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Analysis of Sulphur Cinquefoil in British Columbia

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Province of British Columbia
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SUMMARY

Sulphur cinquefoil (*Potentilla recta* L.), an introduced plant in North America, is believed to displace native plant species in undisturbed habitats and may alter the functioning of ecosystems by lowering biodiversity. Despite concern about this species, little information is available about its impact on ecosystems, and no information specific to British Columbia is available. Preliminary indications are that this weed has a fairly wide ecological adaptation, however, it is currently only reported as a problem in the Bunchgrass, Ponderosa Pine, and Interior Douglas-fir biogeoclimatic zones.

A better understanding of sulphur cinquefoil, with specific reference to how it develops, reproduces, and survives in the conditions prevalent in British Columbia, is necessary to further our understanding of the situation. As a basis for study, an accurate inventory of existing populations should be conducted, and its ecological limits determined to confirm which ecosystems and habitat types are suitable for establishment and persistence. The impact of this weed on biodiversity must be quantified through research into the relative competitiveness of sulphur cinquefoil with other plant species and its influence on the dynamics of the various host ecosystems. In addition, the economic consequences of sulphur cinquefoil infestations must be characterized to give clearer direction for a management plan.

Management inaction during the time necessary to complete these investigations could result in a needless expansion of any current problem. A multiagency management program should be developed and refined as information from research and monitoring efforts becomes available.

Effective forest and range management, with an emphasis on maintaining vigorous plant communities, are the basis for managing the sulphur cinquefoil invasion. Integrated vegetation management, using biological, chemical, and cultural controls where necessary, should be employed. Potential biological control agents should be investigated using a key species list for rapid preliminary screening. However, since the search for a suitable biological control could be very long and costly, the nature and extent of the sulphur cinquefoil problem in British Columbia should be determined before committing resources to a full biological control program. Chemical controls should continue to be limited to spot treatment of new or small, isolated weed populations. A prevention strategy involving extension to resource users and the general public must be initiated. The sulphur cinquefoil problem could be reduced by raising public awareness of the issues and promoting responsible land use.

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1 INTRODUCTION

Sulphur cinquefoil (*Potentilla recta* L.), a native of Europe and Asia, was introduced to North America over a hundred years ago and has spread rapidly. Although it has never been documented quantitatively, it is believed to displace native plant species in undisturbed habitats, and may alter the functioning of ecosystems by lowering biodiversity (Rice 1991). As a consequence, various jurisdictions have declared it a noxious weed and engaged programs of attempted eradication and control.

In British Columbia, concern is expressed through designation of sulphur cinquefoil in the Weed Control Act as a noxious weed in the North Okanagan, Thompson-Nicola, and Columbia-Shuswap regional districts. Despite considerable concern, little information is available about the impact of sulphur cinquefoil on ecosystems in North America, and no information specific to British Columbia is available. To address the general concern and the lack of information, the objectives of this problem analysis are:

1. To synthesize information on the biology, ecology, and distribution of sulphur cinquefoil.
2. To document the current and potential impacts of sulphur cinquefoil in British Columbia's ecosystems.
3. To determine appropriate management strategies to reduce the negative impacts of sulphur cinquefoil.
4. To identify gaps in the information on the biology, ecology, and management of sulphur cinquefoil and recommend research, monitoring, extension, and management activities to address the sulphur cinquefoil problem in British Columbia.

2 BIOLOGY AND NATURAL HISTORY

2.1 Taxonomy

Except where noted, taxonomy follows Kartesz and Kartesz (1980).

- Family: Rosaceae
- Subfamily: Rosoideae
- Tribe: Potentilleae
- Binomial: *Potentilla recta* (L.)
- Synonym: *P. sulphurea* Lam. (Werner and Soule 1976)
- Varieties: var. *sulphurea* (Lam. and DC.) Peyr.; var. *obscura* (Nestler) Koch.; var. *pilosa* (W.) Led.; var. *recta*
- Common names: sulphur cinquefoil (Canada Weed Committee 1969); rough-fruited cinquefoil (Looman and Best 1979); upright cinquefoil (Fernand 1950); five-finger cinquefoil; yellow cinquefoil.

2.2 Morphology and Growth Habit

Physical Description Sulphur cinquefoil is a leafy stemmed erect plant, 15–70 cm tall, with a sparse covering of rough hairs on the stems and leaf stalks. One or several stems emerge from the plant's rough, woody rootstock.

Leaves are deeply toothed into a digitate (fingerlike) formation of five to seven oblong leaflets, 3–14 cm long. The green leaflets have a sparse covering of rough hairs on both surfaces and are paler in colour on the under-surface. Leaf veins are more noticeable on the lower surface than on the upper surface. Basal leaves form on long petioles; petiole length decreases the further from the base the leaves form, with leaves at the top of the stems being sessile.

Each plant forms several flowers at the end of erect stalks branching from the main stem in a cyme inflorescence. Flowers are 15–25 mm in diameter, composed of five pale yellow or sulphur petals, five green sepals, subtended by five bracts below the sepals; most flowers have 25–30 stamens and many ovaries. The fruits are oval-shaped achenes; they are approximately 1.2 mm long, dark brown with lighter coloured, branching ridges on the surface, and a prominent narrow, winged margin. Many fruits form in each flower (Werner and Soule 1976; Looman and Best 1979; Douglas et al. 1991).

Genetics and Hybridization Sulphur cinquefoil has two known chromosomal counts (Werner and Soule 1976). In its native ranges in Eurasia, plants display more intraspecific variation (two chromosome counts $2n = 28, 48$) than those in North America (one chromosome count $2n = 28$). This strongly suggests that only a portion of the total genetic variability was introduced to North America.

Sulphur cinquefoil is closely related to other members of the genus *Potentilla*. Hybrids of *P. recta* and *P. tabernaemontana* Aschers. are reported to occur naturally and have also been produced under controlled conditions (Goswami and Matfield 1975). Pollen tubes and initiation of seed set were also stimulated in sulphur cinquefoil by the European native, *P. argentea* L., but fertilization was not completed (Goswami and Matfield 1974). Sulphur cinquefoil is also genetically very similar to species of the genus *Fragaria*, and *P. recta* pollen has a very similar morphology to the commonly cultivated strawberry (*Fragaria* × *ananassa* Duchesne). However, tests to hybridize *Fragaria* and *Potentilla* were unsuccessful (Maas 1977).

Growth Habit and Phenology Sulphur cinquefoil is a long-lived perennial, reproducing both by seeds and vegetatively. If moisture is not limiting and the seed is located on the soil surface (through disturbance of the soil, for example) where it can receive light, germination is possible any month of the growing season (Baskin and Baskin 1990). Plants germinating in the spring establish woody taproots in their first growing season. Established plants produce new shoots early each spring from near the outside edges of the root system and produce an annual growth ring on their roots. The central core of the taproot slowly rots away during successive growing seasons. In eastern North America, it generally takes six or more years for the root to completely disintegrate. Long-lived plants form a circle of upright stems with old stem and leaf tissue in the centre. Other plant species have been observed growing inside this ring of root material (Werner and Soule 1976).

A basal rosette of long-petioled leaves forms in late April to May. In the grass- and shrub-dominated ecosystems of northwestern United States, sulphur cinquefoil is one of the first plants to initiate spring growth (Rice 1993). Plants in that area bolt, producing flowers from June to late July, and setting and distributing seed from late July to August. The foliage begins to senesce in August, and the above-ground portions of the plant completely desiccate by late August. Fall regrowth of basal leaves is possible and rapid under moist, mild conditions; plant growth continues until freezing temperatures are sustained (Rice 1993).

