United States Department of Agriculture
NATURAL RESOURCES CONSERVATION SERVICE
Invasive Species Technical Note No. MT-3
July 2006

Ecology and Management of Dalmatian toadflax (*Linaria dalmatica* (L.) Mill.)

Jim Jacobs, NRCS Invasive Species Specialist
Sharlene Sing, Research Professor, Montana State University, Bozeman

Abstract

Dalmatian toadflax is a short-lived perennial herb native to the Mediterranean coastal regions of Europe and western Asia. Its name is derived from the Dalmatian Coast of the Adriatic Sea located within its native range. This species has escaped cultivation as an ornamental, a source of fabric dye, and as a medicinal plant to become an invasive weed. Dalmatian toadflax has been reported in all but nine Montana counties, with particularly heavy infestations in Broadwater, Jefferson, Lewis and Clark, and Bighorn Counties (see Figure 1). A distribution increase graph from the Invaders Database (http://invader.dbs.umt.edu) suggests that Dalmatian toadflax is currently in the exponential population growth phase of invasion in Montana, making it a considerable threat to resource conservation in this state. Dalmatian toadflax is adapted to a wide range of habitats but it is most problematic in dry, open grassland and forest sites, along roadsides, and on disturbed sites with coarse, well-draining soils. Grass production can be 2.5 times lower in dense infestations than similar areas without Dalmatian toadflax.

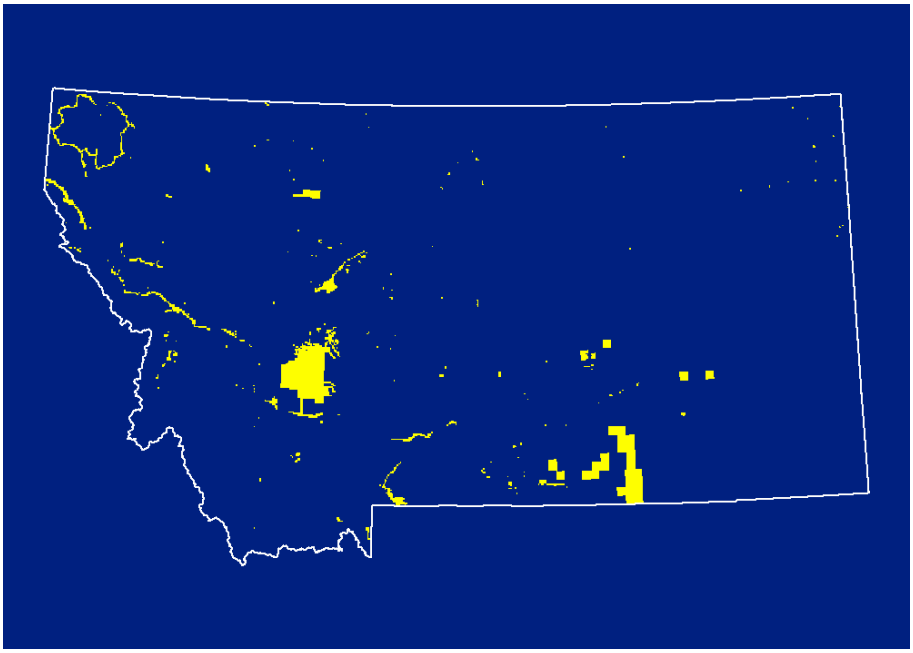

Figure 1. Dalmatian toadflax infestation (yellow) reported in Montana in 2001. Each yellow dot on the map represents one section reporting Dalmatian toadflax. Permission to use this map was granted from Diana Cooksey, Adjunct Instructor, MSU-LRES and Coordinator of Montana Agricultural Potential System (MAPS). Additional information about section based maps can be found at: http://www.montana.edu/places/mtweeds/databasedev.html.

Dalmatian toadflax seedlings are not considered to be effective competitors with established plants or seedlings of native grasses. However, once established, populations of Dalmatian toadflax are very competitive with both grasses and forbs, and are therefore difficult to eradicate. Maintenance of competitive plant communities is essential to preventing the spread of this weed. The extensive reproductive root system of Dalmatian toadflax and the ability of its seeds to persist for up to ten years in the soil enable it to regenerate after all types of control applications.

Six insect species have been approved for release in the United States as biological control agents for Dalmatian toadflax. The most recently introduced species, *Mecinus janthinus*, commonly known as the toadflax stem-mining weevil, has been observed to reduce toadflax populations in Canada, Washington, and Montana. Other insect species attack toadflax roots, growing points of the stem, seeds and flowers.

