ELEMENT STEWARDSHIP ABSTRACT
for

Cirsium arvense

Canada Thistle, Creeping Thistle, Californian Thistle

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Species Code:
PDAST2E090

Scientific name:
Cirsium arvense (L.) Scop. Early nomenclature is recorded in Detmers (1927).

Common name
CANADA THISTLE is the common name used in the United States and Canada. Outside North America the plant is also referred to as Creeping Thistle and Californian thistle (Jessep 1989).

Diagnostic Characters:
Cirsium arvense is an erect perennial rhizomatous thistle, usually 0.5 - 1.0 m tall, distinguished from all other thistles by 1) creeping horizontal lateral roots; 2) dense clonal growth; and 3) small dioecious (male and female flowers on separate plants) flowerheads. Four varieties are recognized: var. *vestitum* Wimm. & Grab. (leaves gray-tomentose below); var. *integrifolium* Wimm. & Grab. (leaves glabrous below, thin, flat, and entire or shallowly pinnatifid); var. *arvense* (leaves glabrous below, thin, flat, and shallowly to deeply pinnatifid); var. *horridum* Wimm. and Grab. (leaves glabrous below, thick and wavy, with many marginal spines) (Moore 1975). The most common variety of the species in North America is *horridum*. All varieties are interfertile, and one plant of var. *integrifolium* produced seedlings of all four varieties (Detmers 1927). Within each variety there are numerous genotypes, which vary in appearance and in response to management activities. Additionally, *Cirsium arvense* changes morphology in response to environmental conditions (Nadeau and Vanden Born 1989).

Chromosome number for all *Cirsium arvense* varieties is $2n = 34$ (Moore and Frankton 1974). There are approximately 350 species worldwide in the genus *Cirsium* (Moore and Frankton 1974).

Cirsium arvense can be confused with other thistles, especially bull thistle (*Cirsium vulgare*), and the closely related musk thistles (*Carduus* sp). Distinguishing characteristics of *Cirsium arvense* are 1) flowerheads small (<2.5 cm high) and dioecious) and 2) stems <u>not</u> conspicuously spiny-winged (Moore and Frankton 1974). All species of *Cirsium* ("plumed thistle") have a pappus with branched hairs, in contrast to the unbranched pappus hairs on *Carduus* ("plumeless thistle") (Moore 1975).

Phenology of *Cirsium arvense* varies with ecotype, but follows a general pattern. In Washington state, overwintering Canada thistle roots develop new underground roots and shoots in January and begin to elongate in February (Rogers 1928). Shoots emerge March - May when mean weekly temperatures reach 5^{o} C. Rosette formation follows, with a period of active vertical growth (about 3 cm/day) in mid-to-late June. Flowering is from June to August in the U.S., and June to September in Canada, when days are 14 to 18 hours long (Hodgson 1968, Van Bruggan 1976, Moore 1975): *Cirsium arvense* is a long-day plant (Linck and Kommedal 1958, Hunter and Smith 1972).

Excellent illustrations of Cirsium arvense may be found in Detmers (1927), Rogers (1928) and Haderlie *et al.* (1987).

Stewardship Summary

Despite its common name, Canada thistle is native to Europe and was apparently introduced to North America in the early 17th century (Hansen 1918). *Cirsium arvense* was declared a noxious weed by the state of Vermont in 1795 (Hansen 1918). By 1918 it was on the noxious weed lists of 25 northern states and by 1991 it had been declared noxious by at least 35 states and 6 Canadian provinces (Moore 1975). It is now widespread in all U.S. states and Canadian provinces between 37 and 58-59 degrees N (Moore 1975).

Cirsium arvense is invasive in prairies and other grasslands in the midwest and Great Plains and in riparian areas in the intermountain west. It is particularly troublesome in the northwest and north-central states, and in southern Canada (Moore 1975). Canada thistle spreads primarily by vegetative means, and secondarily by seed.

Cirsium arvense has numerous ecotypes that respond differently to management activities. Some infestations may be completely controlled by one technique, while others will only be partially controlled because two or more ecotypes are present within the population. Additionally, *Cirsium arvense* responds differently to management under different weather conditions. Therefore it is often necessary to implement several control techniques, and to continuously monitor their impacts.

Where possible it is best to kill all *Cirsium arvense* plants within a site. Where resources are limited two strategies are recommended: 1) Target *Cirsium arvense* clones based on location, controlling plants in high quality areas first, then in low quality areas. Treat entire clones to prevent resprouting from undamaged roots: 2) Target female clones to reduce seed production and additional spread of *Cirsium arvense*. However, some apparently "male" clones are self-fertile.

Control techniques for natural areas are constrained by the need to minimize damage to native species. The best option in prairies and other grasslands is to first enhance growth of native herbaceous species by spring burning, and then cut or spot treat Canada thistle with glyphosate when it is in late bud or early bloom (usually June). It is necessary to prevent shoot growth for at least two years to deplete roots and kill Canada thistle. Several biological control agents have been released against Canada thistle but overall they provide little or no control at the population level although they may weaken and kill individual plants.

THREATS POSED BY THIS SPECIES

Natural areas invaded by *Cirsium arvense* include prairies and other grasslands in the midwest and Great Plains and riparian areas in the intermountain west. *Cirsium arvense* threatens natural communities by directly competing with and displacing native vegetation, decreasing species diversity, and changing the structure and composition of some habitats. Species diversity in an "undisturbed" Colorado grassland was inversely proportional to the relative frequency of Canada thistle (Stachion and Zimdahl 1980). Canada thistle invades natural communities primarily through vegetative expansion, and secondarily through seedling establishment.

Cirsium arvense presents an economic threat to farmers and ranchers. Infestations reduce crop yield through competition for water, nutrients and minerals (Malicki and Berbeciowa 1986) and interfere with harvest (Boldt 1981). In Canada, the major impact of *Cirsium arvense* is in agricultural land, and in natural areas that have been disturbed or are undergoing restoration (White et al. 1993). In the U.S., it is a host for bean aphid and stalk borer, insects that affect corn and tomatoes (Moore 1975), and for sod-web worm (*Crampus* sp.) which damages corn (Detmers 1927). In Bulgaria *Cirsium arvense* is a host for the cucumber mosaic virus (Dikova 1989). In addition to reducing forage and pasture production, Canada thistle may scratch grazing animals, resulting in small infections (Moore 1975).

Range:

Cirsium arvense is native to southeastern Europe and the eastern Mediterranean (Moore 1975) and possibly to northern Europe, western Asia and northern Africa (Detmers 1927, Amor and Harris 1974). It now has a near global distribution between 37 and 58-59 degrees N in the northern hemisphere (Moore 1975), and at latitudes greater than 37 degrees S in the southern hemisphere exclusive of Antarctica (Amor and Harris 1974). *Cirsium arvense* occurs throughout Europe, northern Africa, western and central Asia, northern India, Japan, China, and northern North America, South Africa, New Zealand, Tasmania, and southeastern Australia (Dewey 1901, Rogers 1928, Hayden 1934, Amor and Harris 1974).

In 1975, Canada thistle's range was an estimated 9,770,000 km^2 in North America, extending over an area 2090 km north to south, and 4700 km east to west (Moore 1975). *Cirsium arvense* infestations here are particularly troublesome in the northwest and north-central states, especially north of the 35th parallel (Dewey 1991), and in the southern part of Canada (Moore 1975). The species range is determined by rainfall, temperature, and daylength. The northern limit of the zone of highest density in Canada corresponds with the -18^o C (0 F) mean January isotherm, whereas the southern limit of the species is probably controlled by high summer temperatures and short-day length (Moore 1975).

Optimal growth occurs at 77^o F day and 59^o F night, in mesic soil with high nitrogen (15-30 ppm) (Haderlie et al. 1987). In Montana the plant grows best where rainfall averages 50-75 cm/year (Hodgson 1968), while in Australia the heaviest infestation occurs where annual rainfall averages 70-100 cm (Amor and Harris 1974).