2.3 Reproduction and Dispersal

Reproduction by Seed In Michigan, Werner and Soule (1976) observed production of up to 1650 seeds per plant. Seed set relies heavily on wind- or insect-mediated cross-pollination, but self-pollination is also possible (Batra 1979). Based on densities of 2.7 plants per square metre, approximately 4400 seeds per square metre can be produced in a well-established population each year (Werner and Soule 1976).

Seed Dispersal When mature, most seed is distributed by falling passively to the ground (Werner and Soule 1976). The importance of other seed-dispersal mechanisms has not been specifically documented, but seed is potentially distributed by birds, small mammals, ungulates, and other grazing animals in many ways:

- ingested seeds which pass through the digestive tract;
- in small mammal caches;
- in plant material used for nests and burrows; and
- in soil trapped in ungulate hooves.

Human activities also provide several potential vectors for seed dispersal:

- in topsoil, gravel, and other quarried materials;
- in plant material caught in the undercarriage, doors, and wheel spokes of all-terrain vehicles, trucks, and cars;
- in soil stuck to earth-moving equipment, all-terrain vehicles, trucks, and cars;
- in plants collected for fresh and dried floral arrangements;
- through cultivation of sulphur cinquefoil as an ornamental species; and
- in plant material cut for hay or bedding for livestock.

Seed Dormancy and Longevity All seeds of sulphur cinquefoil are dormant at maturity; most shed this dormancy over two years in the soil. Dormancy is broken by a combination of soil moisture, exposure to light at the soil surface, and diurnal temperature fluctuations. No germination occurs in darkness. Once the dormancy is broken, seeds do not re-enter dormancy and will decay if they fail to germinate (Baskin and Baskin 1990).

Seed survival in excess of two years has been recorded (Baskin and Baskin 1990), establishing the potential for a persistent soil seed bank. However, the ultimate longevity of seeds in the soil and the relationship between soil conditions and the rate of seed decay is yet unknown.

Vegetative Reproduction Sulphur cinquefoil does not reproduce vegetatively by conventional methods such as runners or rhizomes, but through "offspring" plants which sprout from the decayed ringed root system of an older plant (Werner and Soule 1976). This method of reproduction does not result in broad dispersal of plants as the "offspring" grow close to the former root system of the parent plant. The importance of vegetative reproduction relative to reproduction by seed is unknown.

2.4 Plant Longevity and Mortality

The age of a sulphur cinquefoil plant can be estimated by counting the rings (frost signatures at the end of annual root growth) in the taproot. This method is only accurate to the sixth year, when substantial decay in the central portion of the root sets in. Estimates based on the diameter of the root ring indicate that 20-year-old plants are not uncommon in eastern North America (Werner and Soule 1976). Using this method to estimate the age of herbaria specimens, it appears that most sulphur cinquefoil plants collected in British Columbia in the last 20 years are less than six years old.

2.5 Ecology

Habitat In its native habitats in southeastern Europe and southwestern Asia, sulphur cinquefoil ranges widely, from marine shorelines to pine-dominated forests, and from sea-level to over 2300 m. Sulphur cinquefoil is most common on hillsides in grass- or shrub-dominated habitats in a Mediterranean climate. In observed populations, it is never associated with a 100% canopy cover of other vegetation, and is normally found in areas with less than 90% vegetative cover (Schaffner and Tosevski 1994).

In North America, sulphur cinquefoil is a pioneer or invader species, found from the earliest successional stages following disturbance until an extensive woody overstorey is present (Werner and Soule 1976). As such, sulphur cinquefoil populations in eastern North America are often continuous over large areas of roadside, areas of soil and vegetation disturbance, and dry, unworked fields. It is also seen in margins of wooded habitats, but not under a forest canopy (Werner and Soule 1976).

In the northwestern United States, sulphur cinquefoil occurs in grassland and open forest, particularly in logged areas and other sites associated with soil disturbance. It is also reported to rapidly invade rangeland that is not overgrazed (Rice et al. 1991). Rice (1993) reported a wide ecological amplitude for sulphur cinquefoil; it was documented in a variety of forest, shrubland, and grassland habitats in the northwestern United States. The populations were not limited by aspect and were found up to 2000 m in elevation. In Montana, sulphur cinquefoil is reported to grow best on coarse-textured soils, at low to mid-elevation, with moderate moisture in habitats similar to spotted knapweed (*Centaurea maculosa* Lam.) (Rice 1991). A survey of 85 sites infested with sulphur cinquefoil found spotted knapweed on 60% of those sites (Rice 1993).

In British Columbia, sulphur cinquefoil populations are also associated with roadsides, vegetation disturbance, and abandoned agricultural fields (R. Cranston, B.C. Ministry of Agriculture, Fisheries and Food, pers. comm., 1994; P. Youwe, B.C. Ministry of Forests, pers. comm., 1994). Sulphur cinquefoil has been documented in the Bunchgrass (BG), Ponderosa Pine (PP), Interior Douglas-fir (IDF), Interior Cedar-Hemlock (ICH), Coastal Douglas-fir (CDF), and Coastal Western Hemlock (CWH) biogeoclimatic zones (Meidinger and Pojar 1991), but is mainly found in association with early seral stages in the IDF zone (Douglas et al. 1991).

Sulphur cinquefoil is commonly associated with sites containing diffuse knapweed (*Centaurea diffusa*) populations in British Columbia (R. Cranston, B.C. Ministry of Agriculture, Fisheries and Food, pers. comm., 1994; P. Youwe, B.C. Ministry of Forests, pers. comm., 1994).

Sulphur cinquefoil does not appear to be restricted by soil texture; it is found on all soils except pure silt, but grows mainly on sandy-clay-loam soils (Rice 1993), with dense growth reported on clay soils (Rice 1991). In areas of higher precipitation or occasional flooding, sulphur cinquefoil requires coarse-textured stony soils that permit rapid drainage (Rice 1993).

In eastern Canada, Werner and Soule (1976) reported sulphur cinquefoil in areas with 750–1250 mm mean annual precipitation, or where less than 1% of the minimum daily temperatures fall below 0°C in May, and less than 5% fall below 10°C in July.

Population Attributes and Dynamics The literature contains few quantitative measurements of sulphur cinquefoil populations and none are specific to British Columbia. In Michigan, sulphur cinquefoil on abandoned cropland increased from 12% vegetative cover on a field in its first year fallow to 24% on a field left fallow for 10 years. Density on the field fallow for 10 years was 2.7 plants per square metre, and densities as high as 39 flowering plants per square metre were observed (Werner and Soule 1976). Without an overstorey of other vegetation, the strong root system presumably enables it to out-compete other pioneer species, which would account for the increased plant cover in older populations.

In Montana, sulphur cinquefoil populations are reported to attain densities similar to that of spotted knapweed infestations (Rice et al. 1991). At sites sampled in the northwestern United States, sulphur cinquefoil attained canopy covers of up to 75% of the plant community, though on the majority of sites plant covers ranged from 5 to 15% (Rice 1993). On most of these sites, infestations were confined to patches of 4ha or less, but more than 25% were 40 ha or larger, and some exceeded 400ha.

Little documentation of sulphur cinquefoil growth in British Columbia exists, and estimates of geographic extent have been completed only in the Kamloops Forest Region. Its presence in this region is documented by forest cover mapsheet (Figure 1). This preliminary assessment was based on field staff opinion and shows the actual area occupied by sulphur cinquefoil relative to the area that could potentially be infested. Results indicate that of most mapsheet areas infested with sulphur cinquefoil, only 1–5% of the area that could be occupied by this weed is actually infested. Few mapsheet areas are classified as high infestation (i.e., > 35% of the area that could be occupied by sulphur cinquefoil is actually infested). No quantitative measurements of the area infested with sulphur cinquefoil or estimates of population trends have been made.

