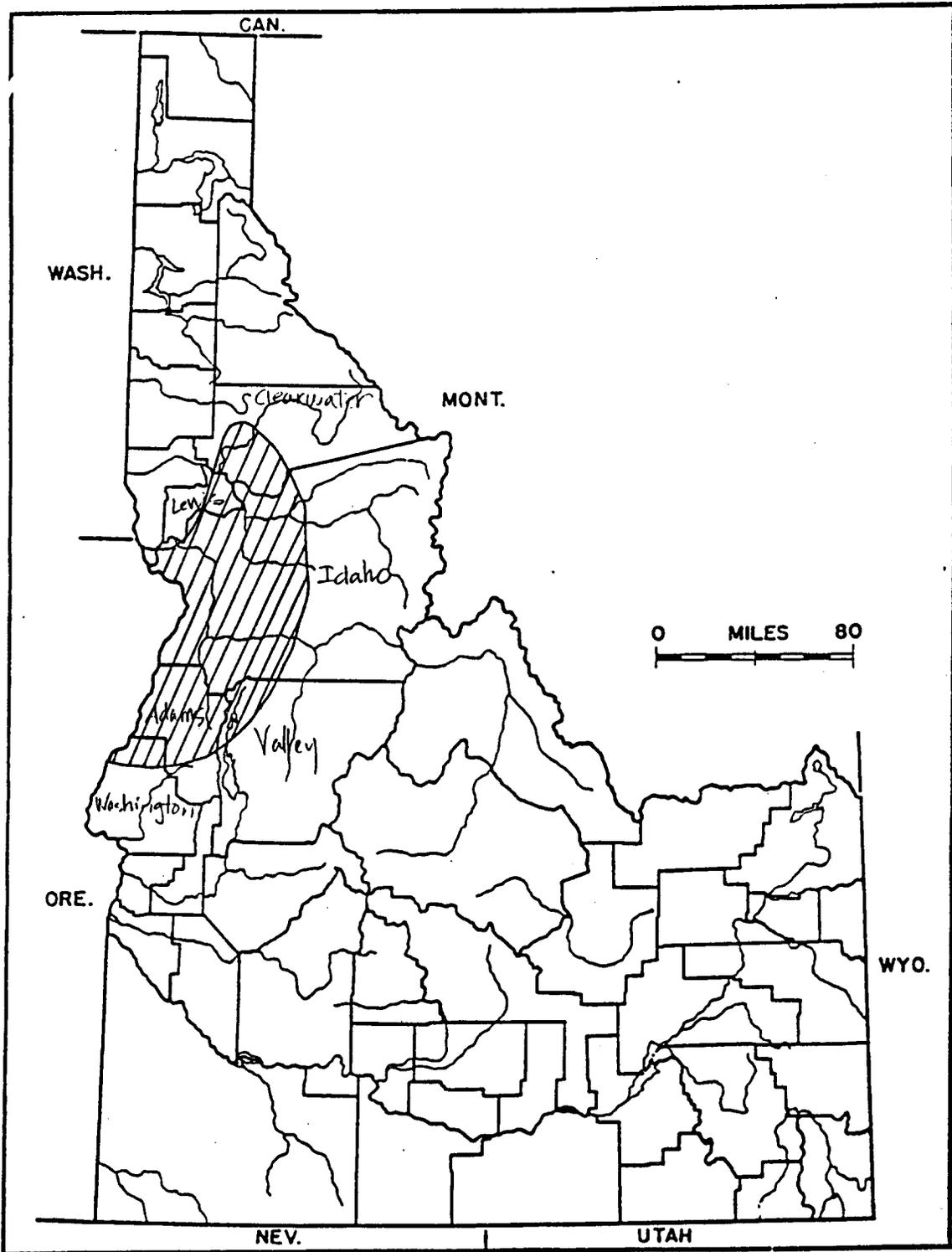


Figure 27. — Generalized vegetation map of Oregon and Washington (based partially on Hayes (1959), Küchler (1964), and Poulton (1962)).

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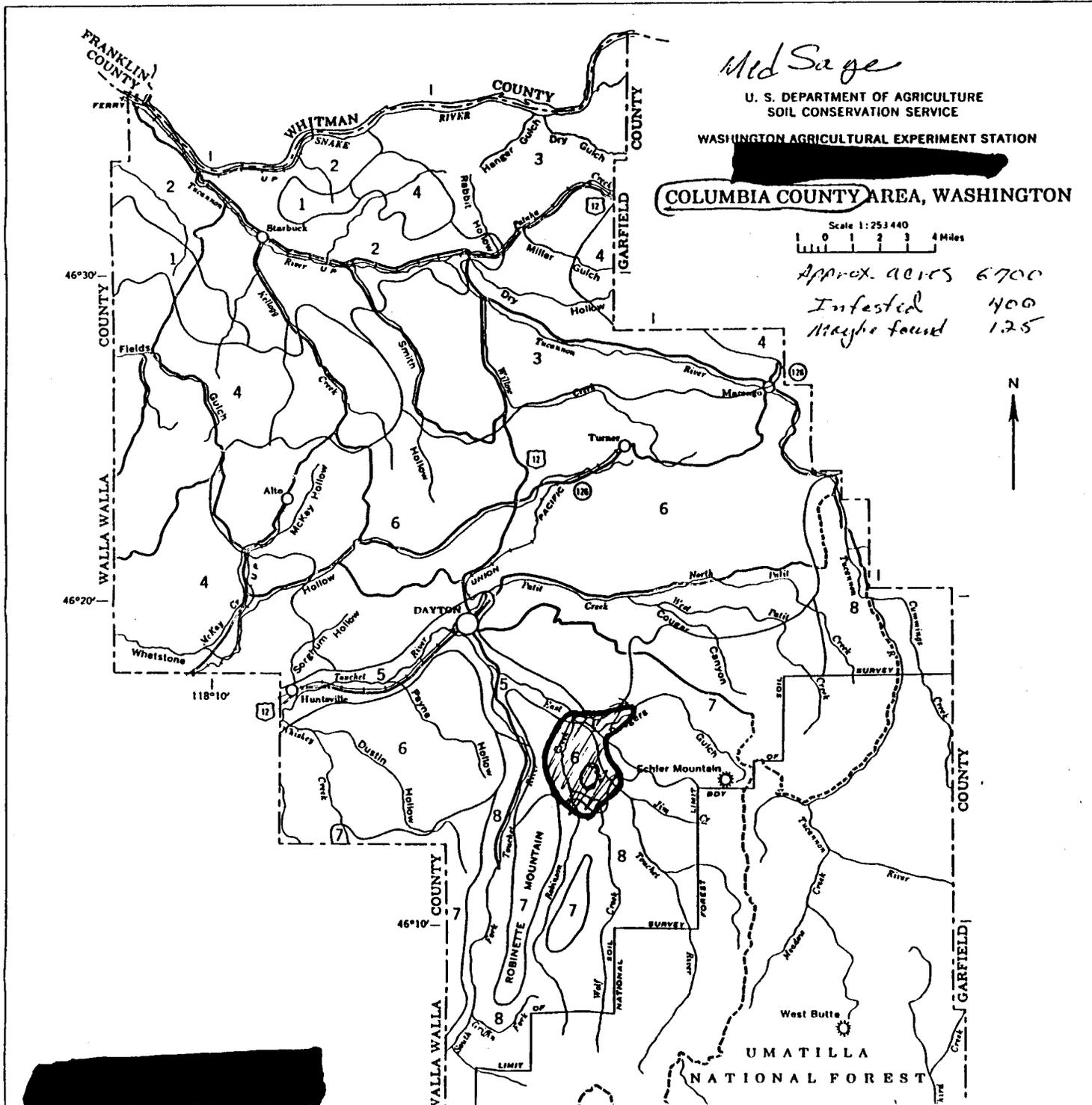
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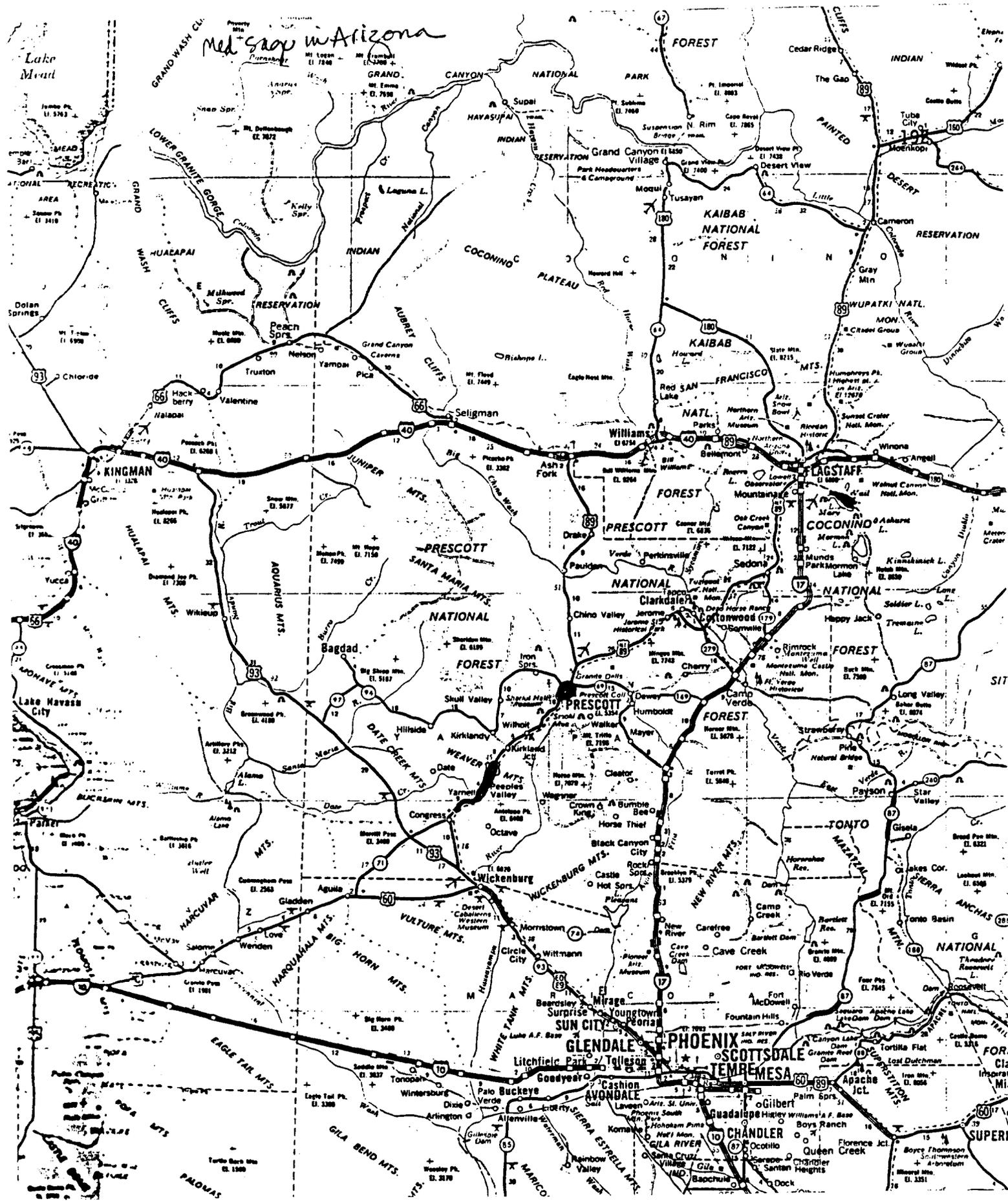
WASHINGTON AGRICULTURAL EXPERIMENT STATION

COLUMBIA COUNTY AREA, WASHINGTON

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Approx. acres 6700
Infested 400
Plants found 125





Med. Canyon in Arizona

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LOWER GRANITE CORRAL

HUALAPAI WASH. CLIFFS

GRAND CANYON RESERVATION

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EAGLE TAIL MTS.

GRAND CANYON

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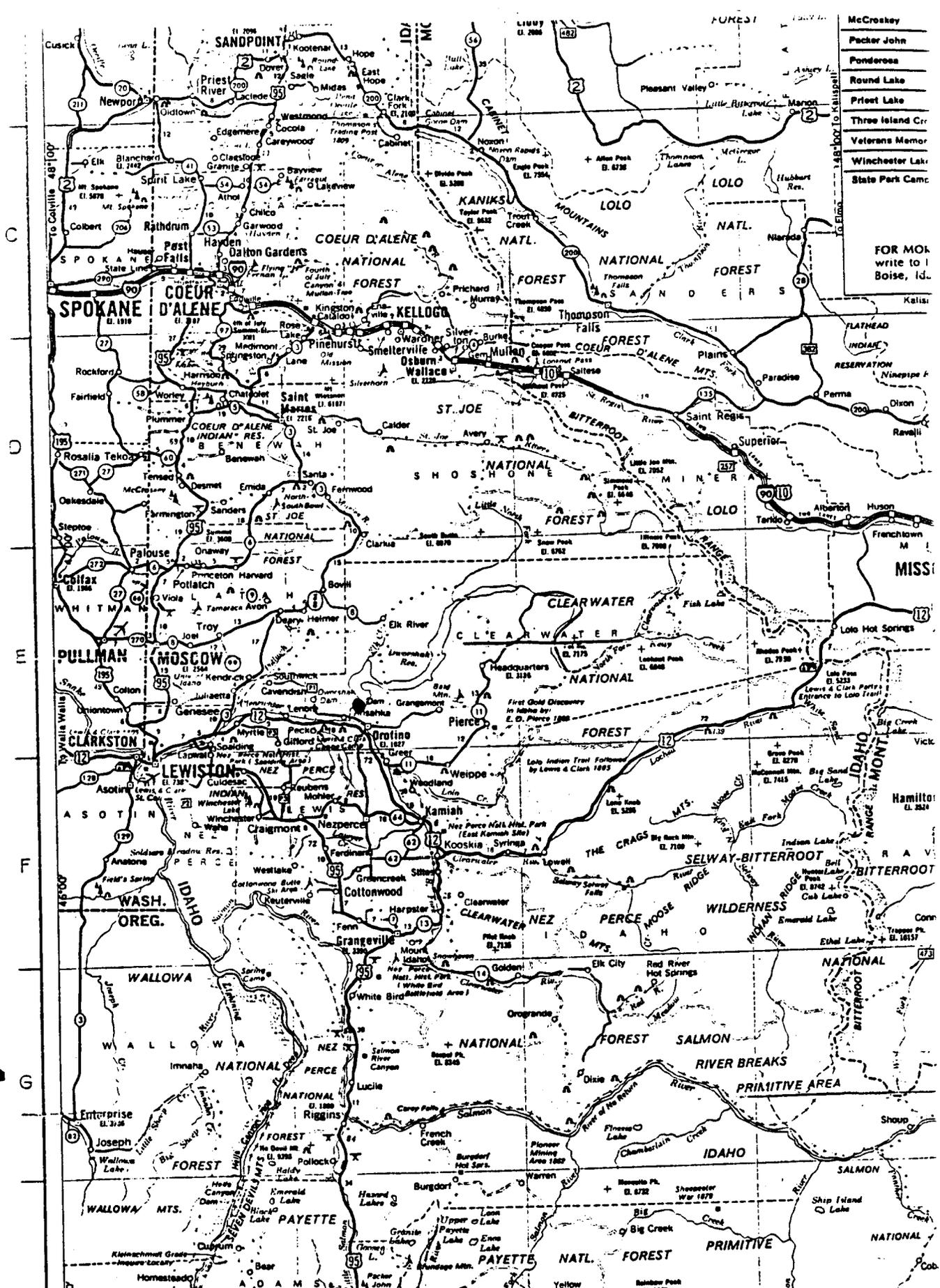
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LAKE MEAD



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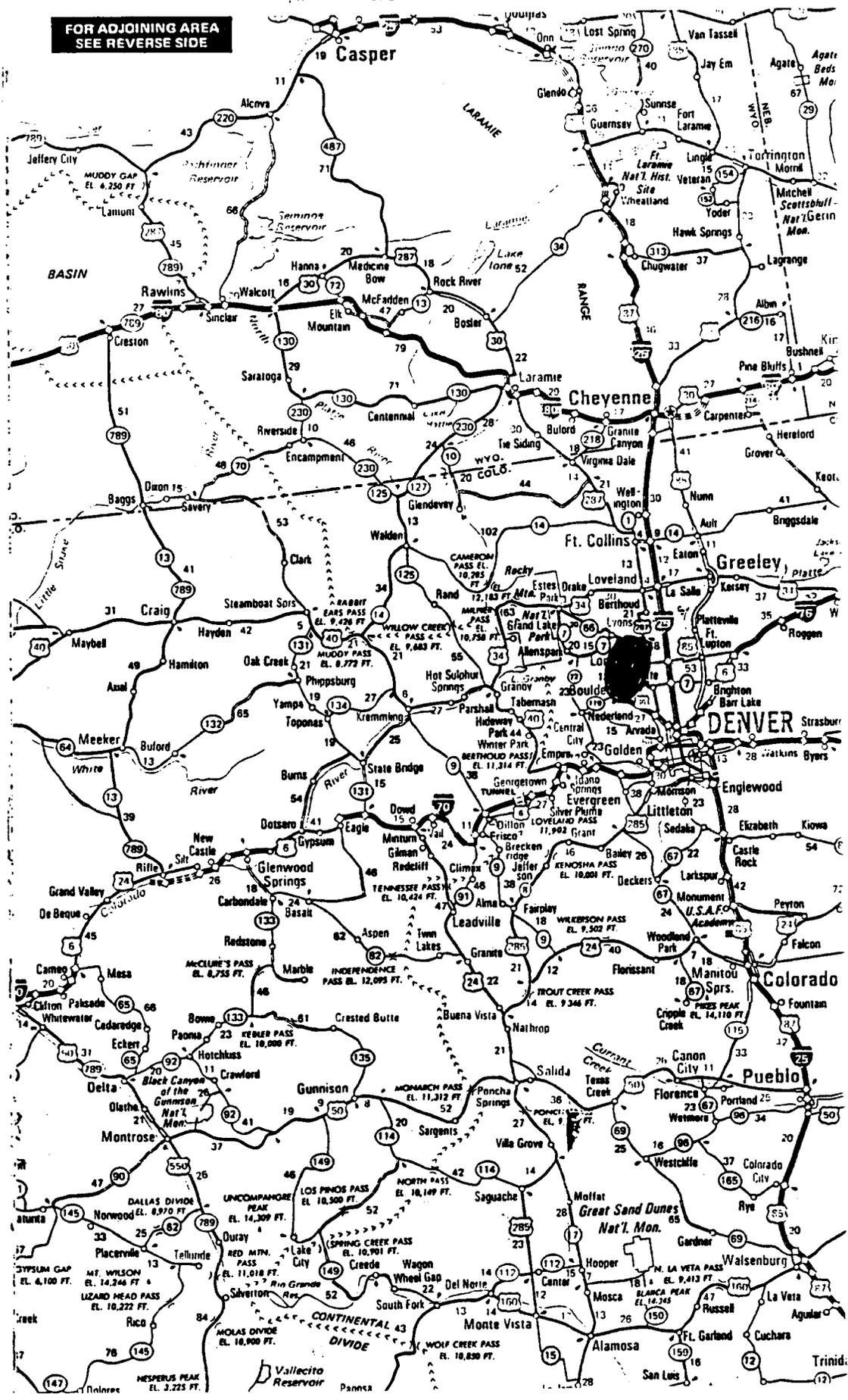
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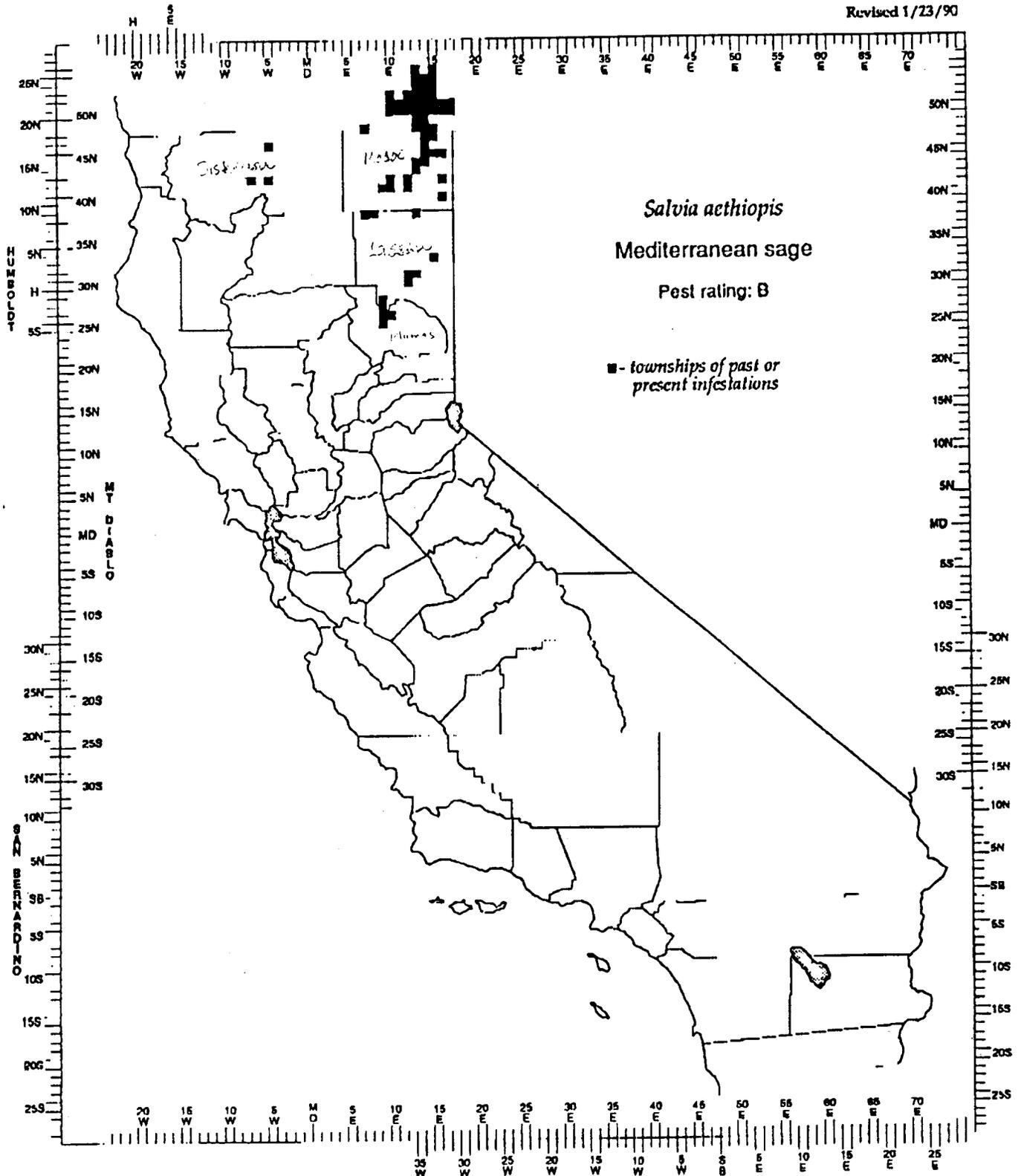
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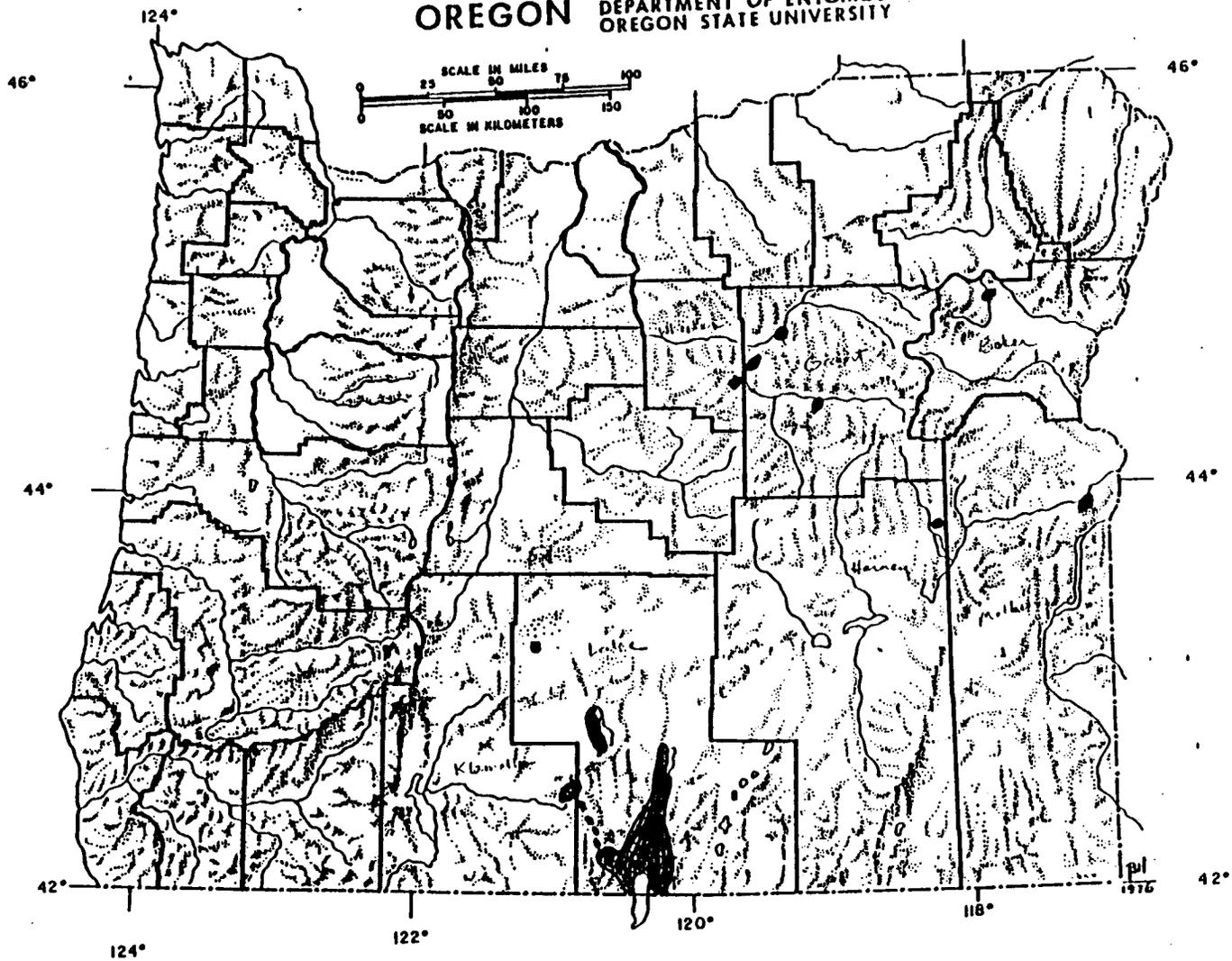


STATE OF CALIFORNIA • DEPARTMENT OF FOOD AND AGRICULTURE
DIVISION OF PLANT INDUSTRY • ANALYSIS & IDENTIFICATION/BOTANY

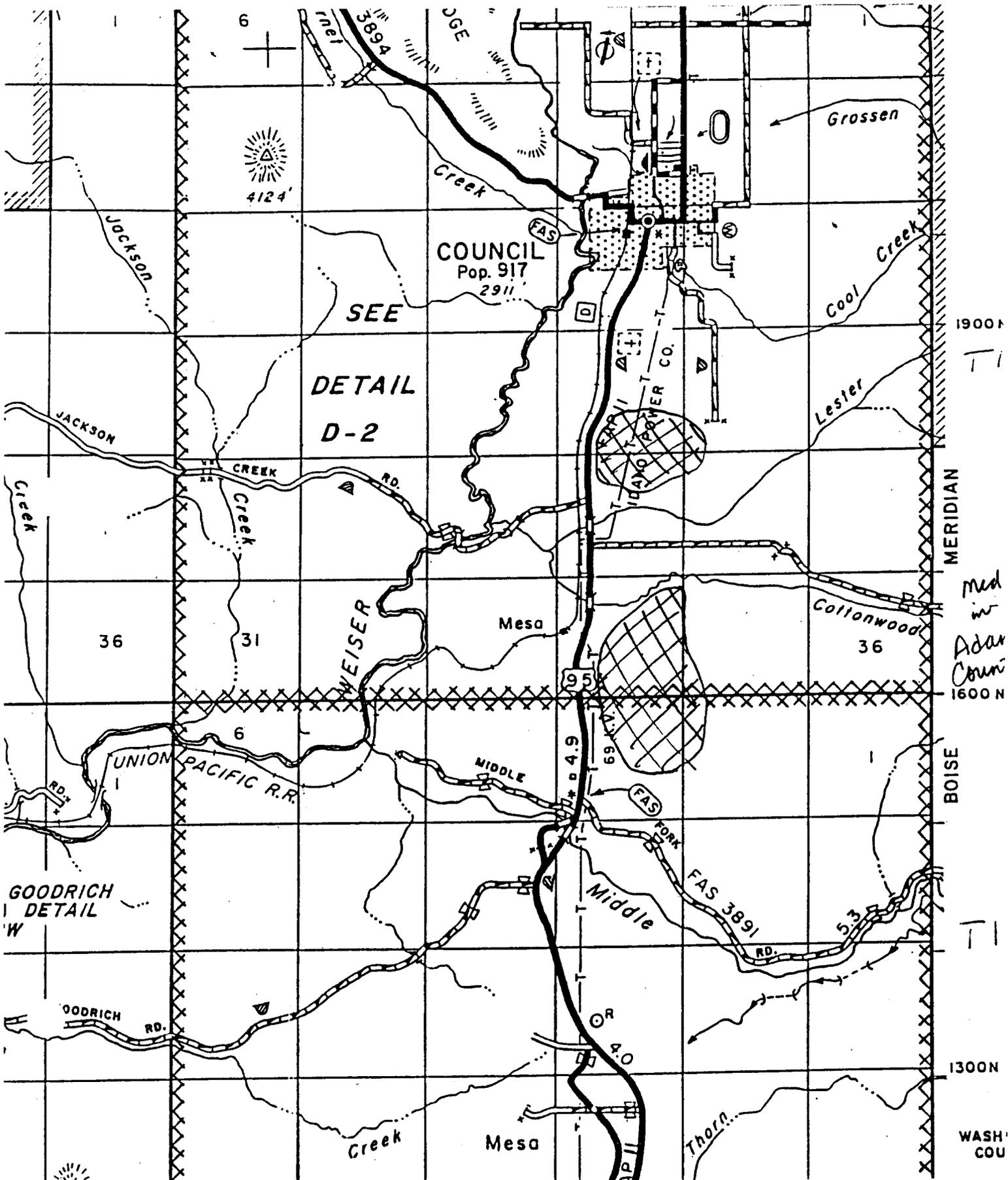
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OREGON DEPARTMENT OF ENTOMOLOGY
OREGON STATE UNIVERSITY



-  Approximate distribution of Mediterranean sage, *Salvia aethiopis*, in Oregon.
-  Distribution of the crown/root weevil, *Phrydiuchus tau* and release sites (●) of the crown/root weevil, *P. spilmani*.