Habitat:

Cirsium arvense occurs in nearly every upland herbaceous community within its range, and is a particular threat in prairie communities and riparian habitats. In the Great Plains Canada thistle invades wet and wet-mesic grasslands as well as prairie potholes in the Dakotas. It also invades riparian areas and along irrigation ditches from the western plains across the northern half of the intermountain west to the Sierra Nevada and Cascade ranges. In the upper Midwest (Wisconsin and Illinois) *Cirsium arvense* is found in degraded sedge meadows, growing on tussocks elevated above the normal high water line. In Canada, *Cirsium arvense* is frequent in prairie marsh (Thompson and Shay 1989) and sedge meadow (Hogenbirk and Wein 1991). Throughout its range it is common on roadsides, in oldfields, croplands, and pastures, in deep, well-aerated, mesic soils. In eastern North America, it occasionally occurs in relatively dry habitats, including sand dunes and sandy fields, as well as on the edges of wet habitat, including stream banks, lakeshores, cleared swamps, muskegs and ditches (Moore 1975).

Canada thistle is shade intolerant. It grows along the edges of woods (both deciduous and coniferous), but is rarely found within forests.

Cirsium arvense grows on all but waterlogged, poorly aerated soils, including clay, clay loam, silt loam, sandy loam, sandy clay, sand dunes, gravel, limestone, and chalk, but not peat (Rogers 1928, Korsmo 1930 [cited in Moore 1975], Bakker 1960, Hodgson 1968, Moore 1975). It grows best on mesic soils: in a transplant experiment, Hogenbirk and Wein (1991) determined that *Cirsium arvense* cover increased 5- to 13-fold when sods were moved from a wetland to a mesic location. *Cirsium arvense* can tolerate soils with up to 2% salt content (Reed and Hughes 1970).

Reproduction:

FLOWERS
Cirsium arvense produces numerous small flowers clustered in heads that are typically 1-1.5 cm in diameter and 1.3-1.5 cm tall. Flower color ranges from lavender to pink or white. Flowering is triggered by long days. Ecotypes vary in their light requirements, with some ecotypes blooming during 16 hour days, and others during 14 hour days; at shorter daylengths, flowering can be temperature dependent (Hunter and Smith 1972). Studies indicated Canada thistle required 14 hours of daylight/day to flower in South Dakota (Lym and Zollinger 1995), 15 hours of daylight/day in Nebraska (Hoefer 1982) and over 15 hours of daylight/day in Idaho (Haderlie *et al*. 1987).

The blooming period is longer in northern locales than in more southerly areas; In Canada flowering begins mid-June to early July and continues into September (Moore 1975), while in Idaho and Montana flowering begins early July and continues into August (Hodgson 1964, 1968).
Cirsium arvense is usually dioecious, with male and female flowers produced on separate plants. Female (pistillate) flowers can be readily distinguished from male (staminate) flowers by the absence of pollen (abundant in male flowers) and presence of a distinct vanilla-like fragrance (Rogers 1928), as well as by shorter corolla lobes (2.8 mm vs 4.8 mm; Kay 1985). In seed, female flowers have a larger pappus (23 mm vs 11 mm) and larger involucre (19 mm vs 13 mm; Kay 1985).

Under good growing conditions, female plants produce an average of 29 flowering shoots/m^2, each with an average of 41 heads/shoot and 59 seeds/head (Bakker 1960). Total florets (individual flowers within each flowerhead)/plant varies by clone, and can range from approximately 100 (Hayden 1934) to 430-1120 (LaLonde and Roitberg 1989). Although traditionally considered dioecious, up to 26% of "male" plants are actually self-fertile hermaphrodites (male and female flowers on the same plant), capable of producing seeds: In Britain, 15% of clones with "male" flowers were actually hermaphrodites that produced 10-65 seeds/flowerhead, and an additional 11% of plants were subhermaphrodites that produced 2-10 seeds/flowerhead (Kay 1985). Hermaphrodites closely resemble typical male flowers (Kay 1985). Incidence of hermaphrodism varies by locality, and some areas have plants that are nearly or all truly dioecious (Lloyd and Myall 1976). Clones and individual stems can be imperfectly dioecious; Hodgson (1964) found that male and female flowers developed on separate stems grown from a single clone.

With the exception of hermaphrodites, *Cirsium arvense* flowers are obligate outcrossers. Flowers are almost exclusively insect-pollinated (Derscheid and Schultz 1960, Lalonde and Roitberg 1994). More insect species visit *Cirsium arvense* than other *Cirsium* or *Carduus* species due to the "accessibility of its copious nectar" (Ellis and Ellis-Adam 1992). Although *Cirsium arvense* may help maintain diversity of pollinating insects in this way (Ellis and Ellis-Adam 1992) it negatively impacts native plant communities and may thus have an negative impact on overall insect diversity as well.

Stigmas are receptive for 3 or more days when pollen is abundant, and over 5 days when pollen availability is low (Lalonde and Roitberg 1994). Seed set in females is constrained by pollen availability and is highest when male and female plants are near each other but decreases sharply when female plants are >50 m distant from male plants (Lalonde and Roitberg 1994).

SEEDS

Seeds (achenes) range in size from 2.5-3.2 mm long, and average 1 mm in diameter (Rogers 1928). Ripe seeds have a tawny color (Rogers 1928). Seed weight varies by ecotype, ranging from 0.67-1.52 mg/seed (Hodgson 1964) and averaging 1.08 mg (Terpstra 1986). Mean seed weight is highest in seeds produced early in the summer, and declines over the season (Lalonde and Roitberg 1989).

Seed set is highest when male and female plants are intermixed, and decreases when female plants are >50m from male plants (Lalonde and Roitberg 1994). Seed formation has been documented when male and female plants are 50-90 m apart (Bakker 1960, Hayden 1934), 50-100 m apart (Lalonde and Roitberg 1994), 180 m apart (Detmers 1927) and 390 m apart (Amor and Harris 1974). Flowers must be open 8-10 days before seeds are mature enough to germinate (Derscheid and Schultz 1960).

Females produce an average of 40-59 seeds/flowerhead (Hayden 1934, Bakker 1960, Kay 1985), and "males" average 6 ± 4 seeds/head (Kay 1985). Seed production is much higher with insect pollination (40-85 seeds/head) than wind pollination (0.2-0.8 seeds/head) (Derscheid and Schultz 1960). Seed production and viability is higher under full sun than low light (Bakker 1960).

A single plant produces an average of 1500 seeds, and up to 5300 seeds (Moore 1975). Multiple plants produced an average of 100-64,300 viable seeds/m^2 in Australia (Amor and Harris 1974), and up to 30,200/m^2 in Holland (Bakker 1960).

SEED DISPERSAL

Seed dissemination occurs 2-3 weeks after pollination (LaLonde and Roitberg 1989). The pappus breaks off easily from the seed, often leaving seeds in the flowerhead. Most *Cirsium arvense* seeds apparently land near the parent plant; <10% of seeds found 10 m from the parent plant still had a pappus attached (Bakker 1960). On the other hand, some long-distance dispersal occurs as evidenced by the 0.2% of seeds found with a pappus still attached 1 km from the parent plant (Bakker 1960).

Cirsium arvense seeds spread as a contaminant in agricultural seeds (Rogers 1928) in hay and in cattle and horse droppings and on farm machinery. They may also be transported by water (Hope 1927).

GERMINATION

Germination is affected by genotype, planting depth, substrate stratification, temperature, day length, and seed freshness. Germination and dormancy vary with ecotype, and some ecotypes have consistently low germination rates and/or long dormancy periods (Hodgson 1964).

Seeds germinate best at shallow depth (1 cm [Kolk 1947], 0.5 -1.5 cm depth [Wilson 1979], 1.5-5.3 cm [Terpstra 1986]), but seed longevity increases with increased depth of planting. Seed viability appears to be a function of dormancy; once dormant, seeds remain viable until conditions change (Roberts and Chancellor 1979). Conditions change frequently for seeds planted at a shallow depth, or in cultivated soil, hence, most seed in farm fields germinates within the first year and the remainder rapidly loses viability. Bakker (1960) determined that seed buried 1 cm deep lost all viability after 10 months, while seed buried 40 cm deep retained 35-39% viability after 30 months. Some buried seed remained viable for at least 21 years in the U.S. (Toole and Brown 1946) and 26 years in Denmark (Madsen 1962). Seed buried 106 cm deep had higher viability than seed buried 20 cm deep (Goss 1925 cited in Detmers 1927), and 40% of seeds remained viable after 30 months storage at 50 cm depth under water (Bakker 1960).