Competition with Other Plant Species There are no specific data on the relative competitiveness of sulphur cinquefoil. The plant appears to be intolerant of complete shade as it is not known to persist under a 100% canopy cover of other vegetation (Schaffner and Tosevski 1994). Its perennial nature and large root reserves likely give it a competitive

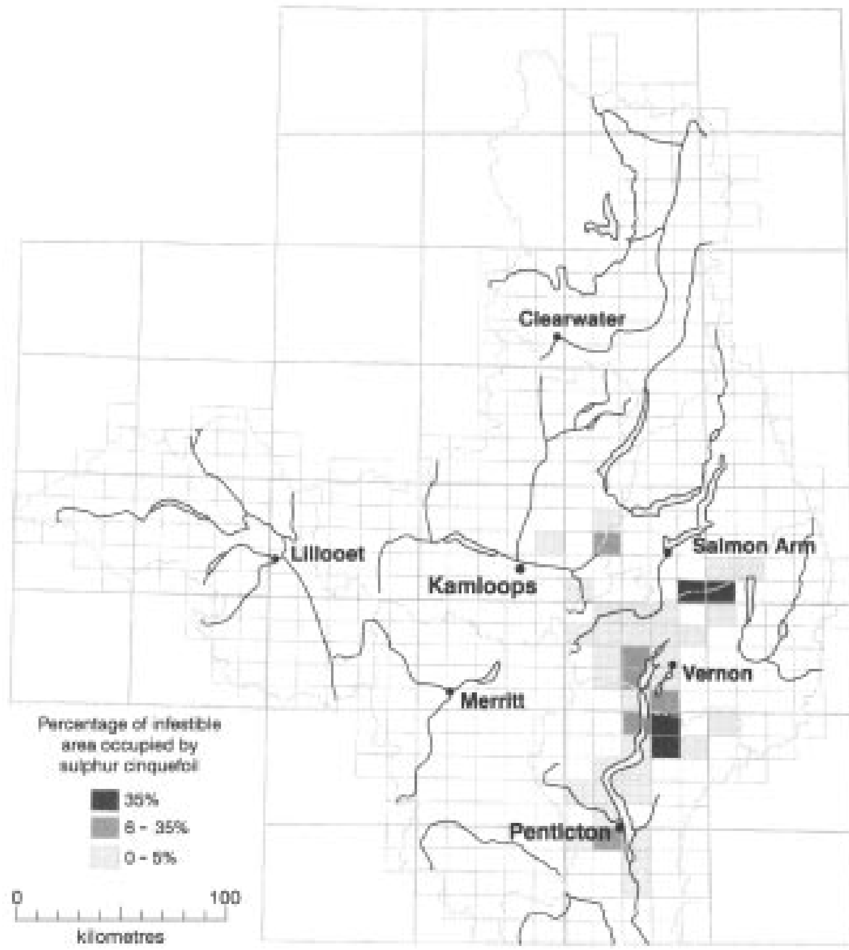

FIGURE 1 *Sulphur cinquefoil infestations in the Kamloops Forest Region of British Columbia. Grid lines delineate the forest cover mapsheet boundaries.*

advantage in open-canopied situations, but the relative advantage of these attributes remain unquantified. Rice et al. (1991) attributed reduced grass production to sulphur cinquefoil competition, but this was not documented quantitatively. Sulphur cinquefoil is reported to be displacing spotted knapweed and competing successfully with leafy spurge (*Euphorbia esula* L.) on several sites in Montana (Rice 1993). Sulphur cinquefoil may also be displacing diffuse knapweed on sites in British Columbia where knapweed vigour is being reduced by introduced biological control agents (P. Youwe, B.C. Ministry of Forests, pers. comm., 1994). Sulphur cinquefoil is not known to be allelopathic.

Influence on Soil Chemistry and Biology The influence and interaction of sulphur cinquefoil with chemical and biological soil processes are largely unknown. As a pioneer species on disturbed soil, it may help to bind soil and prevent erosion (Werner and Soule 1976). Sulphur cinquefoil has no known mycorrhizal associations and its interactions with other soil biota remain unquantified.

Sulphur cinquefoil has a tannin content of 17–22% dry weight, concentrated in the roots (Herrman 1957). The breakdown of annual growth and root exudates likely releases these plant chemicals into the soil, but their influence on soil chemistry and water quality have not been examined.

Herbivory of Sulphur Cinquefoil There are no reports of sulphur cinquefoil toxicity to animals that consume it. Sulphur cinquefoil represents a very minor component of the diets of cattle (*Bos taurus*), mule deer (*Odocoileus hemionus*), and elk (*Cervus elaphus*) in western North America (Campbell and Johnson 1983; Rowland et al. 1983; T. Ross and B. Wikeem, B.C. Ministry of Forests, pers. comm., 1995). Campbell and Johnson (1983) found that *Potentilla* spp., of which sulphur cinquefoil was a component, comprised 2.5, 0.3, 1.3, and 0.2% of the winter, spring, summer, and fall diets respectively, of mule deer. Winter elk diets in New Mexico contained 1.1% *Potentilla* spp. (Rowland et al. 1983). In the lower Rocky Mountain Trench of British Columbia, cattle, elk, and mule deer diets averaged 0.4, 0.2, and 0.3% *Potentilla* spp., of which sulphur cinquefoil was a constituent (T. Ross and B. Wikeem, B.C. Ministry of Forests, pers. comm., 1995). The high tannin content of sulphur cinquefoil likely lowers its palatability relative to many other forage and browse species, making sulphur cinquefoil a non-preferred species for most grazing animals (Werner and Soule 1976). Even when forage and browse choice is limited, cattle have been reported to graze the bitter-flavoured spotted knapweed preferentially over sulphur cinquefoil (Rice 1991). Feeding by small mammals or birds on sulphur cinquefoil plants or seeds is unknown.

Insects and Diseases Associated with Sulphur Cinquefoil Appendix 1 lists insects associated with sulphur cinquefoil in North America. A survey in the northeastern United States identified over 47 species of phytophagous insects and pollinators on sulphur cinquefoil (Batra 1979). The insect collection included two species that attack strawberry plants, emphasizing the close phylogenetic relationship between sulphur cinquefoil and members of the *Fragaria* genus. Damage to sulphur cinquefoil by these insects is limited. Collections in the northwestern United States identified six additional insects on sulphur cinquefoil, including three that are known pests on cultivated strawberries (Rice 1993). Literature survey and field reconnaissance in Eurasia identified 24 phytophagous insect species (Appendix 2) associated with sulphur cinquefoil in its native range (Schaffner and Tosevski 1994).

A survey of sulphur cinquefoil populations in Montana found a bright orange and black rust fungus (*Phragmidium ivesiae*) on 79% of the sites (Rice 1993). No measures of its effects on sulphur cinquefoil were reported. This fungus is also known to occur on several of the sulphur cinquefoil populations in British Columbia (R. Cranston, B.C. Ministry of Agriculture, Fisheries and Food, pers. comm., 1995), but the distribution of the rust is unquantified. Three plant diseases have also been associated with sulphur cinquefoil populations:

- *Septoria rectae* Greene (U.S. Department of Agriculture 1960)
- *Phytophthora cactorum* (Leb. & Cohn) Schroet. (Moore et al. 1964)
- *Septoria potentillae* (Hollos 1926)

The type and abundance of plant diseases on sulphur cinquefoil in British Columbia is unknown.

Ethnobotanical Uses The word *Potentilla* is derived from the Latin word *potens*, meaning powerful. The name alludes to the supposed medicinal value of some species in this genus. Alcohol extracts of sulphur cinquefoil are said to have a low-level, androgenous action similar to that of methyl testosterone (Komar et al. 1981). Its selection for testing in this Russian experiment suggests it has been used as a folk medicine in eastern Europe. The possible medicinal value, however, has not been thoroughly studied.

