Conservation Assessment For Western Moonwort (Botrychium hesperium)

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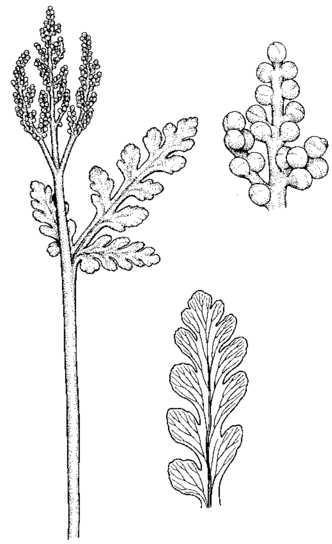

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This Conservation Assessment was prepared to compile the published and unpublished information on the subject species or community. It does not represent a management decision by the U.S. Forest Service. Though the best scientific information available was used and subject experts were consulted in preparation of this document, it is expected that new information will arise. In the spirit of continuous learning and adaptive management, if you have information that will assist in conserving the subject taxon, please contact the Eastern Region of the Forest Service Threatened and Endangered Species Program at 310 Wisconsin Avenue, Milwaukee, Wisconsin 53203.

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EXECUTIVE SUMMARY

Botrychium hesperium is a small fern with a disjunct distribution in the Rocky Mountains and the Upper Great Lakes region. Due to a number of differences between plants in each of these regions, Great Lakes populations may be separated in the future as a new species endemic to the Great Lakes called Botrychium michiganense. B. hesperium is often found growing with other species of Botrychium, but can also be found in fairly large numbers in pure stands. Across its range, it generally prefers an open habitat, often in areas that have been disturbed in the past, such as roadside ditches, tailings ponds, and gravel pits. Plants have also been found on sand dunes. Soils are often sandy or gravelly. Most details about the biology of B. hesperium are generalized from studies of other moonwort species. Much of the life-cycle occurs underground. Populations of aboveground sporophytes fluctuate and individual plants may not appear every year, complicating attempts to adequately inventory populations. Like other moonworts, B. hesperium is dependent on a mycorrhizal relationship; thus concerns about species conservation must consider this relationship. No information is available on managing habitat to maintain the species. Potential threats are not well understood, but some level of disturbance may be necessary for plant establishment. Once established, natural plant succession and the same human activities that originally created the disturbed site may be considered threats, along with agriculture and forestry in some areas. Since the species is small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, range, and habitat. Much basic research on B. hesperium biology is lacking.

INTRODUCTION/OBJECTIVES

One of the conservation practices of the USDA Forest Service is designation of Regional Forester's sensitive species. The Eastern Region (R9) of the Forest Service updated its Sensitive Species list on February 29, 2000. Part of that process included identification of priority species for Conservation Assessments and Strategies. A group of Botrychium species (Ophioglossaceae; Adder's-Tongue Family) was one of those priorities.

The objectives of this document are to:

-Provide an overview of current scientific knowledge for Botrychium hesperium.

-Provide a summary of the distribution and status of Botrychium hesperium, both rangewide and within the Eastern Region of the USDA Forest Service.

-Provide the available background information needed to prepare a subsequent Conservation Strategy.

The genus Botrychium, family Ophioglossaceae, are small ferns typically divided into three subgenera in North America (Lellinger 1985, Wagner and Wagner 1993a). One subgenus, Osmundopteris, is only represented in our area by B. virginianum, the rattlesnake fern, which is common around the world (Wagner 1998). Plants within subgenus Sceptridium, grapeferns, are medium-sized and decidedly evergreen (Lellinger 1985). Subgenus

Botrychium, the moonworts (including B. hesperium), are often rare, local, and small plants that are difficult both to locate and positively identify.

North America is a center of diversity for moonworts (Wagner and Wagner 1994) and the upper Great Lakes Region, along with the northwestern U.S. and adjacent Canada, are two of the richest areas (Wagner and Wagner 1990a, Wagner 1998). Twenty-three species of North American moonworts are now recognized (Wagner and Wagner 1994) compared to earlier interpretations of only six species (Clausen 1938).

The problems in distinguishing moonwort species are considerable (Wagner and Wagner 1990a), including the tendency of different species of moonworts to grow together at one site, the natural variation in form due to microhabitat variability, the small size of the plants, and the difficulty of making good herbarium specimens. However, decades of work, primarily by the late Dr. Herb Wagner and his associates, have clarified the taxonomy of the group, habitat preferences, and the ranges of individual species. Several rare species within subgenus Botrychium are now recognized in the Upper Great Lakes region.

Botrychium hesperium is a small plant, growing to only 5–20 cm tall. It has been recognized as a distinct species only since 1983, as it was formerly considered a subspecies of the more common B. matricariifolium (Wagner and Wagner 1983). It has a disjunct distribution, primarily occurring in the Rocky Mountains of the United States and Canada, but is also found in the Great Lakes region.