Germination rates are highest in loam and sand substrates, but are zero in rubble or turf (Bostock and Benton 1983). Optimum germination occurs at pH 5.8 - 7.0 (Wilson 1979). Seed viability is very low (0.5%) after passage through bovine digestive tracts (Lhotska and Holub 1989).

Seed germinates best at temperatures of 25-30^{o} C (Bakker 1960, Amor and Harris 1974), but can germinate at lower temperatures in high light conditions. Young seeds germinate well in high light-, and old seeds in low light-conditions (Kolk 1947 cited in Moore 1975).

In Australia germination rates from 40 populations averaged 78% $\pm$ 2% (range 52-97%; Amor and Harris 1974). Some seeds germinated the year they formed, but most germinated the following spring (Rogers 1928); In England >90% of germination occurs in April and May (Roberts and Chancellor 1979). Fresh seed may have low or high germination rates: Bakker (1960) reported 14% germination with fresh seed, 34% after 3 months and 44% after 6 months, and no germination thereafter when planted 1 cm deep in Holland. However, Hayden (1934) and Derscheid and Schultz (1960) reported that fresh seed had the highest germination, up to 95%, six month old seed had 10-27% viability, and 2-year old seed had 15-71% viability.

The vast majority of germinating seeds develop into female plants (94-100%; Lalonde and Roitberg 1994).

ROOTS

Cirsium arvense spreads primarily by vegetative growth of its roots. The root system can be extensive, growing horizontally as much as 6 m in one season (Rogers 1928). Most patches spread at the rate of 1-2 m/year (Amor and Harris 1975).

Cirsium arvense has two types of roots; horizontal and vertical. Horizontal roots produce numerous shoots, while vertical roots store water and nutrients in their many small branches.

Most *Cirsium arvense* roots can be found directly below the above-ground shoots, with little extension beyond the border of a patch (Donald 1994). Apparently, the horizontal roots give rise to shoots frequently as they expand the range of a patch. Horizontal roots grow within 15-30 cm of the soil surface, and typically grow in a straight line for 60-90 cm, then bend down and grow vertically. Another horizontal root system is usually initiated at the downward bend (Rogers 1928). The horizontal roots are widest at the "bend", and can reach a maximum of 2 cm in diameter, although in sand roots rarely exceed 0.6 cm in diameter (Rogers 1928).

Vertical roots can grow as deep as 6.8 m (Rogers 1928) but most roots are in the upper 60 cm of soil (Haderlie et al. 1987). *Cirsium arvense* roots commonly reach a depth of 1.5 m in one-year old plants, and 2 m in 2-10 year old plants (Nadeau 1988). Root weight averages 1100 g/m^2 and decreases with depth, from 500 g/m^2 in the top 30 cm, to 350 g/m^2 in 31-60 cm, and 250 g/m^2 in 61-90 cm depth (Donald 1994).

Individual roots live up to two years (Rogers 1928). New root buds develop in autumn after the death of aerial shoots (McAllister 1982). Root bud development is highest under short days and moderate temperatures (autumn), and root bud elongation is greatest under long days and high temperatures (summer) (McAllister 1982).

Root growth and survival are affected by environmental factors, especially soil moisture, soil temperature, and substrate. Under high soil moisture, Canada thistle roots are susceptible to damping off (Bakker 1960). Root length increases in the top 30 cm of soil when growing season moisture is reduced, which increases drought tolerance in established plants (Lauridson *et al.* 1983). However, dry winters can result in mortality due to desiccation of roots (Lauridson *et al.* 1983). In northern locales (Sweden) mild winters are linked to spread of *Cirsium arvense*, as growth begins earlier in the spring when more roots survive the winter (Gustavsson 1994). *Cirsium arvense* roots are cold-sensitive, injured when directly exposed to cold temperatures for 8 hours at -2^o C, and dying after 8 hrs at -6^o C (Dexter 1937, Schimming and Messersmith 1988). Canada thistle roots usually survive subfreezing temperatures when insulated by soil, snow cover, and vegetative cover. Canada thistle roots also develop cold-tolerance with increased exposure to the cold (Schimming and Messersmith 1988). It is suspected that deep roots (>30 cm below the soil surface) are more susceptible to freezing than shallow roots (Schimming and Messersmith 1988), because they do not develop cold-tolerance. Root growth varies by substrate. The most extensive root growth occurs on moist clay but growth is reduced on excessively wet soils, and on droughty soils including sand, gravel, and hard-pans (Rogers 1928).

Root carbohydrate reserves follow an annual cycle. Reserves are lowest in early June, just before flowering. Root reserves begin to increase in early fall as shoot growth declines (Hodgson 1968, Bakker 1960, Arny 1932, Welton et al. 1929).

SHOOTS

Shoots begin to emerge when the average weekly temperature is 5^o C, and emergence is highest when temperature is 8^o C (Hodgson 1968). In Montana shoots usually begin to emerge in the second week of May (Hodgson 1964) while in Nebraska shoots emerge beginning 22 March, and flowering begins about 1 June (Hoefer 1982). Growth is more vigorous under 25/15^o C (day/night) regime than colder (15/5^o C) or warmer (30/22^o C) regimes, with 13 and 15 hours of light (Hoefer 1982). However, when the soil is warm (17^o C) and air temperatures moderate (15/5^o C) as is common in autumn, Canada thistle grows vigorously (Hoefer 1982).

Primary shoots grow as rosettes for 2-4 weeks, then elongate (bolt) and develop flower buds some 10 weeks after emergence. Shoots elongate at the rate of 3 cm a day in late June, to an average of 65-138 cm (Hodgson 1964). Secondary shoots, produced from root buds, emerge throughout the summer. Thus, several growth stages may be simultaneously present.

Root buds are inhibited by the presence of the main shoot (both leaves and stem tissue), primarily due to a competition for water between root buds and the main shoot (Hunter *et al*. 1985). When the main shoot is removed (e.g. as by mowing), the root buds are released, and new shoots emerge rapidly, especially when humidity is high.

Most root buds are produced in the center of a patch (up to 800/m^2) near the soil surface (root bud density decreases with depth; Donald 1994). Each meter of root averages 12.8 - 24.4 root buds, each capable of forming a new shoot (Donald 1992). Nadeau and Vanden Born (1989) found an average of eight shoots are produced per meter of root.

Shoot density varies greatly, depending on substrate, moisture conditions, light availability, competition, and season, among other factors. Recorded shoot densities range from 3.2/m^2 (Hodgson 1964) to 230/m^2 (Donald 1994); averages of 6-70/m^2 are frequently reported (Donald 1992 and 1993b, Zimdahl and Foster 1993). Bakker (1960) found an average density of 39 shoots/m^2 with 41 flower heads per shoot in open sites, and a density of 11 shoots/m^2 with 18 flower heads per shoot in shaded areas. Shoot density varies across a patch, and is usually densest near the center and lowest on the edges (Donald 1994).

Shoot density is positively correlated with rainfall during the previous growing season; density increased following a year of above-normal precipitation, and decreased the year following a growing season drought (Donald and Prato 1992). In North Dakota shoot density approximately doubled between late summer and the following spring, from 2 shoots/m^2 in August to 4.6 shoots/m^2 the following June (Donald 1993). Shoot density and root growth are closely correlated: areas with highest shoot density also have the highest underlying root biomass and highest density of adventitious root buds, and also more deep roots (Donald 1994).

In established clones, shoot production increased with increased nitrogen (Nadeau 1988, Nadeau and Vanden Born 1990), indicating that *Cirsium arvense* infestations may be more severe on high-nitrogen soils. This may explain presence of *Cirsium arvense* in degraded wetlands, or wetlands with lowered water tables. On the other hand, shoot production by young plants is stimulated more by favorable temperature and moisture regimes than by nitrogen levels (Nadeau 1988).

In Russia, Mikhailova and Tarasov (1989) determined that the majority of shoots in a clone were both mature and vegetative; less than 10% were either young or sexually reproductive.