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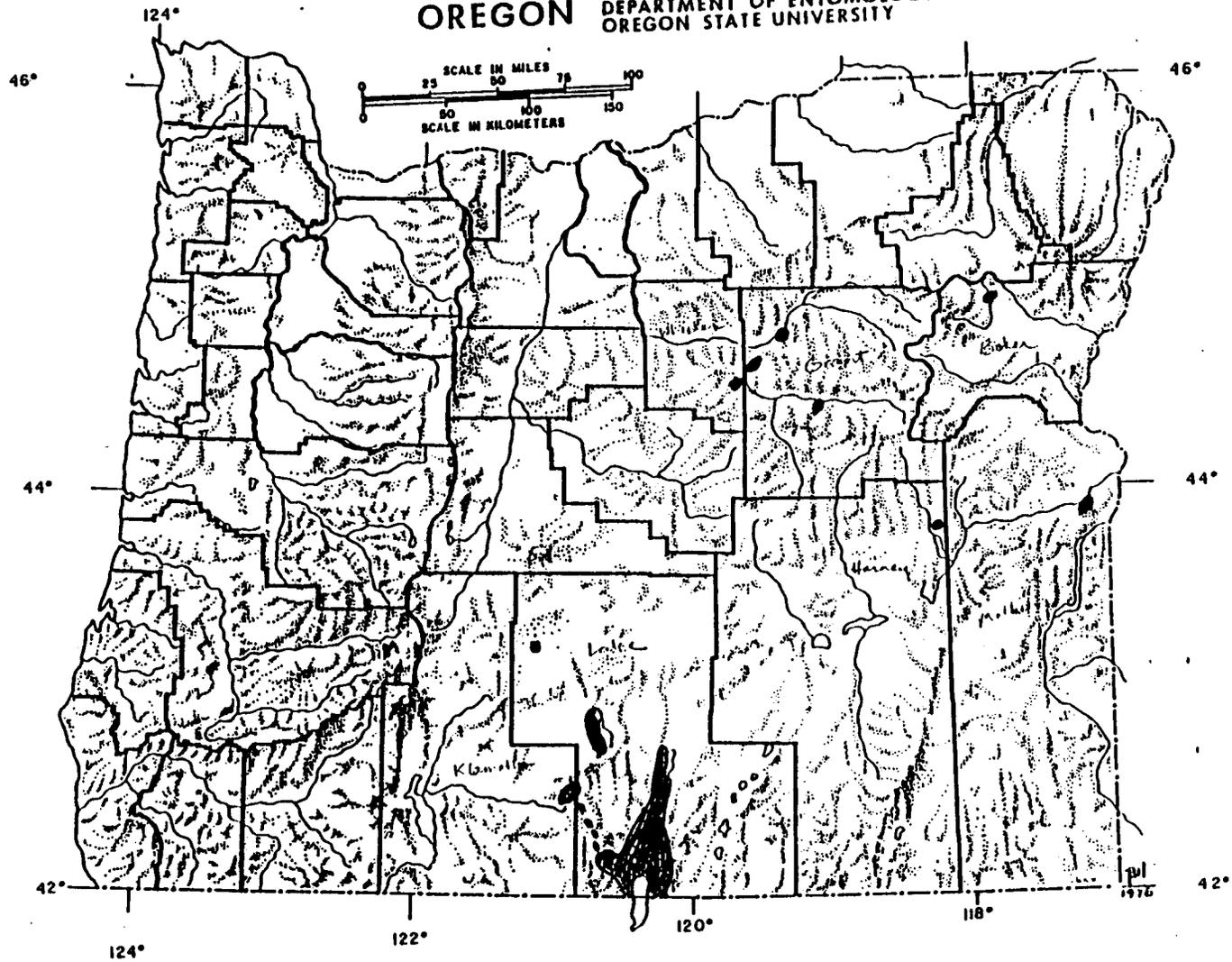
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-  Approximate distribution of Mediterranean sage, *Salvia aethiopis*, in Oregon.
-  Distribution of the crown/root weevil, *Phrydiuchus tau* and release sites (●) of the crown/root weevil, *P. spilmanni*.

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CHAPTER 11

MEDUSAHEAD

H. Miller, D. Clausnitzer, M. Borman²

IDENTIFICATION

During the seedling stage in late fall or early spring medusahead (*Taeniatherum caput-medusae*) may be recognized not only by its bright green color but also the awn and lemma which remain attached throughout the development of the seedling (Turner et al. 1963; Miller 1993 personal observation). As medusahead starts to mature in late spring and early summer (depending on the weather), the plant turns a dark tan color with different shades of a purple-red color both on the stem of the plant and the seedhead. As the plant reaches full maturity the purple-red color fades into a lighter tan color. At this time the plant is completely dry and ready to disperse seed (H. Miller 1993-1994 personal observation). By about mid-August medusahead is the color of straw.

Medusahead seedlings are slender, delicate-looking, and very bright green in color immediately after germination. The seedling starts producing leaves, and, as the seedling matures, the first leaf produced eventually turns brown and falls off as more leaves are produced (H. Miller 1993-1994, personal observation). As

² Oregon State University

medusahead matures during late spring, a seedhead starts to develop, wrapped in leaves and having visible, relatively soft awn tips. As the plant continues to mature, the seedhead becomes totally visible and the awns stick straight up from the seed. It is not until the plant starts to dry out, going from a purplish color to a tan color, that the awns start to take on the twisted appearance by which the plant is customarily identified (H. Miller 1993-1994, personal observation).

Height of the plant varies from 20 - 50 centimeters. The stems are wiry and slender and contain a few short, narrow leaves. Soon after the plant matures the leaves dry and wither leaving the plant with a wiry stem and a very "heavy-headed" appearance (Turner et al. 1963). Medusahead contains two or sometimes three spikelets each of which contain one seed. The average number of seeds per spike is 8 - 15 (Turner et al. 1963; H. Miller 1993, personal observation). Most plants produce single spikes, but large individuals can have multiple spikes (D. Pyke 1993, personal communication). In addition, medusahead has two kinds of awns. Both are flat, and the longest of the two contains barbs that point upward and can be felt by rubbing in the opposite direction. The longest of the two awns is attached to a seed that is approximately 1/4 inch long. The shorter of the two awns ranges between 1/4 and 1 inch in length and arises below the seeds at the nodes of the central axis of the spike. It remains attached after the seed

(with the attached long awn) shatters (Turner et. al. 1963). As stated by Turner et al. (1963), "These short awns represent the two glumes of each spikelet which arise below each seed." The rachis is continuous rather than jointed (articulate) like bottlebrush squirreltail (*Sitanion hystrix*). Medusahead glumes remain intact even after the seed shatters.

Medusahead has the capability to tiller. At times it is possible for one seed to produce up to 5 plants (H. Miller 1994, personal observation).

ORIGIN, HISTORY, AND DISTRIBUTION

Medusahead (*Taeniatherum caput-medusae*) is an annual grass native to Eurasia, where there are three distinct subspecies. *Taeniatherum caput-medusae* ssp. *caput-medusae* exists in Spain, Portugal, southern France, Morocco, and Algeria. *Taeniatherum caput-medusae* ssp. *crinitum* occupies the Mediterranean region from Yugoslavia eastward to Afghanistan. The range of *Taeniatherum caput-medusae* ssp. *asperum* overlaps that of the other two subspecies (Young 1992).

There has been repeated discussion as to exactly which taxon has been introduced into the United States. Currently it is suggested by Young (1992) that *Taeniatherum caput-medusae* ssp. *asperum* (Simk.) Melderis is the correct taxon for the medusahead that is located in the western United States.

Medusahead was first collected in the United States in the Umpqua Valley, southwestern Oregon in 1884 (Turner et al. 1963) and again in Roseburg, Oregon, in 1887 (Turner et al. 1963; Young 1992). Medusahead was abundant in the upper Willamette Valley of Oregon by 1915. After medusahead was discovered in Oregon it started heading east and south and was discovered by G.R. Vasey in 1901 near Steptoe, Washington where it started spreading rapidly, around 1914 from Steptoe Butte.

Medusahead was discovered near Mountain Home, Idaho as early as 1930 (Young 1992). Although it was discovered in southern Idaho, medusahead was first collected in Idaho in 1944 near Payette (western Idaho) by J.F. Pechanec. Ranchers reported that it occurred in this area (Washington County) of Idaho as early as 1942 (Young 1992; Sharp and Tisdale 1952). Overall, since initial discovery, medusahead has infested thousands of hectares of rangeland in California, Oregon, Washington, and Idaho and continues to expand its influence in these states as well as Nevada and Utah. It has been suggested that medusahead could possibly, or already does, also exist in Arizona, Montana, and New Mexico. Following is a breakdown by state of historical and current knowledge of medusahead infestations.

OREGON:

As of 1963, half of Oregon's 36 counties were known to be infested with medusahead. Five of these counties occur west of the Cascade mountain range and 13 are located in eastern Oregon with southwestern Oregon having the largest geographical area of medusahead. This area contains over 1,500,000 acres included within the periphery of known infestations. In eastern Oregon in the early 1960s, approximately 500,000 acres were infested with medusahead. At this time ranchers started expressing concern even though medusahead was not known to occur within the high desert (Turner et al. 1963). Currently it is not known how many thousands of acres of medusahead occur in Oregon; however, medusahead is currently expanding in rangelands where it was once thought impossible.

WASHINGTON:

In 1969 a circular pamphlet prepared by C.J. Goebel, J.R. Nelson and G.A. Harris of the Forestry and Range Management Department at Washington State University stated that at that time medusahead had already infested 120,000 to 150,000 acres in eastern Washington. In addition, it was indicated that the potential area was much greater.

IDAHO:

As indicated in the introduction, Idaho was the hardest-hit state in medusahead's initial invasion. By 1952 the medusahead infestation was approximately 30,000 acres and was rapidly. Min Hironaka believed that by 1952 150,000 acres of rangeland were in fact infested (Turner et al. 1962). The Bureau of Land Management estimated 700,000 acres were infested by 1959 (Young 1992). In 1961 Hironaka reported that medusahead had spread, in about 15 years, from a few isolated patches to more than 750,000 acres in Idaho (Turner et al. 1963). Currently it is believed that medusahead occupies an area much greater than 750,000 acres, with a more accurate figure being close to 1,000,000 acres (Bob Callahan, personal communication 1994).

CALIFORNIA:

Medusahead spread south through the mountain valleys of western Oregon and eventually reached the upper Sacramento Valley of California by 1900 (Young and Evans 1969; Murphy and Turner 1959). Medusahead was first discovered in California in Los Gatos in 1908 (McKell et al. 1962). In 1959, medusahead was considered "a grave problem as far as adequate control is concerned" on Northern California rangelands (Murphy and Turner 1959). By 1959, since medusahead's original foothold in California in the early 1900s, it had spread 600 miles south of the Oregon border and was found existing in Ventura County (Murphy and Turner 1959). Since this

initial invasion of California, medusahead has spread through the annual dominated ranges of northern and central California (Young and Evans 1969). Current estimations for medusahead in the Great Basin of northeastern California (extending across Modoc and Lassen Counties), according to Dr. James Young (1994 personal communication), is approximately 5 million acres. As far as other areas of California are concerned, Dr. Young believes that medusahead has invaded all other suitable sites. Medusahead has since spread across California and is now affecting areas in northern Nevada and western Utah.

NEVADA:

Within Nevada, a little less than 100,000 acres of land is occupied by medusahead with most of the concentration occurring in northeastern Nevada within Elko County (J. Young personal communication 1994). Elko County currently has three small infestations as a result of medusahead moving south from Idaho and west from Utah. The Lake Lahontan desert does not allow the medusahead to move in from west. However, it is possible that livestock being moved around the state could have transferred the medusahead. Overall, Nevada seems to be able to avoid extreme problems with medusahead because of its salt deserts and coniferous forests (J. Young, personal communication 1994).

UTAH:

Medusahead currently occupies approximately 2000 acres primarily in the northern part of Utah located within Cash and Boxelder Counties along the Idaho border (Dr. Steve Dewey, Utah State University, personal communication 1994). In addition, a small amount of medusahead has also been found in Weber County which lies south of Boxelder County.

MONTANA:

According to Roger Sheley, Montana State University extension weed specialist, Montana has no medusahead (personal communication 1994). The long, cold winters common in Montana have likely prevented invasion by medusahead.

WYOMING:

According to Tom Whitson (personal communication 1994), University of Wyoming extension weed specialist, Wyoming has no reported infestations of medusahead. However, Mr. Whitson does believe that there could be a few spots of medusahead near the Utah border. He believes that it is minimal.

POTENTIAL INVASION

Medusahead has invaded a large area and in places become dominant. It occurs where there is a "Mediterranean" type climate,

with annual precipitation of 10 to 40 inches occurring during fall, winter, and spring (Major et al. 1960). Seasonal distribution of precipitation is more important than total amount of precipitation (Parish 1956). The upper limit for medusahead growth seems to be about 50 inches (Major et al. 1960).

Infestations occur primarily in former sagebrush-grass or bunchgrass communities that receive 10 to 20 inches of precipitation (Sharp and Tisdale 1952). In these drier areas, medusahead is at a competitive advantage where extra moisture collects due to topography, where east or north exposures decrease evaporation, or where high soil clay content within 10-12 inches of the surface provides longer water-holding capacity (Dahl and Tisdale 1975). It does well in soils that have vertic properties--clays that shrink, swell, and crack. Soils that stay moist through summer do not seem to support medusahead (Turner et al. 1963).

Well-drained, coarser textured soils with poorly developed profiles, areas above 4500 feet elevation, and sites receiving less than 9 to 12 inches of annual precipitation may be less susceptible to invasion (Horton 1991), although current observations indicate potential on other soils. According to Young (1992), on the western edge of the Great Basin, medusahead in non-meadow situations is largely restricted to low sagebrush plant communities. He has posed the question, "Would medusahead's restriction to clay soils change over time as this appears to have

happened in cismontane California?" Some observations of its occurrence on loamy soils have been noted (Young 1992; L. Eddleman 1993, personal communication). In addition, as mentioned in Young's (1992) paper: " Burgess Kay made the chilling observation that ... medusahead occupied many sites with coarser-textured soils." No comparisons of establishment, survival, and reproduction of medusahead on these different soil textures has been undertaken.

Medusahead in suitable areas represents the highest stage of succession in annual communities, succeeding Russian thistle, mustards, and cheatgrass.

IMPACTS

Within its range of adaptation, medusahead crowds out other annuals and outcompetes perennial seedlings. Where it is allowed a foothold, it tends to form exclusive stands that are reinvaded by other vegetation very slowly if at all. There is evidence that squirreltail can reinvade medusahead stands.

The dense, long-lasting litter layer formed by medusahead can burn readily. Frequent fires destroy the shrub component of the community without destroying significant amounts of medusahead seed. The subcanopy mounds and microphytic crusts characteristic of the native community disappear (Young 1992).

The persistent root system in soil associated with perennials is lost. Although the litter layer may be of some value in protection of soil from wind and water erosion (Turner et al. 1963), the short-lived roots of medusahead will not hold the soil as well as the root network of an established perennial community (Hironaka 1965).

Wild birds eat very little medusahead seed (Goebel and Berry 1976). Captive chukar partridges fed on medusahead ate the seeds readily, but they appeared to be largely indigestible (Savage et al. 1969).

Medusahead is almost worthless as forage for cattle and sheep (Turner 1965). Animals will graze it for a short time early in spring during the pre-head stage, especially if there is not a heavy standing litter layer (Hironaka 1965). It has been estimated that grazing capacity can be reduced 50% to 80% after a few years of medusahead infestation (Hironaka 1961). Where medusahead has replaced cheatgrass stands, grazing capacity is reduced to 50 to 75% of what it was formerly (Harris and Goebel 1976).

Chemical analysis reveals that the composition of medusahead is comparable to many desirable forages in moisture content, crude protein, crude fat, crude fiber, and lignin (Bovey et al. 1961), but coarseness due to high silica content makes it unpalatable to livestock. Awns can cause mechanical injury to animals.

BIOLOGY AND ECOLOGY

Medusahead seeds germinate in fall, winter, or spring, especially in October or November. Root growth can proceed through the winter, when little above-ground growth may be apparent. Winter root growth is mostly downward extension of the primary root, with greater lateral development in spring (Hironaka 1961). Medusahead roots have been measured as deep as 40 inches (Hironaka 1961). Growth then accelerates in the spring, with seed heads appearing around the end of May, and flowering occurring in the first part of June. Seeds mature generally near the end of June or the beginning of July, a few weeks later than many other annuals (Young 1992; Sharp and Tisdale 1952; Hironaka and Tisdale 1958). Medusahead is primarily self-pollinating (Young 1992). Seeds tend to remain on heads until fall.

Medusahead stays green longer than associated annuals, which explains its preference for sites with some extra moisture. As it matures, it gradually may take on a purplish color before finally becoming brown or tan.

Most medusahead germination occurs at 10 to 15° C. Germination drops off considerably at higher temperatures until after an afterripening period of about 180 days (Young et al. 1968). Medusahead can thus avoid premature germination, and wait for cool, wet conditions in the autumn.

Medusahead seed can germinate well after three years (Nelson and Wilson 1969) and can remain in the soil for that long in annually decreasing numbers (Kay 1965; Sharp et al. 1957).

Medusahead seeds are covered with small silica barbs (Young 1992). These enable it to cling to and be dispersed by animals, clothing, and machinery. Dispersal can also occur through animal droppings or by wind and water (Furbish 1953; Turner et al. 1963).

Medusahead litter is slow to decompose due to its high silica content (Young 1992), causing buildups of litter 5 to 10 cm thick. This litter layer may inhibit seedlings of some species by shading, and keeping their seeds from gaining contact with the soil. Medusahead seeds can germinate when the seeds are out of contact with the soil. The humidity and temperature conditions within the litter can stimulate medusahead germination. If the initial root dries out and dies, a new root can later develop when moisture conditions improve (Young 1992 and Young et al. 1971).

The success of medusahead is based on several factors:

- 1) Plastic, prolific seed production: Uncrowded medusahead can produce six or more seedheads per plant, while crowded dense stands may produce one head per plant (Murphy and Turner 1959). A head may contain over 20 seeds. In a natural situation there can be 4,000 to 10,000 medusahead seeds per square meter (Harris and Goebel 1976).

2) Fast, complete germination rate compared to competitors: Germination has been observed eight to ten hours after moistening, at low temperatures (10 C) and droughty conditions (-11.4 bars) (Harris 1977). Germination rates are often over 90% (Sharp et al. 1956).

3) Autumn germination followed by fast deep root growth: Medusahead does not produce branching roots until roots have penetrated relatively deeply.

4) Ability to grow in winter: This allows it to have a well-developed, deep root system by spring warmup, giving it an advantage over most competitors.

5) Suberized roots: These allow it to conduct water from deeper sources through dry upper horizons (Harris 1977).

6) Thick, persistent litter layer: This inhibits seedlings of other species and can cause intense fires that can kill or injure its competitors.

7) Low palatability to grazing animals: Grazers will eat competing plants rather than medusahead, conferring additional competitive advantage due to the high silica content of tissues.

Medusahead is likely to invade areas in which the native vegetation has been weakened by overgrazing, intense fires, or cultivation. It can also take over from previously established weeds such as cheatgrass.

We know that medusahead is capable of establishing in highly disturbed communities, but we do not know if it is capable of establishing and maintaining itself in diverse communities of native perennial plants. If it can, implications are ominous for achieving dominance on those sites in which it becomes established and for additional expansion when normal disturbances such as fire or ant and rodent activity occur.

MANAGEMENT

CULTURAL

Spring plowing after most of the medusahead has germinated has given some control, with results of up to 95 percent reduction in medusahead. Discing has also produced some results (50% control reported), and has been used as a follow-up to plowing (Erickson et al. 1956; Higgins and Torell 1960; Harris and Goebel 1976). These measures may not be practical under certain conditions of terrain or soil. The results from cultural efforts are much greater if combined with burning or especially herbicide treatment. Control of 100% has been reported by combining plowing or discing with 2 lb/A of dalapon or amino triazole (Erickson et al. 1956).

BURNING

Burning medusahead stands can destroy significant amounts of seed, reducing the stand (reportedly by 60 to 95 percent) in the

next growing season (Murphy and Lusk 1961; Harwood 1960). Slow fires that burn downslope or against the wind are most effective (Murphy and Turner 1959), and should be carried out during the soft dough stage of seed development. High moisture content in the seed accentuates the effects of burning (McKell et al. 1962). Burning the stand once will not diminish medusahead sufficiently for successful reseeding with wheatgrasses. Combining burning with mechanical or chemical treatment usually improves both (Harris and Goebel 1976) by removing litter, destroying some seed, and allowing seed to contact the soil to germinate and become vulnerable to treatment (Torell et al 1961).

CHEMICAL

The use of herbicides is now limited because of restrictions on their use on public land.

Good results have been obtained by the pre-emergence application of soil-active herbicides such as atrazine, bromacil, and siduron.

Atrazine (1 pound/acre active ingredient in late fall) and bromacil (1/2 pound/acre in early spring or fall) has selectively controlled medusahead in stands of perennial grasses. Atrazine injures and kills Sandberg's bluegrass (*Poa sandbergii*); bromacil does not appear to have this shortcoming (Turner 1965). Sandberg's bluegrass is an important species in resisting reinvasion by annuals.

Pre-emergence applications of 3 lb/A siduron plus 0.3 lb/A picloram have been effective (Young and Evans 1970), as has been EPTC at 2 to 8 lb/A (Kay and McKell 1963).

Paraquat has given very poor medusahead control under eastern Oregon conditions. (Turner 1965).

Foliar applications of dalapon have been effective when applied during the vegetative stage, usually mid-April to early May. Two or 3 pounds per acre has been the usual rate, resulting in 96 to 100% control (Torell and Erickson 1967; Kay 1963; Higgins and Torell 1960).

One pound per acre (active ingredient) of isocil has reportedly been effective in controlling medusahead (Turner et al. 1963).

Combining herbicides with mechanical treatment or burning has shown very good results. Burning followed by fall application of 1.2 liters/ha of Roundup before minimum-till drill seeding has allowed establishment of crested wheatgrass and Russian wildrye (Horton 1991).

BIOLOGICAL

Recent work (Grey 1994, personal communication) indicates that crown rot (*Fusarium culmorum*), a common pathogen found on wheat, causes severe disease on medusahead while having a less severe impact on squirreltail and western wheatgrass (*Agropyron smithii*), making the fungus a possible biological control agent. Further

research is needed to examine other root pathogens of medusahead found in the Great Basin region.

Forcing livestock to heavily graze medusahead stands before seedset may reduce the seed crop appreciably if done over several years (Horton 1991).

REVEGETATION

Revegetation and grazing management must follow any control efforts in order to prevent medusahead from reestablishing dominance (Major et al. 1960). Broadcast seeding perennial grasses into stands of medusahead without some prior control of the weed has been very unsuccessful. Good results have been obtained with control, primarily on sites that are suitable for tillage. Shallow, steep, or rocky sites of low potential are much more difficult to revegetate (Turner 1965).

Treatment of two successive crops of annual weeds enhances survival of wheatgrass seedlings by reducing the weed seed reserve. Again, combined treatments of two tillages, or tillage combined with herbicide or burning is most effective (Torell and Erickson 1967). Newly established wheatgrass stands will suppress but not eliminate medusahead.

If herbicide use precedes reseeding, it is important to wait until residual herbicide activity subsides. Several weeks are required with dalapon, whereas atrazine and isocil take about a

year to break down sufficiently (Turner et al. 1963). Seeding techniques that remove the herbicide from the drill row facilitate seedling establishment while still providing weed control between rows and eliminate the need to wait for the herbicide to break down.

Crested wheatgrass, because of its high vigor and competitiveness, is a good choice for reseeding medusahead stands (Torell and Erickson 1967). Intermediate wheatgrass has also been successfully used. Sowing in late autumn or early spring using a rangeland drill is the usual practice (Robocker and Schirman 1976; Turner 1965).

INTEGRATING STRATEGIES FOR SUSTAINABLE LONG-TERM MANAGEMENT

Medusahead competes most severely when desirable species are overgrazed (Higgins and Torell 1960). Grazing management, plus control and reseeding of new infestations while they are still small (Christen et al. 1974), are the best strategies for long-term management.

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CHAPTER 12

OXEYE DAISY

Bret E. Olson and Roseann T. Wallander³**IDENTIFICATION**

Oxeye daisy (*Chrysanthemum leucanthemum* L.) is a perennial herb with oblique, shallow, branched rhizomes and strong adventitious roots (Howarth and Williams (1968). Basal stems are prostrate and will root, the other stems are erect and simple or slightly branched (30-80 cm). Stems are glabrous to slightly pubescent. Basal leaves are on long stalks, spatulate to round, and dentate. Stem leaves are spiral, sessile, and narrow lanceolate or ligulate coarsely toothed often with lobes at the base. Flower heads are mostly solitary on long terminal peduncles, 2.5 - 5.5 cm in diameter.

The cotyledons of seedlings open above the soil surface (epigeal germination). The first true leaf is lobed. The cotyledons wither soon after the first leaves develop and the stem (hypocotyl) does not elongate above the ground. A rosette of leaves is considered a juvenile plant (Howarth and Williams 1968). It is not known whether oxeye daisy can flower and produce seed its first year.

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ORIGIN, HISTORY AND DISTRIBUTION

Fruits of oxeye daisy have been identified from the Iron Age and from the Roman period. It appeared in Britain during the post-glacial period along with other weeds. Besides the British Isles, oxeye daisy is distributed throughout Europe to northern Scandinavia, Lapland, and central and Russian Asia (Howarth and Williams 1968). Italians use oxeye daisy in salads; it was used more extensively in the past as a food item. Oxeye daisy was carried as a contaminant in seed to North America and New Zealand. Because it is showy, it is often planted as an ornamental.

In the Northeastern United States this plant has escaped cultivation and has naturalized. Many landowners will not mow oxeye daisy plants in their lawns because of its showiness. Oxeye daisy is locally abundant in the Great Plains (Great Plains Flora Association 1986). It grows along roadsides, in waste places, and pastures in western and south central Montana (Dorn 1984). It is the most common roadside weed in the Pacific Northwest (Taylor 1990). However, its general distribution in the United States has not been described.

POTENTIAL INVASION

Oxeye daisy occurs chiefly in native and introduced grasslands, meadow and pasture, on waste ground, along railway

embankments and roadsides. Its abundance is often closely associated with the intensity of cutting or grazing.

IMPACTS

The ecological, environmental, economical or sociological impacts of oxeye daisy have not been documented.

BIOLOGY AND ECOLOGY

Besides reproducing vegetatively along a rhizome, oxeye daisy is a prolific seed (achene) producer. A vigorous daisy plant growing in a grass field produced about 26,000 seeds; smaller plants at the same site produced from 1,300 to 4,000 seeds per plant (Dorph-Peterson 1925). Salisbury (1942) noted that an oxeye daisy plant may produce 2,688 offspring per year. Seeds become viable ten days after flowers open (Georgia (1914)). Usually the seed is dispersed by wind close to the parent plant because it lacks a pappus, but it may also be carried by animals. In the past, oxeye daisy seeds have contaminated grass seed sold in the U.S (Georgia 1914, Gilkey 1957).

Ripening of the achene is not followed by a period of dormancy unless enforced by environmental conditions. Germination is insensitive to light, nitrates, chilling, and sulphuric acid treatments. Thus, oxeye daisy seeds will germinate throughout the growing season, but most seedlings become established in

spring (Howarth and Williams 1968). Oxeye seedlings are considered to be drought tolerant. Seeds that do not germinate in the spring or summer may remain viable for a long time. In a buried seed trial, 82% of the seeds were still viable after 6 years, 1% of the seeds were viable after 39 years (Toole and Brown 1946).

At about the 6-leaf stage the primary root starts to be replaced by a well developed system of laterals which are relatively shallow. As the rhizome system develops, the main root system no longer becomes important. The plant is characterized as a hemicryptophyte.

An individual oxeye daisy plant may consist of one to many rosettes on the soil surface. Each rosette usually produces only one flowering stem. A population of oxeye daisy can form a dense mat of rosettes. As the plants bloom a field may appear "white as snow".

Oxeye daisy is commonly found on basic or neutral soils, whereas it is less common on acid soils (Howarth and Williams 1968). Ferdinandsen (1918) characterized oxeye daisy as a basophile growing optimally at pH 6.5-7.0.

Ellenburg (1950) noted that oxeye daisy was indifferent to water and soil friability, but has a moderate requirement for nitrogen. He thought that its requirements were very similar to *Plantago lanceolata*, *P. major*, and *Cirsium arvense*, with which it

often grows. Boutin and Morisset (1988) found that oxeye daisy allocates more biomass to the root system at the expense of allocation to flower heads when grown under low nutrient levels. Low nutrient levels had little effect on allocation to leaf material. Allocation to reproductive effort was higher under low light levels than under high light levels, indicating a strategy of maximizing seed production when shaded by other plants. Reproductive effort was unaffected by nutrient level.