Sheep and goats will graze Dalmatian toadflax once they are trained to eat it and have been used to reduce weed biomass and seed production. Cows and livestock have also been observed to browse on Dalmatian toadflax. Herbicidal control requires high application rates and repeated applications. Picloram (1 qt./acre), metsulfuron (1.5 oz./acre), clorsulfuron (1.5 oz./acre), and imazapic (12 oz./acre applied in the fall) applied at bloom in May or June or to fall re-growth have resulted in short-term reduction of Dalmatian toadflax populations. The longevity of control will depend on site conditions, the intensity of competition from other plant species, and grazing management. Cultural controls (tilling, mowing, and burning) when applied alone are generally ineffective in controlling Dalmatian toadflax, but may improve the effectiveness of herbicidal, biological, and grazing control when used in an integrated management program.

Biology and Identification

Two species of Dalmatian toadflax are considered noxious in the United States: broad-leaved Dalmatian toadflax (*L. dalmatica*) and narrow-leaved Dalmatian toadflax (*Linaria genistifolia*). Both are in the Scrophulariaceae (figwort) taxonomic family. Only the broad-leaved species is known to be invasive in Montana. Both Dalmatian toadflax species and yellow toadflax (*Linaria vulgaris*) have hybridized in the laboratory so incidents of natural hybridization should be expected.

Seeds. Dalmatian toadflax is a perennial that can produce copious amounts of seeds. A single plant growing under ideal conditions can produce several hundred thousand long-lived seeds. Environmental conditions and plant competition can have a major influence on the number of seeds produced. Dalmatian toadflax populations were observed to produce an average of seven seeds per plant where there was a competitive plant community, compared to 79 seeds per plant where competitive plants were sparse in Jefferson County, Montana. Prescribed fire increased seed production to 355 and 158 per plant, respectively, at the low-competition versus high-competition site. Prescribed fire increased Dalmatian toadflax seed production from an average of 29 to 1,328 seeds per plant on one study site. Studies have shown that seeds can maintain viability when in the soil for ten years or more.

Seedlings. Some seeds germinate in the fall, but most germinate in the spring, as early as March on south-facing slopes. Emerging shoots are thin and delicate with fine linear leaves. Dalmatian toadflax seedlings are not strong competitors due to their low tolerance of droughty conditions

compared to co-occurring species. In greenhouse competition studies, seedlings of bluebunch wheatgrass (*Pseudoroegneria spicata*) were over two times more competitive than Dalmatian toadflax seedlings when the two species were planted at the same time. Seedling root development is initially slow; however, in nine weeks seedlings roots are capable of growing up to 20 inches deep and producing vegetative buds that can give rise to new shoots.

Roots. Dalmatian toadflax can produce deep taproots and thick creeping rhizomes that are nearly white in color. Underground adventitious buds on the root and root crown of a well-established plant can generate reproductively viable 'daughter' stems. Vegetative regeneration from buds on root crowns and lateral roots partly explains the competitiveness of Dalmatian toadflax. Energy stored in the roots allows shoots to grow regardless of competition from a healthy plant community. Root energy reserves are greatest in the fall and lowest pre-bloom in June.

Figure 2. The roots of Dalmatian toadflax showing the top part of the thick taproot and lateral rhizomes running left and right.

Vegetative Stems. Shoots from root or crown buds begin emerging early in the spring. However, emergence continues through June so that relatively sparse stands in the spring may become denser in the summer. Leaves are alternate along the stem, heart-shaped and broadest at the leaf base, and clasping the stem. Both stems and leaves are hairless and have a thick waxy coating that gives their surface a whitish to bluish appearance. Short, prostrate stems with tightly clustered linear leaves giving the plant a rosette-like appearance grow from root buds in the fall. These rosette-like plants may remain green through the winter and develop flowering shoots in the following summer.

Figure 3. A Dalmatian toadflax stem showing the heart-shaped, hairless, clasping leaves and the waxy surface.