Because of its perennial nature and showy flowers, sulphur cinquefoil is also used in horticulture. A cultivated variety, "Warrensii," has been developed in addition to common varieties of the species (Wyman 1977; New Royal Horticultural Society 1992).

2.6 Distribution

Eurasia Sulphur cinquefoil is reported to occur sparsely in England, in central and southern Europe from central France and Germany to central Spain, and in Sicily and the Middle East. It also occurs in the mountains of North Africa, western and central Asia to approximately 100°E, and south to Asia Minor and northern Iran (Werner and Soule 1976). However, recent field surveys of western, central, and southeastern Europe could not locate sulphur cinquefoil in the upper Rhine valley, the Alsace, the Swiss Jura; the alpine regions of Switzerland, Italy, and France; or in eastern Austria, southern Hungary, and northern Romania, even though these areas have been listed as within its distribution (Jordan and Tosevski 1993). The survey did locate sulphur cinquefoil in Macedonia, northern Greece, and western Turkey and Bulgaria.

North America Sulphur cinquefoil has a wide geographic spread in North America and is found in as wide a variety of habitats as reported for Europe and Asia. In the east, it extends to the Maritime provinces of Canada and the northeastern seaboard of the United States. Heavy infestations occur in southern Ontario and Quebec and throughout the Great Lake states (Werner and Soule 1976). Scattered populations are found throughout the Canadian and American prairies (Looman and Best 1979). Populations can be found in Montana, Wyoming, eastern Washington and Oregon (Rice 1993), and southern interior British Columbia, with scattered populations along the Pacific coast of British Columbia, Washington, and Oregon. In the south, it extends into Georgia and Texas (Werner and Soule 1976). In the north, it is not known north of 53°N (Werner and Soule 1976).

British Columbia Sulphur cinquefoil is common in southern British Columbia (Douglas et al. 1991). Based on collections for herbaria, populations extend approximately from the southern Cariboo through the Thompson, Nicola, and Okanagan valleys, the Shuswap, Fraser River Canyon, and East and West Kootenays. Scattered populations also occur in the lower Fraser Valley, Gulf Islands, and on southwestern Vancouver Island (Figure 2).

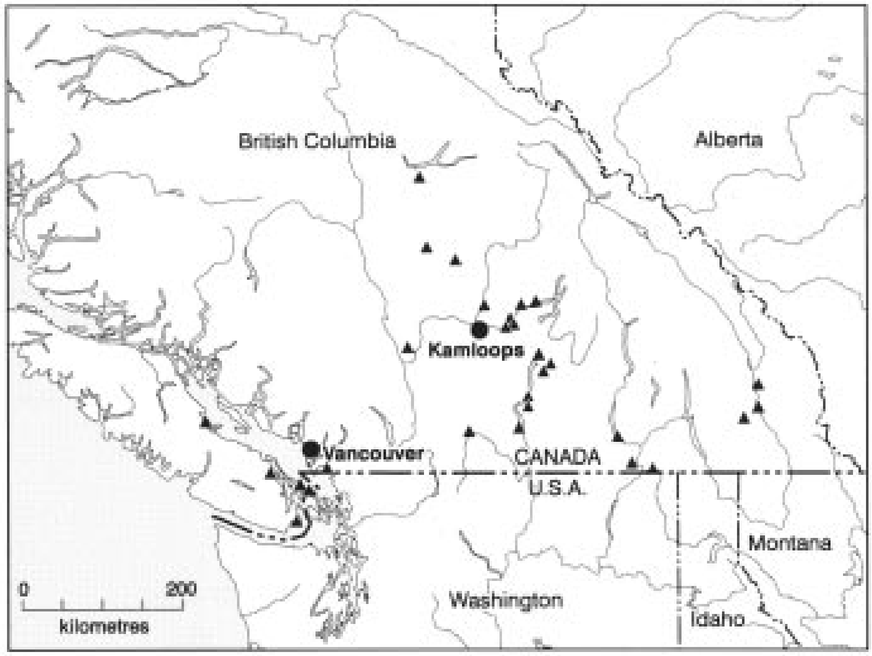

FIGURE 2 *Collection localities of sulphur cinquefoil herbarium specimens in British Columbia, 1914–1994.*

2.7 Spread and Potential Distribution

North America The exact time and location of sulphur cinquefoil introduction to North America is unknown. The first reported collection in North America was in southern Ontario in 1897 (Werner and Soule 1976). The first known collection in western North America was on western Vancouver Island in 1914. Vancouver Island is the terminus of a transcontinental railway, which is a likely vector for sulphur cinquefoil's early spread. By 1940 sulphur cinquefoil had been identified in the adjacent Washington and Idaho (Forcella and Harvey 1981) and collections had been made in the Canadian prairies. By 1950 it was recorded from Newfoundland and Nova Scotia to Ontario and was spreading rapidly (Werner and Soule 1976). In 40 years it has spread to its present geographic distribution.

Sulphur cinquefoil is widely distributed in North America and, on a broad geographic basis, there are probably few areas left in which it can persist where it is not already established. However, this weed will continue to spread into habitats that match its ecological adaptation within the various regions of the continent in which it has established. Rice et al. (1991) compared the spread of sulphur cinquefoil in dry forest and grassland ecosystems of the Pacific Northwest to that of spotted knapweed. Forcella and Harvey (1981) predicted that populations of sulphur cinquefoil will expand exponentially in the Pacific Northwest states over the next decade. These assessments, however, remain neither confirmed nor denied by experimental data.

British Columbia Herbaria records indicate that sulphur cinquefoil was first detected in British Columbia in 1914 on Vancouver Island. By 1940 it had been collected in the southern Cariboo, northern Okanagan, and the Kootenays. It presumably disseminated rapidly over the following decade, and by the 1950s could be found throughout the Shuswap, Thompson, and Okanagan valleys, approximately in its present distribution.

Sulphur cinquefoil is now a permanent component of the biota of British Columbia and will occur in all habitats suitable to its growing parameters. Further work is required to establish its ecological limits and to define its potential distribution in British Columbia. However, based on present distribution estimates and herbaria collection records, we can assume that sulphur cinquefoil distribution is contiguous in suitable habitats within the BG, PP, IDF, and CDF biogeoclimatic zones (Figure 3), and is a transient component of dry subzones of the ICH and CWH.

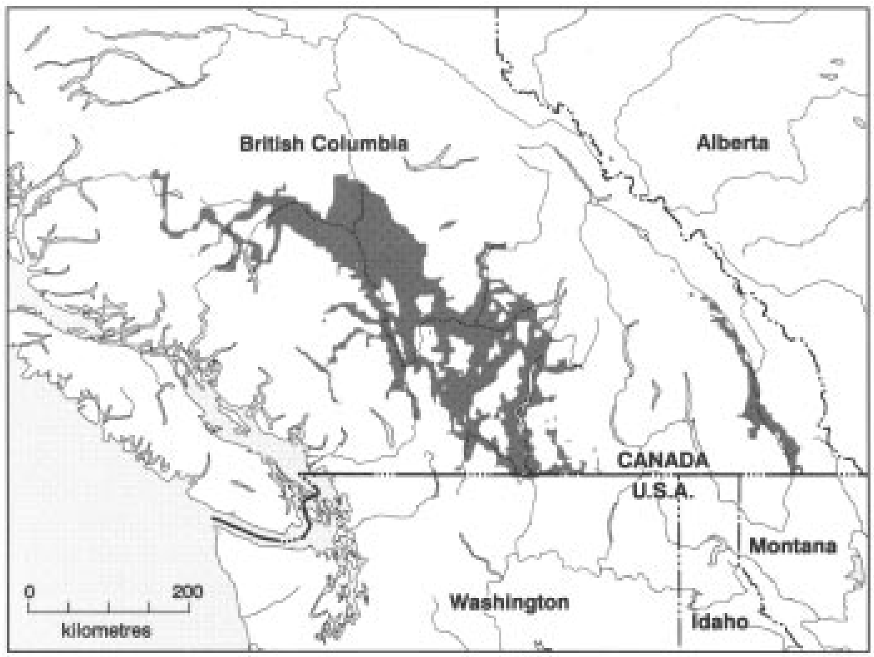

FIGURE 3 *Potential distribution of sulphur cinquefoil in British Columbia.*

2.8 Research and Monitoring Recommendations

Biology Further study of the biology of sulphur cinquefoil, with specific reference to how the species develops, reproduces, and survives in the conditions prevalent in British Columbia, is necessary to increase our understanding of this plant. Research is needed on several aspects of sulphur cinquefoil biology:

- phenology in British Columbian ecosystems
- measures of seed production and longevity in the soil seed bank
- plant longevity in British Columbian ecosystems
- seed distribution vectors and measures of their importance
- life tables and mortality at various life stages

Although such research is important to the overall understanding of sulphur cinquefoil, none of these potential research topics is a priority to determine the initial scope and direction of management of this weed in British Columbia.

Ecology As a basis for study of sulphur cinquefoil, its ecological amplitude must be determined to confirm the ecosystems and habitat types that are suitable to its establishment and persistence. This will ultimately define its distribution and potential areas of impact in British Columbia.

Explicit in the definition of sulphur cinquefoil as a problem species is its assumed displacement of other plant species and the myriad organisms that depend on these vegetation complexes, as well as the negative economic consequences for industries based on these natural resources. The "threat to biodiversity" (Rice 1991) must be quantified. Research should be conducted into the competitiveness of sulphur cinquefoil relative to other plant species, its persistence at various seral stages in different ecosystems, and its influence on the dynamics of various ecosystems. Moreover, even if sulphur cinquefoil is shown not to impair the functioning of ecosystems in British Columbia, the economic consequences of infestations must be characterized to give management activities a clearer direction and to determine the degree and expense to which they should be undertaken. A priority research program for this weed should involve characterization of the ecological amplitude and the relative competitiveness of sulphur cinquefoil. Related research, such as the identification and distribution of insects and diseases on sulphur cinquefoil in British Columbia, may aid in the management of this species.

Inventory An accurate inventory of existing sulphur cinquefoil populations is fundamental to the definition of the sulphur cinquefoil problem in British Columbia. The inventory should be comprehensive and conducted at a scale relevant to ultimate management units for the weed. The inventory should include the following information on each sulphur cinquefoil population in British Columbia:

- geographic location
- biogeoclimatic classification of location
- other defining habitat attributes (slope, aspect, soils, etc.)
- seral stage of the habitat relative to the Potential Plant Community
- extent (area of infestation)
- density
- canopy cover
- co-dominant plant species

Inventory information will provide objective direction for the nature, degree, and location of management activities for sulphur cinquefoil. An inventory will also serve as a baseline for monitoring population dynamics and the effectiveness of various management activities. An inventory of this scope will require considerable resources and time, but it could promote effective management over the long term and it could be conducted in conjunction with an inventory of other weeds of management interest. The cost of a comprehensive inventory would be offset by the savings realized in reducing overlap and redirecting resources from areas that do not require intensive management.

Before undertaking the intensive inventory, a relatively quick and inexpensive province-wide survey should be conducted of the presence or absence of sulphur cinquefoil on a broad geographic basis (on 1:100 000 Geological Survey of Canada mapsheets or 1:50 000 forest-cover maps).

This will promote efficiency when the comprehensive inventory is conducted.

3 MANAGEMENT STRATEGIES

Definition and quantification of the ecological limits of sulphur cinquefoil and its impact on the biodiversity of British Columbia are important for setting the scope and direction of management activities. However, management inaction while these investigations are carried out could result in needless expansion of any current problem. A management program should be developed with the participation of all groups and agencies having a direct interest in land management. Participation should be encouraged from the Ministry of Agriculture, Fisheries and Food; Ministry of Environment, Lands and Parks; First Nations; Ministry of Forests; private land holders; municipalities; and regional districts. Management planning should begin immediately and should be refined as information from research and monitoring efforts becomes available.

Integrated vegetation management, using biological, chemical, and cultural controls where necessary, should be employed. The following sections outline options for controlling sulphur cinquefoil in British Columbia.

3.1 Biological Control

General Approach of Biological Control Biological control uses a weed's natural enemies (chiefly insects and pathogens) to reduce the weed below a desired level and to establish a long-term balance between the control organism and the weed. When effective, biological controls can provide self-perpetuating, self-distributing, continual control of weeds and are therefore the best overall long-term control strategy. Biological controls rarely kill the plant directly, but reduce its vigour or reproductive capacity, giving an advantage to competing vegetation.

Before they can be introduced and used in North America, biological controls must be thoroughly tested to ensure that they will not harm any native plants or any introduced plants of cultural or economic importance. The screening process is crucial and can take several years to complete.

No biological controls have been approved for sulphur cinquefoil in North America, but surveys for potential agents have begun in Europe. Preliminary work has identified three insects as potential biological control agents of sulphur cinquefoil: *Tinthia myrmosaeformis* (Lepidoptera: Sesiidae), *Anthonomus rubripes* ab *femoratus* (Coleoptera: Curculionidae), and an unidentified pyralid moth (Lepidoptera: Pyralidae). Work on their life histories and host specificity have begun (Schaffner and Tosevski 1994).

Desired Characteristics of Biological Control Agents Any control that can effectively reduce the vigour or reproductive potential of sulphur cinquefoil would further the long-term goal of reducing population levels of the weed in British Columbia. From this perspective, any biological control agent would be desirable. The most important criteria for potential agents are that they meet the requirement for host specificity;

that is, they will feed on—and damage—only sulphur cinquefoil. The screening tests must be thorough because of the close phylogenetic relationship between sulphur cinquefoil and other North American *Potentillas* and species such as strawberry. In fact, as strawberries are of significant economic importance, some have questioned whether a suitable biological control will ever be found (Batra 1979).

Plants for Testing Biological Control Agents Seventy-four species of *Potentilla* are found in North America north of Mexico, with more than 100 subspecies and varieties (Kartesz and Kartesz 1980). Most of these species are native to North America or have circumboreal distribution, and a potential biological control agent must be benign to these species or incapable of occupying the habitats in which these plants occur. Many native and introduced *Potentilla* species are used as ornamental shrubs or have other cultural uses (Appendix 3). Therefore, any potential negative economic or social effects of the agent must be considered.

Not all *Potentillas* in North America, however, need to be tested for host specificity. Introduced species that are weeds or have no economic or cultural value need not be considered. Two introduced species, silvery cinquefoil (*Potentilla argentea* L.) and Norwegian cinquefoil (*Potentilla norvegica* L.) have no consequential cultural or economic value in North America, although they have been recommended for use as ornamental shrubs (Wyman 1977; New Royal Horticultural Society 1992). In fact, they are considered problem weeds in some areas (Werner and Soule 1976). Another introduced species, *Potentilla sterilis* (L.) Garcke, although not a problem weed, is of no consequence in North America. Appendix 4 lists *Potentilla* spp. for testing host specificity in the screening of biological control agents for sulphur cinquefoil.

A cross section of North American species from other genera in the Rosaceae family should also be tested. Particular attention should be directed toward members of the Potentilleae tribe including, but not restricted to, species of *Chamaerhodos*, *Geum*, *Fragaria*, *Sibbaldia*, and *Waldsteinia*.