Oxeye daisy is unaffected by frost and tolerates drought well, although it is usually found in more moist areas. It is a pioneer species in several habitats exposed to soil drying. During periods of water stress, deeper rooting species, e.g. *Taraxacum officinale* wilt before oxeye daisy (Howarth and Williams 1960).

Horses, sheep and goats graze oxeye daisy, but cows and pigs tend to refuse it because of its acridity (Howarth and Williams 1968). When oxeye daisy plants are not grazed they gain an advantage over more desirable forage plants in pastures (Gilkey 1957). Howarth and Williams (1968) stated that oxeye daisy is not a striking feature of grasslands which are lightly grazed in the British Isles, and its abundance is partly related to the intensity of cutting or grazing. This suggests that it requires reduced competitiveness from existing vegetation through grazing, or possibly a disturbance to establish. On the other hand, Kydd

(1964) found that canopy coverage of oxeye daisy was highest under "undergrazing" and "unadjusted" cattle grazing treatments compared with "overgrazing", rotational grazing, or haying with the aftermath grazed twice treatments. The unadjusted pastures were grazed frequently, and cattle numbers were not adjusted to the herbage base which resulted in close autumn grazing and light spring grazing.

In a grazing trial using cattle and sheep where oxeye daisy was a dominant member of the community (20.2% canopy coverage), Norman (1957) found that oxeye daisy increased greatly in the continuous cattle grazing treatment. Increases were much smaller with close rotational grazing by cattle, and close rotational and continuous grazing by sheep. The canopy coverage of oxeye was essentially unchanged under lenient cattle grazing.

The effects of intensive cattle grazing on oxeye daisy have recently been assessed in southwestern Montana (Olson and Wallander unpublished data). Two years of intensive grazing reduced densities of oxeye seedlings and rosettes, but had no effect on densities of adult plants compared with densities in adjacent, ungrazed exclosures. Nonetheless, by reducing densities of the recruitment age classes, the seedlings and rosettes, densities of adult plants would have decreased in subsequent years if the study could have been continued. Intensive grazing had minimal impact on the associated perennial

grasses. The cattle tended to pull up many of the oxeye adult stems, as if they had initially intended to graze the plant, but changed their mind, possibly because of its acridity. However, overall use on the daisy was similar to use on the other vegetation, so there was no strong avoidance to the plant. Based on the European studies, sheep would probably have had a more significant impact on oxeye daisy than cattle.

Decapitation of the inflorescence promotes the rapid development of many lateral stems. When cows eat ripe seedheads, less than 40% of the seeds passing through the cow are viable (Howarth and Williams 1968). This is a considerable reduction in seed numbers, but an oxeye daisy plant may produce 1,300 to 4,000 fruits (Dorph-Petersen 1925), indicating that many seeds will survive the gastrointestinal tract of the ruminant.

Horse manure may contain seed of oxeye daisy (personal observation), and it is likely that other large ungulates may ingest, and then pass seed in their feces. Animals may also pick up seed in their fleeces or coats. Hay from pastures infested with oxeye daisy may contain seed; in southwestern Montana the first cutting of hay often coincides with the beginning of seed set.

MANAGEMENT

Oxeye daisy is generally not found in intensively cultivated areas because its shallow root system is easily killed. In pastures, Georgia (1914) recommended mowing plants as soon as the first flowers open to eliminate seed production, however, mowing may stimulate shoot production and subsequent flowering if the growing season is long enough. Oxeye daisy became the dominant plant in a field 14 months after herbicides were used to kill existing plants, followed by plowing and disking (Marks and Mohler 1985).

Howarth and Williams (1968) reported that oxeye daisy is moderately resistant to some 2,4-D based herbicides, except at high rates (5 lb/acre 2,4-D). In the early 1970s, Roche (unpublished data) compared 2,4-D at 2 lbs AI per acre with Tordon 22-K at 2 oz. for their effectiveness in controlling oxeye daisy on a mountain meadow in eastern Washington. Across these herbicide treatments, he applied nitrogen fertilizer at four different rates (0, 40, 80, 160 lbs as N, using ammonium nitrate-sulfate) beginning in 1972. Some plots were refertilized in 1973, 1975, and 1976; others were not refertilized to assess residual effects. Another set of plots were fertilized at the same rates but were not treated with either herbicide. Both herbicides were effective at reducing canopy cover of oxeye daisy, but fertilizer alone was almost as effective as the herbicides. Eighty pounds of N was the most cost effective

treatment after 7 years. Grass yields increased 500% with high levels of N. Forage production in 1981, five years after the last fertilization treatment, was still 2.5 times greater than the control. On a mountain pasture in southwestern Montana, Fay (unpublished data) applied 1.5 pt of Tordon with 1 qt 2,4-D per acre on a heavily infested oxeye site in 1990. There was 100% control for 2 years.

Effective biocontrol strategies have not been developed for this weed, presumably because this species is not yet perceived as a serious threat to plant communities. Unfortunately, an introduced plant can invade thousands of hectares during the time required to introduce biocontrol agents.

Livestock grazing may be a potential solution for controlling oxeye daisy. Livestock grazing will seldom eradicate a weed, but at least livestock can minimize spread by reducing seed production, and potentially the competitiveness of the weed.

Sheep (or goats) would be the most likely class of livestock to control this species because they readily graze it, as they graze most forbs. However, many infested areas have fencing and handling facilities that are appropriate only for cattle. In addition, sheep grazing on mountain rangelands is often uneconomical because of predation by coyote, bear, and mountain lion.

Roche (personal communication) found that herbicides can control oxeye daisy, however rodent burrows create small areas of bare soil, exposing seeds from the seedbank to mineral soil and minimal competition. As with any revegetation effort, it would be imperative that purchased seed not include weedy species. Given its long viability in the seed state, seedbanks can potentially reinfest a site for many years.

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CHAPTER 13

PERENNIAL SOWTHISTLE

Robert Parker⁴

There is some controversy concerning species classification of the two perennial sowthistles. Some authorities consider them to be the same species but different subspecies, while others divide them into separate species. In this review we will consider them as the same species, marsh sowthistle (Sonchus arvensis ssp. ulignosus) and perennial sowthistle (S. arvensis). We know considerable more about perennial sowthistle than marsh sowthistle and much of what is written refers to perennial sowthistle.

Sowthistles are members of the Asteraceae or sunflower family. The genus name *Sonchus* means thistle in Greek. Sowthistles are sometimes used by man and animals. Livestock will occasionally graze the leaves and roots can be roasted and used as an additive or replacement for coffee.

Perennial sowthistle is also known by the following names: field sowthistle, creeping sowthistle, gutweed, and field milk-thistle.

⁴ Washington State University

IDENTIFICATION

Perennial sowthistle is a deep-rooted perennial that spread by seeds and creeping roots. The roots are reported to extend 5 to 10 feet in depth and are wide spreading horizontally producing shoots from root buds nearly 2 feet deep, thus establishing large colonies.

Plants are usually 2 to 5 feet tall. The erect stems are smooth or glandular, hairy, leafy, hollow, branched near the top, and exudes milky juice when injured. Leaves are alternate and have a clasping base and mildly prickly margins which vary from deeply toothed to nearly entire. The principal leaves divide into 2 to 5 (occasionally 7) lobes along each side, usually with the tip lobe longer or broadly triangular; or with all the leaves mostly unlobed or merely toothed; the earlike projections of the clasping leaf bases are small and rounded at the tips. Upper leaves are fewer and much smaller than the lower ones. The numerous flower heads are arranged on the terminal branches in false umbelliferous cymes. The flowers when open are 1 to 2 inches wide and rich yellow in color. Perennial sowthistle is distinguished from marsh sowthistle by the gland tip hairs on the flowering stalk and head. There are no other distinguishing characteristics to separate the two perennial sowthistles. The plants can flower from June to October or frost, and as early as April in the warmer regions. The flowers are insect and self

pollinated. The seed is dark reddish brown to dark brown, 1/8 inch long at maturity, oblong, slightly narrowed at each end, with 5 to 7 distinct, lengthwise ribs on each side, the ribs are strongly cross-ridged, but not the furrows in between. A tuft of white pappus bristles (parachute) 0.4 to 0.5 inch long are attached to the terminal end of each seed. Viable seed is being produced 6 to 8 days after the flowers open. The seed is dispersed by wind, water, animals and man.

Plant propagation is mainly from creeping roots and very small broken-off fragments can form new plants. Most seed germinates at the 0.2 to 0.4 inch depth in the soil.

ORIGIN, HISTORY AND DISTRIBUTION

Perennial sowthistle is a native of the temperate regions of Europe or Eurasia and is now found throughout the world and considered a common or serious weed in many countries. It was first collected in the United States in 1814 in Pennsylvania and was the first of the sowthistles to be reported. The seed was apparently introduced into the United States in contaminated crop seed. It is widely distributed in North America, and considered noxious in many states and provinces. Perennial sowthistle is a vigorous competitor for nutrients in several crops. It invades disturbed sites such as cultivated fields, roadsides, and overgrazed pastures. The weed can infest many crops. Factors

contributing to optimum sowthistle growth are good soil moisture, moderate temperatures, adequate light and a neutral pH. Soil moisture is one of the environmental factors that will limit sowthistle growth even when other factors are not limiting. Optimum sowthistle growth occurs when soil moisture is at field capacity. Sowthistle fails to grow in dryland and rangeland areas that receive less than 9 inches of annual precipitation. It is adapted to many soils but grows more vigorously in soil with a pH of 6.2 to 7.2. Sowthistle will grow from near sea level to elevations over 5,000 feet. High temperatures slow their growth and consequently limit them to northern climates or higher elevations particularly in the southwest.

POTENTIAL INVASION

Perennial sowthistle has probably already spread throughout the range in North America where it is most adapted. The weed is continuing to fill in niches within the area. It is locally frequent to occasional throughout the northern United States and southern Canada, becoming rare in the South, Central, and Southwestern United States. Distinct areas of infestation are found in other parts of the United States.

Perennial sowthistle likes fresh to wet, heavy deep loams and clay soils rich in nitrates and humus. It is also an indicator of underground moisture.

IMPACTS

Perennial sowthistle is common in gardens, grainfields, cultivated crops, meadows, roadsides, ditchbanks, and fertile waste areas. It is most troublesome in the grain growing regions of the north central states and in Manitoba and Saskatchewan. Perennial sowthistle is a moderate to vigorous user of nitrogen and competitor for space. Not much is reported on the effects of the weed on crop yields. In Manitoba 70 shoots per m² reduced oat yields by 25%. In Michigan 96 and 88 shoots per m² during a dry year reduced soybean and dry bean yields by 87% and 83%, respectively. Light infestations sometimes are not recognized as a crop hazard. However, a light infestation can become a serious problem quickly. It has also been reported an alternate host of pine needle rust.

BIOLOGY AND ECOLOGY

In general sowthistles require high light intensities, such as sunny days, to stimulate germination, emergence, and vigorous growth. When shaded, perennial sowthistle will produce fewer but larger leaves to compensate for reduced sunlight. Once the crop is removed, sowthistle can flower and produce seed. Perennial sowthistle heads harvested 6 days after blooming had an average of 6% viable seed, and 8 days after blooming to have 65% viable

seed. Each plant will produce about 9,750 seed. Seed germinates best from 77 to 86 F. In 3 to 5 years, 80% of initial seed in the soil will have germinated. Seeds are primarily disseminated by wind and secondary dispersal occurs by adhering to animals and farm equipment.

It is cross-pollinated so flowers must be open before seed can be produced. Seeds are developed early and are ready to germinate 6 to 8 days after the flowers have opened. Each seed is attached to a pappus (parachute) that can be carried by air currents.

Single plants spread by means of seed and roots to develop patches. Seed scattered by wind develop into sprinklings of plants through the countryside, that creates a different problem than that associated with most other noxious weeds.

MANAGEMENT

Planting weed-free crop seed and controlling weeds on field borders where plants can begin establishment can prevent initial field infestations. Crop rotation, tillage, and herbicides can reduce the impact and further reduce propagation. Chemical and mechanical control before or after the crop is planted or harvested will minimize the infestation for that season or the next. Crops such as corn and small grains reduce light intensity need by sowthistles for germination, emergence and growth.

Eradication of perennial sowthistle as with most other plants is extremely difficult. In order to eradicate the plant from an area, the plant has to be controlled as well as all root fragments and viable seed in the soil.

Mechanical/Cultural Control

Perennial sowthistle root reserves are decreased more by spring cultivation while in the rosette stage with seven to nine leaves than at a later growth stage. Following tillage with perennial crop, infestations can be reduced up to 80%. Tilling perennial sowthistle roots into small segments will reduce its ability to spread, provided that conditions are not optimal for regrowth. However, tillage also can spread the roots. The optimum depth for perennial roots to emerge is 2 to 4 inches. Roots remaining on the soil surface have higher mortality than if buried because root segments will dry and decay. Root segments 1 inch or smaller can produce new plants. Fallowing for a year beginning in the fall and cultivating every 3 weeks in the spring reduces perennial sowthistle stands 75 to 90%. Infestations in pastures can be suppressed effectively by grazing cattle or sheep.

Cultivation from spring until freeze-up will kill a high percentage of thistle plants. However, cultivation from immediately after harvest of small grain one year until freeze-up the next year was more effective. A duckfoot field cultivator or

blade is the most satisfactory implement; a one-way disk is also fairly effective. If there is considerable plant residue on the area to be cultivated, it may be necessary to use the moldboard plow for the first operation. Equip the cultivator with wide sweeps (12 to 60 inches) that overlap 3 to 4 inches. Keep them sharp; be sure they are kept flat when in the soil and operating at a depth of 4 to 5 inches. The same is true for the one-way disk. Keep the disks sharp and operate at a depth of 4 to 5 inches. Each root must be cut by each cultivation.

It takes 10 to 15 days for new shoots to emerge after the roots have been cut. Another 10 to 15 days elapse before there are enough leaves to produce more food than is need for growth. Therefore, little plant food is stored in the roots and the root reserves are being used for plant growth for a period of 3 to 4 weeks. Cultivation at the end of each 3- to 4-week period causes a continuous drain on the root reserves. The food supply in the roots is eventually depleted and the plants die.

Combining intensive cultivation for part of the season with the production of a crop and chemical application is generally more practical than an entire season of cultivation. Income from the crop is obtained and erosion hazards resulting from a season of cultivation are greatly reduced.

Mowing before flowers have been open 1 week will prevent most seed production. However, mowing will not control the plant.

Biological Control

At this time no biological control agents have been successfully established on perennial sowthistle in the United States.

Chemical Control

Several herbicides are registered that will control perennial sowthistle. Selection of the herbicide depends on the site the weed is to be controlled. Specific herbicide recommendations can be obtained from most state cooperative extension services, fieldmen, and herbicide manufacturer representatives. Some of the herbicides that control or partially control perennial sowthistle are glyphosate (Roundup), clopyralid (Stinger), picloram (Tordon), 2,4-D, dicamba (Banvel), tribenuron (Express), amitrole (Amitrol-T), dichlobenil (Casoron), and terbacil (Sinbar).

Control of perennial sowthistles is most effective in the late rosette to bud stage. At the 5 to 7 leaf stage, carbohydrates produced from photosynthesis are translocated from leaves to roots to initiate root development. Herbicide application at this time will result in the greatest downward translocation and hence, reduction in root production. Most phenoxy-type herbicides will give moderate control of perennial sowthistles and if applied before blooming and will prevent seed production.

Post-harvest herbicide applications will also reduce stands. Best control is accomplished when applied one week before the first frost.

Prevention of seed production is more important for perennial sowthistle than for most other noxious weeds. It can be done by mowing or spraying at the proper time. Since a high percentage of seeds are ready to germinate after flowers have been open 8 to 10 days, mowing cannot be delayed more than 1 week after blooming. Likewise spraying with 2,4-D must be done before blooming.

To control or eliminate perennial sowthistle, use intensive cultivation, nonselective herbicides, certain competitive crops, selective herbicides, or combination of cultivation, crops and chemicals. Research conducted by South Dakota State University in the 1960's combinations of cultivation, competitive cropping and herbicides, reduced the sowthistle stands 95 to 100% in 2 years.

CHAPTER 14

PURPLE LOOSESTRIFE

Barbra Mullin*

IDENTIFICATION

Purple loosestrife (*Lythrum salicaria*) is a stout, erect perennial herb that sends up multiple stems from a strongly developed root system. The plants range in height from 1.5 to over 10 feet (0.5 to 3.5 meters). The stem is four to eight sided and can be either smooth or hairy. These erect stems are tough, almost appearing to be woody at the base. Leaves are lance shaped and cordate, attached to the stalk without stems in an alternate, opposite, or whorled pattern.

The flowers are arranged on a spike which is from two inches to three feet long. Individual flowers have 5 to 7 petals with 8 to 10 stamens of various lengths. Petals are typically magenta (purple) but can range from white to pink to deep purple or even red. Flowers open from July through September or October. The fruit is a capsule containing many small seeds. Mature capsules are brown, 1/8 to 3/16 inch long, and persist through the winter on the plant stalk. Seeds are angular, 1 mm long, and light tan. Seed production is prolific, each spike being capable of producing

* **Montana Department of Agriculture**

up to 120,000 seeds.

Seedlings are extremely small with oval cotyledons. Young plants generally have opposite, oval leaves attached oppositely or whorled on the stem.

Lythrum virgatum, a closely related species that often hybridizes with *L. salicaria*, is very similar but is glabrous, with narrower leaves that are acute rather than cordate at the base.

ORIGIN, HISTORY, DISTRIBUTION

Purple loosestrife (*Lythrum salicaria*) comes from European and Asian centers of distribution, although the exact geographical origins are unknown (Hulten, 1971). It was introduced in to North America from Europe in the early 1800's both as ship ballast and as horticultural stock. It comes from very similar areas in Europe and Asia and shows a high pre-adaptation to North American habitats. It was so well established by the 1830's that Torrey and Gray (1840) referred to it as "probably native" in their first edition of A Flora of North America.

It was well established along the New England seaboard by the 1830's and spread into vast stretches of interior drainage basins. As agricultural settlements moved west, wetlands, watersheds, and forests were cleared for cropland and pasture. This provided disturbance and stress to native wetland plant communities that allowed invasion by purple loosestrife. Development of early

canals, such as the Erie Canal, Delaware Canal, Raritan Canal, Morris Canal, and feeder segments, also provided both disturbance and habitat for establishment of purple loosestrife. Early studies show that the spread of *Lythrum* was closely related to canal traffic moving inland from northeastern shipping estuaries. All evidence suggests that the early phase of spread of *Lythrum salicaria* into the interior of North America was by waterborne commerce into recently disturbed or stressed habitats.

Between 1881 and 1900 canal traffic declined and railroads took over both priority shipments and much of the bulk cargo shipments. Most of the loosestrife establishment during this time period occurred along maritime commerce routes and at coastal or inland ports. Very little spread can be attributed to railroads. Coastal sites in the maritime states and provinces continued to show some colonization from 1901 to 1940. During this time period the first establishments were reported from marine estuaries in the Pacific Northwest, suggesting that, again, marine commerce was the principle mode of spread. Transcontinental railroad routes and the construction of the first state and federal highways networks seemed to have very little effect on the spread of purple loosestrife. The range of purple loosestrife has greatly expanded since 1941. Colonization of the northern Midwest is nearly complete, with infestations occurring in western Minnesota, the upper Red River Valley in North Dakota, into Manitoba, and the

wetlands of Lakes Winnipeg and Manitoba. The most dramatic expansion, however, has been in the arid West. This may be tied to the expansion of irrigation projects in the West. Recent purple loosestrife infestations in California, Idaho, Washington, and Wyoming are all in irrigation areas. When new superhighways were built with well-drained crowns and cut through ridges and valleys that old highway systems followed, it broke open past barriers to the movement of purple loosestrife along highways.

Purposeful introduction of *Lythrum salicaria* may have occurred very early and has become an increasing problem in the recent history of its spread. It was recommended in early herbal medicine works and was found in many early herb gardens. With the decline in interest in medicinal herbs, this is not a likely source of spread in North America. Purple loosestrife is also recommended as an ornamental and was noted in early literature as a "plant of great beauty" to be used along banks of water. Plantings of supposedly "sterile" ornamental hybrids of purple loosestrife continue to be a potential source in infestations due to movement of both plants parts and seeds from accidental crosses with wild types.

POTENTIAL INVASION

Purple loosestrife (or lythrum) is usually associated with moist and marshy areas. It is often found in ornamental settings

and can escape from these areas into aquatic sites such as streambanks or shorelines of shallow ponds. Infestations can become dense and impede water flow in canals and ditches.

IMPACTS

Purple loosestrife impacts the diversity of our native wetland ecosystems. Infestations lead to severe wildlife habitat degradation and loss of species diversity. It crowds out wildlife-supporting native vegetation such as cattails and bulrushes. Songbirds don't eat the small seeds. Muskrats can not use it for food or shelter. Waterfowl are affected when dense impenetrable stands of loosestrife eliminate nesting sites and open water. The thick matted root system can rapidly fill in irrigation ditches, resulting in decreased water flow and increased maintenance.

BIOLOGY AND ECOLOGY

Purple loosestrife (*Lythrum salicaria*) is an invasive, introduced, aquatic and wetland plant capable of growing in habitats from wetlands to moist wet soils on upland sites.

Seed dispersal is mainly by water, but seeds can also be transported on the feet and bodies of waterfowl and other birds, as well as numerous wetland animals. Most seeds sink, then rise to the surface upon germination. These cotyledon stage seedlings, as well as other plant parts, are buoyant and can be transported by

water currents to take root in other locations.

The major root branches become thick and woody in mature plants. The aerial shoots die in the fall but these dead stalks may persist for one to two years, making stands of purple loosestrife very dense. New shoots arise the following spring from buds at the top of the root crown.

Infestations of purple loosestrife appear to follow a pattern of establishment, maintenance at low numbers, and then dramatic population increases when conditions are optimal. Purple loosestrife first takes hold in wetland habitats that have been disturbed or degraded from draining, natural drawdown in dry years, or siltation. Once established it can spread to any other wetland situation. Seeds are usually present in such numbers and germinate in such high densities that native seedlings are suppressed. Loosestrife crowds out native vegetation and eventually becomes a virtual monoculture.

From a distance purple loosestrife may be confused with a number of other plants, including fireweed (*Epilobium*), blue verbena (*Vervain*), dotted gayfeather (*Liatris*), germander (*Teucrium*), smartweed (*Polygonum*), dame's violet (*Hesperis*), woodland salvia (*Salvia*), or foxglove (*Digitalis*). Upon close examination purple loosestrife is readily distinguished from these other plants by its multiple-sided stems and spike flower arrangements.

MANAGEMENT

Eradication of purple loosestrife requires an end to seed production and a depletion of viable seeds and plant parts from the soil. To do this, most infestations must first be treated with herbicide to eliminate the majority of the plants before seed production (late June through July). These same areas should receive follow-up spot treatments the same year to prevent escaped plants from producing seed (August). In succeeding years the infested sites must be revisited to find and eliminate plants that originate from seed and root stocks in the soil.

Persistence and dedication to a long term monitoring program is the key to eradication on each infested site. These sites must be resurveyed and treated yearly until no viable seeds or rootstocks remain in the soil. When resources or terrain limit the amount of area that can be treated, large infestations can be segmented into units that are geographically separated from the other populations in the infested area. As long as seeds are being produced in any wetland environment, there will be opportunities for wildlife to pick up seeds and spread them to other wetlands.

Educating the public about purple loosestrife should be a major part of the weed control strategy. Prevention is always the best method of weed control. Since loosestrife is a popular ornamental plant, the public needs to be very much aware of and involved in a loosestrife control program. They need to know that

they can no longer cultivate purple loosestrife or any of the horticultural varieties of loosestrife. Recent research from the University of Minnesota and from Montana State University indicate that even the so called sterile varieties of loosestrife set viable seed when pollinated by either *Lythrum salicaria* or *Lythrum virgatum*. An embargo on the importation of loosestrife seed and plant parts and listing it on the state noxious weed list aids in implementing a management plan. The embargo should include *L. salicaria*, *L. virgatum*, and all hybrids.

Land managers should adopt a suggested management program and requirements for horticultural plantings. These include: 1) Removal of all purple loosestrife plants from horticultural plantings; 2) Clip and bag flower heads from all purple loosestrife plants growing more than 500 feet from a waterway or wetland before seed production begins to prevent seed set; 3) Remove all purple loosestrife plants growing within 500 feet of a waterway or wetland; and 4) Prevent all new plantings or transplanting of purple loosestrife in the area.

CONTROL MEASURES

Several management practices aid the control of purple loosestrife. These include chemical, physical, and biological. Each infestation site should be individually evaluated to determine the appropriate control measure. Factors to be considered include

the proximity and type of vegetation on the site, the nature of the water involved (flowing or still), and the utilization of the site and the water (domestic, irrigation, recreation, or scenic value).

Chemical Control

The following chemicals are labeled for use in sites where purple loosestrife is known to occur. Extensive research on the chemical susceptibility of loosestrife has not been conducted to date. The rates shown in this section have demonstrated some control of purple loosestrife at some sites. Adequate and accurate coverage is critical for effective chemical control. As weed densities increase, spray coverage should also increase.

Refer to the current label for recommended application rates, approved sites, and application restrictions and precautions. The label may also recommend additional adjuvants and compatible colorants.

Glyphosate (Rodeo)

1. Selectivity: Rodeo is highly non-selective, killing broadleaf and grassy plants.
2. Rate: Apply 4 pints per acre as a broadcast spray or as a 1% solution using handheld equipment. Rodeo is registered for use in and around water; do not apply within ½ mile upstream of a potable water intake in flowing water or within

a ½ mile of a potable water intake in a standing body of water.

3. Surfactant: Use 2 or more quarts of a nonionic surfactant per 100 gal. of spray solution. Use a nonionic surfactant labeled for use with herbicides and in water. Surfactant must contain 50% or more active ingredient.

4. Plant growth stage at application: Apply to actively growing plants; early to late bloom appears best. Although best results are achieved during late bloom, the results are only slightly less effective at early bloom. Since glyphosate takes 1-2 weeks to impact the plants, late applications can allow some production of seed. It is important, therefore, to begin early or plan to clip and bag the seed heads prior to late applications.

5. Time of year for application: Mid July to early September is recommended for best results.

6. Special considerations: Use selective spot treatment applications to avoid unnecessary impact to adjacent nontarget plants which are essential to revegetate the area left bare by the killed loosestrife.

2,4-D

1. Selectivity: 2,4-D selectively kills broad leaf plants. Damage to grasses and grass-like plants can occur under

conditions of high temperatures or over application. Careful spot spraying is recommended for suppression of purple loosestrife.

2. Rate: Effective rates have been 1 to 2 quarts or a 1/2% to 1% solution in 100 to 200 gallons per acre. There are several 2,4-D labels registered for use around water. PBI/Gordon Amine 400 has a special local need (24c) registration for purple loosestrife suppression in some states. Contact your state Department of Agriculture for registrations specific to your state. Do not contaminate domestic or irrigation water.

3. Surfactant: Use of a surfactant can improve the effectiveness of 2,4-D. Follow the recommendations on the 2,4-D and surfactant labels.

4. Plant growth stage at application: Apply when the plants are actively growing or until the mature seed stage. Early bud to early bloom appears most effective.

5. Time of year for application: Apply whenever the plants are actively growing. Fall application must be done before a killing frost.

6. Special considerations: Application should be on a spray-to-wet basis, with spray volume increasing as the weed density increases. Refer to the label for all precautions.

Triclopyr (Garlon)

1. Selectivity: Garlon selectively controls broadleaf plants and is a very effective brush killer. Damage to grasses and grass-like plants can occur under some conditions. Spot spraying is recommended.
2. Rate: Recommended rates are from 1/2 to 2 gallons of Garlon in 20 to 200 gallons of spray mixture per acre. Control of larger plants will require the greater volume of water.
3. Surfactant: Surfactants can improve effectiveness. Follow the label for recommended rates.
4. Plant growth stage at application: Plants should be at bud to mid-bloom and actively growing.
5. Time of year for application: Recommended time for application is from mid-July to mid- August.
6. Special considerations: Triclopyr is labelled for use on non-irrigation ditchbanks but cannot be used in aquatic settings. Seasonally dry wetlands can be treated. Do not contaminate water.

Application Equipment and Methods

All equipment used to apply herbicides must be clean, maintained, and calibrated to assure that the equipment is functioning properly and is applying the designated amount of

chemical.

There are a variety of sprayers available, including backpack sprayers and truck or boat mounted sprayers. Experience has shown that wick applicators can be effective in applying chemical to control loosestrife. Wick application is very labor intensive, and the higher concentration of herbicide (33% glyphosate) requires that care be used. Aerial application is not approved for any recommended herbicides at this time.

It is important to leave as much of the surrounding beneficial vegetation as possible to fill in where the loosestrife is killed. This is accomplished by careful spot spraying with low pressures, large droplets, and narrow patterns. Drift reduction agents can be used in some situations to increase the droplet size and lower the potential for drift. Dyes and colorants are extremely helpful aids in accomplishing uniform application without skips and overlaps.

Physical Control

Hand removal

1. It is difficult to get all the roots and stems when pulling or digging, so select hand removal sites carefully. Small infestations can be controlled by this method but it is seldom effective for older plants or large infestations.
2. Pulling is most effective on 1- to 2-year-old plants because they have immature root systems. Carefully remove as

much of the root and stems as possible, since all pieces can sprout and form new plants.

3. Pulling is easiest when water level is at or slightly above the ground surface.

4. Try to minimize soil disturbance. Bare or disturbed soil will favor loosestrife seedlings.

5. Disposal of plants and roots is best accomplished by piling, drying and burning. If it is a small infestation, bag and remove all material and burn it at a site away from water. Take care to prevent spread of any seed from the transported plants.

Cutting

CAUTION! Cutting can spread purple loosestrife plants since cut portions can resprout. Cutting is not effective and requires a return to the site year after year.

Burning

CAUTION! Burning seems to favor loosestrife rather than native plants.

Flooding

CAUTION! Changing water levels may enhance spread by increasing the sites where purple loosestrife seeds can

germinate, grow, and produce more seeds.