Flowers. Under field conditions, Dalmatian toadflax apparently requires both a winter dormancy period and exposure to temperatures between 50° and 68° F (10° to 20° C) to initiate flowering, which may explain its northerly geographic distribution. Because it is a short-lived perennial with individual plants living an average of three to five years, seed production is important to stand survival. Flowering begins in June and can continue through September and into November under ideal conditions. The flowers are bright yellow with an orange center, are shaped similar to the blossoms on snapdragon, have a distinct spur at the base, and are relatively widely spaced on spike-like racemes (see Figure 4). The racemes form at the growing tip of the primary stem and secondary flowering stems can grow from buds in the leaf axils which gives the plant a branched appearance. Flowering is indeterminate; blooming occurs from the base of the stem toward the elongating stem tip and new flowers are produced as long as conditions are favorable. Stems can grow to over three feet (one meter) tall. Starting in July, flowers develop into cylindrical capsules that may contain 40 or more seeds. Stems die when soil moisture is depleted or in freezing temperatures. However, once dead, the stout stems can remain upright and disperse seeds throughout the winter.

Figure 4. Dalmatian toadflax flowers showing the snapdragon-like shape, prominent spur at the base of the flower, and branching at the leaf axils.

Spread. In cases other than intentional horticultural plantings, spread of Dalmatian toadflax occurs predominantly through seed dispersal. Most seeds fall within five feet (1.5 m) of the parent plant. Dalmatian toadflax seeds are small (about the size of an alfalfa seed) with a papery wing that may facilitate wind dispersal. Long-distance wind dispersal has been suggested during the winter when seeds fall from upright stems onto crusted snow. Birds, other wildlife, and domestic animals that consume the seed capsules may disperse seeds long distances when undigested, viable seeds pass through their digestive tracts. Population expansion is achieved through short-distance seed dispersal and by vegetative propagation from creeping roots. On cultivated land, root fragments clinging to farm implements can initiate new infestations.

Habitat. Dalmatian toadflax is adapted to a wide variety of habitats from open grasslands and savannas, to open forest sites. Infestations are commonly found on well-drained, coarse-soils, and on steep slopes that are prone to erosion disturbance. The natural disturbance on these sites provides opportunities for competition-free establishment compared to heavier soils and level sites with competitive plant communities. Grazed lands not given sufficient rest between grazing events are susceptible to Dalmatian toadflax invasion. A site disturbed by mining, road construction or where the competitiveness of the plant community is compromised is also susceptible to invasion.

Management Alternatives

Herbicide[1/]

The thick waxy leaf cuticle, long-lived seeds, and robust, creeping, reproductive root system are biological characteristics of Dalmatian toadflax that present a challenge for effective herbicidal management. Results of herbicide trials on Dalmatian toadflax have been variable with very good control in some applications to nearly no control in other applications of the same treatment. Site conditions including soil characteristics and the presence of competitive plants, and the chemistry, rate, and timing of application will affect the results of herbicide management of Dalmatian toadflax.

Herbicide applications on fall re-growth or in the spring up to early bloom have been most successful in controlling Dalmatian toadflax. The waxy leaf surface may be less developed at these times compared to summer allowing more herbicide to enter the plant. Plants are also actively growing at these times which facilitates the movement of herbicide to target sites. Herbicide application at pre-bloom may have the greatest long-term Dalmatian toadflax suppression because root reserves are at their lowest level at that time.

Herbicides effective for controlling Dalmatian toadflax are listed in Table 1. In addition, chorsulfuron (Telar®) is also effective; however it is not currently labeled for Dalmatian toadflax control. Herbicide trials have shown that Dalmatian toadflax can be controlled for up to three years with chlorsulfuron or metsulfuron (1.5 oz./acre with a non-ionic surfactant) applied in the fall or spring, or with picloram (1 qt./acre) applied in the spring up to early bloom. Imazapic (12 oz./acre with 1 qt. methylated seed oil-MSO) is most effective when applied to late fall re-growth.

Table 1. Chemical and product name, recommended application rate, soil residual half life, and ecotoxicity of herbicides commonly used to control Dalmatian toadflax.

Chemical Name	Product Name	Rate/Acre	Half Life-Days	Ecotoxicity (LC_{50}/EC_{50})
Imazapic	Plateau	12 oz.	31-233	>100 mg/L
Metsulfuron	Escort/ Cimarron	1.5 oz.	14-180	>150 mg/L
Picloram	Tordon	1-2 qt.	90	10-100 mg/L

Grazing

Dalmatian toadflax vegetation contains alkaloids thought to be mildly toxic to grazing animals. In the western states, no toxic effects have been observed in animals that utilize this weed. Cattle, sheep, and goats have been observed to eat Dalmatian toadflax, but it is often not their preferred forage, and timing of palatability is still under study. Cattle have been observed to eat the pre-bloom stems in the spring, sheep will utilize the weed throughout the summer, and goats have eaten Dalmatian toadflax in the spring and fall. Sheep and goat grazing may be a good option for management of infestations that are difficult to access.