Key Species for Preliminary Biological Control Screening The list of plant species for testing host specificity is extensive and will require a substantial investment of time and money to complete. Given the costs involved with the full screening process, a list of key species has been developed for preliminary screening. Initial screening costs can be reduced by eliminating candidates that attack any of these key species, as damage to these plants at any level would most likely preclude approval for their release in British Columbia.

Key species include species at risk in British Columbia or those with significant cultural or economic importance to the province. Plants at risk have been classified into red- and blue-listed species: red-listed plants are those which are rare or endangered, blue listed (watch list) are those which are infrequent, locally frequent, or locally common, but may become vulnerable in the near future because of continued land development or use (B.C. Conservation Data Centre 1993). Table 1 lists key species for testing potential biological controls for sulphur cinquefoil and the reason for including them.

TABLE 1 *Key species for preliminary screening of potential biological control agents for sulphur cinquefoil*

Species	Reason for concern[a]
Fragaria × *ananassa* Dcne.	Economic
Potentilla anserina ssp. *anserina* L.	Cultural: native food plant
P. anserina ssp. *pacifica* (T.J. Howell) Rousi	Cultural: native food plant
P. biennis Greene	Blue list
P. biflora Willd. ex Schlecht.	Red list: rare
P. diversifolia var. *perdissecta* (Rydb.) C.L. Hitchc.	Red list: rare
P. elegans Cham. & Schlecht.	Red list: rare
P. fruticosa L.	Economic, cultural: ornamental
P. glandulosa Lindl.	Cultural: native medicine
P. hippiana Lehm.	Blue list
P. ovina Macoun	Red list: rare
P. paradoxa Nutt. ex Torr. & Gray	Red list: endangered
P. quinquefolia (Rydb.) Rydb.	Red list: rare
P. rivalis Nutt.	Blue list

[a] Three reasons for concern are listed. Plants are either of economic or cultural significance to the province (Turner et al. 1990) or the plant species is at risk and is blue or red listed by the B.C. Conservation Data Centre (1993).

Key Habitats for Biological Control Agent Reconnaissance Further work is needed on the ecological limits and relative competitiveness of sulphur cinquefoil in various habitats in British Columbia to identify those areas where this weed is most problematic. To date, sulphur cinquefoil has only been reported as a problem weed in the grassland and dry forest ecosystems of the Southern Interior. Therefore, habitats approximating the BG, PP, and IDF biogeoclimatic zones are a logical starting point to address current sulphur cinquefoil infestations in British Columbia. Reconnaissance for biological control agents should be focused on habitats in Eurasia with similar ecological attributes.

3.2 Chemical Control

General Approach of Chemical Control In British Columbia, chemical control programs are used to contain or eradicate small, new infestations of sulphur cinquefoil. In these areas the risk of invasion to land not yet infested is greater than the negative consequences of using the chemical. A large-scale chemical eradication or control program is undesirable because it could be both prohibitively expensive and have many potential primary and secondary effects on nontarget organisms. The use of chemical control is also limited by the type of habitat where the sulphur cinquefoil occurs (type of soil and location relative to water sources), and thus cannot be used as a general control method.

Desired Characteristics of Chemical Controls A single-application herbicide is preferable because it eliminates the increased costs and risks of introducing a chemical several times to the same site. Because sulphur cinquefoil has large root reserves and a capacity for rapid regrowth after defoliation (Werner and Soule 1976; Rice 1993), an effective single-application herbicide should be systemic. Concerns for water quality and effects on nontarget organisms dictate that a preferred chemical agent should bind to the soil and not move with groundwater. The chemical should break down rapidly in the environment and the products of its dissociation should be benign to soil, air, water, and nontarget organisms.

Registered Chemical Controls No chemicals are specifically registered for sulphur cinquefoil control in Canada. Spot treatment of this weed can be conducted with glyphosate or picloram under their label requirements for other broadleaf or perennial weeds. As with all herbicides, the label requirements should be read and followed before any specific application.

Potential Chemical Controls Little work has been done on the efficacy or cost effectiveness of sulphur cinquefoil chemical control methods in British Columbia. The work which has been completed demonstrates effective chemical control options for sulphur cinquefoil are available.

Dhinsda (1976) tested the effect of various application rates and repeat applications of three chemical treatments: potassium salt of picloram; tri-isopropanol amine of picloram and 2,4-D; and amine of 2,4-D. Five-year results indicated that annual applications of 2,4-D treatments above 1.12kg ai/ha applied at the bud stage for thr ee to four years gave effective control of sulphur cinquefoil. A single application of picloram, or a 1:4 mixture of picloram and 2,4-D, applied when plants were in early bud stage also gave adequate control over five years.

Cranston et al. (1990) established demonstration plots to test the effects of picloram and 2,4-D amine on sulphur cinquefoil. They found summer-applied picloram at 0.56 and 0.28kgai/ha pr ovided excellent control for 36 months. Picloram applied at 0.12kgai/ha , or 2,4-D applied at either 1.12 or 2.24kgai/ha, only pr ovided control for the year of application.

3.3 Cultural Control

General Approach of Cultural Control Cultural weed control uses various physical methods that prevent weeds from establishing or distributing themselves, disrupt or remove plants or parts of plants, increase intraspecific competition, or modify the habitat to make it unsuitable for the weed's establishment or growth. Cultural controls can reduce weed populations by one or more of the following techniques:

- preventing distribution of plant material or seeds through human activity
- managing ecosystems to prevent excessive soil disturbance and promote healthy, competitive vegetation resistant to weed invasion
- dislodging or physically disturbing the weed (e.g., mowing, plowing, chopping, crushing, burning, hand pulling, and livestock trampling)
- reducing weed reproduction through destruction or disturbance of its reproductive parts
- reducing vigour (increasing the susceptibility to intraspecific competition) through repeated defoliation, thereby depleting root reserves, or habitat modification (e.g., irrigation, deliberate flooding, shading, burning, mulching, or revegetating with other plant species)

Desired Characteristics of Cultural Control The most desirable cultural control for any weed species is prevention of new infestations. Early recognition of new weed infestations can also simplify their control. An effective prevention strategy should include a campaign to increase the public's ability to identify sulphur cinquefoil and to increase awareness of how management and recreation affect the spread and establishment of this weed. This should be coupled with promotion of sound land use practices that maintain the integrity of the ecosystem and prevent establishment of this and other undesirable plant species.

In habitats managed in their natural state, suitable control techniques must only minimally disturb the soil and other vegetation. Otherwise, conditions could be created that may be suitable for the invasion by other weed species or the re-establishment of sulphur cinquefoil. Moreover, mass disruption of the ecosystem to control this weed may have significantly more effect on nontarget vegetation than the presence of sulphur cinquefoil itself.

Because of the highly variable and often rough topography of British Columbia, increased costs will likely preclude the use of mechanized cultural controls on all infestations outside agricultural fields, roadsides, or relatively level landscapes. As with all control options, cultural controls must be cost effective relative to suitable alternatives.

Available Cultural Controls Because of the large woody roots, which can store considerable energy reserves and send up new shoots quickly after defoliation, sulphur cinquefoil is not controlled by occasional mowing (Werner and Soule 1976). The same would likely apply to techniques that trample, crush, or break the plants. Sulphur cinquefoil can be controlled by plowing and then planting to a clean-cultivated crop (Darlington et al. 1940 cited in Werner and Soule 1976), but this cannot be applied over grassland and forest ecosystems that are managed in their natural state. Discing and reseeding to grass has been successful at one site in British Columbia, with complete control of sulphur cinquefoil in the area treated (R. Cranston, B.C. Ministry of Agriculture, Fisheries and Food, pers. comm., 1995). While the efficacy of fire, flooding, or mulching is unknown, these methods would likely not be used because of their uncontrolled effects on nontarget vegetation.