Revegetation

If revegetation is necessary, use native grasses, cattails, or rushes that are adapted to aquatic/moist conditions, so that the infested area can be treated with selective herbicides that will control purple loosestrife seedlings but not harm the seeded vegetation.

Biological Control

Biological control does not eradicate or contain the target pest, but if successful, suppresses the weed population to a non-detrimental level. Six species of insects have been identified with a high potential as control agents. Three of these species have been screened by the International Institute of Biological Control (IIBC) in Switzerland and have been approved for field release in the United States. These species are:

Hylobius transversovittatus (a root-mining weevil.)

This species attacks the vascular system of the roots and may result in the death of the plant.

The weevil has been field released in Minnesota, New York, Oregon, Pennsylvania, Washington, and Ontario, Canada.

Galerucella pusilla and *G. californiensis* (leaf-feeding

beetles), have been cleared by the USDA-APHIS for field release.

Three other species: *Nanophyes marmoratus*, *N. brevis* (flower feeding beetles), and *Bayeria marmoratus* (a gall fly) have been screened by the IIBC. All appear to be sufficiently host specific to be proposed for field release in North America.

Use of biological control agents should be carefully monitored, with prudent site selection. If eradication of purple loosestrife is the goal for an area, biocontrol agents should only be released in areas that are totally inaccessible to other control measures.

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CHAPTER 15

RUSH SKELETONWEED

Roger L. Sheley and Joseph M. Hudak*

IDENTIFICATION

Rush skeletonweed (*Chondrilla juncea* L.) is a herbaceous, relatively long-lived perennial member of the sunflower family. Its life-cycle begins in the fall with seed germination and seedling establishment as well as regrowth from perennial roots. Plants usually overwinter as rosettes resembling common dandelion (*Taraxacum officinale*). The hairless basal leaves are 2 to 5 inches long and 1/2 to 2 inches wide. Rush skeletonweed grows anytime temperatures are above freezing, but usually initiates rapid spring growth in March or April.

During late spring, a spindly stem elongates from the center of the rosette reaching 1 to 4 feet tall. At this time, the basal leaves have deep, irregular teeth that generally point backward toward the stem base. The stem has a few narrow, inconspicuous leaves which gives the plant a skeleton-like appearance. An important characteristic of rush skeletonweed is the stiff downward pointing hairs on the lower 4 to 6 inches of the stem. The remainder of the stem is relatively smooth or has a few rigid

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hairs. All plant parts, including the leaf, stem and roots exude a milky latex when cut or broken.

Flowering begins in early summer and continues until fall along with seed development. The bright yellow flowers develop along the stem and branch tips either singly or in clusters of two to five flowerheads. Although flowerheads are less than 1 inch in diameter, and appear as a single flower they consist of many flowers (9 to 12). Seeds mature 9 to 15 days after flowers open. An individual plant is capable of producing over 20,000 seeds, but first year plants usually produce from 250 to 350 seeds. The light brown or black ribbed, pappus-bearing seeds grow to about 1/8 inch in length. These seeds are dispersed by wind to open sites, while parent plants die back to the soil surface. This life-cycle is repeated with the arrival of fall precipitation.

ORIGIN, HISTORY AND DISTRIBUTION

Rush skeletonweed is native to Asia Minor and the Mediterranean region, including North Africa. It has successfully invaded Australia, Argentina, Italy, Lebanon, New Zealand, Portugal, Spain, United States, and former Yugoslavia (Parsons and Cuthbertson 1992). Rush skeletonweed was first reported in the United States near Spokane, Washington in 1938. It was found in Idaho and Oregon during the 1960's, and currently infests over 6.2 million acres of rangeland in the Pacific Northwest and California.

A small infestation was found in Sanders County, Montana, in 1991. A year later, several small infestations were found in Lincoln County. In 1994, several new infestations were found in both counties.

IMPACTS

Detrimental

Rush skeletonweed reduced wheat yield 80% in south-eastern Australia (Groves and Cullen 1981). Rush skeletonweed competes for soil moisture and nutrients (primarily nitrogen), and the wiry stem interferes with harvesting. On rangeland, rush skeletonweed can form dense monocultures. It displaces indigenous plants, dramatically reduces rangeland forage production, and threatens the cattle industry. This species spreads from rangeland to adjacent cropland.

Beneficial

In Australia, rush skeletonweed is a drought-tolerant pasture plant. It is palatable and nutritious for sheep in the rosette and early flowering stage and has become a grazed component of low quality pastures in many parts of south-eastern Australia (Cuthbertson 19967). When rain is adequate, this species can be a major source of pollen for honey bees. A golden honey is produced from rush skeletonweed nectar (Clemson 1985).

POTENTIAL FOR INVASION

Cool winters and warm summers with winter and spring rainfall, but without severe drought, are optimum conditions for the growth and reproduction of rush skeletonweed. Summer temperatures of at least 59° F appear to be necessary for flower and seed production, but seed production can be limited by drought.

Rush skeletonweed has been recorded in habitats receiving 9 to 59 inches of precipitation (Moore 1964). This weed dominates disturbed areas such as roadways, waste areas, and areas weakened by drought or improper grazing. Big sagebrush/needle and threadgrass, bluebunch wheatgrass/Sandberg's bluegrass, and bitterbrush/bluebunch wheatgrass are some of the habitat types that are susceptible to invasion by rush skeletonweed. Good condition native vegetation is seldom invaded by rush skeletonweed (McVean 1966).

BIOLOGY AND ECOLOGY

Variability

Over 300 morphologically distinct forms of rush skeletonweed have been recognized; three are widespread in the United States. These forms, designated A, B and C, have narrow, intermediate and broad rosette leaves, respectively. Rush skeletonweed plant form differs in inflorescence morphology, fruit characters, potential

for regrowth from roots, and susceptibility to specific biological and chemical controls.

Germination and Emergence

Rush skeletonweed seeds display virtually no dormancy. Seeds germinate within 24 hours under optimal conditions (59-86° F). Buried seeds germinate within a year or two even if less than 0.3 inches of rain falls at one time. However, seedlings require continuous rainfall for 3 to 6 weeks for successful establishment. During drought, most seedlings die without emerging.

Roots

Rush skeletonweed roots reach 8 feet with little lateral growth, except in very sandy or gravelly soils where lateral roots are formed. When rush skeletonweed roots are severed, they produce shoots which can reach the soil surface from depths to 4 feet (Moore 1964). Taproot cuttings as small as 1/2 inch wide and 1 inch in length can produce new plants under moist conditions. In general, the ability of shoots to emerge from roots increases with the size of root fragments, but decreases with depth of burial.

MANAGEMENT

In many areas, managing rush skeletonweed should focus on PREVENTION and ERADICATION. Existing infestations should be

eradicated with diligence. Once the weed becomes widely established, an integrated strategy of cultural, chemical, and biological controls should be implemented to reduce the frequency of the weed to manageable levels.

Preventing Rush Skeletonweed Invasion

Rush skeletonweed infestations dominate the panhandle region of Idaho. This situation teaches us to vigorously prevent further encroachment. By implementing an intensive prevention program, we may be able to keep rush skeletonweed from encroaching into new areas.

In order to prevent rush skeletonweed invasion, seed dispersal must be limited. Seeds are dispersed mainly by wind, water, trains, vehicles and machinery. It is important to refrain from driving vehicles and machinery through rush skeletonweed infested areas during the seeding period, and to wash the undercarriage of vehicles and machinery before leaving infested areas. Livestock should not graze weed infested areas during seed formation. Before being moved to weed-free range, livestock grazing infested ranges should be transported to a holding area for 10 to 14 days after grazing.

Recreationists spread weed seeds. To prevent seed spread, campers, hikers, off-road vehicle enthusiasts, and horse-back riders should brush and clean equipment and animals. "Weedy plant

material" should be placed into a hot fire before leaving an area.

Proper livestock grazing is essential to maintain competitive grass plants, which will help prevent rush skeletonweed encroachment. A grazing management plan should be developed for any management unit involved in a rush skeletonweed prevention program. Management should include altering the season of use and stocking rates to achieve proper grass utilization. Grazing systems should include altering the season of use, rotating livestock to allow plants to recover before being regrazed, and promote litter accumulation.

An integral part of any weed prevention program is to contain neighboring weed infestations. It is critical rush skeletonweed be contained along highways, railways and waterways (weed dispersal corridors) preventing seed transportation. This requires annual applications of picloram (Tordon 22K).

Detecting new infestations and implementing eradication programs is the second step to preventing the invasion of rush skeletonweed. Systematic surveys along weed dispersal corridors are necessary to detect weed infestations early. Once an infestation is found, an eradication plan should be designed and implemented which includes an outline of the infestation boundaries, control treatments, control schedule, revegetation plans, follow-up monitoring, and costs.

CONTROL MEASURES

Mechanical Control

Diligent hand pulling or grubbing can provide effective control of very small infestations. Hand pulling above ground plant parts is marginally effective. Successful hand pulling requires removal of plant growth 2 or 3 times per year for 6 to 10 years because new plants will emerge from severed roots and buried seeds. Removing rush skeletonweed plants is best accomplished when the soil is wet. Plants should be destroyed by burning in a very hot fire to ensure seed and root kill.

Mowing and cultivation are ineffective methods for controlling rush skeletonweed. Mowing does not affect carbohydrate reserves, and only limits seed production in very dry years. Cultivation spreads root fragments and may actually increase the infestation.

Cultural Control

Planting competitive legumes, such as alfalfa (*Medicago sativa*), has increased soil fertility and effectively reduced populations of rush skeletonweed in crop-pasture rotations (Wells 1969). Dense stands of legumes compete for soil moisture and shade rush skeletonweed plants. However, the level of pasture management needed to effectively control the weed is difficult to achieve. Integrating competitive plantings with biological controls has proven effective in Australia.

Proper grazing by sheep can reduce or prevent production of rush skeletonweed rosettes and seed. Continuous, rather than rotational grazing, produces the lowest densities of the weed. Moderate grazing is as effective as heavy grazing in controlling rush skeletonweed because heavy grazing decreases the competitive ability of desired species. Integrating the use of competitive plantings, sheep grazing, and biological control agents appears to have potential for managing rush skeletonweed infestations.

Chemical Control

Rush skeletonweed is difficult to control using herbicides. Successful chemical control depends on specific conditions of the site and usually requires an aggressive re-application program. Historically, picloram (Tordon 22K) has been applied at 2 quarts per acre to rosettes to control rush skeletonweed. An application of 2,4-D amine at a rate of 2 quarts per acre provides some control. In Idaho, picloram (Tordon 22K, 1 quart per acre) plus 2,4-D (2 quarts per acre) gave the best control (Cheney, Belles and Lee 1980). In Australia, recent studies showed that a single application of clopyralid (Stinger[®], 1.5 pints per acre) reduced rush skeletonweed shoots approximately 60% three years after application (Heap 1993). Mixing clopyralid (Stinger[®], 1.5 pints per acre) with dicamba (Banvel DMA[®] 2 quarts per acre) gave the best long term control, reducing the number of shoots 75% three

years after application. Annual applications were necessary to provide 95% control of rush skeletonweed. Herbicides are most effective when applied to plants that are infected with biological control agents.

High rates of nitrogen fertilizer minimized the effect of rush skeletonweed upon both wheat and pasture yields under moist conditions (Myers and Fitzsimon 1965). Nitrogen increased the size of rush skeletonweed plants, but density decreased. Apparently, nitrogen reduces weed density by increasing competition.

Biological Control

Three biological control agents have been released for control of rush skeletonweed in North America; a rust, a mite, and a midge (Cullen 1974). The rust, *Puccinia chondrilla*, infects Form A of skeletonweed causing pustules that erupt through the leaf and stem surface which reduces the plants ability to photosynthesize and desiccates leaves. Severe rust infections can control Form A of rush skeletonweed, while light infections reduce seed production and viability.

The rust spores are carried by wind and rain. The disease moved about 5 miles within four generations and 200 miles after 12 generations. The spores can be collected and released on new weed infestations. Spores require 6 hours of both dew and darkness to germinate and establish a rust infection. Several strains of rust

specific to Form B have been collected, however, they have not proven effective under field conditions.

The gall mite, *Aceria chondrillae*, induces the vegetative and floral buds to form leafy galls causing stunting of the plant and greatly reducing seed production. This small parasite is the most damaging of the three biological control agents, but is only effective on Form A plants. The gall overwinters in the central bud of the rosettes without inducing gall formation. As the stem elongates, the mites colonize newly formed floral buds. As females reproduce, the galls swell. As the gall dries, the mites emerge and crawl to other buds or rush skeletonweed plants. The plant can be covered with as many as 4000 galls when 4 or 5 generations of the insect occur per year.

The only biological control agent which attacks all three forms of rush skeletonweed is the gall midge (*Cystiphora scmidtii*). The midge deforms plants and reduces seed production by feeding on the rosettes, stem leaves and stems of rush skeletonweed. The gall midge overwinters in the rosettes, emerges in April and is active through October. Females lay eggs in plant tissue, which cause some obstruction of nutrient movement within the plant. Despite a relatively short generation time, the gall midge impact is less than either the rust or mites, and their sensitivity to climatic variation is high. Therefore, the gall midge may not overwinter well.

Integrated Weed Management

No single treatment provides long-term control of rush skeletonweed so an integrated strategy must be adopted. The first line of defense is to prevent introductions of the weed. Systematic surveys, early detection and the implementation of an eradication program on small infestations is the second line of defense. Once the weed becomes established, integrating various combinations of competitive plantings, crop-pasture rotations, sheep grazing, biological control agents, herbicides and possibly fertilizers can reduce rush skeletonweed to manageable levels. The key component of any successful weed management program is sustained effort, constant evaluation, and the adoption of improved strategies.

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CHAPTER 16

RUSSIAN KNAPWEED

T.D. Whitson, K.G. Beck and D.W. Koch*

Russian knapweed (*Centaurea repens* L.) is considered a noxious weed in 412 counties within 21 western U.S. States. Range and weed scientists consider it a serious habitat invader because of its aggressive nature and allelopathic properties. In Wyoming, infestations increased from 11,300 ha in 1959 to 46,500 ha in 1987. Infestations were first reported in Colorado in 1928. Reports now indicate that over 20,000 ha of Colorado rangeland currently are occupied by Russian knapweed. The Bureau of Land Management estimated the average annual rate of spread to be 8% in the northwestern U.S., with an annual loss of 55% in livestock carrying capacity.

Russian knapweed is an aggressive perennial weed reproducing from seed and adventitious buds on a creeping root system (Fletcher and Renney, 1963; Moore and Frankton, 1974). It invades open, disturbed ground, suppresses growth of surrounding plants and once established, forms a single species stand. Russian knapweed infestations increase primarily by vegetative means; it does not

* University of Wyoming, Colorado State University, and University of Wyoming, respectively

reproduce extensively from seed (Watson, 1980). Roots grow 2 to 2.5 m and 5 to 7 m deep in the first and second seasons, respectively (Agadzhanyan and Agadzhanyan, 1967; Frazier, 1944; and Ivanova, 1966). Russian knapweed develops radially, with single plants covering as much as 12 m² in two seasons (Frazier, 1944; Ivanova, 1966; and Selleck, 1964). A single plant may produce 1,200 seeds which remain viable 2 to 3 years (Ivanova, 1966).

Selleck (1964) observed that infestations increased in dry locations, but decreased in moist areas, apparently caused by competition with perennial grasses. Perennial grasses can compete effectively with many noxious perennial weeds including Russian knapweed and produce livestock forage. In addition to forage production losses this perennial weed greatly impacts wildlife habitat. Russian knapweed competes with desirable vegetation for soil moisture and nutrients (Berezovski and Raskin, 1971; Papov et al., 1973).

Russian knapweed causes major economic losses in rangeland. Losses in Wyoming and Colorado are more than \$2 million annually. In addition to habitat losses, plants ingested as fresh or dried forage are toxic to horses, causing a neurological disorder, nigropallidal encephalomalacia (Young et al., 1970a; Young et al., 1970b).

Cropland infested with Russian knapweed often is abandoned (Berezovskii and Raskin, 1971; Maddox et al., 1985; and Renney and

Dent, 1958). Even though control might be achieved temporarily with herbicides or in the future with insects, long-term populations reductions must include competitive plant species to occupy bareground once infested by Russian knapweed.

Russian knapweed infests 21 states in the U.S., mostly in the semiarid to arid West (Maddox, et al., 1985). Infestations in the West are increasing. In 1928, six Colorado counties reported Russian knapweed infestations (Rogers, 1928); however, by 1985 over 20,200 hectares were infested in 22 counties (Maddox et al., 1985). Twenty-six Colorado counties reported infestations in an unpublished 1989 survey; however, only 41% of the counties responded. In Wyoming approximately 11,300 hectares were infested with Russian knapweed in 1959 (Harrington, 1959). Wyoming infestations have increased annually by an 11% average rate, occupying about 46,500 hectares by 1987. Simmons (1985) reported that Russian knapweed spreads annually at a 8% rate, and causes a 55% average annual reduction in livestock carrying capacity. This is depicted in a Russian knapweed distribution map from 1920 to 1980 for the Northwest (Figure 1).

Although it is accepted that Russian knapweed is allelopathic (Anderson, 1960; Berezovskii and Raskin, 1971; Evstratova et al., 1973; Fletcher and Renney, 1963; Renney and Dent, 1958; and Stevens and Merrill, 1985), control through plant competition should be exploited. Four years of winter rye (*Secale cereale*) or wheat

(*Triticum aestivum*) monoculture reduced Russian knapweed by 99 and 78%, respectively, when crops were harvested for silage or grain (Sulima, 1968). Russian knapweed is sensitive to light competition. Root and shoot dry matter and flower production declined and leaf area increased as light intensity was decreased (Dall'Armellina and Zimdahl, 1988). Preliminary studies done at the University of Wyoming suggest that plant competition could be used as an important part of a Russian knapweed management system.

However, there is limited data on interference between Russian knapweed and rangeland grasses. Research conducted at Colorado State University indicates that western wheatgrass (*Agropyron smithii* Rydb. var. 'Arriba') germination may be suppressed but not eliminated when exposed to Russian knapweed aqueous extracts (Appendix Table 1); whereas, smooth brome (*Bromus inermis* Leyss.) germination was not reduced. Seedling shoot and root growth of these grasses were negatively impacted by Russian knapweed aqueous extracts, but western wheatgrass may be less sensitive. Interference experiments between Russian knapweed and western wheatgrass or smooth brome indicate that Russian knapweed and smooth brome competed with one another for limited resources but Russian knapweed and western wheatgrass did not compete (Hanson, 1991).

At the 1989 Knapweed and Leafy Spurge Symposia, scientists agreed that integrated weed management systems need to be developed

to recover land infested by these species. However, there has been limited research oriented toward the development of such systems. In a project funded by CSRS Western Region IPM in 1986, Whitson et al. (1989) demonstrated that a single season of herbicide application, followed by seeding perennial grasses, resulted in 88 to 93% leafy spurge (*Euphorbia esula*) control six years after seeding. Four of the perennial grasses used in that experiment averaged 85% establishment. Traditional approaches to controlling leafy spurge have relied on repetitive herbicide treatments, usually annually or biennially. Field observations with perennial grasses suggest a Russian knapweed management system exists which combined reduced herbicide input and revegetation of infested land with desirable plant species. Thus, repetitive annual herbicide applications currently are recommended and used.

With present technology, many improved grass species seeded in late fall or winter can be established when seedbeds are properly prepared. An initial herbicide treatment or mowing is important to suppress problem perennial weeds before seeding. Pasture and hayland seedings without tillage have been successful, but there has been little work in which grasses were seeded into perennial weed-infested rangeland using current technology (Koch et al., 1984; and Mueller-Warrant and Koch, 1980). Whitson et al., 1989, reported that some grass species established more successfully than others without tillage in a leafy spurge-infested range previously

treated with glyphosate. With Russian knapweed, however, tillage of surface residue will be necessary to hasten decomposition of allelochemicals which accumulate from foliage (Fletcher and Renney, 1963).

Important grass characteristics to be considered for long-term control of problem weeds such as Russian knapweed include: (1) adaptation to the soil and climate; (2) ease of establishment; (3) competitiveness with weeds; (4) palatability and nutritive value, particularly for late-season use; (5) dry matter productivity; and (6) stand longevity.

Two species, having these characteristics are Crested wheatgrass (*Agropyron desertorum*), and Russian wildrye (*Elymus junceus*), they initiate growth early in the spring and have been shown to compete well with leafy spurge (Koch et al., 1989). These two species are adapted to dryland sites with as little as 20 cm of precipitation per year and both have persisted for 30 years or more. The new cultivar 'Bozoisky' has much more seedling vigor than common Russian wildrye (K. Asay, Logan, UT, pers. comm. and Koch, 1990). Russian wildrye also maintains higher nutritive value in late season than most other grasses (Koch et al., 1990). Legumes are not well adapted to the semi-arid sites being studied and reduce herbicide options for control of Russian knapweed after renovation.

The use of herbicides to control Russian knapweed before establishing perennial grasses is an important part of a management system. In order to determine proper time of herbicide application, the best choice of herbicides and their lowest possible use rates to provide adequate control of Russian knapweed three experiments were established by Whitson and Baker in 1989 (Table 1). Control with herbicides in the experiment was greater when applications were made when Russian knapweed was either at the bloom or seed stage rather than the rosette or early growth stage. Effective controls for two years after treatments of greater than 95% were obtained with applications of picloram at 0.38 lb ai/A and above, clopyralid at 0.25 lb ai/A and above and the combination of clopyralid+2,4-D+picloram at 0.18+1.0+0.25 lb ai/A.

FIGURE 1.

Russian knapweed distribution and spread in the Northwest, 1920-1980.

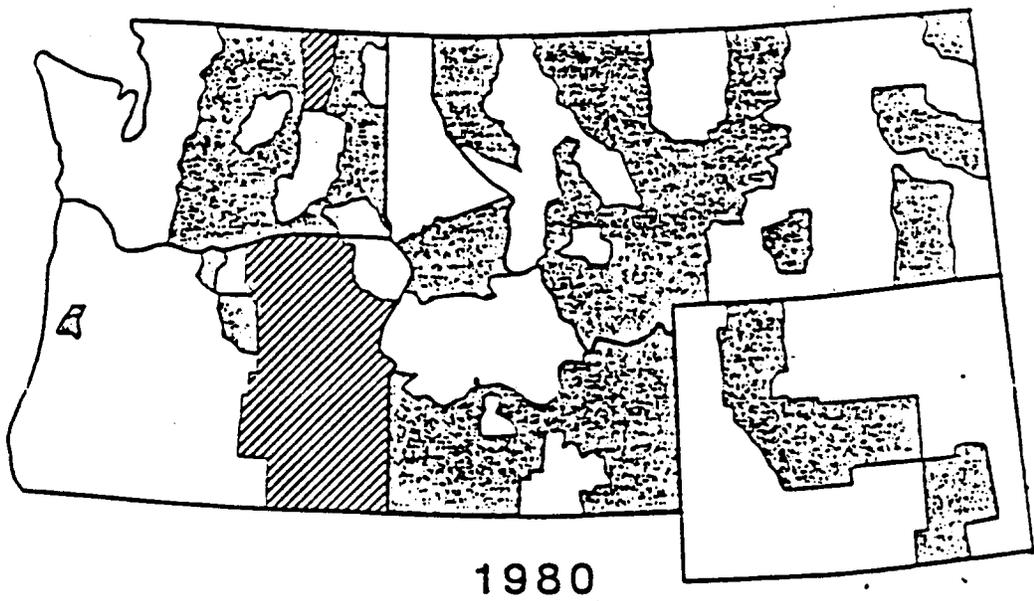
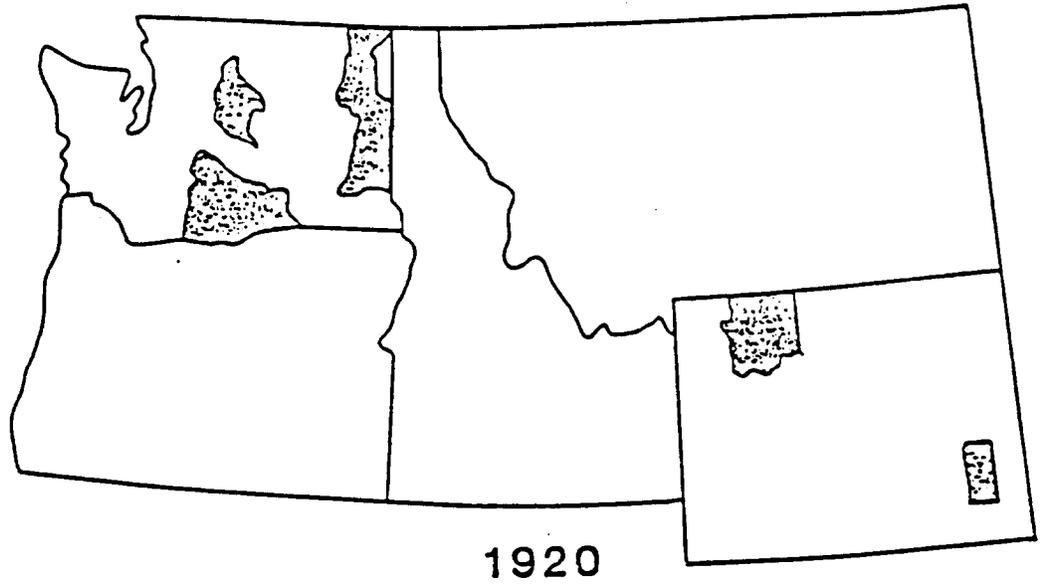


Table 1. Russian knapweed control with various herbicides in North Central Wyoming.

Treatment	Rate lb ai/a	Boysen Reservoir		
		5/18/89	7/7/89	10/9/89
Picloram	0.375	96	100	99
Picloram	0.5	99	100	100
Picloram	0.635	99	100	100
Picloram+2,4-D	0.375+1.0	99	100	99
Picloram+2,4-D	0.5+1.0	99	100	99
Picloram+2,4-D	0.635+1.0	100	100	100
Clopyralid+2,4-D	1.19	35	97	84
Clopyralid+2,4-D	1.58	61	95	96
Dicamba+2,4-D	1.0+2.0	24	36	35
Dicamba+2,4-D	2.0+2.0	10	35	78
2,4-D	2.0	4	0	0
Dicamba	2.0	11	55	77
Dicamba	4.0	59	64	86
Dicamba+Tordon	0.5+0.125	86	97	92
Banvel+Garlon	0.5+0.25	4	18	18
Dicamba+Starane	0.5+0.5	0	4	30
Dicamba+Stinger	0.5+0.125	58	70	83
Clopyralid	0.188	56	80	89
Clopyralid	0.25	87	98	96
Clopyralid	0.375	96	95	99
Clopyralid+2,4-D+ Picloram	0.18+1.0+0. 25	98	100	99
Clopyralid+L-77	0.188+0.25% v/v	46	81	84
Picloram+L-77	0.375+0.25% v/v	96	100	99

Evaluation June 29, 1994/July 8, 1991.

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CHAPTER 17

SQUARROSE KNAPWEED

Cindy Talbott Roché*

IDENTIFICATION

Squarrose knapweed (*Centaurea virgata* Lam. subsp. *squarrosa* Gugl.) is a member of the thistle tribe in the sunflower family (Asteraceae). Its woody crown is covered by one or more clusters of rosette leaves produced atop branches off a stout taproot. Several to many profusely branched stems grow 1 to 3 feet tall from each crown. The stalked, deeply lobed basal leaves often wither by flowering time. Stem leaves are not stalked and have fewer lobes progressively up the stems. Uppermost leaves are bract-like. Flower heads are borne singly or in pairs at the tips of the branches. The heads are smaller than other knapweeds in the West, 1/4 to 3/8 inch long and 3/16 inch wide, each containing only 4 to 8 rose-purple or pink flowers. On the bracts that surround the flower head, the terminal spine is longer and stouter than are the 4 to 6 pairs of lateral spines. It usually spreads outward or curves backward toward the base.

The shape of the head and bract are somewhat similar to diffuse knapweed, but squarrose knapweed heads are a more slender

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urn shape. The heads are deciduous at maturity by the development of a well-defined abscission layer at the base of the head. Heads normally contain 1 to 4 seeds, but empty seed heads are common. Seeds are 3/16 to 1/4 inch long, including the whitish plume, which may be up to 1/3 as long as the body or may be entirely absent. Seeds are golden to dark brown with faint linear stripes and an oblique scar where they detach from the head.

References containing additional photographs, line drawings or descriptions of squarrose knapweed include Abrams and Ferris (1960), Holmgren and Anderson (1976), Munz and Keck (1973), Roché and Roché (1991, 1993), Welsh et al. (1987) and Whitson et al. (1991).

ORIGIN, HISTORY AND DISTRIBUTION

Squarrose knapweed is native to Bulgaria, Lebanon, Anti-Lebanon, Transcaucasia, northern Iraq, Iran, Afghanistan and Turkestan (Wagenitz 1975).

Squarrose knapweed was collected from Big Valley, Lassen County, California, in July and August 1950 (Howell 1959). In 1950 the squarrose knapweed on the Kramer Ranch in Big Valley extended about 100 yards from both sides of the road into a recently disked summer fallow field on one side and a stand of grain on the other (Bellue 1952). A history of the Lassen County population written by J. B. Phillips (Bellue 1952) indicates that squarrose knapweed

was first noted about 1934-1937, by the lessee who used the ranch as sheep pasture. The land was also used as an overnight campground by several sheep men when they trailed their bands from the Sacramento Valley to higher ranges in the summer and returned them in the fall. By 1952, the largest known infestation covered an area about one mile wide by three miles long, running from the top of Big Valley Mountain down onto the valley floor and extending over several ranches (Bellue 1952). A distribution survey found plants on Highway 299 between Bieber and Nubieber, on the summit of Big Valley Mountain, along the abandoned state highway running from the top of Big Valley Mountain to Pittville, along the county road between Pittville and the town of Fall River Mills on the south side of Fall River, and extending four miles into Shasta County (Bellue 1952). Squarrose knapweed was first documented in Siskiyou County around 1969, which had spread to approximately 300 acres surrounding Hawkinsville, northwest of Yreka by 1988 (Ed Hale, Ag. Commissioner, pers. comm.). At this time the size of infestations in the three other northern California counties were estimated as follows: Lassen, approximately 800 to 1,000 acres in the northwestern part of the county (Big Valley and Big Valley Mountain); Shasta, 200 acres in the eastern part of the county; Modoc, approximately 5 acres along roadsides and railroad rights-of-ways (Joseph Wagner, BLM, pers. comm.). The current (8/94) distribution of squarrose knapweed in California is mapped in seven

counties: Del Norte, Lassen, Modoc, Plumas, Shasta, Siskiyou and Trinity (Barbe 1994).