[1/]Any mention of products in this publication does not constitute a recommendation by the NRCS. It is a violation of Federal law to use herbicides in a manner inconsistent with their labeling.

Recent studies show that sheep and goats can be used to manage Dalmatian toadflax. Sheep trained to eat Dalmatian toadflax consumed nearly 90 percent of the weed vegetation with little effect on grass or other forb species. Sheep grazing initially increased Dalmatian toadflax density, most likely due to increased root-sprouting, but in the long-term it is expected that densities of Dalmatian toadflax will decrease under sheep grazing management. Sheep and goats will consume flowers and thereby reduce seed production. Grazing with sheep or goats after herbicide application may be used to reduce Dalmatian toadflax regeneration, potentially increasing the time between herbicide re-applications. Toadflax seed capsules appear to be a preferred food for many grazing animals. However, to prevent spread of Dalmatian toadflax seeds through their feces, grazing animals that may have consumed these seeds should be contained and fed weed-seed free forage for five days before being moved to weed-free areas.

Biological

Six biological control insects have been released in the United States to control Dalmatian toadflax (see Table 2). Two insects released to manage yellow toadflax (*Linaria vulgaris*) also attack Dalmatian toadflax, and there are four insects currently being considered for host-specificity testing in Europe.

The flower beetle, *Brachypterolus pulicarius*, and the seed capsule weevil, *Rhynusa* (formerly *Gymnetron*) *antirrhini*, have established throughout western North America but have not proven to be effective in controlling Dalmatian toadflax. The toadflax moth, *Calophasia lunula*, is also well established and distributed throughout in the western region. The larvae (caterpillars) defoliate all stages of Dalmatian toadflax but only apparently influence the vigor or density of seedlings. The toadflax root-boring moth, *Eteobalea intermediella*, and the toadflax root-galling weevil, *Gymnetron linariae*, were first released in Montana in 1996 but efforts to verify their establishment and assess their impact on target weed populations have been significantly impeded by their cryptic lifestyle.

The toadflax stem-mining weevil, *Mecinus janthinus*, has shown promise for controlling Dalmatian toadflax in areas of southern British Columbia and Northern Washington where reductions in density and vigor have been reported. The adults of this weevil feed on the leaves and deposit eggs in the stems beginning in May. The larvae develop and feed in the stem where they mine the central part of the stem and disrupt water movement to leaves and flowers. Larvae generally require a stem of >9 mm to successfully develop into adults. Pupation occurs within the stem in early August; fully developed adults remain within the natal stem where they over-winter. Canadian researchers report that over-wintering survival of *M. janthinus* has been greatest at sites that maintain significant snow cover over the course of the winter. This weevil prefers hot, dry, forested areas or grasslands with greater than 30 percent total vegetation cover as protection against extreme summer heat.

Table 2. Biological control insects for management of Dalmatian toadflax, the site of attack on the plant, insect life stage and plant life stage for collection, and the collection method for re-distribution.

Insect	Type	Site of Attack	Collection	Collection Method
Brachypterolus pulicarius	beetle	flower	adult	sweep net/tray
Calophasia lunula	moth	foliage	larval	tray
Eteobalia intermediella	moth	roots	pupal/adult	n/a
Rhinusa antirrhini	weevil	seeds	adult	sweep net/tray
Rhinusa linariae	weevil	root	adult	n/a
Mecinus janthinus	weevil	stem	adults	tray

Cultural

Cultural control methods applied by themselves including tilling, mowing, burning, hand pulling and grubbing are not effective for reducing Dalmatian toadflax populations due to regeneration from the extensive reproductive root system. Irrigation and fertilization to increase the competitiveness of grasses should only be applied after herbicide suppression. Mowing has little effect on root reserves but may reduce flower and seed production if repeated often. Carefully-timed cultural methods may improve the effectiveness of other control practices.

Burning. Prescribed burning will not control Dalmatian toadflax. The soil below a prescribed burn does not reach temperatures hot enough to kill roots or rhizomes. Prescribed burns can double Dalmatian toadflax biomass and increased seed production ten-fold. If prescribed burning is used as a management practice in Dalmatian toadflax infestations, herbicidal control or sheep or goat grazing should also be used to prevent increasing Dalmatian toadflax.