GROWTH

Plants grow rapidly from seed, developing roots 1.5 m deep at the end of the first growing season, and flowering the second year (Rogers 1928). Seedlings first develop a branched primary root 5-10 cm deep, and then produce their first true leaves (Bakker 1960). Roots grow rapidly in young plants, up to 1 cm/day in the first 13 weeks (Nadeau 1988). A four-month old plant had a 101 cm root, with 19 shoot buds (Detmers 1927). After just 18 weeks, plants averaged 11 m of roots (Nadeau and Vanden Born 1989), 26 aboveground shoots, 154 underground shoots, and 111 m of roots (diameter >0.5

mm); if these roots were cut into 10 cm long pieces, each piece could have produced an additional 930 shoots.

Growth is strongly influenced by environmental factors. Seedlings require high light and low competition to survive (Moore 1975, Hodgson 1968, Bakker 1960). Thus, Canada thistle apparently has difficulty becoming established from seed in undisturbed areas. Amor and Harris (1974) reported no seedling establishment from seed artificially sown in pastures, whereas 7%-13% of seeds sown on bare dirt emerged, and 78%-93% of these seedlings became established.
Seedlings grow rapidly under high humidity (90-100%), with a 50% increase in stem height and both shoot and root weight compared to seedlings growing at 50% humidity (Hunter et al. 1985).

Drought may favor or disfavor *Cirsium arvense*. The plant's vigor decreases with drought conditions (Hansen 1918), especially in autumn (Boerboom and Wyse 1988a) although in Sweden, *Cirsium arvense*'s long root system allows it to tolerate dry summers better than annual crops (Gustavsson 1994). Established plants develop drought tolerance by increasing root length in the top 30 cm of soil (Lauridson *et al.* 1983). However, shoot density decreases the year following a growing season drought (Donald and Prato 1992).

VEGETATIVE SPREAD

Cirsium arvense spreads vegetatively through horizontal growth of the root system, which can extend 4-5 m radially in one season (Bakker 1960). Individual clones can reach 35 m in diameter (Donald 1994).

Cirsium arvense readily propagates from stem and root fragments and thus plowing or other soil disturbance can increase thistle densities (Nadeau and Vanden Born 1989). Small root fragments (2 cm) can survive and produce clones up to 2.8 m across within one year (Rogers 1928). Hayden (1934) reported plants developing from root fragments as small as 0.5 cm, and 95% establishment from 1 cm long root fragments. Root fragments are able to produce new shoots, independent of the presence of root buds (Nadeau 1988). Rogers (1928) stated that a six week old root fragment can still regenerate a plant.

Partially buried stem fragments have much higher survival than fully buried fragments, as the cut stems remain photosynthetically active (Magnusson *et al.* 1987). Regrowth from stem fragments is highest in mid-June (>70%) and lower thereafter (0-55%) (Magnusson *et al.* 1987).

MISCELLANEOUS

Both roots and leaves may be mildly allelopathic. Extracts from roots and foliage reduced radicle growth, but did not inhibit germination, of several crop and weed species (Stachion and Zimdahl 1980).

American Indians quickly became familiar with *Cirsium arvense* and purportedly used an infusion of its roots for mouth diseases (Rousseay and Raymond 1945 [cited in Moore and Frankton 1974]). The Chippewa considered it to be "tonic, diuretic and astringent" (Densmore 1928). Rogers (1928) indicated that young shoots and roots "can be used in the same ways as asparagus", and were eaten in Russia and by Native Americans. The nectar of *Cirsium arvense* flowers purportedly makes good honey (Rogers 1928).

Restoration Potential:

No studies on the recovery potential of *Cirsium arvense* infested areas were found but recovery will be influenced by the control method employed. Areas treated with repeated discing, repeated mowing, or broadcast herbicide application usually have little or no native vegetation remaining. Areas treated with less aggressive techniques, such as prescribed fire, spot-applied herbicides, biocontrol agents, or infrequent mowing, usually retain most of the native community. Fire may be the least damaging treatment method, because in many habitats it stimulates growth of native vegetation which subsequently competes with Canada thistle. Increasing the native component of the invaded community reduces the potential for *Cirsium arvense* re-invasion by decreasing bare soil (and opportunity for seedling establishment) and increasing competition (thereby reducing rate of vegetative invasion).

Combining biocontrol and prescribed fire or mowing may help control Canada thistle and promote restoration, but this is still in the experimental stage.

Management Requirements:

Cirsium arvense should be removed from high quality natural areas when it is first observed. The plant is very tenacious and difficult to control once established. In lower quality areas, management effort should be influenced by the extent of invasion; greater effort is warranted in areas that have new and/or small invasions which are more likely to be eliminated or contained.

Management Programs:

Cirsium arvense management programs should be designed to kill established clones since the species spreads primarily by vegetative expansion of the root system. Prevention of seed production is a secondary consideration since spread by seeds is relatively rare. On the other hand, seedlings are the most susceptible growth stage (Bakker 1960). In areas that are susceptible to thistle invasion but which have not yet been invaded, management programs should be implemented to prevent the species from becoming established.

It is important to understand the biology of *Cirsium arvense* as control is greatly influenced by clonal structure (Donald 1994), growth stage (Tworkoski 1992), season of treatment, weather conditions, ecotype (Hodgson 1964), soil type, and control method(s) used. A single control method is rarely effective and it is often necessary to use two or more methods at any given site (Lee 1952, Donald 1992, Diamond 1993). In addition, treatments or combinations that are effective at one site may be ineffective at others (Frank and Tworkoski 1994).

It takes at least two growing seasons to determine whether a particular control method is effective. Several studies have recorded a temporary decline in *Cirsium arvense* in the first year after treatment, followed by a return to the pre-treatment conditions the second growing season (Zimdahl and Foster 1993).

The literature on Canada thistle control focuses on agricultural systems. Management in natural areas is more difficult due to the need to protect native species and communities. At this time, there are no control methods suitable for wide-spread use in natural areas that eradicate, rather than reduce, Canada thistle.

Management strategies should be adjusted to reflect weather conditions. For example, drought stress reduces the effectiveness of most herbicides against *Cirsium arvense* (Haderlie et al. 1987), but increases the effectiveness of mechanical controls (Hansen 1918, Johnson 1912). Thus, mowing or burning would be preferred strategies under drought conditions.

BIOLOGICAL CONTROL

Overall, biocontrol currently provides little or no control of Canada thistle populations, although some agents weaken and kill individual plants. Most potential biocontrol organisms are not adequately synchronized with *Cirsium arvense*'s life cycle in North America to induce high mortality. Management that delays *Cirsium arvense* maturation, such as mowing or burning, may help synchronize the susceptible thistle growth stage to the biocontrol agent life cycle (Forsyth and Watson 1985a).

Cirsium arvense has few or no effective natural enemies in its native habitat, where it is also considered a severe agricultural weed (Peschken 1971). In all, more than 130 species, including diseases, birds, and >80 insects, attack Canada thistle (Maw 1976). At any one site in its native range, however, an average of 4.5 insect species attack *Cirsium arvense* but in general they cause little damage, as their densities are usually low and most species consume little plant material (Freese 1995). In North America, larvae of the native painted lady butterfly (*Vanessa cardui*; Lepidoptera) feed on Canada thistle and other related thistles and cause extensive defoliation within localized areas, but impact varies year to year due to migration patterns (Story *et al*. 1985).

At least 7 insect species have been intentionally or unintentionally released for Canada thistle control in North America and a few of them cause conspicuous damage. The beetle *Cassida rubiginosa* was introduced accidentally in 1902 and defoliates plants (Maw 1976). Larvae of the intentionally introduced biocontrol weevil *Ceutorhynchus litura* feed on stems of Canada thistle. The introduced stem-galling fly *Urophora cardui* attacks thistle shoots but has little impact. Larvae of the fly *Orellia ruficauda* (Diptera) damage seed heads. The beetles *Altica carduorum* and *Lema cyanella* feed on Canada thistle's leaves. The seed weevil *Rhinocyllus conicus* was introduced to control musk thistle (*Carduus nutans*) and other related *Carduus* and *Cirsium* thistles and lays eggs in Canada thistle flowerheads. The weevil *Larinus planus* is a seed head feeder but it has had little impact on Canada thistle and attacks native thistles. Two pathogens have also been considered for use against Canada thistle. The rust *Puccinia punctiformis* and the fungus *Sclerotinia sclerotiorum* attack shoots and roots respectively. Of all these biocontrol organisms, *Orellia ruficauda* and *Puccinia punctiformis* appear to inflict the most significant damage (Maw 1976, Forsyth and Watson 1985a), but even this is probably not sufficient to control Canada thistle populations.