In Utah, the weed was first collected from Tintic Junction, Juab County, in August 1954 (Howell 1959). Minutes of a meeting concerning squarrose knapweed held in Nephi, Utah, in November 1954, indicate that the weed was seen near the grain elevators in 1928, and that a seed company employee in Delta observed its occurrence in 1938 (Roché and Roché 1989). In 1954 the weed was found in varying densities over an area of about 5 square miles of depleted rangeland west of Tintic in Juab County, Utah (Tingey 1960). By 1960 it had spread along the highway from Eureka for about 7 miles into Tooele County and along the foothills into Utah County as far as Elberta along highway 50 and 6, and along the cattle trails over the Tintic Mountains (Tingey 1960). It had also appeared along Highway 50 and 6 from Tintic to Jericho, spreading out through the valley for about 30 miles. Scattered plants infested 400 to 500 acres east of the Star Ranch in northeastern Juab County and a small patch grew along Highway 91 south of Santaquin (Tingey 1960). In 1989 the core of the Utah population was estimated at 10,000 acres, with 5 counties affected: Juab, Tooele, Millard, Utah and Sanpete. Scattered plants had been found over 37,000 acres of BLM land west of Tintic Junction, but no estimate of the area actually infested with squarrose knapweed is available (Roché and Roché 1989).

Squarrose knapweed was discovered in Oregon by Dan Sharratt in 1988 near Long Creek, Grant County (Roché and Roché 1989). The infestation was estimated as 200 acres within an area of 800 acres in 1988, reduced to 25 acres by 1993 (Dennis Isaacson, Oregon Dept. Agric, pers. comm.). The second discovery of squarrose knapweed in Oregon was made in June 1991 by Bill Decker in Malheur County 38 miles west of Vale (Roché 1992). The infestation between Highway 20 and the Malheur River was less than 0.5 acre in size. A single squarrose knapweed plant was found intermingled with diffuse knapweed in Clackamas County in 1992 on the Clackamas Ranger District, Mt. Hood National Forest (D. Isaacson, pers. comm.).

Squarrose knapweed has not been reported from Idaho, Montana, Nevada or Washington.

BIOLOGY AND ECOLOGY

Squarrose knapweed is a long-lived perennial (Abrams and Ferris 1960, Wagenitz 1975). Although listed as a biennial in at least one source (Keffer 1978), field observations in Oregon and Utah found small rosettes with large taproots and successive rows of weathered leaf bases, indicating that they were not seedlings. Under unfavorable conditions, plants appear to remain as taprooted rosettes for years before developing flowering stems. Crowns that branch from under the soil surface to form multiple rosettes and an accumulation of bare, weathered flower stalks are characteristic.

This morphology also appears to be an adaptation to harsh growing conditions, such as cold temperatures and drought. In the Flora of Turkey, the U.S. specimens key to subspecies *squarrosa* (Group A) of *Centaurea virgata*, which is found mainly in Inner Anatolia (Wagenitz 1975). Much of the plateau of Inner Anatolia lies between 2500 and 3300 feet elevation, falling to a large salt lake in the center (Davis 1965). The climate is harsh, characterized by erratic precipitation, temperature extremes, wind and devastating hail storms (Davis 1965). Precipitation falls predominantly as snow in winter and spring. Winter temperatures are lower than Mediterranean climates and, in summer, temperatures soar during the day and drop suddenly at night. Humidity is very low in summer with a correspondingly high saturation deficit.

Squarrose knapweed flowers from June to August, followed by seed dispersal from August through the winter. The seed dissemination habit of squarrose knapweed is unique among adventive *Centaurea* species in the western U.S. Historically, most movement of squarrose knapweed in the western U.S. has been associated with sheep (Bellue 1952, Tingey 1960, Roché and Roché 1989). It is ideally suited to this mode of transport because the recurved spines of the capitula, like those of burdock (*Arctium*) or cocklebur (*Xanthium*), perfectly complement the wool of sheep in a manner analogous to a Velcro® fastener. At fruiting time, the heads are closed (retaining the seeds) and deciduous; consequently

seeds are readily spread by animal wool, hair or fur (Wagenitz 1972). No reference has been found regarding the initial introduction of this species, but it is possible that seed was carried in wool, either on sheep or woolen products. Squarrose knapweed was among the 526 species introduced in France by seed cleaned out of fleece at Juvénal Gate, where imported wool was washed for 200 years, starting in 1686 (Thellung 1912).

At seed maturity, attachment of heads to the stems weakens along an abscission layer at the base of the head, so that slight motion of the plant causes heads to drop. Although many heads fall near the base of the parent plant, not all the heads drop during late summer and fall. Heads remaining on plants into the following spring greatly extend the distribution period. Distribution by vehicles and trains appears increasingly important, judging by the expansion of squarrose knapweed along ORV trails, roads and railroads.

In Utah, most squarrose knapweed grows on big sagebrush-bunchgrass rangeland, but it also extends up into the juniper-dominated rangeland and down into the salt desert shrub range, particularly in sandy or gravelly washes. It also competes with crested wheatgrass in rangeland seedings. In northern California, squarrose knapweed grows on dry rocky sites of degraded juniper-shrub savanna with scattered western juniper and ponderosa pine and chaparral-type understory (Roché and Burrill 1992). In Oregon, it

has invaded juniper-Idaho fescue rangeland and big sagebrush-bunchgrass rangeland with cheatgrass.

POTENTIAL INVASION

In the Great Basin and Intermountain foothills, the sagebrush and juniper range types appear to be susceptible to invasion by squarrose knapweed. By the time squarrose knapweed was discovered, much of the rangeland in these vegetation types in Juab and Utah counties was "greatly misused in the past and in poor condition" (Stoddart 1945). The sagebrush type was "made up chiefly of common sagebrush (*Artemisia tridentata*) with a little rabbitbrush and mixed grasses, mostly cheatgrass." Juniper rangelands were characterized by *Juniperus utahensis* with a sparse understory of sagebrush, Russian thistle and cheatgrass. In addition, perennial vegetation had been removed entirely in areas plowed for dryland wheat production and abandoned after two or three years, cheatgrass areas which were repeatedly burned and on sheep trails traveled by 100 to 150 thousand sheep twice a year (Stoddart 1945). Since that time, many of the more productive sites (deeper soils) have been reseeded with crested wheatgrass. Squarrose knapweed has also invaded crested wheatgrass seedings.

IMPACTS

A long-lived perennial, squarrose knapweed appears better adapted than diffuse knapweed to the harsh climate of the shrub steppe rangeland in the Great Basin and high desert of eastern Oregon. Like the other knapweeds, squarrose knapweed competes with forage species on rangeland. In the rosette stage, it may equal diffuse or spotted knapweed in palatability and nutritive value, but the mature plant is also unpalatable. Its rosettes are grazed by sheep during late winter and spring (Roché *et al.* 1992).

MANAGEMENT

Squarrose knapweed is probably more abundant in eastern Oregon, southern Idaho and Nevada than has been reported. This is because careful observation is necessary to detect squarrose knapweed amid the already widespread diffuse knapweed. Areas adjacent to livestock trails, recreational vehicle routes and locations linked by current commerce with Utah and northern California would be priority survey sites.

Small infestations may be eradicated as they are found by grubbing, cultivation or herbicides. Stout taproots resprout when broken off, making hand pulling ineffective. Tingey (1960) reported that squarrose knapweed forms adventitious buds well below the root crown. Cultivation and grubbing should cut the root at least 8 inches below the soil surface to prevent new shoots growing from the root. When dislodged by a single disking, rosettes

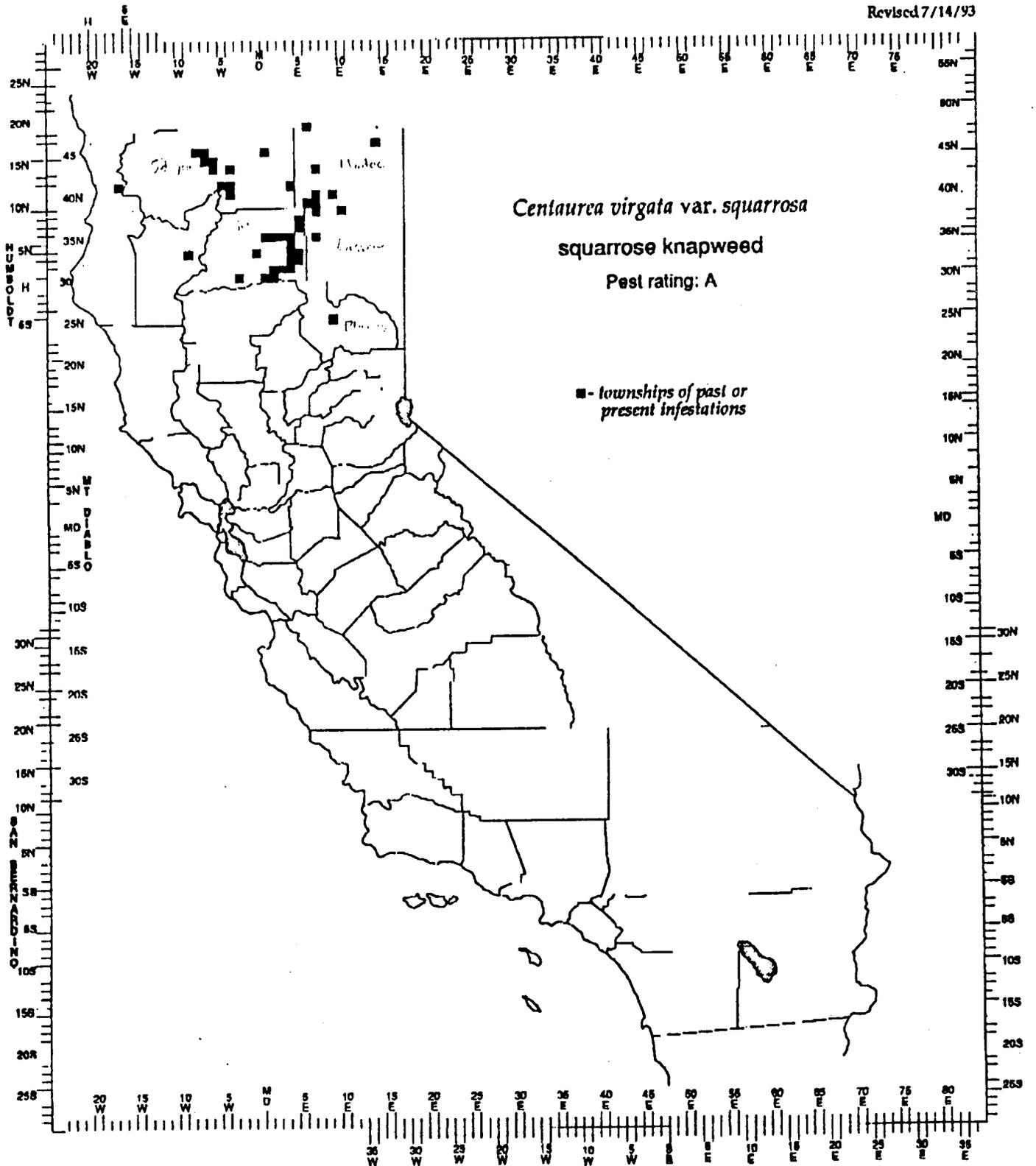
continue to grow if they are attached to a piece of root that touches the soil. Large rangeland infestations may be managed with a combination of herbicides, improved grazing management and revegetation with perennial forage species. Spot treat surviving plants and seedlings until no additional plants can be found. How long seeds remain viable in the soil is not known. Seeds protected by remaining in heads that fall to the ground and become buried probably last longer than unprotected seeds, but long persistence is not indicated in either case (Tingey 1960).

Two insects introduced for biological control of diffuse and spotted knapweed also reduce seed production in squarrose knapweed. These gall-forming flies, *Urophora affinis* and *Urophora quadrifasciata*, are widespread in all areas where the other knapweeds occur.

Several herbicides are registered for control of knapweeds on rangeland, with varying degrees of residual activity for control of later germinants. Specific recommendations vary by site and are available through the State Extension Weed Specialist.

STATE OF CALIFORNIA • DEPARTMENT OF FOOD AND AGRICULTURE
DIVISION OF PLANT INDUSTRY - ANALYSIS & IDENTIFICATION/BOTANY

DETECTION MANUAL
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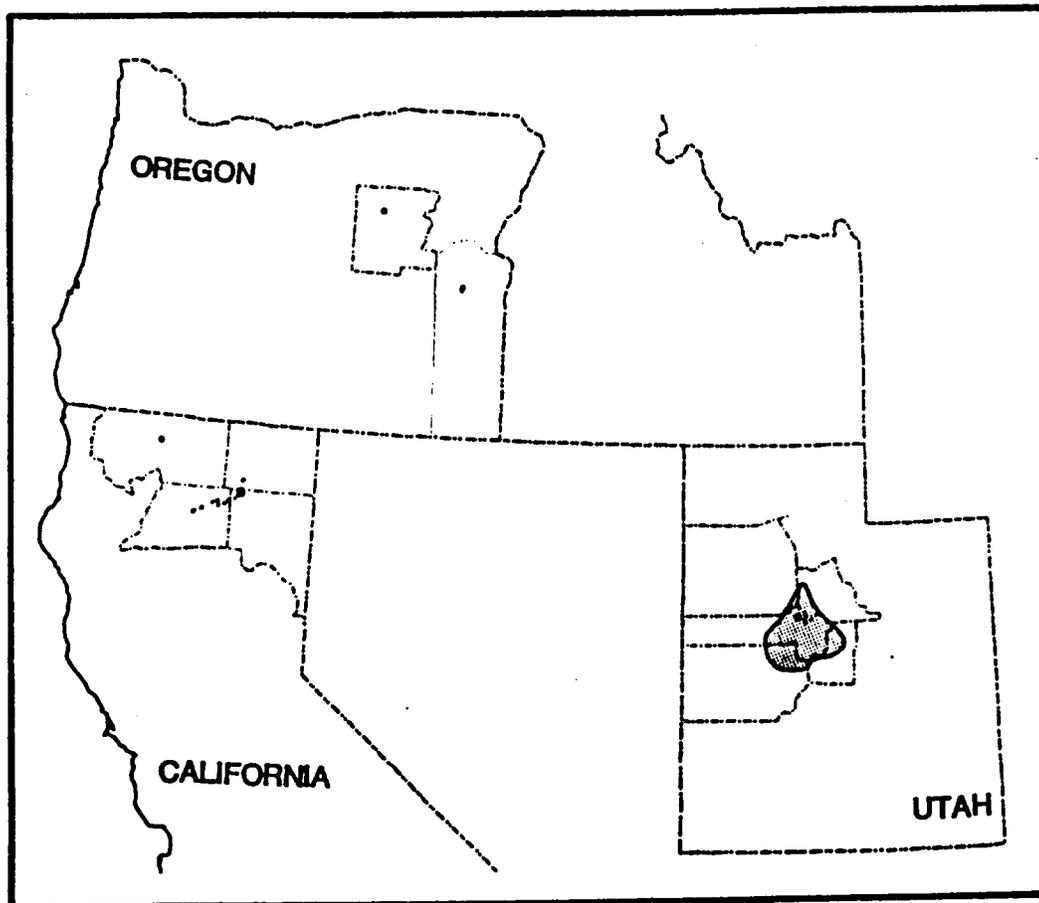


Figure 2. Location of squarrose knapweed populations in California, Oregon, and Utah. No detailed survey has been done in Utah. All known infestations occur within the shaded area.

TABLE 1. Effect of *U. quadrfasciata* gall load on squarrose knapweed seed production

Galls/ Seed Head	% of Seed Heads ¹	Filled Seeds/ Seed Head Mean ± Standard Deviation
0	21	1.79 ± .85
1	24	.58 ± .78
2	24	.14 ± .47
3	18	.11 ± .35
4	9	.02 ± .15
5	3	.06 ± .25
6-8	1	0

¹Sample size = 500

seed. The seed coat and pappus were often visible surrounding the insect puparium. The maximum number of galls found per head was 8, corresponding to the total number of flower ovaries normally available. Seed production was dramatically reduced with a single gall per head (Table 1). Seeds per head correlated negatively ($r = 0.86$) with increasing gall number through 4 galls. Sixty-four percent of the heads produced no filled seeds (Table 2). Heads without filled seeds contained one or more galls (Table 2). All of the sampled ungallo heads contained at least one seed. Total seed production from the 500 heads was 289 seeds. The average number of seeds per gram was 360 seeds. The sampled squarrose knapweed heads averaged 8.8 mm long and

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CHAPTER 18

SULPHUR CINQUEFOIL

Peter Rice*

IDENTIFICATION

Sulfur cinquefoil (Potentilla recta L.) is a member of the rose family. Prior to flowering sulfur cinquefoil has an appearance similar to marijuana. The leaves are composed of 5-7 leaflets attached in a palmate pattern to a central leafstalk which is attached to an upright stem (Figure 1). The leaflets are toothed about halfway to the midvein. There are numerous leaves (up to 7 or 8) along the length of the stem, but only a few leaves attached to the base of the stem. The length of the leafstalk and size of the leaflets decrease up the stem until the leaves are directly attached to the stem near its top. The erect stems are usually single to several, upright, 12 to 28 inches tall, and with no or only a few slender branches. The perenniating caudex is short and attached to a woody root. The root is persistent and may exhibit some lateral growth, but there are no rhizomes.

The inflorescence is a many flowered open cyme elevated above most of the leaves. Five pale sulfur yellow petals are equal to or slightly longer than the five subtending green sepals and five

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additional small bracts. The individual flowers are 0.6 to 1.0 inch wide and shaped like an open flaring cup. There are 25-30 stamens and numerous pistils. The small (1/20 inch long) comma shaped seeds are slightly flattened, brownish-purple, and covered with netlike pattern of veins. This reproductive structure is actually a one seeded fruit called an achene. Long (up to 1/4 inch) slender pointed hairs project outward at right angles to the stem and leafstalks, these are underlain with much shorter hairs spreading at different angles more or less parallel to the stem.

There are at least 29 species of cinquefoils (*Potentilla*) found in the Columbia Basin. Most of these are morphologically distinct, but the introduced sulfur cinquefoil (*Potentilla recta* L.) is sometimes confused with native northwest cinquefoil (*Potentilla gracilis* Dougl.). Northwest and sulfur cinquefoil both have palmately compound leaves. Northwest cinquefoil is the most widespread native species, and is common at the same low and mid elevations as sulfur cinquefoil. Northwest cinquefoil is seldom weedy, but sometimes does reach locally heavy cover values in high elevation or subalpine sagebrush-bunchgrass rangelands. Hitchcock & Cronquist (1973) recognized seven varieties of *P. gracilis*. These native varieties exhibit different leaflet shapes, depth of leaflet serrations, pubescence patterns on stems and leaves. Initial recognition of sulfur cinquefoil as a different species is

hindered against the wide morphological variability of northwest cinquefoil.

The misidentification of sulfur cinquefoil as a variety of native northwest cinquefoil has contributed to the unchecked expansion of this exotic. The following list of contrasting characteristics are suggested to help separate sulfur cinquefoil from the varieties comprising the species northwest cinquefoil. The value of these contrasting characteristics of course depends on the growth stage of the plant. I have listed them in approximate order as to utility for identification in the field (Table 1). The first three contrasting characteristics are particularly helpful (Figure 1). Stem and leafstalk pubescence on northwest cinquefoil is short relative to the diameter of the stem or leafstalk. These short hairs on northwest cinquefoil are either spreading at multiple angles or appressed flat to the stem or leaf surface. The long hairs on sulfur cinquefoil are long relative to stem and leafstalk diameter. The long sulfur cinquefoil hairs project outward at distinct right angles to the stem. Several specimens should be examined for as many of the listed characters as possible because of the variability of the native species.

Table 1. Separating sulfur cinquefoil (P. recta) from the varieties of the native northwest cinquefoil (P. gracilis)

Northwest Cinquefoil (<i>Potentilla gracilis</i> Dougl.)	Sulfur Cinquefoil (<i>Potentilla recta</i> L.)
1. short spreading hairs leafstalk & stems	1. longer hairs at right angle to leafstalk & stem
2. few stem leaves, mostly basal leaves	2. numerous stem leaves, fewer basal leaves
3. seed coat smooth	3. seed coat has netlike pattern (reticulate)
4. most with a dense woolly (tomentose) underleaf	4. sparse coarse-stiff pubescence so both sides of leaf are similar.
5. short rhizomes	5. woody root with short perenniating caudex
6. flowers brighter yellow	6. flowers paler yellow or sulfur yellow
7. leaves more green to gray	7. leaves more yellowish
8. about 20 stamens	8. 25 or more stamens
9. leaflet serrations sometimes deep	9. leaflet serrations 1/2 way to midvein

Sticky cinquefoil (*Potentilla glandulosa* Lindl.) is a second widespread native. In areas of limited size it is not uncommonly a co-dominant. Sticky cinquefoil is easy to identify as it has pinnately compound leaves and a sticky resin exudes from glands on the leaflets and flower buds.

ORIGIN, HISTORY, AND DISTRIBUTION

Sulfur cinquefoil (Potentilla recta L.) is native to Eurasia, an origin similar to spotted knapweed and leafy spurge. The first collection in North America was made somewhat before 1900 in Ontario (Britton and Brown 1897). Sulfur cinquefoil had become a well established weed in eastern Canada, northeast United States and Great Lakes region by the 1950's (Werner and Soule 1976). Scattered populations also had been recorded in southern British Columbia. The earliest records of sulfur cinquefoil in the five state area (WA, OR, ID, MT, WY) of the Columbia Basin are in Table 2.

Table 2. Earliest county records for sulfur cinquefoil (P. recta) in the states of the Columbia Basin.

STATE	YEAR	COUNTY
ID	1934	Bannock
WA	1937	Whatcom
MT	1947	Ravalli
WY	1947	Park
OR	1988	Morrow

Sulfur cinquefoil has spread to at least 30 counties in the western two thirds of Montana (Figure 2). Glacier and Yellowstone National Parks also have sulfur cinquefoil populations. Idaho has reported infestations in 14 counties and Wyoming 5. This weed has also been found in at least 12 counties in Washington and 1 in Oregon. This rapid spread over large geographic areas (Figure 3)

is similar to the exponential spread pattern of spotted knapweed and leafy spurge although sulfur cinquefoil was introduced several decades later.

In March 1991 sulfur cinquefoil was placed on the Montana Noxious Weed List as a Category 2 weed species, those undergoing a rapid expansion and with potential for significant economic and environmental impact. In 1994 the State of Montana moved sulfur cinquefoil to Category 1, those weed of environmental and economic significance that are known to be widespread and well established.

POTENTIAL INVASION

Sulfur cinquefoil has a wide ecological amplitude. This exotic has become a permanent or "naturalized" member of the flora of the Columbia Basin. Rice (1993) conducted a summary analysis of ecological and management data collected for 85 sulfur cinquefoil sites in Montana. Infestations were found as high as 6580 feet (Figure 4). Conifer (39% of the sampled sites), grassland (57%), shrubland (2%), and seasonal wetland (2%) ecosystems are susceptible to invasion. The weed was found in 31 different habitat types in 15 series (Pfister et al. 1977 and Mueggler and Stewart 1980) (Table 3).

The seasonal wetland sites were coarse textured soils with a high cobble fraction; subject to spring flooding followed by rapid drainage and drying.

Sulfur cinquefoil does not seem to be limited by soil texture; it was found on sites with all soil textures except pure silt (Figure 5). The most common textures were sandy clay loams (31%) and sandy clays (19%). Pure loams and sands comprised only 2% and 1% of the sites, respectively. All other soil textures ranged between 5% and 9%. We cannot say which soil textures are most susceptible to sulfur cinquefoil as we do not have data on the proportionate area of the state by soil texture.

Table 3. Habitat series supporting sulfur cinquefoil.

ECOSYSTEM TYPE	SERIES	# of HABITAT TYPES
CONIFER	ponderosa pine	4
	Douglas-fir	6
	spruce	3
	grand fir	2
	subalpine fir	2
	western red cedar	1
	western hemlock	2
	SHRUBLAND	bitterbrush
skunkbrush		1
GRASSLAND	western wheatgrass	2
	bluebunch wheatgrass	4
	Idaho fescue	3
	rough fescue	2
SEASONAL WETLAND	Kentucky bluegrass	1

Some sulfur cinquefoil sites were relatively free of other noxious weeds, but the majority of the sites had one or more additional noxious weeds present (Table 4).

Spotted knapweed was most often associated with sulfur cinquefoil. The habitat requirements for sulfur cinquefoil appear to be similar to those of spotted knapweed. Reports from land managers indicate that the spotted knapweed is declining while the sulfur cinquefoil is increasing on numerous sites where the two weeds are co-located. Preferential grazing of up to 30% of the spotted knapweed was often observed with only trace utilization of sulfur cinquefoil. Sulfur cinquefoil was even found competing successfully with yellow starthistle (Centaurea solstitialis L.) and leafy spurge (Euphorbia esula L.) on several sites.

Table 4. Noxious weeds found in association with sulfur cinquefoil.

NOXIOUS WEEDS FOUND WITH SULFUR CINQUEFOIL	
associated weed	% of sites
dalmatian toadflax	5
Saint Johnswort	13
leafy spurge	2
field bindweed	1
Canada thistle	11
spotted knapweed	60
diffuse knapweed	5
whitetop	2

Roadsides, wastepieces, abandoned fields, and clearcuts are particularly susceptible to early colonization and rapid dominance by sulfur cinquefoil. Initial colonization was often on disturbed soil sites. Sulfur cinquefoil is now successfully invading low disturbance sites, including native communities that are remote from any apparent anthropogenic influence. This weed it is now common in natural grasslands, shrubby areas, and open canopy forests. Shading from dense overstory prevents its establishment in mature forests, but it can successfully occupy natural gaps in the forest canopy.

IMPACTS

The initial colonies have already expanded to over 100 acres in size on one quarter of the sites evaluated by Rice (1993) in Montana (Figure 6). Several colonies have expanded to over 1000 contiguous acres. Although large infestations are not uncommon the majority of the colonies are still small, half being less than 10 acres in size.

Canopy cover is a useful measure of the severity of a weed infestation on individual sites and the ability of that weed to out compete other plants (Figure 7). Sulfur cinquefoil often becomes a significant component of the plant community, and has proceeded to dominance on many sites. At 75% of the sampled sites sulfur cinquefoil was more than 5% of the plant cover, and on half of the

sites the sulfur cinquefoil proportion exceeded 15%. The weed accounted for half or more of the total cover on 14% of the sites, reaching relative cover values as high as 75%.

In spite of its abundance, sulfur cinquefoil is avoided by most grazing animals. Utilization was less than 1% on 98% of the sites. Two percent of the sites had 1-5% grazing on sulfur cinquefoil. This trace grazing usually consists of removal of the bud and flower tops from a limited number of plants. Intensive grazing systems can increase utilization above 5%, but sulfur cinquefoil appears to be one of the last plants selected. The low preference is believed to be a result of a high concentration of phenolic tannins in the leaves and stems.

BIOLOGY AND ECOLOGY

Rice (1993) recorded growth stages in 1991 and 1992 (Table 5). Sulfur cinquefoil is one of the first plants to emerge in the spring, one of the fastest plants to greenup in the fall in response to late summer/early fall rains, and continues to grow until freezing temperatures are sustained.

Table 5. Phenology of sulfur cinquefoil.

GROWTH STAGES OF SULFUR CINQUEFOIL	
early/mid March	first basal leaves emerge
April	basal rosette fully formed
May	bolt
late May / early June	bud stage
June	bloom
July	seed set
late July / early Aug	seed dispersal begins
August	leaf senescence
Sept/Oct	fall greenup with new basal leaves
late Oct	growth stops after extended freeze

MANAGEMENT

Sulfur cinquefoil is in a rapid expansion phase. The weed is increasing its geographic distribution. The number of new colonies is increasing exponentially. Many of these infestations are reaching environmentally severe size and density.

Correct identification is the first step in controlling this noxious weed. Initial recognition can be difficult because of the large number of cinquefoils in Montana and the adjoining states. Sulfur cinquefoil is most often confused with the widespread native northwest cinquefoil (*P. gracilis*) (Figure 1). Montana State University Extension Bulletin 109 provides identification guidelines, line drawings, and color photos (Rice et al., 1994).

A Pacific Northwest Extension Publication (PNW 376) (Callihan et al. 1991) also provides color photos.

Table 6. The three most useful characteristics to separate sulfur cinquefoil (Potentilla recta) from northwest cinquefoil (Potentilla gracilis).

KEY FIELD TRAITS SEPERATING THE TWO CINQUEFOILS	
sulfur	northwest
long right angled hairs	short spreading hairs
many stem leaves, few basal leaves	few stem leaves, many basal leaves
net-like seed coat	seed coat smooth

Sulfur cinquefoil was pre-adapted to Montana's semiarid climate, but escaped the insect & disease organisms that co-evolved in its native Eurasian habitat. USDA evaluated sulfur cinquefoil for insects and diseases in the eastern United States prior to 1960. They were primarily concerned about sulfur cinquefoil being an alternate host for pathogens that might threaten economic crops. They reported three fungal species, but no insects or higher plant parasites. A 1979 survey (Batra) focused on finding insects on sulfur cinquefoil that might have the potential for use as biological controls of the weed. Batra's survey found 31 insects, including a number of pollinators, associated with sulfur cinquefoil and several fungi. None of the organisms appeared to have significant impact on the weed. Biocontrol options were

dismissed as unfeasible because of a close genetic relationship between cinquefoils and strawberries, both of which are in the rose family.