Tilling. Tilling is not practical for managing Dalmatian toadflax. It requires cultivation beginning in early June and must be repeated every seven to ten days. This disturbance is more likely to spread root fragments that can develop into new infestations than reduce infestations. Disturbance also favors establishment of the weed from seed. Tilling should only be used in combination with herbicidal management and re-vegetation.

Re-vegetation. Competitive plants are important in preventing infestations of Dalmatian toadflax. However, there is little information on re-vegetation of infestations with grasses or other species. Research in Wyoming showed Bozoisky Russian wildrye, Hycrest crested wheatgrass, and Luna pubescent wheatgrass were competitive with Dalmatian toadflax and limited its re-establishment. On healthy grassland sites, herbicidal suppression of Dalmatian toadflax has successfully restored perennial grasses. Often Dalmatian toadflax invades steep sites with coarse soils and low productivity. On these sites it is difficult to justify the expense of re-vegetation based on economic return. Aerial seeding of native grasses on sites burned by wildfire has been successful in preventing the spread of Dalmatian toadflax.

Refer to Montana Plant Materials Technical Note 46, 'Seeding Rates and Recommended Cultivars,' and Extension Bulletin EB19 'Dryland Pasture Species for Montana and Wyoming' for seeding rate guidance and re-vegetation species selection. State and area resource specialists can help determine the most appropriate, site-specific species mix, timing of seeding, and seeding methods.

Integrated Pest Management

Plant community composition and Dalmatian toadflax density are important considerations in planning IPM for Dalmatian toadflax infestations. Research has shown that in rangeland plant communities with high canopy cover of a diversity of forb species, and low density of Dalmatian toadflax, herbicidal control decreased forb cover with little or no significant reduction in Dalmatian toadflax density. This result suggests that there may be a threshold of Dalmatian toadflax density below which herbicidal control does more harm to the plant community than good as measured by toadflax control. Based on these results, herbicide application over a large-scale infestation of Dalmatian toadflax with an average density of ten flowering stems/m^2 or less is most likely not justified. On these sites grazing with sheep or goats along with prescribed cattle grazing management, or as an alternative, release of *Mecinus janthinus*, should be used to prevent an increase in Dalmatian toadflax and potentially reduce density over the long-term. Infestations with greater than 25 flowering stems/m^2 and a healthy grass stand should be sprayed to reduce Dalmatian toadflax density below ten stems/m^2. Biological control or prescribed grazing should then be used to maintain Dalmatian toadflax at low levels. On harsh sites with low productivity, prescribed grazing or biological control should be used to reduce Dalmatian toadflax. Grazing and *Mecinus janthinus* are not compatible because the grazing animals consume the Dalmatian toadflax stems where the insects live and over-winter. Currently, *Mecinus janthinus* is the most promising biological control agent for managing Dalmatian toadflax.

An integrated Dalmatian toadflax weed management program will include prevention, early detection and small-scale eradication, containment, and large-scale population reduction. Prevention is guided by how Dalmatian toadflax spreads and its requirements for establishment and includes maintaining competitive plant communities and preventing seed imports by using weed-free feed and seed, cleaning equipment before application on weed-free areas, and containing grazing animals that have fed in Dalmatian toadflax infestations for five days before moving them to weed free areas. Early detection and small-scale eradication is achieved through persistent survey and herbicide application. Dalmatian toadflax populations are contained by herbicidal control of population boarders and satellite populations, control actions that reduced seed production such as sheep or goat grazing and biological control insect releases, and cultivation of competitive plants. Large-scale population reduction is achieved over the long-term by applying management alternatives such as prescribed grazing that includes sheep or goat grazing, and biological control insects that reduce the Dalmatian toadflax population fitness and increase the fitness of desirable, competitive plant populations.

References

Coombs, E. M., J. K. Clark, G. L. Piper, and A. F. Cofrancesco, Jr. (eds). Biological control of invasive plants in the United States. Oregon State University Press, Corvallis. Pages 380-395.

Lajeunesse, S. 1999. Dalmatian toadflax. In: Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis. Pages 202-216.

Wilson, L.M., Sing, S.E., Piper, G.L., Hansen, R.W., De Clerck-Floate, R.A., MacKinnon, D.K., and Randall, C.B. 2005. Biology and biological control of Dalmatian and yellow toadflax. Report FHTET-05-13, USDA Forest Service.