A combination of biocontrol agents, or of biocontrol agents and herbicides, may provide better control of Canada thistle than any single agent. It has been suggested that at least three biocontrol organisms may be needed for effective Canada thistle control (Forsyth and Watson 1985a) In western Canada, where *Cassida rubiginosa* and *Puccinia punctiformis* do not occur, *Cirsium arvense* is a much greater problem than in the eastern part of Canada, where these organisms are present. In Ontario there appeared to be a synergistic relationship between infestation of thistle by *Ceutorhynchus litura* and infection by the rust *Puccinia punctiformis*. 87% of rust-infected thistles were mined by weevils compared with 32% of uninfected shoots (Peschken and Beecher 1973). Such an effect is not reported for sites in western Canada (Peschken and Wilkinson 1981). Impacts of *Ceutorhynchus litura* are also enhanced when Canada thistle is infected with the fungal pathogen *Sclerotinia sclerotiorum*. *Ceutorhynchus* mining may have significant impacts after *Sclerotinia* infection under drought conditions, especially in the western Great Plains (Bourdot et al. 1995). Vegetative shoots were most susceptible to the disease (Bourdot *et al.* 1995) but the disease was not transferred to shoots that emerged after the initial infection. This disease is therefore most effective as a control method if applied after the majority of shoots have emerged. Disease development, however, requires high moisture conditions which are less likely as the growing season progresses in most areas (Bourdot *et al.* 1995). Thus, timing of application is critical, and varies between sites and years.

Schroeder (1980) suggested that a combination of root- and shoot-feeding insects will be needed for effective biological control but no root feeders are known that cause substantial damage to *Cirsium arvense* (Ang *et al.* 1995). The organisms tested for biological control were not simultaneously tested for tolerance to herbicides (Trumble and Kok 1982) but it appears that 2,4-D can be applied at low rates in conjunction with the rust *Puccinia punctiformis* to achieve better control than either treatment alone (Haggar et al. 1986).

Leaf-feeding Painted Lady Butterfly (*Vanessa cardui*)

Larvae of the native Painted Lady Butterfly (*Vanessa cardui*) feed on *Cirsium arvense* and other *Cirsium* species, and can defoliate and kill individual plants (Detmers 1927, Rees 1991). Painted lady typically occurs in southern states, including California, and is itself infected by a virus that keeps its populations low. Every 8-11 years, populations explode and the butterflies migrate north where they can temporarily be very effective biocontrol agents. Viral infection spreads rapidly in large painted lady butterfly populations, however, and within a year or two the butterfly populations drop again (Rees 1991).

Leaf-feeding Beetle *Cassida rubignosa*

Cassida rubignosa was accidentally introduced to the US in 1902 (Barber 1916 in Ang et al. 1995). This beetle causes severe defoliation of Canada thistle in Virginia and Maryland (Ang *et al.* 1995) but only minimal damage in Quebec (Forsyth and Watson 1985a). Defoliation by *Cassida rubignosa* is most effective at high insect density on young plants (Forsyth and Watson 1985a), but under field conditions this insect is not synchronized with young thistles and thus causes minimal damage. Ang *et al.* (1995) determined that *Cassida rubignosa* significantly reduced thistle biomass and survival. At a density of 20 beetles/plant, over two-thirds of the thistles died by the end of the growing season. *Cassida* impact was substantially greater during drought conditions, and roots were "devastated" by attacks of 10 beetles/plant (Ang *et al.* 1995). However, damage by *Cassida rubignosa* is rarely sufficient to reduce thistle growth in the field (Diamond 1993). *Cassida rubignosa* larvae are themselves parasitized by fly, wasp, and beetle species (Tipping 1993). In addition, *Cassida* have low dispersal rates and rarely move more than 2 m from the release site within 26 days (Tipping 1993). Adults oviposit at the release point, regardless of thistle density (Tipping 1993). For effective control, beetles must be deposited on thistle rosettes at approximately 4 m intervals, or at least in each patch within a site.

Stem-mining weevil *Ceutorhynchus litura*

Between its initial introduction in North America in 1967 and 1985, the stem-mining weevil *Ceutorhynchus litura* became established in five Canadian provinces and Montana (Peschken and

Wilkinson 1981, Story et al. 1985). *Ceutorhynchus litura* can reduce overwinter survival of *Cirsium arvense* but thistle stands recover by shoot recruitment from unattacked plants (Rees 1990). Females feed on leaf tissues and lay eggs in feeding cavities. The developing larvae mine leaves and migrate inside stems to the root collars (Rees 1991). Unfortunately, *Ceutorhynchus litura* larvae mine the parenchyma tissue of the stem pith and do not damage vascular bundles, so water translocation is not affected (Peschken and Wilkinson 1981). While thistles usually survive the stem mining, the holes left by departing larvae provide entrance sites for other arthropods, nematodes, and disease organisms which cause high mortality of belowground shoots (Rees 1990). However, production of new shoots from underground roots the following spring offsets shoot mortality caused directly and indirectly by *Ceutorhynchus litura* (Rees 1990).

Seed Head Predator *Orellia ruficauda*

Orellia ruficauda is a small fly that deposits its eggs in *Cirsium arvense* flower heads. Damage occurs when developing larvae eat the seeds in mid-summer (Detmers 1927). This may reduce seed production and seed dispersal (Forsyth and Watson 1985b). In one study 20-85% of seed heads were attacked, and 20-80% of seeds within each attacked seedhead were damaged. Forsyth and Watson (1985a) reported that *Orellia ruficauda* occurred in up to 70% of flowerheads and destroyed 22% (range 0-90%) of the seeds/head. Seed predation causes only limited suppression of *Cirsium arvense*, however, as the plant spreads primarily by vegetative means (Diamond 1993, Forsyth and Watson 1985a). While flies avoid laying eggs in male flowerheads and preferentially select female flower heads, the developing larvae do not eat enough seeds in a flowerhead to affect either the individual seed head or the population (Lalonde and Roitberg 1992b). Apparently, flies lay only a few eggs in any one flower head, and avoid laying eggs in previously-infested flower heads (Lalonde and Roitberg 1992a).

Other Natural Enemies

The Chrysomelid beetle *Altica carduorum* weakens Canada thistle by defoliating it and feeding on its flower heads. It was first regarded as a promising control agent because of its specificity and continuous feeding habit, but has proven unsatisfactory because of its own susceptibility to predation (Peschken et al. 1970, Story et al. 1985, Schaber et al. 1975). *Cleonus piger* is a root-feeding weevil that can cause wilting and plant death, but plants usually regenerate from damaged vascular tissue (Forsyth and Watson 1985a). The leaf spot disease *Septoria cirsii* is host specific to *Cirsium arvense*, and causes severe damage to *Cirsium arvense* plants in the field, inhibiting seed germination and root elongation, and causing leaf chlorosis and necrosis (Hershenhorn *et al*. 1993). This disease has been proposed for consideration as a biological control organism.

BURNING

Cirsium arvense response to fire varies from positive to negative, depending on season of burn, soil moisture, and location. Dormant season burning stimulates growth of native herbaceous species which compete with Canada thistle. Growing season fire damages native species as well as Canada thistle.

In a mesic grassland in Oregon, dormant season fire reduced Canada thistle flowerhead and seed production. Flowering plants had equal density in burned and unburned plots (55-61/m^2) but produced 50% fewer flowerheads in the burned plots (18/shoot vs 36/shoot, respectively; Young 1986). Additionally, plants in the burned plots produced an average of 1.2 "functional" or seed-producing flowerheads/shoot, compared to 16.3/shoot in the unburned plots. Dormant season burning (December or April) also stimulated production of numerous small Canada thistle shoots, resulting in higher density but equal biomass (Young 1986).