Hand pulling sulphur cinquefoil is likely an effective control measure, if the entire root is removed with the plants (root fragments can resprout under suitable conditions). Because it is labour-intensive, hand pulling is impractical for large infestations.

Sulphur cinquefoil is intolerant of complete shade. Land management practices that allow other vegetation to increase in cover, and therefore contribute to a concomitant decline in sulphur cinquefoil, should be promoted. Grazing should be managed with appropriate timing, intensity, frequency, and duration to leave adequate vegetation. Abandoned or fallow cropland should be planted with a perennial plant cover or tilled occasionally to control weeds. Soils disturbed by logging, road, or other construction should be revegetated as soon as possible with desirable species. Deforested sites should be planted with trees soon after harvest to promote a quick return to a closed canopy.

3.4 Research and Monitoring Recommendations

Biological Control Biological control is the best long-term solution to problem weeds, but it can be very time-consuming and expensive to initiate. Given the close relationship between sulphur cinquefoil and other *Potentilla* and *Fragaria* species, and the large number of native and introduced plants that must be screened, the search for a suitable biological control could be the longest and most costly in the history of North America. British Columbia should therefore provide support for a preliminary biological control screening program, but should confirm the nature and extent of the sulphur cinquefoil problem before committing resources to a full program. The results of inventory and habitat-impact research would then dictate the degree of the province's participation in a multi-jurisdictional effort for the biological control of this weed. The impact that sulphur cinquefoil has in British Columbia compared to its effects in other areas of North America could be a useful guide in determining the necessary contribution of various jurisdictions and agencies in controlling this weed.

Chemical Control Chemical control on areas outside of croplands will likely continue to be restricted, except for spot treatments of new or small, isolated weed populations in suitable habitats. Public demand for safe and prudent use of chemicals dictates that additional research should be directed toward finding products that are both effective controls of this weed and benign to nontarget organisms. Alternative chemical controls may also be needed if sulphur cinquefoil develops resistance to the existing chemical options. Development and testing of effective and more environmentally compatible chemical products should continue.

Cultural Control The limited information available indicates that a prevention program coupled with hand pulling and management practices that promote high canopy cover of other vegetation are effective cultural controls for vegetation managed in its natural state. Plowing and reseeding with desired vegetation is an effective control on land managed for agronomics. The relative effectiveness and cost efficiency of each of these techniques needs to be researched or demonstrated, but this is not a priority for addressing management issues for sulphur cinquefoil in British Columbia.

3.5 Management and Extension Recommendations

Biological Control No biological controls are currently available for sulphur cinquefoil.

Chemical Control For land managed in its natural state, chemical control should continue to be limited to spot treatment with selective herbicides on new or small infestations in areas that are otherwise not infested. However, in areas with widespread infestations, chemical control would result in only temporary control because of the high likelihood of reinvasion from adjacent weed populations, and therefore is not recommended.

Sulphur cinquefoil must also be considered in the chemical control of other weed species. For example, sulphur cinquefoil is resistant to clopyralid; when this chemical is applied to control other weed species such as spotted knapweed, the sulphur cinquefoil population may expand because the co-dominant weed species is eliminated (Rice 1993).

Cultural Control A prevention strategy involving extension to resource users and the general public must be initiated. Much of the sulphur cinquefoil problem in British Columbia could be reduced by raising public awareness of the weed and promoting responsible land use.

In agronomic situations (fallow cropland, cultivated pastures) sulphur cinquefoil should be eliminated through plowing and reseeding to more desirable vegetation. For lands managed in their natural state, hand pulling can be used where it is cost effective.

APPENDIX 1 Insects associated with *Potentilla recta* L. in North America (Batra 1979; Rice 1993)

Coleoptera	Buprestidae	*Chrysobothris* sp.
	Cantharidae	*Chauliognathus* sp.
	Chrysomelidae	*Longitarsus* sp.
		Sumitrosis ancoroides
	Curculionidae	*Calomycterus setarius* Roelofs
		Centroinoqna striqata
		Gymnetron pascuorum (Gyllenhal)
		Hypera nigrirostris (F.)
		Otiorhynchus ovatus (L.)
	Nitidulidae	*Brachypterolus pulicarius* L.
Diptera	Cecidomyiidae	*Mycodiplosis inimica* (Fitch)
		Mycodiplosis thoracica (Fitch)
	Syrphidae	*Sphaerophoria contigua* (Macquart)
		Sphaerophoria philanthus (Meigen)
		Toxomerus geminatus (Say)
		Toxomerus marginatus (Say)
Hemiptera	Berytidae	*Jalysus spinosus* (Say)
	Miridae	*Lygus lineolaris* (Palisot de Beauvois)
		Psallus sp.
	Tingidae	*Corythucha marmorata* (Uhler)
Homoptera	Aphididae	*Acyrthosiphon* sp.
		Aphis sp.
		Macrosiphina sp.
		Macrosiphum euphorbiae (Thomas)
	Cercopidae	*Philaenus spumarius* (L.)
	Cicadellidae	*Agallia constricta* Van Duzee
		Aphrodes bicinctus (Schrank)
	Flatidae	*Anormenis* sp.
	Membracidae	Unidentified Membracid sp.
	Pseudococcidae	Unidentified Pseudococcid sp.
Hymenoptera	Formicidae	*Lasius neoniger* Emery
		Leptothorax sp.
		Monomorium minimum (Buckley)
	Halictidae	*Dialictus mitatus* (Smith)
		Dialictus uncinus (Sandhouse)
		Halictus ligatus Smith
Lepidoptera	Blastobasidae	Unidentified Blastobasid sp.
	Gelechiidae	*Monochroa fragariae*
	Geometridae	Unidentified Geometrid sp.

Appendix 1 *Continued*

Lepidoptera *(continued)*	Noctuidae	*Lacinipolia* sp.
		Pyrrhia umbria (Hufnagel)
		Unidentified Noctuid sp.
	Tortricidae	*Platynota* sp.
		Sparganothis sulphurana (F.)
	Sesiidae	*Synanthedon bibionipennis*
Orthoptera	Gryllidae	*Oecanthus* sp.
Psocoptera	Ectopsocidae	*Ectopsocopsis cryptomeriae* (Enderlin)
Thysanoptera	Idolothripinae	Unidentified apterous Idolothripid
		Unidentified winged-form Idolothripid
	Thripidae	*Frankliniella fusca* (Hinds)
		Frankliniella tritici (Fitch)

APPENDIX 2 Phytophagous insects associated with *Potentilla recta* L. in Eurasia (Schaffner and Tosevski 1994)

Coleoptera	Bruchidae	Unidentified Bruchid spp.
	Buprestidae	*Coroebus elatus*
	Curculionidae	*Anthonomus rubripes* ab *femoratus* (Gyllenhall)
		Eusomus ovulum
		Rhychnites aethiops
	Scarabaeidae	*Blithoperta* sp.
Diptera	Cecidomyiidae	Unidentified Cecidomyid sp.
Heteroptera	Lygaeidae	*Metopoplax* sp.
Homoptera	Aethalionidae	*Ulopa* sp.
	Aphidae	Unidentified Aphid spp.
	Cercopidae	Unidentified Cercopid sp.
	Fulgoridae	*Fulgora* sp.
	Ortheziidae	*Orthezia* sp.
	Tettigometridae	Unidentified Tettigometrid sp.
Hymenoptera	Cynipidae	Unidentified Cynipid sp.
	Tenthredinidae	*Fenella* sp. *Macrophya annulata* *Allantus* sp.
Lepidoptera	Arctiidae	*Diacrisia* sp.
	Hesperidae	*Pyrgus malvae*
	Pyralidae	Unidentified Pyralid sp.
	Sesiidae	*Tinthia myrmosaeformis*
	Stigmellidae	*Stigmella* sp.
Thysanoptera	Thripsidae	*Thrips* sp.