Rice (1993) collected root and crown boring insects from sulfur cinquefoil plants on numerous sites in Montana. Six species have been isolated from these collections. Identifications, primarily from larval lifestage forms, have been furnished by Ding Johnson (University of Idaho), Bill Good & Jim Story (MSU Corvallis Ag Experiment Station), and William Lanier (MSU Entomology Dept). Three of the identified species are known to be pests on strawberry. The strawberry crown moth (Synanthedon bibionipennis (Boisduval)) is the most common of the insects found in sulfur cinquefoil plants in the Montana study; larval specimens were collected from 11 sites. Otiorhynchus ovatus, a strawberry root weevil, was collected on two sites in northwest Montana. A total of nine larvae and one adult were culled. Monochroa fragariae and a flat-headed borer (Chrysobothris spp.) were each found on two sites. One adult and 1 larvae of Centroinogna strigata were found and one unidentified larval specimen of the Order Coleoptera was collected.

The State of Montana has initiated a search in the eastern Mediterranean area for insect pests of sulfur cinquefoil that might be useful as biocontrols agents. Field releases of any such insects would be a decade or more in the future.

Table 7. Insects found feeding in sulfur cinquefoil in Montana.

INSECTS FOUND ON SULFUR CINQUEFOIL		
ORDER	Family	species
LEPIDOPTERA BUTTERFLIES	Sesiidae Clear-winged Moths	<u>Synanthedon bibionipennis</u> strawberry crown moth
LEPIDOPTERA BUTTERFLIES	Gelechiidae Gelechid Moths	<u>Monochroa fragariae</u> strawberry crown miner
COLEOPTERA BEETLES	Curculionidae Snout Beetles	<u>Otiorhynchus ovatus</u> strawberry root weevil
COLEOPTERA BEETLES	Buprestidae Metallic Wood Boring Beetles	<u>Chrysobothris sp.</u>
COLEOPTERA BEETLES	Curculionidae Sub Family: Baridinae	<u>Centroinogna strigata</u>

Rice (1973) found a bright orange and black colored rust fungus (Phragmidium ivesiae Syd.) on sulfur cinquefoil at 79% of the sampled sites (Table 8). The potential control value of this rust fungus has not been evaluated. It appears to be well adapted to its host.

Table 8. Rust fungus (Phragmidium ivesiae Syd.) on sulfur cinquefoil.

ORANGE RUST FUNGUS (<u>Phragmidium ivesiae</u>) ON SULFUR CINQUEFOIL	
degree of spore development	% of sites
heavy	13
moderate	28
light	38
not evident	21

If the infestation consists of a limited number of plants, hand grubbing can be effective. The top growth dies back each winter and annual vegetative regrowth can only be initiated from the root crown. The spreading lateral root structure allows digging tools to be slipped under the crown and easy removal of the perennating tissue. Mowing is not effective. The plants respond by developing heavier rootstocks and increased canopy cover near ground level.

Selective herbicides are the most effective tool for controlling larger populations of sulfur cinquefoil at this time. Tordon 22K (1 pt/acre or 0.25 lb a.e. picloram/ac) applied in the fall or spring up to late bud stage will provide several years of control. The ability of sulfur cinquefoil to green-up in response to late summer and fall rains increases the potential effectiveness of fall Tordon treatment. The fall growth is an emergence of new

basal leaves from the root crown. Spring application (rosette through bud) of 2,4-D ester (2 qts/ac or 2 lbs a.e. 2,4-D/ac) also provides good control, but without the multi-year residual activity obtained from Tordon. 2,4-D ester may be a better choice where the potential for water contamination is significant. On more typical dryland sites Tordon is preferred because the residual activity will suppress re-establishment from seed in the soil bank.

Expanded herbicide trials for sulfur cinquefoil control were initiated in 1991 and 1992. A variety of chemicals at different rates and timings are being tested (Duncan 1993). The efficacy of 2,4-D amine was less consistent than the 2,4-D ester formulation. A mix of Banvel and 2,4-D amine (1 qt/ac + 1 qt/ac) applied at the rosette stage had an efficacy similar (97%) to 2,4-D ester one year after application. However, the efficacy of the Banvel + 2,4-D amine mix declined when applied at later growth stages. The Banvel + 2,4-D treatment is considerably more expensive than 2,4-D ester alone or Tordon. Tordon at 1 pint/acre still appears to be the most consistently effective chemical prescription from the rosette stage through fall applications, including the flowering period (Duncan 1993).

Seed in the soil is viable for at least three years. Even with Tordon treatments it is necessary to conduct appraisal surveys of treated sites in subsequent years. Systematic re-treatments should be planned if eradication is the management goal.

Recognition of seed longevity and annual monitoring is particularly necessary if hand grubbing techniques are used.

Transline or Stinger (clopyralid) should not be used on sulfur cinquefoil. Transline is a very effective herbicide for spotted knapweed while having less impact on non-target forbs. One of those forbs resistant to Transline is sulfur cinquefoil. Spotted knapweed and sulfur cinquefoil are often co-located and a Transline application to these mixed stands will release the sulfur cinquefoil.

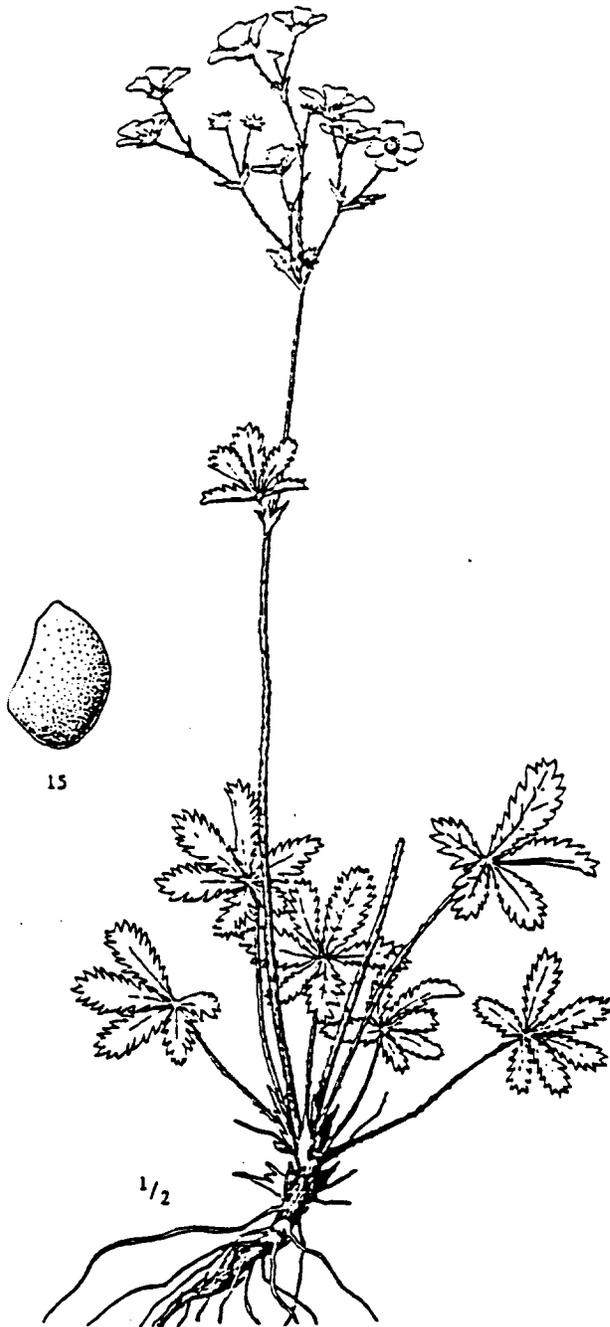
Most livestock grazing practices accelerate the dominance of sulfur cinquefoil over grasses and other forbs, including several noxious weeds. Sulfur cinquefoil is unpalatable to most livestock, possibly because of a high tannin content. Some utilization has been observed under intensive grazing in confined pastures. On open range or at low stocking rates most livestock prefer spotted knapweed over sulfur cinquefoil. Animals will graze off the spotted knapweed flowering tops while completely avoiding sulfur cinquefoil. Spotted knapweed seed production is lowered relative to sulfur cinquefoil, and because sulfur cinquefoil is a long-lived perennial while spotted knapweed is a short-lived perennial the population dynamics favor the replacement of spotted knapweed with sulfur cinquefoil. The abundance of native forbs and grasses continues to decrease whichever exotic is most successful.

Goats are the only animals that have been reported to select for sulfur cinquefoil.

Early detection of new colonies and an aggressive chemical control program with eradication as the goal is a feasible management strategy for areas outside the zone of major infestation. IPM techniques will have to be developed to control sulfur cinquefoil at environmentally and economically acceptable levels within the major infestation zone.

Figure 1.

NORTHWEST CINQUEFOIL
Potentilla gracilis Dougl.



SULFUR CINQUEFOIL
Potentilla recta L.

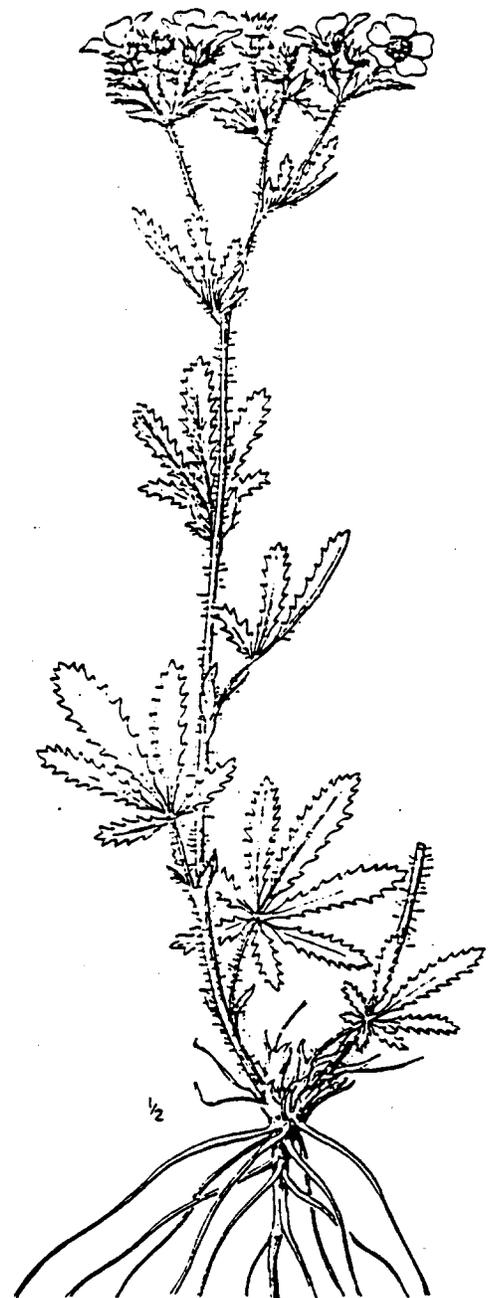


Figure 2.
 Potentilla recta (SULFUR CINQUEFOIL) FOR 1875-1993 IN THE NORTHWEST REGION

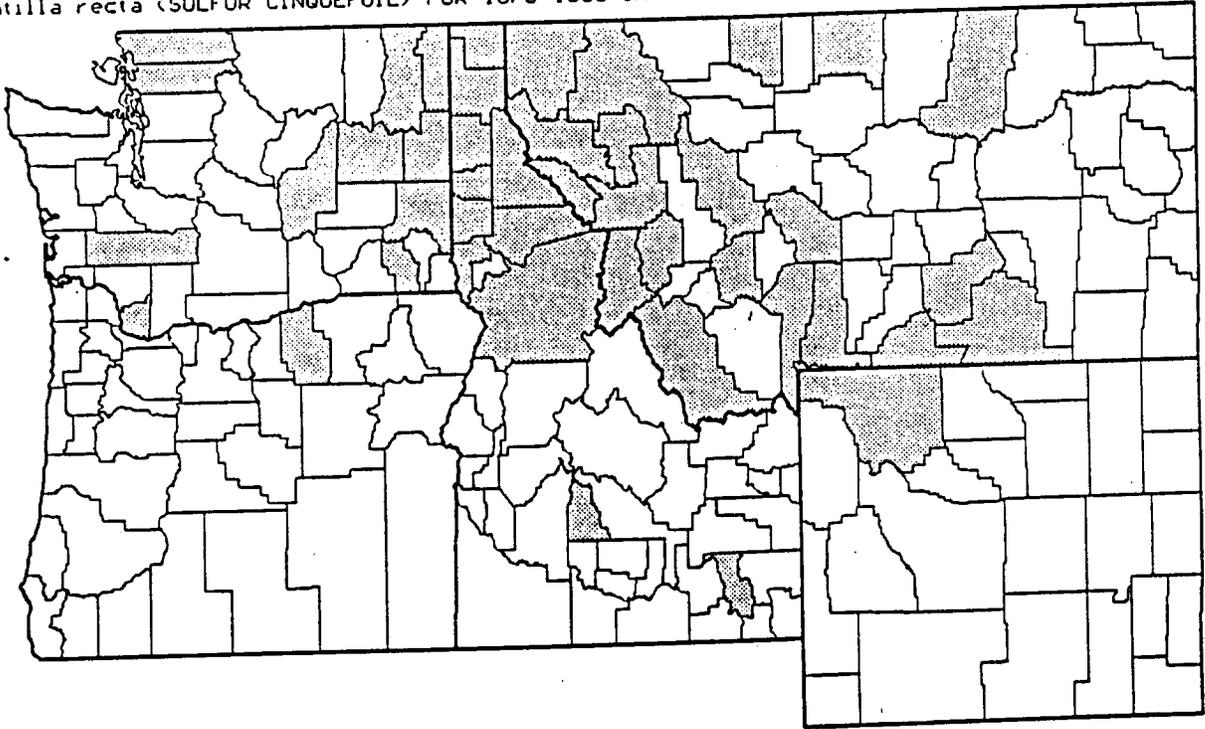


Figure 3.
 Potentilla recta INCREASE IN NORTHWEST STATES
 $y = -13.496072 + 1.260395 * x^1 - 0.005147 * x^2 + 0.000008 * x^3$

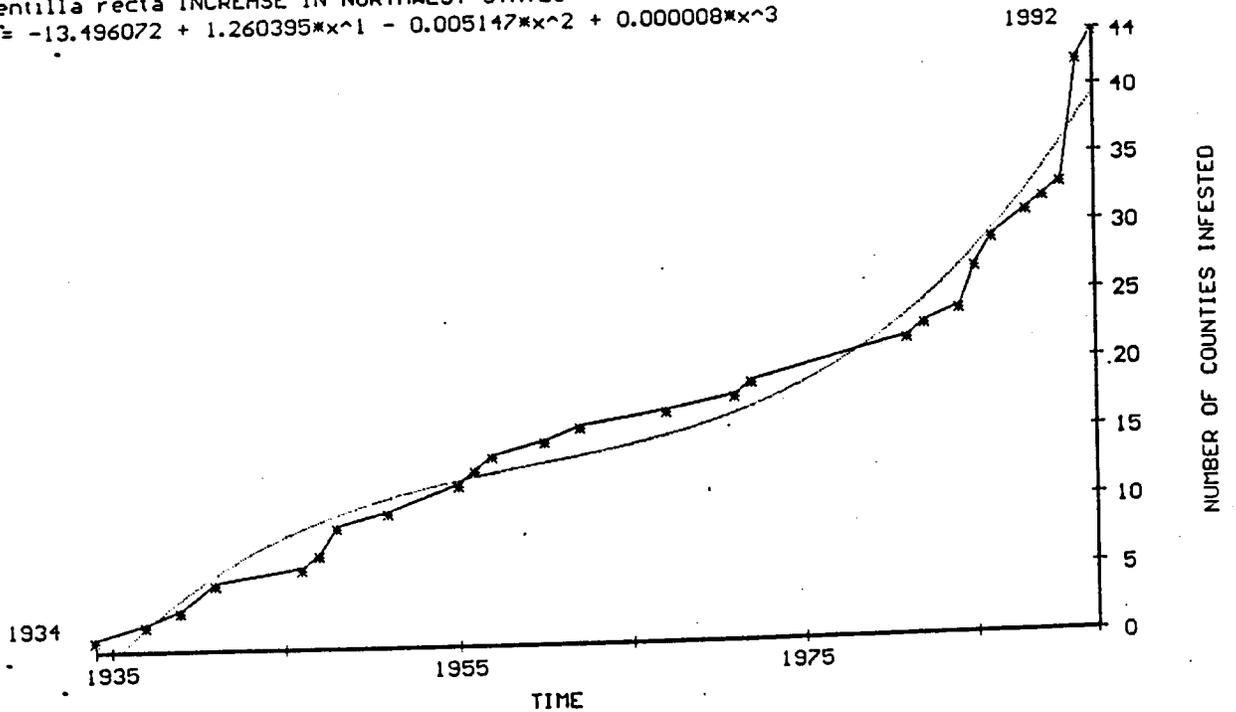


Figure 4. ELEVATIONAL DISTRIBUTION

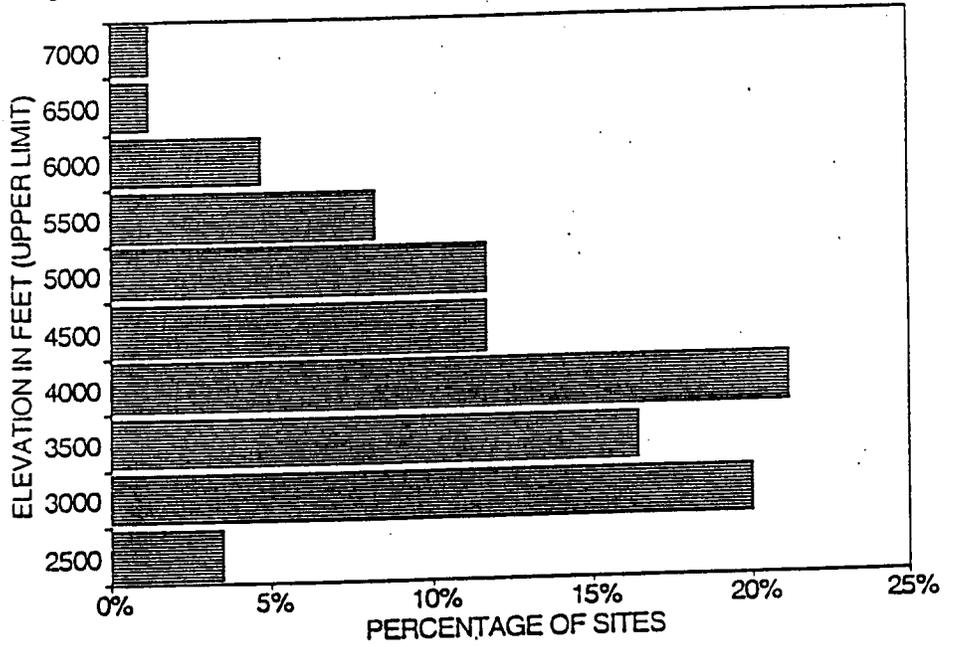


Figure 5. DISTRIBUTION OF SOIL CLASSES

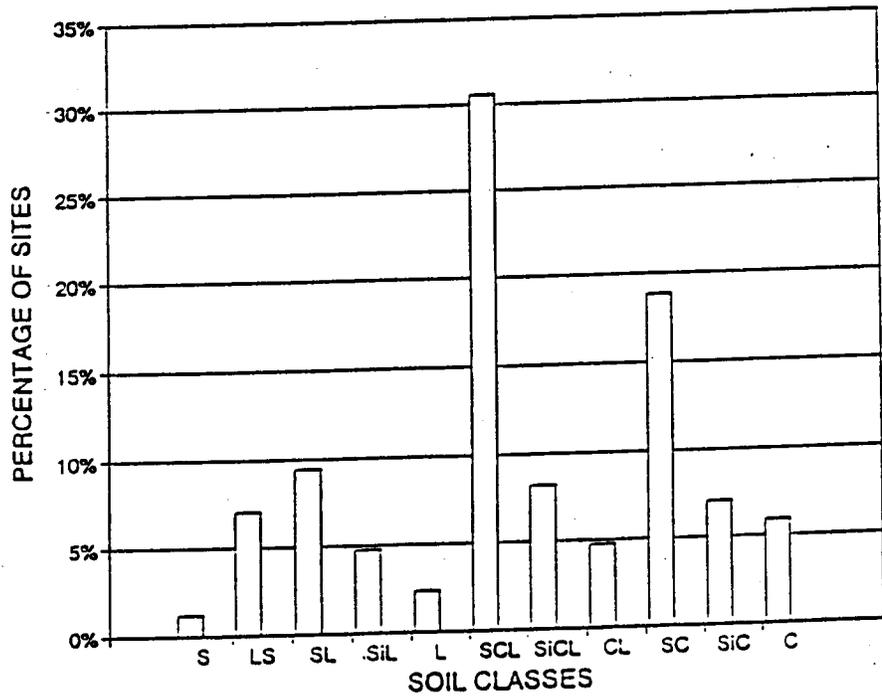


Figure 6. SIZE OF SULFUR CINQUEFOIL INFESTATIONS

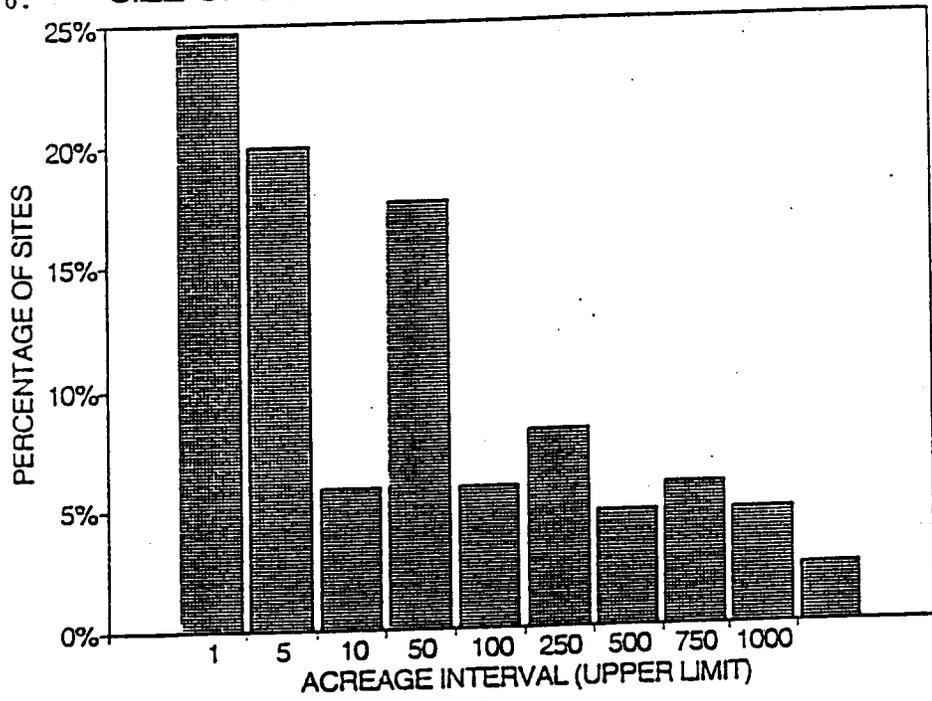
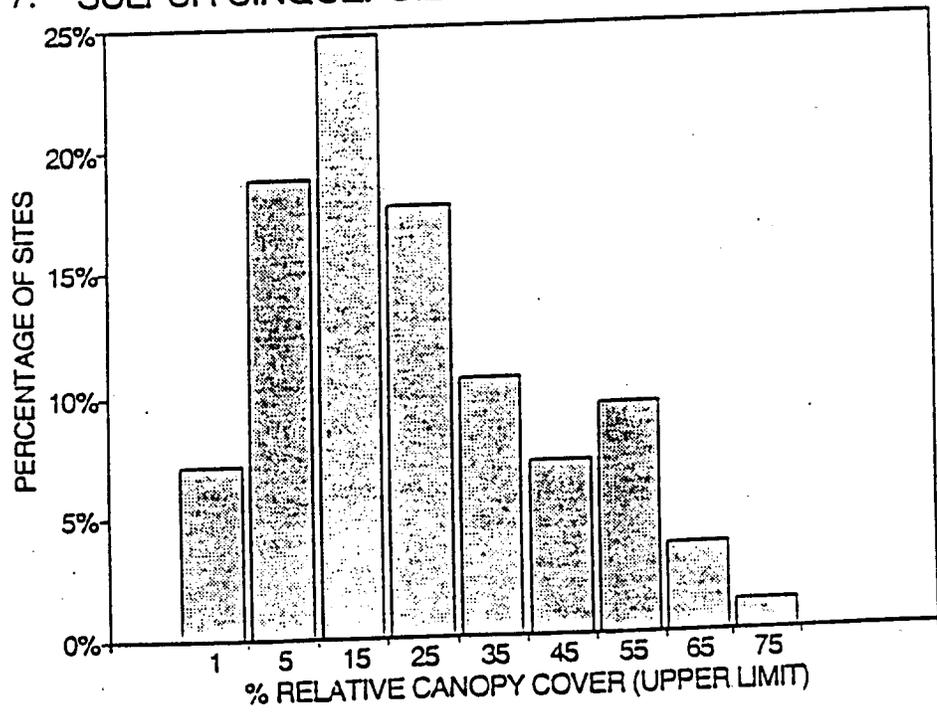


Figure 7. SULFUR CINQUEFOIL RELATIVE CANOPY COVER



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CHAPTER 19

YELLOW AND ORANGE HAWKWEEDS

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IDENTIFICATION

Yellow hawkweed (*Hieracium pratense* Tausch.), and orange hawkweed (*H. aurantiacum* L.) are members of the sunflower family (Asteraceae). They are among eleven species of hawkweeds introduced into North America from Europe. They differ from the native hawkweeds by lacking upper stem leaves; having stems branched at the tip; having flowers in closely clustered, rather than open, terminal groups; and having leafy stolons.

Yellow and orange hawkweed are difficult to distinguish when not in flower. Plants in the vegetative stage have a low-growing rosette of oblong or narrowly elliptical leaves. The entire plant is covered with hairs; those on the leaves are long and spreading; those on the stems are bristle-like. Each rosette has about 10 leaves that narrow at the base to short petioles with narrow margins. The leaves are usually smooth-margined, though sometimes slightly toothed, green or yellow-green above, and paler beneath. Both species contain a white sap. Shallow, fibrous roots do not

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tightly anchor plants to the ground, allowing plants to be easily uprooted.

A rosette produces a single, erect flowering stem, which has 1-3 small, bract-like leaves on the lower portion. Flowers are produced in clusters of 3-15 heads, arranged in a tight, branched, round-topped inflorescence at the end of the flower stalk. Bracts on the flower head are of unequal length, and arranged in 2 to 3 more or less overlapping rows. Flower heads are similar to those of dandelions, having only ray flowers. Disc flowers, like those in the center of a daisy, are absent. Seeds (achenes) are cylindrical, and have a single circle of white or tawny bristles at one end.

Yellow hawkweed is also known as field or meadow hawkweed. Rosette leaves are oblong, 1-4 inches long and 0.5-2 inches wide, and slightly toothed. Leaves are light green, with long hairs on both the upper and lower surface. Each rosette produces a single flowering stem 2-15 inches high. Dark, bristle-like hairs along the entire length stand at right angles to the stem. No more than 1-3 small, reduced leaves are found on the lower half of the stem. The inflorescence of 5-15 bright yellow flowers is arranged in a tight cluster at the top of the stalk. Each flower head is about half an inch in diameter when in full bloom. Seeds are columnar, brown, and have a yellowish pappus.

Orange hawkweed is also known as king-devil hawkweed, red-devil, devil's paintbrush, Grim-the-collier, missionary weed, red daisy, and golden mouse-ear hawkweed. In England, orange hawkweed is grown as an ornamental, known as fox-and-cubs (Clark 1973). It is easily distinguished from all other hawkweeds by its bright orange to red-orange flowers. The entire plant, including the flower heads, is covered with dark, bristle-like hairs. Hairs are black, gland-tipped, and sometimes matted in appearance. Basal leaves are spatula-shaped or elliptical, 2-5 inches long and 1/4 - 1 inch wide. The slender flower stem is 3-12 inches tall and leafless or with 1-2 small, stalkless leaves. There are 5-20 heads, arranged in compact, round-topped clusters. Achenes are oblong, brown and columnar. Pappus bristles are brownish.

ORIGIN, HISTORY AND DISTRIBUTION

The origin of both yellow and orange hawkweed is central and northern Europe. They were introduced into North America during the late 1800's and have become naturalized and weedy in much of the northeastern United States (Rickett 1973). Their western expansion is relatively recent.

In Europe, orange hawkweed is part of a large, diverse taxon originating from a restricted area in northern and central Europe (Tutin et al. 1970). In its natural range, it occurs primarily in the mountains, though is widely cultivated elsewhere. It has not

been reported in southern or eastern Europe. From Europe, it has spread to North America (Hulten and Fries 1986), New Zealand (Grundy 1989), and Japan (Suzuki and Narayama 1977).

Orange hawkweed was introduced in Vermont in 1875 as an ornamental (Voss and Bohlke 1978) and within 25 years had spread throughout much of New England, west to Michigan (Voss and Bohlke 1978) and into Canada from New Brunswick to Ontario (Britton and Brown 1970). It is now widely distributed throughout the eastern seaboard, extending west to Minnesota and Iowa, and south to Virginia and North Carolina (Johnson 1977). It has been reported along the eastern slope of the Rocky Mountains in Colorado (Weber 1990).

Orange hawkweed was first reported in the Intermountain West from a specimen collected in Spokane, WA in 1945 (Marion Ownbey Herbarium, Washington State University, Pullman). Subsequent reports of orange hawkweed were in 1960 from Kitsap County, Washington, and Multnomah and Deschutes counties, Oregon (Abrams and Ferris). It is found in all of the ten northernmost counties of Idaho except Nez Perce county. It has been reported in the Lower Mainland in British Columbia, Canada (Guppy 1976) where it infests pastures, old fields, roadsides pastures, lawns, and idle land. It has been planted in all areas of the U.S. as a garden ornamental, and is often found escaped from cemeteries and gardens.