In North Dakota, dormant season burning reduced the relative abundance of *Cirsium arvense* by stimulating growth of native vegetation (Carlson 1987). Growing season fires reduced thistle density but harmed native species (Smith 1985). Plots burned in mid-June had heavy seed production July through September, while plots burned mid-July to mid-August had numerous seedlings in August and September but they failed to survive the winter (Smith 1985).

In Alberta, Canada, spring burning in a marsh favored growth of native species and did not alter *Cirsium arvense* biomass (Thompson and Shay 1989). An August fire increased biomass and shoot density of *Cirsium arvense*, which averaged 63 g/m^2 vs 5 g/m^2, and 20 $shoots/m^2$ vs 0.9 $shoots/m^2$, on burned and unburned plots, respectively (Thompson and Shay 1989). Seedling density also increased following the summer fire. In another wetland in Alberta, Canada, *Cirsium arvense* cover was not affected by fire (Hogenbirk and Wein 1991), but increased when the wetland area was subjected to drought.

CHEMICAL

Most studies of herbicide use are focused on reducing *Cirsium arvense* in agricultural areas, and are not directly applicable to use in natural areas. For example, Jaeger (pers. comm.) stated that boom spray application of 2,4-D for Canada thistle control in Kilen Woods State Park, Minnesota was ineffective because it set back the succession of natural communities, actually opening areas for thistle invasion. Other herbicides can have similar impacts on native vegetation.

The following factors should be considered when using herbicides against Canada thistle:
· Their effectiveness is contingent upon *Cirsium arvense* growth stage, environment (Tworkoski 1992), ecotype (Hodgson 1970), and genotype (Frank and Tworkoski 1994).
· Different ecotypes respond differently to the same herbicide, so what is effective at one locale, or on one clone, may not be effective in other locales or clones (Frank and Tworkoski 1994). It is important to vary herbicides used at a site to prevent clones tolerant to one herbicide from becoming dominant (Frank and Tworkoski 1994). When selecting an alternative herbicide it is best to use one with a different mode of action (mechanism by which it kills plants) to minimize chances that plants are not tolerant to both herbicides.
· In many habitats *Cirsium arvense* goes dormant shortly after native species, so there is only a limited window to apply herbicides when native species will not be affected.
· It is important to treat an entire clone, as not all shoots and roots in a clone remain physically connected (Donald 1992).
· For all herbicides except 2,4-D, two or more applications give better control than a single application, regardless of seasonal sequence (spring-fall treatment gave equal control to fall-spring treatment; Zimdahl and Foster 1993, Donald 1993).
· *Cirsium arvense* is best treated with herbicides in early spring or in fall and fall treatments are usually more effective than spring treatments (Haderlie et al. 1987, Darwent *et al.* 1994a, Lym and Zollinger 1995). Herbicide absorption is enhanced in late summer and fall, when plants are in the rosette stage (Hunter et al. 1990), as shoot-to-root translocation is greatest at that time (Darwent *et al.* 1994a).

Hunter (1996) found that control is improved if thistles are cut in late July and the resprouts treated with glyphosate about 4 weeks later in late August (the 'August rosette stage'). Second best treatment time is at flower-bud stage, when root reserves are lowest, particularly under droughty conditions (Haderlie *et al.* 1987). However, native species can be damaged by growing season herbicide application.

Canada thistle's deep, well-developed root systems make it resilient to most control methods including herbicides. However, *Cirsium arvense* undergoes several growth stages during the growing season and during certain stages root carbohydrates are depleted. Root carbohydrate depletion is related to growth stage and is greatest when flowering occurs, but replenishment is related only to environmental conditions, and generally occurs in late summer and fall. Younger growth stages (spring) are likely more susceptible to herbicide, but the root system is larger and more difficult to kill in spring before the flower stalk emerges; older growth stages (fall) are somewhat less susceptible, but the root system is depleted and smaller, and assimilates are naturally moving from the leaf tissues to the root system (Tworkoski 1992). More assimilate (and hence herbicide) moves into the roots under short days and low temperatures (fall) than long days and warm temperatures (summer; McAllister 1982).

Herbicide effect is enhanced when 1) *Cirsium arvense* roots are weakened during the growing season by herbicide treatment, crop competition, or frequent mowing or tilling; and 2) new shoots are stimulated to grow. Suitable herbicides (e.g. glyphosate) should be applied to new growth when leaves are green (September or October). Avoid applying herbicide to old leaves (thick cuticle limits absorption) or to drought-stressed leaves.

<u>Clopyralid (Stinger or Transline), Clopyralid plus 2,4-D (Curtail)</u>
Clopyralid plus 2,4-D (sold under the tradename Curtail) provides the best and most consistent control of Canada thistle in agricultural areas (Lym and Zollinger 1995), but may damage native forbs and shrubs. Clopyralid is a relatively selective post-emergence herbicide that kills certain broadleaf weeds and woody plants but does little harm to others such as members of the mustard family (Brassicaceae) or to grasses and other monocots. It is especially effective against members of the sunflower, buckwheat and pea families (Asteraceae, Polygonaceae and Fabaceae, respectively). The basis of this selectivity is not well understood for clopyralid or other auxin-type herbicides like 2,4-D or triclopyr (sold under the tradename Garlon). Clopyralid may have limited soil residual and is most effective on short (young) thistle shoots. Control was "excellent" on 5-15 cm tall shoots, very good on 30 cm tall flowering shoots; and poor on 80 cm tall shoots (Donald 1992). Annual applications in early June at 70+280 g ai/acre (clopyralid + 2,4-D) resulted in elimination or near-elimination of all Canada thistle roots in the top 50 cm of soil after 2-4 years.

Fall application of Clopyralid delayed shoot emergence by two weeks, and reduced shoot density the following summer (Donald 1993). The impact of clopyralid increased with increased application rate, and application of 840 g/ha had the greatest impact. One fall application with clopyralid at 560 g/ha prevented almost all *Cirsium arvense* shoot emergence the following spring.

<u>Glyphosate (Roundup, Rodeo)</u>
Glyphosate is a non-selective systemic herbicide that kills all vegetation green at the time of application. It has little or no soil residual. Glyphosate impacts *Cirsium arvense* by reducing the number of root buds and regrowth of secondary shoots, more than by reducing root biomass (Carlson and Donald

1988). No root bud regrowth occurred when glyphosate was applied at 0.28 kg/ha (Carlson and Donald 1988). Translocation of glyphosate is significantly greater in plants at the bud to flowering stage than in younger plants (Sprankle et al. 1975), and is greatest when plants are in the 'August rosette stage' (Darwent et al. 1994, Hunter 1995). The root is larger at the rosette stage, diluting the effect of glyphosate, but herbicide concentrations in the root are still up to 3 times higher at this time (Hunter 1995) because more herbicide is translocated when leaves are in vegetative (rosette and shoot-elongation) stage than in flowerbud or flowering stage (Hoefer 1982). In the laboratory, 4 times more glyphosate was translocated to the roots of rosettes than flowering plants (Hunter 1995).

Fall is the best season for applying glyphosate (Darwent et al. 1994, Lym and Zollinger 1995). For optimal results apply glyphosate under warm conditions prior to the first killing frost and when soil moisture is good, or after plants have adjusted to colder weather. Avoid treating thistles immediately before the first frost (Lym and Zollinger 1995). Plants treated with glyphosate one day before frost had much lower translocation of herbicide to the roots than plants in warm conditions, or plants hardened to cool air and soil temperatures (15/5^{o} C; Hoefer 1982).

Response of *Cirsium arvense* to glyphosate varies among clones (Frank and Tworkoski 1995, Darwent *et al.* 1994a). The majority of damage occurs after 3 days, but glyphosate continues to act on sensitive tissues for up to 45 days (Carlson and Donald 1988). Good soil moisture is important for glyphosate to be effective (Haderlie *et al.* 1987). Glyphosate impact was slightly reduced under severe drought conditions (Lauridson *et al.* 1983).

A low glyphosate concentration (2.5%) was more effective than higher concentrations (5%, 10% and 30%) reducing shoot growth and regrowth 76% at the lower rate and having no effect at the higher rates (Boerboom and Wyse 1988b). At high concentrations glyphosate kills leaves so quickly that they are unable to translocate the herbicide to the roots before they die. Droplet size is also a factor, as large droplets kill leaf tissue more than small droplets (Boerboom and Wyse 1988b). Lower levels of surfactant (MON 0818) are recommended, as glyphosate mixed with high MON 0818 concentrations may kill leaves rapidly (Boerboom and Wyse 1988b).