Ornamentals

P. anglica Laicharding
P. anserina L.
P. arguta Pursh
P. atrosanguinea Lodd. ex D. Don
P. breweri S. Wats.
P. canadensis L.
P. crinita Gray
P. diversifolia Lehm.
P. drummondii Lehm.
P. egedei Wormskj.
P. erecta (L.) Raeusch.
P. fissa Nutt.
P. flabellifolia Hook. ex Torr. & Gray
P. fruticosa L.
P. glandulosa Lindl.
P. gracilis Dougl. ex Hook.
P. hippiana Lehm.
P. multifida L.
P. nivea L.
P. palustris (L.) Scop.
P. pectinisecta Rydb.
P. pensylvanica L.
P. quinquefolia (Rydb.) Rydb.
P. reptans L.
P. simplex Michx.
P. tabernaemontana Aschers.
P. thurberi Gray
P. tridentata (Soland.) Ait.
P. villosa Pallas ex Pursh

Food Plants

P. anserina L. (roots eaten)
P. erecta (L.) Raeusch. (used to produce the spice "tormentil")
P. glandulosa Lindl. (tea)

(Wyman 1977; Turner 1982; Brown 1986; Turner et al. 1990; Cox 1991; Freeman 1991; New Royal Horticultural Society 1992; Hansen and Stahl 1993).

APPENDIX 4 North American *Potentilla* species for the testing of potential biological control agents of sulphur cinquefoil

P. albiflora L.O. Williams

P. ambigens Greene

P. anglica Laicharding

P. anserina L.
ssp. *anserina*
ssp. *pacifica* (Howell) Rousi

P. arguta Pursh
ssp. *arguta*
ssp. *convallaria* (Rydb.) Keck

P. atrosanguinea Lodd. ex D. Don

P. biennis Greene

P. biflora Willd. ex Schlecht.

P. bipinnatifida Dougl.
var. *bipinnatifida*
var. *glabrata* (Hook.) Kohli & Packer

P. brevifolia Nutt. ex Torr. & Gray

P. breweri S. Wats.

P. canadensis L.
var. *canadensis*
var. *villosissima* Fern.

P. collina Wibel

P. concinna Richards.
var. *concinna*
var. *divisa* Rydb.
var. *macounii* (Rydb.) C.L. Hitchc.
var. *rubripes* (Rydb.) C.L. Hitchc.

P. crinita Gray
var. *crinita*
var. *lemmonii* (S. Wats.) Kearney & Peebles

P. diversifolia Lehm.
var. *diversifolia*
var. *multisecta* S. Wats.
var. *perdissecta* (Rydb.) C.L. Hitchc.

P. drummondii Lehm.
ssp. *bruceae* (Rydb.) Keck
ssp. *drummondii*

P. egedei Wormskj.
ssp. *egedei* var. *egedei*
ssp. *egedei* var. *groenlandica* (Tratt.) Polunin
ssp. *yukonensis* (Hultén) Hultén

P. elegans Cham. & Schlecht.

P. erecta (L.) Raeusch.

P. finitima Kohli & Packer

P. fissa Nutt.

P. flabellifolia Hook. ex Torr. & Gray
- var. *flabellifolia*
- var. *grayi* (S. Wats.) Jepson

P. fruticosa L.
- ssp. *floribunda* (Pursh) Elkington

P. glandulosa Lindl.
- ssp. *arizonica* (Rydb.) Keck
- ssp. *ashlandica* (Greene) Keck
- ssp. *ewanii* Keck
- ssp. *glabrata* (Rydb.) Keck
- ssp. *glandulosa*
- ssp. *globosa Keck*
- ssp. *hansenii* (Greene) Keck
- ssp. *micropetala* (Rydb.) Keck
- ssp. *nevadensis* (S. Wats.) Keck
- ssp. *pseudorupestris* (Rydb.) Keck
- ssp. *reflexa* (Greene) Keck

P. gracilis Dougl. ex Hook.
- var. *blasckeana* (Turcz.) Jepson
- var. *brunnescens* (Rydb.) C.L. Hitchc.
- var. *flabelliformis* (Lehm.) Nutt. ex Torr. & Gray
- var. *glabrata* (Lehm.) C.L. Hitchc.
- var. *gracilis*
- var. *permollis* (Rydb.) C.L. Hitchc.
- var. *pulcherrima* (Lehm.) Fern.

P. hickmanii Eastw.

P. hippiana Lehm.
- var. *argyrea* (Rydb.) Boivin
- var. *diffusa* Lehm.
- var. *filicaulis* (Nutt.) Boivin
- var. *hippiana*

P. hookeriana Lehm.
- ssp. *chamissonis* (Hultén) Hultén
- ssp. *hookeriana* var. *furcata* (Porsild) Hultén
- ssp. *hookeriana* var. *hookeriana*
- ssp. *hookeriana* var. *umanakensis* Hultén

P. hyparctica Malte
- ssp. *hyparctica*
- ssp. *nana* (Willd.) Hultén

P. inclinata Vill.

P. intermedia L.

P. millefolia Rydb.
var. *klamathensis* (Rydb.) Jepson
var. *millefolia*

P. multifida L.

P. multijuga Lehm.

P. newberryi Gray

P. nicolletii (S. Wats.) Sheldon

P. nivea L.
ssp. *chionodes* Hiitonen var. *chionodes* Hiitonen
ssp. *chionodes* Hiitonen var. *subguinata* (Lange) Hiitonen
ssp. *nivea* var. *nivea*
ssp. *nivea* var. *tomentosa* Nilss.-Ehle

P. oblanceolata Rydb.

P. ovina Macoun
var. *ovina*
var. *pinnatisecta* S. Wats.

P. palustris (L.) Scop.

P. paradoxa Nutt. ex Torr. & Gray

P. patellifera J.T. Howell

P. pectinisecta Rydb.

P. pensylvanica L.
var. *atrovirens* (Rydb.) T. Wolf
var. *pectinata* (Raf.) Boivin
var. *pensylvanica*
var. *strigosa* Pursh
var. *virgulata* (A. Nels.) T. Wolf

P. plattensis Nutt.

P. pseudosericea Rydb.

P. pulchella R. Br.
var. *elatior* Lange
var. *gracilicaulis* Porsild
var. *pulchella*

P. quinquefolia (Rydb.) Rydb.

P. ranunculus Lange

P. reptans L.

P. rivalis Nutt.
var. *millegrana* (Engelm. ex Lehm.) S. Wats.
var. *pentandra* (Engelm.) S. Wats.
var. *rivalis*

P. robbinsiana Oakes

P. rubella Sorensen

P. rubricaulis Lehm.
var. *dasyphylla* Ledeb.
var. *pedersenii* Rydb.
var. *rubricaulis*

P. rupincola Osterhout

P. saxosa Lemmon ex Greene
ssp. *saxosa*
ssp. *sierrae* Munz

P. sierrae-blancae Woot. & Standl.

P. simplex Michx.
var. *argyrisma* Fern.
var. *calvescens* Fern.
var. *simplex*

P. stipularis L.
var. *groenlandica* Sorensen
var. *stipularis*

P. subjuga Rydb.
P. subviscosa Greene
var. *ramulosa* (Rydb.) Kearney & Peebles
var. *subviscosa*

P. supina L.

P. tabernaemontana Aschers.

P. thurberi Gray
var. *atrorubens* (Rydb.) Kearney & Peebles
var. *sanguinea* (Rydb.) Kearney & Peebles
var. *thurberi*

P. thuringiaca Bernh. ex Link

P. tridentata (Soland.) Ait.

P. vahliana Lehm.

P. villosa Pallas ex Pursh

P. wheeleri S. Wats.
var. *rimicola* Munz & Johnston
var. *wheeleri*

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