Yellow hawkweed occurs in the northern, central, and eastern portions of Europe. It was probably introduced into the U.S. in 1828 (Britton and Brown 1970). It is now found from Quebec to Ontario, and southward to Georgia and Tennessee (Rickett 1973). The first report of yellow hawkweed in the Pacific Northwest is from 1969 in Pend Orielle County, WA.

Yellow hawkweed is a weed of moist pastures, forest meadows, abandoned fields, clearcuts, and roadsides. It has shown a tendency to invade mid to high elevation, pristine environments which are undisturbed. Infestations in the Intermountain West are on both public and private lands. The major infestations of both hawkweeds are centered in northern Idaho, northeastern Washington (extending into the Okanogan Highlands), and northwestern Montana (extending to the eastern foothills of the Rocky Mountains). Yellow hawkweed extends from the Canadian border in the north to the Salmon River corridor in the south. It is found in the eight northernmost counties of Idaho (Boundary, Bonner, Kootenai, Benewah, Shoshone, Latah, and Clearwater) and one county of central Idaho (Valley), four northeastern counties in Washington (Pend Orielle, Spokane, Stevens, and Ferry), and five northwestern counties in Montana (Lincoln, Sanders, Flathead, Missoula, Mineral, and Lewis). In every location it is considered to be spreading rapidly.

A third closely related, introduced hawkweed species, mouse-ear hawkweed (*H. pilosella* L.), is found in the northeastern U.S., southeastern Canada, and in Columbia County, Washington (Roché 1992).

POTENTIAL INVASION

Orange and yellow hawkweeds are among the more recent alien weed taxa to impact the western U.S. During the past 10 years, public concern for the spread of these species has escalated. The rapid pace at which the hawkweeds are currently expanding their range in the inland northwest is a reflection of the particularly invasion-susceptible nature of the region. The rate of spread in the U.S. is difficult to predict. However, their occurrence as weeds in the northeastern states during the last century, and their original distribution in northern and central Europe, suggest that the hawkweeds pose the greatest threat to cooler, moister sites within the region, ranging from the lowlands of the northern Pacific coast to elevations of 5,000 feet or more in the mountain states. The areas most vulnerable to invasion include roadsides, forest meadows, clearings from logging activity, lawns and pastures. They are likely present throughout the northwestern U.S. in flower beds around residences in areas where they are not generally reported as weeds.

IMPACTS

Both yellow and orange hawkweed are aggressive invaders, posing genuine threats to biodiversity and productivity of infested areas. Once established, hawkweeds quickly form dense patches that dominate surrounding forbs and grasses.

The historical pattern of colonization and infestation with the introduced hawkweeds in the eastern U.S. has been primarily in pastures and abandoned fields. In the western U.S., however, preferred habitats appear to be at elevations above 2,000 feet. Consequently these hawkweeds, particularly yellow hawkweed, can be devastating to wildlife habitat, recreation areas, and pristine mountain meadows. On agricultural lands, poorly-managed hayfields and pastures are susceptible to infestation by yellow and orange hawkweed.

Livestock, deer and elk consume hawkweed foliage and buds. The forage productivity of hawkweeds is very low compared to important forages (Table 1). The protein content of leaves appears to be low to moderate, depending on location. Yellow hawkweed leaf protein content ranged from 7% among locations, equal to low quality cured timothy hay, to 11%, that expected in high-quality grass hay. The digestibility of hawkweed leaves (74%) was well above that expected of grass pasture (60-65%), and equal to or higher than expected of commonly used dicotyledonous forages. Flower buds from the same plants were average in digestibility

(64%) but contain twice as much protein (18%) as the leaves. The digestibility data suggest that nutritional components of yellow hawkweed leaves may be utilized by ruminants when they consume plants in good physiological condition.

Research indicates that weed digestibility can depend on the proportion of the weed in an animal's diet. The stiff pubescence and mucilaginous consistency of hawkweeds suggest that the forage value of hawkweed depends on more than digestibility and nutrients. Animal acceptance or ability to consume and utilize large amounts of the material are not known. Seasonal variation in yellow hawkweed forage value, various effects of dietary proportion upon digestibility, and comparative palatability are also not yet known.

Since the spring pattern of hawkweed growth coincides with that of the peak productivity of most forage grass and forb species, the contribution of yellow hawkweed to animal nutrition is does not appear significant, in view of its inherently low productivity.

Literature available does not specifically analyze the overall economic impact of hawkweeds.

BIOLOGY AND ECOLOGY

In Europe, yellow and orange hawkweeds are ruderal species of pastures, roadside cutbanks, disturbed, undeveloped land, abandoned fields and meadows. In most cases they are found in small, isolated pockets. Their highest densities are found on recently

disturbed areas, and they do not persist as dominant members of the early successional community.

Thomas and Dale (1975), in studies of *H. floribundum*, show that new plants begin as either seedlings or as leaves sprouting from stolons, rhizomes or roots (Peterson 1979). Plants will overwinter the first year as rosettes and flower the second summer. As the rosette develops, an erect, slender stem will grow from the center. Yeung and Peterson (1972) showed that flowering in the closely related *H. floribundum* is dependent on photoperiod. Flowering occurs only after exposure to a specific amount and quality of light. Flowers are produced at the end of the stem, which is unbranched except at the apex. Several studies have looked at density-dependent phenomena in the population. For example, the timing and rate of flowering, and the number and viability of seeds, and stolon production are all regulated to some degree by the density of plants in a colony (Thomas and Dale 1975). Plants in the center of the patch, where the density can reach 3500 plants per sq. yd., have a lower rate of flowering (Thomas and Dale 1974). On average, less than 10% of orange hawkweed plants flowered in the middle of the patch (Stergios 1976).

Seeds of mature in the heads, and do not have an after-ripening period (Thomas and Dale 1974, Stergios 1976). Although seeds can germinate soon after they drop from the plant, the highest germination rate was from seeds that were produced the

following spring after exposure to cold temperatures. In a study of the importance of seed to the maintenance of a population, Thomas and Dale (1974) found that in the closely related *H. floribundum*, only 1% of new plants in a population were from seedlings. Viable seeds are produced either sexually (through pollination) or asexually (without pollen) via apomixis. Hybrids are numerous (Voss and Bohlke 1978). Hybrids of orange and yellow hawkweed have been reported in eastern Canada (Lepage 1971).

Movement of hawkweeds over substantial distances from parent colonies, like any that of other seed-bearing species, is normally by seeds. Voss has indicated that hawkweed seeds do not significantly contribute to the population dynamics of colonies of the weedy hawkweeds in North America (Voss). Presumably this refers to populations within a colony. The majority of seeds (80%) are dispersed within the population (colony), and less than 1% are found further than 10 inches from the colony (Thomas and Dale 1974). Seeds that germinated outside the colony and established rosettes often perished from summer drought or low winter temperatures (Johnson and Thomas 1978).

The dominant means of within-colony reproduction in both yellow and orange hawkweeds is by stolons or rhizomes. Orange hawkweed sends out from three to eight long, slender stolons along the soil surface. Yellow hawkweed produces short, stout stolons, accomplishing most of its vegetative spread by shallow, underground

rhizomes (Thomas and Dale 1974). Growth of stolons and rhizomes becomes evident when the plant flowers. These are initiated from axillary buds at the base of rosette leaves. Non-flowering rosettes do not send out stolons or rhizomes.

A new rosette is formed when the end of the stolon or rhizome grows leaves and roots. As the roots develop, the plant becomes established, the stolon or rhizome degenerates, and the new rosette becomes independent (Thomas and Dale 1974). Plants can also start from buds located along a creeping root (Thomas and Dale 1975). However, this is uncommon, and usually only occurs when the root is severed from the parent plant. The new rosette will overwinter, and flower the following summer, and die.

European cytological studies of the subgenus *Pilosella*, which contains both introduced hawkweeds, show that the base number of chromosomes is 9. Polyploids are common in the group; ploidy ranges from diploid ($2x$; $2N=18$) to decaploid ($10x$; $2N=90$) (Skalinska 1976). This situation may give rise to different chromosome races, which show differences in their morphology, habitat preferences and general distributions.

MANAGEMENT

Detection: Early detection of individual plants and small colonies of these species is critical to effective management, because spread is comparatively rapid from such colonizations. Suspected

detections of alien hawkweeds should be reported to the county agricultural agent or county weed supervisor. Voucher specimens should be collected for verification, particularly if new infestations are to be destroyed. It is important to verify that native species are not mistaken for aliens, to ensure that valuable time and resources are not allocated on alien species.

Conventional surveys to determine location of hawkweeds are not practical for management action where extensive infestations of the weed cover a wide area. Detection of yellow hawkweed with high resolution multispectral digital imaging systems has been investigated by Carson, et. al. Digital images recorded from an airplane with a multispectral scanner attached produced images of flowering yellow hawkweed with 1 m resolution. Where yellow hawkweed strongly dominated the vegetation, e.g. where hawkweed cover exceeded 60%, infestations were detectable with high accuracy. Infestations ranging from 20 to 60% hawkweed cover were detectable, but not consistently. Hawkweed cover was not detectable at densities of 20% or less. Refinement of this work may result in greater sensitivity.

Cultural practices: Hawkweeds do not persist in cultivated crops where annual tillage and competitive cropping integrate to suppress them, particularly if effective herbicides are used in the crop production system. The key to maintaining commercially

satisfactory suppression is tillage every year or two, and maintenance of vigorous crop growth for effective competition. Crop plants should be provided adequate soil fertility, free of excessive insect and disease parasitism, and should be harvested in accordance with the principles of good crop care.

Herbicides: Nontilled pastures and meadows should be treated with herbicides before blossoming to prevent seed production. Yellow and orange hawkweeds are effectively controlled using 2,4-D, clopyralid and picloram (Noel et al. 1979, Lass and Callihan 1992b). Studies conducted at the University of Idaho showed that over 50% control was achieved for six years following treatment with clopyralid (Lass and Callihan 1992b). Other herbicides either failed to control yellow hawkweed or suppression was for less than 3 years (Lass and Callihan 1992a). 2,4-D alone has not consistently provided adequate control, but enhances the action of dicamba. Total elimination can only be achieved by ensuring complete treatment of an area with a sufficient amount of an effective herbicide. Clovers and other herbicide-susceptible crops or desirable forbs will likely be severely damaged or killed by herbicides that are effective on hawkweeds. With 99% control of hawkweeds in a pasture, forage yields were dramatically increased. With only 85% control, forage production was reduced by 50%. With no control, forages were completely displaced by hawkweed (Callihan

et al. 1982). Infested pastures should be carefully evaluated before spraying. For best longterm hawkweed control, livestock must be withheld from grazing treated pastures until the grasses have recovered and are producing dense, vigorous forage.

Fertilizer: Hawkweeds benefit from nitrogen fertilizer, so the simple addition of nitrogen fertilizer to a pasture will not result in hawkweed suppression. However, if beneficial plant species, particularly adapted perennial grasses, are sufficiently populous for pasture renovation, and the weeds are suppressed by other means such as treatment with a selective herbicide, fertilizers can aid hawkweed control by stimulating the competitive species. Research has shown that enhanced competition from fertilizer inputs significantly reduce the competitive advantage of the weed (Reader and Watt 1981). Fertilization with nitrogen is effective either before the hawkweed displaces most of the perennial grasses (Reader and Watt 1981), or in concert with a selective herbicide. Early spring treatment, where grasses are present, with both the herbicide and the nitrogen fertilizer are more effective than at other times of the year, because the hawkweed plants are small and because spring rains move the nitrogen into the grass root zone. Hawkweeds are suppressed, allowing the grasses to respond to the fertilizer. If the nitrogen supply is substantial enough to stimulate sufficient grass growth, the competition will maintain

grass dominance for several years. Grazing will inhibit grass dominance, so periodic fertilization, and herbicide will likely be necessary to maintain hawkweed suppression and grass dominance. Such a combination of herbicides and fertilizer will keep hawkweed populations to a satisfactory level and reduce the rate of spread of hawkweed once it becomes established in a field. It will not contain the spread unless total elimination of hawkweed flowering is attained.

Mechanical removal: Mechanical removal of hawkweed control has not proved successful for any but the smallest of significant infestations. This is not an advisable procedure for most circumstances. Digging the plants or otherwise disturbing the roots suppresses the plants temporarily, since the disturbed soil provides a good seedbed for hawkweed seeds previously shed to the soil around the plant. Also, plants can regrow from buds on root, stolon, and rhizome pieces. When hawkweeds are removed in this way frequently enough to prevent flowering, i.e. two or more times per year, this can be an effective means for limiting the establishment of new hawkweed colonies. If mechanically removed frequently enough that hawkweeds do not maintain above-ground growth for more than two weeks, the infestation can be eliminated over a period of several years.

Mowing: Plants continue to grow if the flower heads are cut, and cutting may increase the normal rate of vegetative spread. Flowering of mowed plants is generally delayed, and seeds are produced on shorter stalks. Repeated mowing, especially in lawns, encourages vegetative spread of the patch. Mowing does not provide sufficient control to stop colony expansion or long-distance propagation by seeds. It does not result in control sufficient to comply with noxious weed laws, but it can reduce the overall supply of seeds released into the environment.

Management Coordination: Recent awareness of the rapid expansion of hawkweeds in Idaho resulted in the formation of a Hawkweed Action Committee based in St. Maries, Idaho. This group is a non-profit *ad hoc* organization comprised of local weed control personnel, private landowners, state and federal land managers, and representatives of the timber industry. The purpose is to promote awareness of the problem and the need for an aggressive, well-coordinated, regionally-based hawkweed management strategy against the increasing threat posed by the hawkweeds in the Inland Northwest¹.

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Biological Control:

No biological control parasites are currently available for hawkweeds in North America. The USDA-ARS in Bozeman, MT, and in France, began a search for natural enemies of our alien hawkweeds in Europe in 1993 . Hawkweed-specific parasitic insects appear to be the only hope for solution to the large infestations areas that are not accessible for other control practices. However, the likelihood of finding such biocontrol agents is not yet clear. The University of Idaho has collaborated with this program by conducting surveys of the weeds' distributions and the native insects that attack the native and introduced hawkweeds. The aim of a biological control program for hawkweeds is to identify, screen and eventually introduce natural enemies of the hawkweeds from Europe to reduce the competitive ability of the weeds.

Table 1. Protein and digestibility¹ of yellow hawkweed.

Source	Crude protein	Digestibility	Ash
		----- % -----	

Fresh Leaves	9	74	14
Buds	18	64	10

¹ 24 hr. fermentative *in situ* dry matter disappearance.

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CHAPTER 20

YELLOW AND PURPLE STARHISTLE

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IDENTIFICATION

Yellow and purple starthistle (*Centaurea solstitialis* L.; *Centaurea calcitrapa* L.) are members of the knapweed (*Centaurea* L.) complex in the sunflower family (Asteraceae). They are annual or biennials with a stout taproot, produce a rosette of basal leaves that are deeply lobbed (pinnatifid) mostly less than 8 inches (20 cm) long and 2 inches (5 cm) wide. Stems are rigid and densely branched 1 to 4 feet (3 to 12 dm) tall. Stem leaves are entire and linear. Flower heads are single on the branch ends, and have involucre bracts armed with stout straw colored spines 1 to 1.5 in (1 to 3 cm) long that radiate from the flower head in a star shape. There are few flowers per head, and heads lack ray flowers.

Yellow starthistle is an annual to biennial with yellow flowers. Stems of yellow starthistle can be distinguished from purple starthistle by the decurrent leaf bases that form wings on the stems. Upper leaves are spine tipped. Yellow starthistle stems have thin wooly hairs that persist through the growing

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season. Seeds are of two types. The marginal seeds are dark colored and without bristles (pappus). Central flowers are straw colored and have a white pappus 3 to 5 mm long.

Purple starthistle is a biennial with purple flowers. It can be distinguished from yellow starthistle in the rosette stage by a circle of spines at the center of the rosette. Young stems and leaves are covered with cobwebby hairs that are lost with age. The ventral leaf surface is dotted with resin glands. Seeds of purple starthistle are straw colored with dark brown mottling and have no pappus.

ORIGIN, HISTORY, AND DISTRIBUTION

Yellow starthistle is native to the Mediterranean region of Europe (Roche' and Talbott 1986). The first North American introductions of this species are believed to have occurred in contaminated alfalfa seed shipped to California. The earliest records of yellow starthistle infestation were found in flora analyses of adobe brick from the post-mission period in California (after 1824). Additional early records of yellow starthistle can be found in herbarium specimens collected in California in the middle and late 1800's. In the Pacific Northwest, yellow starthistle was first reported at Walla Walla, WA around the turn of the century. Reports of yellow starthistle spread into perennial and annual grasslands in this region began in the 1920's.

Infestations are currently estimated to be about 800 hectares (8 million acres) in California, 100 hectares (280,000 acres) in Idaho, 55 hectares (135,000 acres) in Oregon, and 60 hectares (148,000 acres) in Washington (Maddox et al. 1985, Roche' and Roche' 1988, Callihan et al. 1989). Yellow starthistle appears to have reached its latitudinal boundaries (north and south), but continues to invade rangeland at rates ranging from 3 to 8 hectares (7,000 to 20,000 acres) per year within these boundaries. Colonies of yellow starthistle have been reported on the great plains, but they only persist for 2 to 4 years and usually do not produce viable seeds. (Barkley 1986)

Purple starthistle is native to the Mediterranean region, southern Europe and northern Africa. It's origins in North America are probably similar to yellow starthistle establishing first in the San Francisco Bay area of California where it became a major problem on annual rangelands. In California, purple starthistle occurs on disturbed sites generally below 1000 m (3000 ft) elevation in the western part of the state, the Cascade Range foothills, the Sierra Nevada foothills, and the Great Central Valley (Hickman 1993). Purple starthistle is a lesser problem in other western states but is reported to occur along railroads and roadways in Oregon, Washington, and British Columbia. Although there are no collections in Montana, it is reported to occur on disturbed sites in Converse county Wyoming (Dorn 1977). Purple

starthistle was reported from Yuma County in Arizona. Purple starthistle does not occur on the great plains, but it is sometimes confused with Iberian starthistle (*C. iberica*).

POTENTIAL INVASION

Starthistles have the ability to invade rangelands throughout the western United States. In the Pacific Northwest, the most susceptible rangelands are those with deep loamy soils, south facing slopes, receiving 30 to 64 cm (12-25 inches) of precipitation (winter/spring peak) (Roche' et al 1994). Yellow starthistle favors sites originally dominated by perennial grasses; primarily bluebunch wheatgrass, Idaho fescue, and Sandberg's bluegrass. This weed does not appear to compete well with sagebrush, but readily invades areas of soil and/or vegetation disturbance within sagebrush habitat types.

The competitive success of yellow starthistle is directly related to its rapid growth and resource capture (Sheley et al. 1993, Sheley and Larson 1994b). However, yellow starthistle seedlings and rosettes are sensitive to resource stress (competition for light, water, nutrients, and space) and are subject to high mortality when stress conditions prevail. In general, yellow starthistle seedlings grow more rapidly than most perennial grass seedlings. This characteristic leads to poor grass stand establishment when new grass seedlings are infested with

yellow starthistle. Once established, vigorous stands of perennial grass have been shown to limit re-invasion by yellow starthistle (Larson and McInnis 1989a, Larson and McInnis 1989b). Perennial grasses that initiate growth in the fall, maintain some growth through the winter months, and continue growth into mid-summer have the best success of competing with yellow starthistle.

In annual-dominated rangelands (e.g. cheatgrass) with deep soil, the rapid and deep penetrating roots of yellow starthistle tend to avoid direct competition with annual grasses (Sheley and Larson 1994c). In areas where cheatgrass is widely dispersed, yellow starthistle root and shoot growth rates can be twice as fast as cheatgrass. This growth attribute results in deep soil penetration by starthistle roots, continued growth well into the latter part of the growing season, and increased starthistle seed production. In such circumstances, yellow starthistle can dominate the site. However, yellow starthistle growth rates tend to decline as plant density increases (cheatgrass and yellow starthistle) and/or soils become shallow (Sheley and Larson 1994c). This shift in competitive ability means that yellow starthistle will take on the role of a secondary or co-dominant species when these conditions prevail.

IMPACTS

Yellow starthistle is a pest in rangelands, grain fields, orchards, vineyards, cultivated crops, pastures, wastelands and roadsides. It forms solid stands that drastically reduce and eliminate forage production and grazing capacity. Cattle will graze yellow starthistle in early spring but it provides below subsistence nutrition value (Calihan et al 1989). Mature plants are unpalatable and livestock (and wildlife) avoid feeding around the spiny plants. On dryland grain fields, yellow starthistle is found at outer boundaries where it reduces yields (Calihan et al 1989).

Yellow starthistle causes injury to livestock. Poisoning occurs in horses, called chewing disease, and results in the inability to eat and drink. Mechanical injury to livestock can result when animals are forced to feed on or around starthistles.

BIOLOGY AND ECOLOGY

Seed production

Yellow starthistle is a winter annual and is dependent upon seed production for population survival. A single yellow starthistle plant has the potential to produce up to 150,000 seeds. In studies near Walla Walla WA, yellow starthistle produced 20 to 120 seeds per plant, depending upon the density of the plants and the amount of spring precipitation (Sheley and Larson 1994a).

Seed dispersal

Yellow starthistle plants produce two types of seed, those with parachute-like plumes and those without plumes. The majority of seeds are plumed and are dispersed at maturity (July through September). Plumeless seeds are retained in the seedhead at maturity and dispersed between November and February. Over 90% of the seeds fall within 2 feet of the parent plant (Roche' 1991). This dispersal pattern tends to form a slow invasion front created by a large numbers of seeds moved short distances by wind.

About sixty percent of the seeds produced by a starthistle population actually survive the process of seed dispersal (Sheley and Larson 1994a). Birds, such as ring-neck pheasants, California quail, house finches, and American finches feed on yellow starthistle seed, and have been implicated in both long and short distance dispersal (Roche' 1991). Finches tend to shell seeds leaving most of the consumed seed non-viable. Quail and pheasants consume whole seeds which may occasionally be passed in a viable form. Other animals (including man), whirlwinds, and vehicles contribute to the long and short distance transport of yellow starthistle seed.

Germination and viability

Yellow starthistle germinates rapidly under a variety of conditions. Under optimum conditions, which is near 68° F with

unlimited moisture, plumed seed initiate germination within 16 hours, and can reach a rate of 16% germination within 24 hours (Sheley et al. 1993). Moreover, within 48 hours, 75% of the plumed yellow starthistle seeds germinate under optimum conditions. In comparison, plumeless yellow starthistle, medusahead, and hedgehog dogtailgrass germination was below 44% with these same conditions. Under dry or salty soil conditions yellow starthistle germination was reduced. The ability to germinate rapidly under favorable and unfavorable field conditions gives yellow starthistle an opportunity to occupy a site by capturing and utilizing resources before neighboring species.

Approximately 95% of the seed of yellow starthistle are viable, and 10% of the seed can remain dormant for more than 10 years (Callihan et al. 1993). In heavily infested areas the soil seed bank of yellow starthistle approaches 13% of total seed production and that these seeds are plumeless (Sheley and Larson 1994a). Seeds lying dormant in or on the soil create a difficult problem for land managers because they allow yellow starthistle to re-invade sites rapidly following most herbicide applications.

Seedlings

Yellow starthistle typically initiates growth in the fall following significant precipitation (.25-.5 in.) (Sheley and Larson 1994a). If seeds are available, the number of yellow starthistle

seedlings will continue to increase until soil moisture and/or soil temperatures become limiting. In studies near Walla Walla WA, yellow starthistle seedling populations reached winter-time (mid-January) densities approaching 2500 plants per square foot. Subsequent frost heaving events reduced seedling populations by about 40%. Ninety-five percent of the seedlings observed in these studies germinated in the fall and completed their life cycle as a winter annual. However, seedlings can emerge in the spring and they can complete their life cycle in the same year, or continue into the next growing season depending upon growth conditions.

Rosettes

Starthistle rosettes form as leaves emerge from the base of the plant. Rosettes generally have 6-15 (up to 28) leaves and range from 1 to 8 inches in length. In our research, all seedlings surviving the frost heaving period went on to become rosettes (Sheley and Larson 1994a). This transition begins in March and continues into May. The rosette growth stage appears to be a very difficult time for yellow starthistle. In most years, 60-75% of yellow starthistle rosettes die by July either from moisture stress or self thinning.

Adults

As starthistles mature, a flower stalk elongates from the center of the rosette ranging in height from 2 inches (dry conditions) to 5 feet (moist non-stressed environments). Flowering can occur as early as June, and their production can continue into September. Flowers are bright yellow (or purple PST) subtended with yellow-green spines 1/4 to 2 inches long. Adult mortality, can occur in stressful environments but in our studies, yellow starthistle adult populations remained statistically constant (approximately 70 plants per square foot) in dry and wet (spring) years (Sheley and Larson 1994a).

In early fall, yellow starthistle plants lose their leaves and dry to a silvery-grey skeleton, with cottony white terminal seedheads. With the arrival of fall rains, seeds on or in the soil begin to germinate, and the cycle is repeated.

MANAGEMENT OF YELLOW STARTHISTLE

The purpose of this section is to provide a conceptual foundation for the management of yellow starthistle. Management strategies for weeds typically include 3 different approaches: (1) **prevention** programs seek to prevent weeds from invading a new site by maximizing the competitive ability of existing vegetation; (2) **containment** programs seek to contain existing weed infestations to sites where they exist and prevent encroachment of the weed to adjacent lands; (3) **control** programs seek to reduce densities of

weeds on areas where they exist and replace weeds with more desirable vegetation. Specific weed control recommendations should be developed in consultation with county extension and weed control agents.

Prevention

Prevention techniques are the least expensive and most effective method of limiting yellow starthistle invasion on productive rangelands. Proper grazing management is an essential element in this strategy, and although additional research needs to be conducted, there are several key grazing elements that can be identified at this time. An effective grazing system should include moderate grazing (typically 30-50% utilization of annual production), altering the season of grazing, rotating livestock to allow perennial plants to recover before being regrazed, and promoting litter accumulation. Such grazing will limit yellow starthistle germination and promote early mortality of seedlings and rosettes through the maintenance of vegetation cover and vigorous grass growth.

Yellow starthistle prevention can not be achieved through grazing management and plant competition alone. Disturbance (soil and plant community disturbance) is a natural component of all plant communities and is an essential part of plant community development and maintenance. Unfortunately, yellow starthistle is

well adapted to take advantage of most grassland disturbances. Therefore prevention programs need to include a rangeland monitoring component so that isolated patches and individuals of yellow starthistle can be identified, flagged, and treated for control. In most cases isolated infestations should be flagged for several years so that treatment effectiveness can be followed through time.

Containment

Containment programs are generally used to restrict the encroachment of yellow starthistle infestations onto adjacent rangeland. An effective method of yellow starthistle containment is to spray the borders of the infested area with a herbicide. This approach concentrates control efforts on the leading edge of yellow starthistle infestations and is designed to address the tendency of yellow starthistle to invade as a slow advancing front formed by large quantities of seed being dispersed short distances from the parent plants. Monitoring programs similar to those previously described (prevention section), should be implemented to locate satellite populations of yellow starthistle within the interior of the rangeland area. Containment programs should be viewed as a 'stop-gap' measure and should be replaced with a control program at the earliest possible date.

Chemical Control

An effective control program requires disruption of the annual cycle of yellow starthistle invasion and the closure of the plant community to rapid re-invasion. Yellow starthistle control involves using combinations of treatments, including herbicide applications (with follow-ups), cultivation and seeding desired grasses. A number of herbicides are available to landowners to initiate the process of yellow starthistle control. Actively growing starthistle seedlings and rosettes are most susceptible to herbicide control and chemicals such as 2,4-D and Tordon 22k can provide effective initial control. Both chemicals are classified as being selective toward broadleaved weeds, but Tordon 22K may kill grass seedlings with less than 3 to 4 leaves.

Starthistles can be controlled by applying 1 pound active ingredient per acre of 2,4-D low volatile ester (LVE). Applications when starthistles are in the rosette growth stage are generally effective but repeated applications may be necessary. Applications of 2,4-D LVE after the rosette growth stage is ineffective. 2,4-D LVE is highly volatile and the label and local weed control district should be consulted for specific advise for each site.

Tordon 22K applied at a rate of .5 pounds active ingredient per acre selectively controls most broadleaves, including starthistles. Either fall or spring applications are effective.

Tordon 22K should be applied in the spring (rosette growth stage) in preparation for a fall seeding, or fall prior to a spring seeding of revegetative grass. Application rates as low as 0.125 and 0.25 pound active ingredient can be applied in the fall to inhibit seed germination of yellow starthistle. Fall grass seeding can proceed following Tordon application if a drill is used (i.e. rangeland drill) that will excavate tordon treated soil from the drill row. Tordon 22K is a restricted use herbicide and should not be used near water and broadleaf crops. Label and local weed control district should be consulted for specific advise for each site. All herbicide application should be done by qualified individuals according to label instructions.

Following initial control, a perennial grass cover should be established on the site to interrupt the cycle of re-invasion. Grass stand establishment will increase the level of resource stress faced by starthistle seedlings and rosettes, limiting their survival and the rate of re-invasion. Oahe intermediate wheatgrass, Tualitin tall oatgrass, Paiute orchardgrass, Covar sheep fescue, Critana thickspike wheatgrass, and Sherman big bluegrass have successfully controlled or reduced the rate of starthistle re-invasion (Larson and McInnis 1989a, Larson and McInnis 1989b). The degree of success or failure of any seeding will depend on the selection of a grass species suited to the site, the density of the established stand of grass and the land

manager's ability to maintain grass vigor. Yellow starthistle growth rates and seed viability require a long-term commitment to starthistle control programs. This commitment will likely include an initial control and vegetation establishment program followed by a program of vegetation management and monitoring with periodic chemical application to control localized infestations. We recommend that land managers refrain from fertilizing new grass seedlings that are infested with yellow starthistle because that practice has been shown to increase starthistle production (Larson and McInnis 1989a).