Haderlie et al. (1987) stated that glyphosate was most effective on fall regrowth, then at flower/bud stage, and least effective in spring when applied to 25 cm tall plants. On the other hand, Devine (1981) found that although glyphosate translocation was slower under low temperatures, total uptake was not affected by growing conditions, and after 5 days 63% of the amount applied was absorbed and 22% exported to the roots regardless of temperature. Glyphosate was unevenly distributed in the root system and concentrated in fibrous roots and new shoot buds (Devine 1981). Between 1% and 2% of glyphosate was extruded by roots (pumped out into the surrounding soil) after 10 days (Devine 1981).

Cirsium arvense response to glyphosate differs between sites and/or clones. In Canada, a single application of glyphosate at 0.45 kg/ha reduced thistle shoot density by >75% at two sites, while 1.8 kg/ha was required to achieve the same level of control at a third site (Darwent *et al.* 1994). Four consecutive annual applications at 0.45 kg/ha reduced *Cirsium arvense* shoot density > 98%, at two sites, but at the third site four annual applications at 1.8 kg/ha were required (Darwent *et al.* 1994a). Most reduction occurred after the first application at all sites.

One or two applications of glyphosate at 1.7kg/ha did not prevent *Cirsium arvense* shoot regrowth, as enough roots remained to allow the plants to survive and resprout (Donald 1993). Fall treatment in two consecutive years decreased shoot density 94% the following fall, and root weight 77% (Carlson 1987). Five years after the treatments, however, thistle densities were the same in treated and untreated areas (Donald and Prato 1992).

Jaeger (pers. comm.) found application of Roundup to individual plants with a Walk-a-Wick applicator was difficult because the thistles were often below grass level. In 1985, park personnel in Minnesota began using a 4-5 gallon Solo backpack tank with the nozzle modified by a brass adjustment to apply a straight stream (not mist) at low pressure. Roundup at 3-4% was mixed with a purple agricultural dye and the mixture dribbled at the top of the stem and allowed to run down the stem. Use of the dye which persisted as a marker of treated plants for up to a week cut both the time involved and amount of herbicide used in half. Plants were treated in the pre-bud stage and rounds were made weekly to assure treatment of plants that were missed earlier.

<u>Chlorsulfuron</u>
Chlorsulfuron is a post-emergent herbicide that primarily suppresses regrowth of Canada thistle, and secondarily reduces the number of root buds and plant weight (Peterson 1983). Addition of growth regulators (chlorflurenol and dicamba) to chlorsulfuron enhanced control of *Cirsium arvense* in the greenhouse, but not under field conditions (Peterson 1983). Thistle density was reduced 2-5 years after spring application of chlorsulfuron (Donald and Prato 1992)

<u>NOT RECOMMENDED</u>

<u>Picloram (Tordon)</u>
Picloram is a restricted use herbicide that may persist for up to 3 years in the soil and is not registered for use in California. It is relatively soluble and thus likely to be carried to the water table by percolating rain or irrigation water. Two to three annual fall applications of picloram at 280 g/ha gradually reduced *Cirsium arvense* density, and both one and three consecutive annual fall applications at 560 g/ha essentially eliminated *Cirsium arvense* (Donald 1993). Haderlie *et al.* (1987) found picloram was the most effective herbicide against Canada thistle but it killed all broadleaved vegetation in treated areas. Picloram accumulates in shoot apices (Sharma and Vanden Born 1973 cited in Donald 1990) and is applied at flower bud stage or to fall regrowth (Haderlie *et al.* 1987).

<u>Dicamba (Banvel)</u>
Dicamba has limited effectiveness on *Cirsium arvense*, and it persists for long periods in the soil making it unacceptable for use in most natural areas. *Cirsium arvense* ecotypes vary in susceptibility to dicamba (Hodgson 1970, Saidak and Marriage 1976).

<u>Metsulfuron (Ally)</u>
Metsulfuron is ineffective against Canada thistle. Three consecutive fall applications did not reduce *Cirsium arvense* "sufficiently" (Donald 1993). Metsulfuron must be applied with another broadleaf herbicide, such as 2,4-D, to suppress Canada thistle (Lym and Zollinger 1995).

<u>2,4-D</u>

Canada thistle ecotypes varied greatly in their susceptibility to 2,4-D (Hunter and Smith 1972) and 2,4-D's impacts on treated plants were erratic (Donald 1990) and less effective than glyphosate or dicamba (Lym and Zollinger 1995). Three consecutive fall applications of 2,4-D did not reduce *Cirsium arvense* "sufficiently" (Donald 1993). Effectiveness of phenoxy herbicides like 2,4-D and MCPA is greater when root carbohydrate reserves are low (Marriage 1981). In agricultural situations, a combination of 2,4-D with fertilization was effective under some circumstances. Hodgson (1968) found combining 2,4-D at .24 to 2.24 kg/ha with 33.6 kg/ha nitrogen and 112 kg/ha phosphorus resulted in better thistle control and higher yields of spring wheat than either herbicide or fertilizer alone.

Five days after application 2,4-D was evenly distributed throughout the root system (Devine 1981). 3.1% of the applied 2,4-D is extruded from the roots (Devine 1981).

<u>Bentazon (Basagran)</u>
Bentazon is a post-emergent contact herbicide that can control topgrowth of Canada thistle when applied to plants roughly 20 cm tall in late spring and summer (Haderlie *et al*. 1987). At this time, however, native vegetation is very susceptible to damage. Bentazon-induced chlorosis was evident in thistles emerging 10 months after treatment, indicating that Bentazon may be stored in roots over winter and transported back to the leaves in spring (Brewster and Stanger 1980).

Thistle density decreased >80% after single applications, applied late May through late June (Brewster and Stanger 1980). Applications in early May treatment were less effective. Repeated applications (two applications at 10-14 day intervals) of 2.2 kg/ha provided better control than single applications at higher rates (3.4 - 6.7 kg/ha; Brewster and Stanger 1980). Split applications provided better control than a single application. A total of 0.84 kg/ha resulted in 84% control with one application, and 92% with two applications (Boerboom and Wyse 1988a). A total of 1.1 kg/ha in one or two applications reduced *Cirsium arvense* by 40%, and by 76% when applied in four applications (Boerboom and Wyse 1988a).

GRAZING, DREDGING, AND DRAINING

Very young plants are eaten by goats or sheep in the spring, but grazing is the least effective control method for Canada thistle (Rogers 1928). Cattle and horses avoid *Cirsium arvense*, and browse on competing vegetation, which results in gradual dominance by *Cirsium arvense*. Heavy grazing breaks up sod, which permits seeding in of Canada thistle.

There are no available data on the effect of stocking rates or grazing intensities on Canada thistle. It seems likely that animal disturbance from conventional grazing encourages the spread of Canada thistle, as has been demonstrated for *C. lanceolatum, C. vulgare*, and *C. undulatum* (Tomarek and Albertson 1953, Ankle 1963, Hetzer and McGregor 1951).

MANIPULATION OF WATER LEVEL AND SALINITY

There is no information on the impacts of manipulating water levels on *Cirsium arvense*, and little on impacts of manipulating soil salinity. Salt was one of the earliest chemicals used to kill *Cirsium arvense*. Applications of 180-640 pounds/acre used in the 1920's killed *Cirsium arvense* (Hodgson 1968). but the species is tolerant of lower salt concentrations. Seed germination is reduced but not prevented by modest concentrations of NaCl; Wilson (1979) recorded germination rates of 83% without NaCL, 67% at 10,000 ppm NaCl, and 14% at 20,000 ppm NaCl (seawater is about 35,000 ppm salt).