Mechanical control

Hand pulling and grubbing can provide effective control of small infestations of starthistles, but because it is costly and labor intensive, mechanical control is not practical on non-crop rangeland. Over a period of years, hand pulling or cultivation can limit seed production and deplete seed reserves. Mowing and burning is an ineffective control of starthistles.

Biological control

Three weevil species (*Bangasternus orientalis*, *Eustenopus villosus*, *Larinus curtis*) and two flies (*Urophora sirunaseva*, *Chaetorellia australis*) have been released in California and the Pacific Northwest during the past 8 years for yellow starthistle

control. All of these agents attack the flowerhead. The goal of these control agents is to either reduce seed production and reduce colonization or establishment of this species. The effectiveness of insect control on yellow starthistle is currently under investigation and it is too early to determine their long-term impact on yellow starthistle populations.

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CHAPTER 21

**THE BIOLOGY AND MANAGEMENT
OF NOXIOUS RANGELAND WEEDS: A SUMMARY**

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Exotic rangeland weeds are a major threat to biodiversity, sustainability, and properly functioning native ecosystems. The magnitude and complexity of these noxious weeds, combined with their cost of control, necessitates using an Integrated Weed Management (IWM) approach. IWM involves the use of several control techniques in a well-planned, coordinated, and organized program to reduce the impact of weeds on rangeland. Inventory and mapping is the first phase of any IWM program. The second phase includes prioritizing weed problems and choosing and implementing control techniques strategically for a particular weed management unit. IWM includes preventing encroachment into uninfested rangeland, detecting and eradication new introductions, containing large-scale infestations using an integrated approach, and often, revegetation. The third phase is adopting proper range management practices as a portion of the IWM program. The IWM program must fit into an overall ecosystem management plan.

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Currently, the majority of western rangelands are relatively intact native ecosystems and are uninfested by noxious weeds. Exotic rangeland weeds are spreading rapidly. Therefore, a critical objective of any ecosystem management program must be to prevent noxious weed invasion. The literature on preventing noxious weed invasion is scanty and poorly understood. Developing a noxious weed prevention program requires a combination of methods aimed at limiting weed encroachment. Preventing noxious weed invasion includes, limiting weed seed dispersal, containing neighboring weed infestations, minimizing soil disturbances, detecting and eradicating weed introductions early, and properly managing plant communities to maintain community structure and limit resource availability for use by weeds.

Riparian areas are the green zones along the banks of rivers and stream and around springs, bogs, wet meadows, lakes, and ponds. They are some of the most productive ecosystems in the west, displaying a greater diversity of plant and wildlife species than adjoining lands. Weed management along riparian zones requires many special considerations because of the sensitive nature of these ecosystems. Prevention, containment and small-scale eradication of invading weeds is important. Proper livestock grazing is essential to maintain competitive vegetation and streambank stability. Some weeds, such as leafy spurge, can be grazed by sheep or goats which helps shift the competitive balance

toward desirable species. Herbicides must be used with care in riparian areas in order to protect non-target vegetation and prevent water contamination. Careful hand applications and spot treatments will help protect non-target vegetation. Timing of applications when run-off is unlikely, use of shorter residual herbicides with low water solubility, and application above the mean high water mark will reduce the possibility of water contamination. Ideally, natural enemies appear well suited for controlling weeds along riparian areas because they do not impact water quality. However, most biological controls stress weeds or reduce seed production, but do not kill the weeds. A main objective in riparian areas is to control weeds IMMEDIATELY to prevent rapid seed dispersal by moving water. Mechanical control and revegetating weed infested riparian areas can be used effectively.

Bull, musk and scotch thistle are members of the sunflower family and thistle tribe. Bull thistle has a short fleshy taproot and grows 2 to 5 feet tall with many spreading branches. Bull thistle is normally a biennial and can germinate in the spring or fall. Bull thistle reproduces and spreads solely from seed. The key to managing bull thistle is to prevent seed formation. Hand-pulling, hoeing, tillage, and applications of auxin herbicides will control bull thistle. Several biological controls are available for controlling bull thistle. Musk thistle is a biennial which

germinates and grows the first years as a rosette. It develops a large, fleshy, corky taproot that is hollow near the soil surface. In its second year, musk thistle bolts and flowering shoots grow from 2 to 6 feet tall. Flowers are solitary and terminal on shoots. Seeds are shiny, striated, yellow-brown, with a white hairlike plume. The average musk thistle plant produces about 10,000 seeds. Seeds readily germinate, but can survive over 10 years in the soil. Managing musk thistle is similar to that of bull thistle.

Scotch thistle leaves are large, green, spiny, and covered with fine dense hairs on both sides. This gives the leaf a grayish-green appearance. First year rosettes are 10 to 12 inches or more in diameter. Leaves may be 2 feet long and 1 foot wide. Leaves have a distinct, white mid-rib. Scotch thistle has a fleshy taproot. As with other biennial thistles, scotch thistle reproduces and spreads solely from seeds and the key to its management is to prevent seed production. Chemical, mechanical, biological methods can reduce seed production and/or control the plants.

Common crupina is a member of the knapweed group of plants. The prominent midvein and large, fleshy cotyledons distinguish common crupina from associated species. Adults have few fleshy lavender to purple flowerheads that are 1/2 inches long. Common crupina is introduced from the Mediterranean region of Europe and

first reported in Idaho in 1969. Since then it has been found in California, Oregon, and Washington and currently infests over 50,000 acres in these four states. Common crupina could potentially invade rangeland throughout most western states. Control of this species currently depends mainly on the use of herbicides which include 2,4-D and picloram. Most sites infested with common crupina requires revegetation to re-establish competitive perennial desirable species.

Dalmatian and yellow toadflax are introduced deep-rooted herbaceous perennials that reproduce by seed and by underground root stalks. The toadflaxes are easily distinguished from other range weeds by the distinctive shape of the bright yellow and orange flowers. Flowers are similar to the domestic snapdragon; distinguish toadflax species from these ornamental species by the presence of a long spur, or tail, at the end of the toadflax blossom and by the perennial nature of the noxious weeds. Ornamental snapdragons are used as annuals. Leaf shape helps distinguish between the different species of toadflax. Although Dalmatian and yellow toadflax do not occupy the large acreages that some of the noxious weeds do, both can be serious localized problems, displacing forages and native vegetation in a wide range of habitat types and climatic zones. Both are unpredictable and difficult to control. Effects of herbicide applications are inconsistent. Biological control agents have had impact on yellow

toadflax but little effect on Dalmatian toadflax. Additional species of insects have been released in Canada and appear to have effect on both weed species.

Diffuse knapweed is normally a biennial, but may live for several years as a rosette before flowering or continue to grow after producing seed to flower again as a short-lived perennial. It grows 1 to 3 feet tall from a deep taproot. Upright stems have numerous spreading branches, which give the plant a ball-shaped appearance and tumble-weed mobility. Bracts surrounding the flower heads are yellowish green with a buff of brown margin. Each bract is edged with a fringe of spines ending with a longer spreading at the tip. Some diffuse bracts are as "spotted" knapweed bracts, especially on heads with lavender or purple flowers, but the longer terminal spine is characteristic of diffuse knapweed. Most knapweeds evolved in the Mediterranean region of Europe. The earliest record of diffuse knapweed in western North America is from an alfalfa field at Bingen, Washington, in 1907. Pulling or cutting can effectively control diffuse knapweed. Manage rangelands so as to maintain a vigorous, competitive stand of desirable vegetation, pull and burn the initial invaders, and chemically control large-scale infestations.

Dyer's woad is a blue-green mustard (Brassicaceae) plant with numerous bright yellow flowers in an umbrella-shaped inflorescence which makes it easy to identify. It normally grows 1 to 3 feet

tall, but may reach over 4 feet. Typically, it has a 3 to 5 foot long taproot and some lateral roots in the upper foot of soil. Rosette leaves, attached by a stalk, are widest near the tip and have soft fine hairs. A native of southeastern Russia, dyer's woad has spread or been taken to many countries; currently, it exists on six continents. It probably came to North America from Europe by eastern United States colonists either as a textile dye crop or as a crop seed contaminant and later as a contaminant in alfalfa seed imported to California from Ireland. Today, dyer's woad persists as a weed in eight western states and threatens to invade others, particularly those with large amounts of rangeland and pastures. Dyer's woad poses a real threat to rangelands, forests, and pastures of the intermountain west due to its ability to dominate plant communities where dense dyer's woad infestations exist. It is estimated that dyer's woad is spreading at an annual rate of 14% on BLM rangelands in the northwest and reducing grazing capacity by an average of 38%. The number of infested hectares on National Forest lands in the Intermountain Region increased more than 35 fold from 1969 to 1985. Dyer's woad behaves as a winter annual, biennial, or short-lived perennial. In the intermountain area, it typically germinates in the fall, remains as a rosette of basal leaves during the following summer and winter, flowers in April and May of the second year and seed ripens in June and July. Dyer's woad spreads to uninfested sites only by seed. Long-range

seed dispersal is often facilitated by moving water such as canals, streams, and rivers. Prevention and early detection are paramount in managing dyer's woad invasion. One of the most important methods of prevention or control is hand roguing; the process of removing individual plants in the field. Roguing is very effective in hard to reach spots such as fencelines, canal banks, wooded areas and may be the only practical control method in difficult terrain or in forests and sites with associated sensitive plants. Plan to hand-rogue dyer's woad 2 to 3 times each year for several seasons. Do not let dyer's woad plants go to seed! Breaking or cutting off the tops does not kill dyer's woad but will encourage it to develop new stems and produce seed later in the season. Excellent control of dyer's woad can be obtained by spraying with 2,4-D in rosette stages. One of the most exciting discoveries with regard to stopping the advance of dyer's woad is the impact that a native rust pathogen, *Puccinia thlaspeos*, has on this noxious weed. Fruit and seed production are completely prevented on almost all infected plants.

Leafy spurge is a long-lived perennial plant that was introduced into the United States in 1827. The weed currently infests over 1.1 million ha in the Northern Great Plains of the United States and Prairie Provinces of Canada. The plant emerges in early spring and produces showy, yellow bracts which appear in late May and true flowers emerge in mid-June. The plant spreads by

both seed and roots and contains a white sticky latex that prevents grazing by many animals. Leafy spurge is found on a variety of terrain from flood plains to grasslands and mountain slopes. The plant reduces the carrying capacity of rangeland to near zero as cattle will not graze in areas with a 10 to 20% leafy spurge cover. Over \$14.4 million is lost each year in North Dakota alone due to reduced forage production and utilization. Herbicides commonly used to control leafy spurge include 2,4-D, dicamba, glyphosate, and picloram. Picloram is the most effective herbicide while a combination of picloram plus 2,4-D is the most cost-effective treatment. Once grasses were established, Russian wildrye, pubescent wheatgrass, big bluegrass, and intermediate wheatgrass were more competitive than other grass species in leafy spurge-infested rangeland and maintained at least a 90% cover for 4 yr. A major program for leafy spurge biocontrol was initiated in the 1980s. Four root-feeding flea beetles, *Aphthona cyparissiae* Koch, *A. flava* Guill, *A. czwalinae* Weise, and *A. nigriscutis* Foudras, and a gall midge, *Spurgia esulae* Gagné have established, reproduced well and have begun to reduce the infestation. A stem boring beetle, *Oberea erythrocephala* Shrank, has established but has not reduced the leafy spurge infestation. Long-term successful control programs should include combination treatments of herbicides and insects and/or grazing animals such as sheep and goats.

Mediterranean sage is a member of the mint family. It has erect, sturdy, squarish stems up to 3 feet tall, opposite leaves and a stout taproot. Seedlings have two oval cotyledons with notched tips. Juvenile plants form a basal rosette that remains close to the ground. Rosette leaves are indented or shallowly toothed and have a stalk 1 1/2 to 3 1/2 inches long. Mature plants have upright stems with clasping leaves that become progressively smaller up the stem. The uppermost leaves are reduced to-purple-tinged bracts having a long tapering point. Mediterranean sage is native to southern and southeastern Europe; introduced in the United States in alfalfa seed. Mediterranean sage has also been planted as a garden flower. The earliest record of Mediterranean sage in the United States is July 1892. Based on current infestations, the steppe, shrub steppe and Ponderosa pine zones in west-central Idaho and eastern Oregon and Washington are susceptible to invasion by Mediterranean sage. Mediterranean sage is an aromatic biennial, reproducing only by seed. Seeds germinate in the spring or fall, depending on moisture, and develop into leafy, prostrate rosettes the first growing season. Young seedlings quickly establish a taproot. Like many other biennials, Mediterranean sage does not adhere to a strict two year life cycle. Rosettes may persist in the vegetative stage for two or more years. Mediterranean sage is a tumbleweed. Seeds are shed as the plants tumble. Thus, the predominant means of long-distance seed

dispersal in Mediterranean sage is through wind dissemination via the tumbling action of plants. Once established, Mediterranean sage is able to spread into non-disturbed land but is not normally found in pristine habitats. Containment and control of Mediterranean sage in the US has been achieved with a number of methods. In eradication of scattered or outlier infestations, individual plants may be dug out with a shovel. Cutting the taproot 2 to 3 inches below the crown when plants are starting to bolt prevents most resprouting (Roché 1991). Cultural methods such as tillage are effective for pastures and abandoned fields where equipment access is feasible. Mowing can prevent seed production if repeated several times during the growing season, as plants will continue to bolt after cutting. Several herbicides effectively control Mediterranean sage, particularly when applied with a surfactant to plants in the rosette stage. Management of the grazing resources to favor the forage species in competition with the weed is necessary for long term success. Biological control of Mediterranean sage using natural enemies shows considerable promise as an effective long-term weed reduction strategy.

Medusahead seedlings can be identified by their bright green color and the attached awn and lemma. As the plant matures it turns a dark tan with different shades of a purple-red color on the stem of the plant and the seed-head. It is not until the plant starts to dry, becoming tan, that the awns take on a twisted

appearance by which the plant is customarily identified. Medusahead was first collected in Oregon in 1884. Medusahead has infested thousands of acres of rangeland in California, Oregon, Washington, and Idaho and is expanding in these states as well as Utah and Nevada. Areas under thrust of invasion are former sagebrush grass or bunchgrass communities that receive 10 to 20 inches of precipitation. Medusaheads success is based on its plastic prolific seed production, rapid germination rate, deep root penetration, winter growth, suberized roots, thick persistent litter layer, and low palatability to grazing animals. In general, medusahead is best managed by combining several control methods with revegetation, followed by proper grazing management.

Oxeye daisy is a perennial herb with oblique, shallow, branched rhizomes and strong adventitious roots. Basal stems are prostrate and will root, the other stems are erect and simple or slightly branched. Stems are glabrous to slightly pubescent. Basal leaves are on long stalks, spatulate to round, and dentate. In the Northeastern United States this plant has escaped cultivation and has naturalized. Oxeye daisy occurs chiefly in native and introduced grasslands, meadow and pasture, on waste ground, along railway embankments and roadsides. Its abundance is often closely associated with the intensity of cutting or grazing. Besides reproducing vegetatively along a rhizome, oxeye daisy is a prolific seed (achene) producer. Ripening of the achene is not

followed by a period of dormancy unless enforced by environmental conditions. Oxeye daisy seeds will germinate throughout the growing season, but most seedlings become established in spring. Oxeye seedlings are considered to be drought tolerant. Oxeye daisy is indifferent to water and soil friability, but has a moderate requirement for nitrogen. Oxeye daisy allocates more biomass to the root system at the expense of allocation to flower heads when grown under low nutrient levels. Oxeye daisy is unaffected by frost and tolerates drought well, although it is usually found in more moist areas. Horses, sheep and goats graze oxeye daisy, but cows and pigs tend to refuse it because of its acidity. Oxeye daisy increases greatly with continuous cattle grazing. Increases were much smaller with close rotational grazing by cattle, and close rotational and continuous grazing by sheep. Based on the European studies, sheep would probably have had a more significant impact on oxeye daisy than cattle. Mowing plants as soon as the first flowers open may eliminate seed production, however, mowing may stimulate shoot production and subsequent flowering if the growing season is long enough. In the early 1970s, Roche (unpublished data) compared 2,4-D at 2 lbs AI per acre with Tordon 22-K at 2 oz. for their effectiveness in controlling oxeye daisy on a mountain meadow in eastern Washington. Across these herbicide treatments, he applied nitrogen fertilizer at four different rates (0, 40, 80, 160 lbs as N, using ammonium nitrate-sulfate) beginning

in 1972. Some plots were refertilized in 1973, 1975, and 1976; others were not refertilized to assess residual effects. Another set of plots were fertilized at the same rates but were not treated with either herbicide. Both herbicides were effective at reducing canopy cover of oxeye daisy, but fertilizer alone was almost as effective as the herbicides. Effective biocontrol strategies have not been developed for this weed, presumably because this species is not yet perceived as a serious threat to plant communities.

Perennial sowthistle is a deep-rooted perennial that spread by seeds and creeping roots. The roots are reported to extend 5 to 10 feet in depth and are wide spreading horizontally producing shoots from root buds nearly 2 feet deep, thus establishing large colonies. Plants are usually 2 to 5 feet tall. The erect stems are smooth or glandular, hairy, leafy, hollow, branched near the top, and exudes milky juice when injured. Perennial sowthistle is a native of the temperate regions of Europe or Eurasia and is now found throughout the world and considered a common or serious weed in many countries. It was first collected in the United States in 1814 in Pennsylvania. Perennial sowthistle has probably already spread throughout the range in North America where it is most adapted. The weed is continuing to fill in niches within the area. In general sowthistles require high light intensities, such as sunny days, to stimulate germination, emergence, and vigorous growth. When shaded, perennial sowthistle will produce fewer but

larger leaves to compensate for reduced sunlight. It is cross-pollinated so flowers must be open before seed can be produced. Single plants spread by means of seed and roots to develop patches. Planting weed-free crop seed and controlling weeds on field borders where plants can begin establishment can prevent initial field infestations. Crop rotation, tillage, and herbicides can reduce the impact and further reduce propagation. Chemical and mechanical control before or after the crop is planted or harvested will minimize the infestation for that season or the next.

Purple loosestrife is a stout, erect perennial herb with multiple stems emerging from a well-developed roots system. Flowers are arranged in a spike which is from 2 to 3 feet long. Individual flowers have 5 to 7 petals with 8 to 10 stamens of various lengths. Petals are typically purple, but can range from white to pink to deep purple or even red. This species comes from European and Asian centers of origin, although the exact centers of origin are unknown. It was introduced into North America as horticultural stock in the early 1800's and was well established by 1830. The range of purple loosestrife has great expanded since 1941. Purple loosestrife is usually associated with moist and marshy areas. It is often found in ornamental setting and can escape from these areas into aquatic sites, such as streambanks or shorelines of shallow ponds. Seed dispersal is mainly by water, but seeds can also be transported on the feet and bodies of

waterfowl and other birds, as well as numerous wetland animals. Education and eradication are central to managing purple loosestrife. In most states, glyphosate (Rodeo) is labeled for use in riparian areas. Two, 4-D amine is a broadleaf herbicide which is effective for controlling this species using repeated applications. It is difficult to control purple loosestrife by hand pulling or digging, can be effective on young (1 or 2 years) plants. Cutting, burning and flooding are ineffective and tend to favor this weed. Six species of insects have been identified with high potential as control agents for purple loosestrife.

Rush skeletonweed is an exotic tap-rooted perennial noxious weed which infests millions of acres in the Pacific Northwest and California. An important characteristic of rush skeletonweed is the stiff downward pointing hairs on the lower 4 to 6 inches of the stem. The remainder of the stem is relatively smooth or has a few rigid hairs. All plant parts, including the leaf, stem and roots exude a milky latex when cut or broken. Rush skeletonweed is native to Asia Minor and the Mediterranean region including North Africa. It currently infests over 6 million acres in North America. Cool winters and warm summers with winter and spring rainfall, but without severe drought, are optimum conditions for the growth and reproduction of rush skeletonweed. Good condition native rangeland is seldom invaded by rush skeletonweed. Over 300 morphologically distinct forms of rush skeletonweed have been

recognized; three are widespread in the United States. Rush skeletonweed seeds display virtually no dormancy. Buried seeds germinate within a year or two even if less than 0.3 inches of rain falls at one time. During drought, most seedlings die without emerging. Rush skeletonweed roots reach 8 feet with little lateral growth, except in very sandy or gravelly soils where lateral roots are formed. In many cases, managing rush skeletonweed should focus on prevention and eradication. Initial introductions should be eradicated with diligence. Once the weed becomes widely established, an integrated strategy of cultural, chemical, and biological controls should be implemented to reduce the frequency of the weed to manageable levels.

Russian knapweed is an aggressive perennial weed reproducing from seed and adventitious buds on a creeping root system. It invades open, disturbed ground, suppresses growth of surrounding plants and once established, forms a single species stand. Russian knapweed infestations increase primarily by vegetative means; it does not reproduce extensively from seed. Cropland infested with Russian knapweed often is abandoned. Even though control might be achieved temporarily with herbicides or in the future with insects, long-term populations reductions must include competitive plant species to occupy bareground once infested by Russian knapweed.

Squarrose knapweed is a member of the thistle tribe in the sunflower family (Asteraceae). Its woody crown is covered by one

or more clusters of rosette leaves produced atop branches off a stout taproot. The stalked, deeply lobed basal leaves often wither by flowering time. Uppermost leaves are bract-like. The heads are smaller than other knapweeds in the West, 1/4 to 3/8 inch long and 3/16 inch wide, each containing only 4 to 8 rose-purple or pink flowers. On the bracts that surround the flower head, the terminal spine is longer and stouter than are the 4 to 6 pairs of lateral spines. The shape of the head and bract are somewhat similar to diffuse knapweed, but squarrose knapweed heads are a more slender urn shape. Squarrose knapweed is native to Bulgaria, Lebanon, Anti-Lebanon, Transcaucasia, northern Iraq, Iran, Afghanistan and Turkestan. Squarrose knapweed was first noted about 1934-1937. Squarrose knapweed has not been reported from Idaho, Montana, Nevada or Washington. Squarrose knapweed is a long-lived perennial. Squarrose knapweed flowers from June to August, followed by seed dispersal from August through the winter. Movement of squarrose knapweed in the western U.S. has been associated with sheep. At fruiting time, the heads are closed (retaining the seeds) and deciduous; consequently seeds are readily spread by animal wool, hair or fur. In Utah, most squarrose knapweed grows on big sagebrush-bunchgrass rangeland, but it also extends up into the juniper-dominated rangeland and down into the salt desert shrub range, particularly in sandy or gravelly washes. It also competes with crested wheatgrass in rangeland seedings. In

northern California, squarrose knapweed grows on dry rocky sites of degraded juniper-shrub savanna with scattered western juniper and ponderosa pine and chaparral-type understory. In Oregon, it has invaded juniper-Idaho fescue rangeland and big sagebrush-bunchgrass rangeland with cheatgrass. In the Great Basin and Intermountain foothills, the sagebrush and juniper range types appear to be susceptible to invasion by squarrose knapweed. Small infestations may be eradicated as they are found by grubbing, cultivation or herbicides. Stout taproots resprout when broken off, making hand pulling ineffective. Cultivation and grubbing should cut the root at least 8 inches below the soil surface to prevent new shoots growing from the root. Two insects introduced for biological control of diffuse and spotted knapweed also reduce seed production in squarrose knapweed. These gall-forming flies, *Urophora affinis* and *Urophora quadrifasciata*, are widespread in all areas where the other knapweeds occur. Several herbicides are registered for control of knapweeds on rangeland, with varying degrees of residual activity for control of later germinants.

Sulfur cinquefoil is a member of the rose family. Prior to flowering sulfur cinquefoil has an appearance similar to marijuana. The leaves are composed of 5-7 leaflets attached in a palmate pattern to a central leafstalk which is attached to an upright stem. The leaflets are toothed about halfway to the midvein. The inflorescence is a many flowered open cyme elevated above most of

the leaves. Five pale sulfur yellow petals are equal to or slightly longer than the five subtending green sepals and five additional small bracts. Sulfur cinquefoil is sometimes confused with native northwest cinquefoil (Potentilla gracilis Dougl.). Northwest and sulfur cinquefoil both have palmately compound leaves. Northwest cinquefoil is the most widespread native species and is common at the same low and mid elevations as sulfur cinquefoil. Sulfur cinquefoil is native to Eurasia, an origin similar to spotted knapweed and leafy spurge. The first collection in North America was made somewhat before 1900 in Ontario. The earliest records of sulfur cinquefoil in the five state area (WA, OR, ID, MT, WY) was 1934. Sulfur cinquefoil has a wide ecological amplitude. Spotted knapweed was most often associated with sulfur cinquefoil. The habitat requirements for sulfur cinquefoil appear to be similar to those of spotted knapweed. In spite of its abundance, sulfur cinquefoil is avoided by most grazing animals. Sulfur cinquefoil is one of the first plants to emerge in the spring, one of the fastest plants to greenup in the fall in response to late summer/early fall rains, and continues to grow until freezing temperatures are sustained. Sulfur cinquefoil is in a rapid expansion phase. Sulfur cinquefoil was pre-adapted to Montana's semiarid climate, but escaped the insect & disease organisms that co-evolved in its native Eurasian habitat. The State of Montana has initiated a search in the eastern

Mediterranean area for insect pests of sulfur cinquefoil that might be useful as biocontrols agents. Selective herbicides are the most effective tool for controlling larger populations of sulfur cinquefoil at this time. Tordon 22K (1 pt/acre or 0.25 lb a.e. picloram/ac) applied in the fall or spring up to late bud stage will provide several years of control. Transline or Stinger (clopyralid) should not be used on sulfur cinquefoil.

Yellow and orange hawkweed differ from native hawkweeds by lacking upper stem leaves, having stems branched at the tip, having flowers branched at the tip, and having leafy stolons. The origin of both hawkweeds is central and northern Europe. They were introduced into North America during the late 1800's and have become naturalized in much of the northeastern United States. Their western expansion is relatively recent. Hawkweeds pose the greatest threat to cooler, moister sites with the region, ranging from the lowlands of the northern Pacific Coast to elevations of 5,000 feet or more in mountain states. Hawkweeds reproduce from seeds, stolons, rhizomes or roots. Hawkweeds can be controlled by repeated tillage. Nontilled pastures and meadows should be treated with herbicides before blossoming to prevent seed production. Yellow and orange hawkweeds are controlled using 2,4-D, clopyralid and picloram. Hawkweed benefits from nitrogen fertilizer, but combining fertilizer with herbicides may suppress hawkweeds and enhance control by providing the understory residual grasses a competitive

advantage.

Yellow and purple starthistle are members of the knapweed complex in the sunflower family. They are annual or biennials with a stout taproot, produce a rosette of basal leaves that are deeply lobbed (pinnatifid) mostly less than 8 inches (20 cm) long and 2 inches (5 cm) wide. Stem leaves are entire and linear. Yellow starthistle is an annual to biennial with yellow flowers. Purple starthistle is a biennial with purple flowers. It can be distinguished from yellow starthistle in the rosette stage by a circle of spines at the center of the rosette. Yellow starthistle is native to the Mediterranean region of Europe. The first North American introductions of this species are believed to have occurred in contaminated alfalfa seed shipped to California. The earliest records of yellow starthistle infestation were found in flora analyses of adobe brick from the post-mission period in California (after 1824). Purple starthistle is native to the Mediterranean region, southern Europe and northern Africa. It's origins in North America are probably similar to yellow starthistle establishing first in the San Francisco Bay area of California where it became a major problem on annual rangelands. Starthistles have the ability to invade rangelands throughout the western United States. In the Pacific Northwest, the most susceptible rangelands are those with deep loamy soils, south facing slopes, receiving 30 to 64 cm (12-25 inches) of precipitation (winter/spring peak).

Yellow starthistle is a winter annual and is dependent upon seed production for population survival. A single yellow starthistle plant has the potential to produce up to 150,000 seeds. In studies near Walla Walla WA, yellow starthistle produced 20 to 120 seeds per plant, depending upon the density of the plants and the amount of spring precipitation. Yellow starthistle plants produce two types of seed, those with parachute-like plumes and those without plumes. The majority of seeds are plumed and are dispersed at maturity (July through September). Plumeless seeds are retained in the seedhead at maturity and dispersed between November and February. Over 90% of the seeds fall within 2 feet of the parent plant. Yellow starthistle germinates rapidly under a variety of conditions. Under optimum conditions, which is near 68° F with unlimited moisture, plumed seed initiate germination within 16 hours, and can reach a rate of 16% germination within 24 hours. Approximately 95% of the seed of yellow starthistle are viable, and 10% of the seed can remain dormant for more than 10 years. Yellow starthistle typically initiates growth in the fall following significant precipitation. Starthistle rosettes form as leaves emerge from the base of the plant. As starthistles mature, a flower stalk elongates from the center of the rosette ranging in height from 2 inches (dry conditions) to 5 feet (moist non-stressed environments). In early fall, yellow starthistle plants lose their leaves and dry to a silvery-grey skeleton, with cottony white

terminal seedheads. Management strategies for weeds typically include 3 different approaches: (1) **prevention** programs seek to prevent weeds from invading a new site by maximizing the competitive ability of existing vegetation; (2) **containment** programs seek to contain existing weed infestations to sites where they exist and prevent encroachment of the weed to adjacent lands; (3) **control** programs seek to reduce densities of weeds on areas where they exist and replace weeds with more desirable vegetation. Starthistles can be controlled by applying 1 pound active ingredient per acre of 2,4-D low volatile ester. Tordon 22K applied at a rate of .25 pounds active ingredient per acre selectively controls most broadleaves, including starthistles. Tordon 22K should be applied in the spring (rosette growth stage) in preparation for a fall seeding, or fall prior to a spring seeding of revegetative grass. Following initial control, a perennial grass cover should be established on the site to interrupt the cycle of re-invasion. Hand pulling and grubbing can provide effective control of small infestations of starthistles, but because it is costly and labor intensive, mechanical control is not practical on non-crop rangeland. Mowing and burning is an ineffective control of starthistles. Three weevil species (*Bangasternus orientalis*, *Eustenopus villosus*, *Larinus curtis*) and two flies (*Urophora sirunaseva*, *Chaetorellia australis*) have been released in California and the Pacific Northwest during the past 8

years for yellow starthistle control.