MOWING, DISCING AND PULLING

Mowing temporarily reduces above-ground biomass, but does not kill *Cirsium arvense* unless repeated at 7-28 day intervals for up to 4 years. This intensity of mowing is not recommended in natural areas, where it would likely damage native vegetation. Mowing just twice a year, in mid-June and September may reduce or contain Canada thistle. When mowing, cut high enough to leave > 9 leaves/stem, or >20 cm of bare stem tissue, as mature Canada thistle leaves and stems independently inhibit development of shoots from rootbuds. When the primary stem is removed, rootbuds are stimulated to produce new shoots that might otherwise be suppressed, especially under low humidity. Under high humidity, root buds are stimulated to develop shoots regardless of presence of stem or leaves (Hunter *et al*. 1985). Cut plants also produce twice the length and weight of new shoots after just seven days under high humidity (100%) than low humidity (50%; Hunter *et al*. 1985).

Early studies recommended mowing at frequent intervals to starve Canada thistle's root systems and remove *it* from farm fields and pastures (Cox 1913, Johnson 1912, Hansen 1918, Detmers 1929). Mowing monthly for a four-year period eliminated practically all thistles (Welton et al. 1929) and mowing at 21-day intervals weakened roots and prevented seed production (Seely 1952). Hodgson (1968) found that mowing alfalfa fields twice annually, at Canada thistle's early-bud to pre-flowering stage (early to mid-June in Montana) and early fall (September) reduced Canada thistle to 1% of its initial value in four years. Mowing two to three times a year can prevent seed set (Hansen 1913, Rogers 1928) but mowing once a year is ineffective (Donald 1990). In order to prevent production of viable seeds, stems must be mown before the flowers open when they have been open for only a few days. Stems with flowers that have been open 8-10 days can develop viable seeds (Derscheid and Schultz 1960).

Tilling can reduce or eliminate *Cirsium arvense*, if conducted repeatedly for several years. Tilling 7-10 cm deep every 21 days (6 cultivations over the growing season) reduced *Cirsium arvense* shoots by 98% in Montana (Hodgson 1958), and "eradicated" *Cirsium arvense* in Idaho (McKay *et al*. 1959). Ecotypes of *Cirsium arvense* differ somewhat in their response to repeated cultivation, but all were controlled by 10 cultivations over 1 1/2 growing seasons (Hodgson 1970). Tilling is not recommended in natural areas, however, because it would severely damage native vegetation and tilling can sometimes spread Canada thistle across and between fields (Willard and Lewis 1939).

Tilling affects only the upper part of the root system and in some cases as little as a quarter of Canada thistles roots are in the top 20 cm of soil reached by normal tillage while the majority of roots are 20-40 cm deep and some roots reach to 1.8 m deep (Nadeau and Vanden Born 1989). New shoots develop after tilling. Root fragments from a single young plant can produce over 900 shoots when the roots are cut into 10 cm fragments (Nadeau and Vanden Born 1989), as typically occurs with discing. Deep tilling (10-20 cm below the soil surface) is more effective than shallow tilling (surface), Fewer shoots are present 40 days after deep tilling and shoots cut at depth require more time to emerge than shoots cut near the surface (Darwent *et al*. 1994).

When tilling is discontinued after early August, new shoots do not produce flower stalks. Repeated tillage, however, kills *Cirsium arvense* by preventing shoot growth and thus depleting roots and their fragments of nutrient reserves (Donald 1990). Leaving large clods (5.3 cm diameter) minimizes seed germination and leaving small clods (1.5 cm diameter) can stimulate germination of seedling which can be killed by retilling or treating with herbicide (Terpstra 1986). Seedlings should be disced or treated with herbicide within 2 1/2 weeks of thistle germination because after that time they will have developed roots that can survive discing and some herbicide treatments (Haderlie *et al*. 1987). Eight percent of seedlings (19 days old) with 2 true leaves resprouted when their tops were cut (Wilson 1979).

In Canada the most successful control method for *Cirsium arvense* is the "August rosette method", consisting of tilling until mid to late-July, applying herbicide in mid-August, and tilling again after 3 weeks (Alberta Agriculture 1993, Saskatchewan Agriculture and Food 1993, cited in Darwent et al. 1994b, Hunter 1996). Darwent *et al*. (1994b) recommend tilling *Cirsium arvense* patches until August 1, waiting 40 days for all shoots to emerge, and then applying glyphosate to the new shoots. Tilling until August 1 ensures that newly emerged shoots will remain as rosettes, as *Cirsium arvense* flowers only under long-days. Waiting 40 days is necessary to obtain adequate shoot emergence, and for shoots to grow large enough for effective glyphosate activity (Darwent et al. 1994b). This method is not practical in most natural areas unless thistles are mown or individually cut near the soil surface instead of tilled.

Reversing this procedure (applying herbicide and then tilling or discing) is ineffective regardless of herbicide type, season of herbicide application, or time between discing and herbicide treatment (Zimdahl and Foster 1993). Destroying shoots by discing releases dormant buds, and may increase the total number of shoots (Zimdahl and Foster 1993). A minimum of 3 days between glyphosate and tilling is needed for glyphosate to damage root system (Carlson and Donald 1988); waiting longer may further increase thistle mortality.

Discing in Mid-June is ineffective, as cut stems readily develop new roots and establish new clones (Magnusson *et al. 1987*). Fewer cut stems survive when discing is conducted in mid-September, and surviving stems do not develop adequate root systems to survive the winter (Magnusson *et al. 1987*). These roots are also more likely to be winterkilled, since disced fields accumulate less snow cover than undisced fields, and soil temperatures are lower (*Cirsium arvense* roots are injured at -2 degrees C and killed at -8 degrees C; Schimming and Messersmith 1988). Discing an all-male population may result in development of female plants.

SMOTHERING

Mulching is impractical. Manure must be spread 2 m thick and cover an area 5-6 m in diameter *Cirsium arvense*, and plants that emerge at the mulch perimeter must be removed. Likewise, mulching with hay is ineffective, as roots extend beyond the covered shoots (Willard and Lewis 1939). Mulching may actually enhance *Cirsium arvense* overwinter survival, as mulch insulates cold-sensitive roots.

However, covering Canada thistle with boards, sheet metal or tar paper can kill the plants (Spence and Hulbert 1935).

COMPETITION

Smother crops may be grown to choke and shade out undesirable species. To be effective against Canada thistle the crop must come up first, grow rapidly during the early summer in order to shade out the thistle, and retain vigor until frost (Rogers 1928). These principles apply in the selection of smother crops on cultivated fields or haylands, but may also be applicable in the selection of native "smother" species in prairie restorations.

Smother crops are used in integrated pest management systems for Canada thistle on agricultural lands (Hodgson 1968) but the smother crops known to be effective are themselves invasive. Alfalfa (*Medicago sativa*) and especially sweet clover (*Melilotus alba* and/or *M. officinalis*) compete with and can reduce spread of *Cirsium arvense*, particularly when mowed as haycrops 3 times/year (Detmers 1927, Rogers 1928). However, these species are persistent and/or invasive in natural areas. Competition from timothy, orchard grass or redtop is ineffective (Detmers 1927).

Competition from tall fescue (*Festuca arundinacea*), in combination with the defoliating beetle *Cassida rubignosa*, reduced *Cirsium arvense* density after three years, but not after two years (Ang 1993). Competition from tall fescue was more detrimental to *Cirsium arvense* than competition from crownvetch (*Coronilla varia*) (Ang *et al.* 1995), and damage increased in when tall fescue was used in combination with *Cassida rubignosa.*

ENVIRONMENTAL

Control efforts may be more successful when *Cirsium arvense* is under environmental stress. The plant is drought and flood sensitive, and its roots are cold-sensitive. Cutting or applying herbicide to shoots after a very severe winter may add sufficient stress to kill plants.

Monitoring Requirements:

Monitor annually for presence of Canada thistle in a site. The best time to search is just before or during the blooming period, which varies from south to north, but corresponds with periods with 14-18 hours of daylight (Linck and Kommedahl 1958, Hunter and Smith 1972). Once patches or individuals are located remove or treat them before they flower and set seed (note that vegetative, and not sexual, reproduction is the primary method of expansion). If Canada thistle is firmly established in a natural area, efforts should be made to eradicate, or at least to contain, the plant rather than simply monitor its spread.

Monitoring Procedure:

Walk through potential habitat; prairies, pastures, roadsides (any open herbaceous community). Abundance can be measured by recording the number of patches and the size of each patch along randomly located transects.

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