B. hesperium was first recognized in the Great Lakes region in June 1985 (Wagner and Wagner 1990b). Eastern plants are larger and have a few other morphological differences compared to western plants (Wagner and Wagner 1990b). As a result, Great Lakes populations may be recognized in the future as a new species termed B. michiganense.

NOMENCLATURE AND TAXONOMY

Scientific Name: Botrychium hesperium (Maxon and Clausen) W.H. Wagner and Lellinger

Synonymy: Botrychium lunaria (L.) Sw. ssp. occidentale A. and D. Löve and Kapoor; Botrychium matricariifolium (A. Braun ex Dowell) A. Braun ex Koch ssp. hesperium Maxon and Clausen; Botrychium matricariifolium (A. Braun ex Dowell) A. Braun ex Koch var. hesperium (Maxon and Clausen) Braun

Family: Ophioglossaceae; Adder's-Tongue Family

Common Name: Western Moonwort

Plants in the Great Lakes region may be segregated as members of a new species. According to Karen Myhre (Minnesota HP Botanist; 9/22/98 message to Sharron Nelson reported in NatureServe 2001), Dr. Herb Wagner intended to separate the eastern

(Michigan and Minnesota) plants of B. hesperium from western plants and name the midwestern plants B. michiganense.

DESCRIPTION OF SPECIES

General description and identification notes

Botrychium hesperium is a small perennial fern only a few inches (to 20 cm) tall. There is a single erect frond divided into a sterile (trophophore) and a fertile (sporophore) segment. There are up to 6 pairs of pinnae, usually approximate or overlapping except in shade forms. The distance between the first and second pinnae is not more than, or only slightly more than, the distance between the second and third pair. The basal pinna pair are commonly much larger and more divided than the next upper adjacent pair. The sporophore is 1–3-times pinnate and 2–3 times the length of the trophophore.

A key to all Botrychium is provided in Wagner and Wagner (1993a), but the difficulty of accurately identifying subtly different species of Botrychium often requires confirmation by an expert. Lellinger (1985) includes descriptions and color photographs of many moonwort species. Cody and Britton (1989) provide descriptions and distribution maps of Botrychium species known to that time in Canada.

Technical description

Plants, exclusive of their roots average 12 (5-20) cm tall, the common stalk about 7 (3-13) cm tall; sporophore relatively tall, 5 (3-10) cm tall, nearly twice as long as sterile segment, 80 percent with 1 or more basal branches 1/3 or more as long as main axis of sporangial cluster; sterile segment gray-green and dull in life, mostly short-stalked, sub-deltate, 2.5 (1-5) cm long; pinnae broadly attached to a relatively wide rachis, crowded to commonly overlapping, ovate to lanceolate with rounded apices, the pinna bases asymmetrical, the lamina margins finely repand; basal pinnae commonly exaggerated, up to twice as long as the adjacent ones, often upright and commonly clasping; spores 37 (29-50) µm in maximum diameter, irregularly and coarsely verrucate, the warts large, prominent, and separated by wide, deep channels (after Wagner and Wagner 1983).

LIFE HISTORY

B. hesperium belongs to subgenus Botrychium (moonworts) within the genus Botrychium. In North America there are also the subgenera Osmundopteris (rattlesnake fern) and Sceptridium (grapeferns) (Lellinger 1985, Wagner and Wagner 1993a). The life-cycle of all three subgenera is similar (Lesica and Ahlenslager 1996). Moonworts are generally smaller than rattlesnake ferns and grapeferns. The plants have both a trophophore (vegetative segment) and a sporophore (fertile segment). Moonwort and rattlesnake fern leaves die back by winter, while grapefern trophophores are present during the winter.

The following information is from research with a variety of Botrychium species. Reproduction in B. hesperium has not been fully researched and there may be life history details specific to B. hesperium that do not follow these general patterns reported for the genus. Lack of specific information on the life history of B. hesperium is a serious management concern.

Vegetative reproduction was not thought to occur in Botrychium (Wagner et al. 1985), but Farrar and Johnson-Groh (1990) documented underground gemmae (bud-like structures at base of plant) in a few species of moonwort. They speculated that asexual reproduction may have evolved as an adaptation to the dry habitat of some moonwort species. They examined B. hesperium but found no evidence of gemma production, indicating that the primary mode of reproduction is sexually through spores.

The spore cases of Botrychium are among the largest of all known ferns and appear like clusters of tiny grapes (hence the name Botrychium, from botrus, Greek for grapes) (Wagner 1998). The number of spores per case is probably the highest known for vascular plants, numbering in the thousands (Wagner 1998). Except for B. mormo, the sporangial opening to release the spores in most Botrychium is over 90° between the two sides of the gap (Wagner 1998). The spores have been measured to disperse by wind about one meter (Hoefferle 1999), but may typically travel much less, perhaps only a few centimeters (Casson et al. 1998). Peck et al. (1990) found that B. virginianum spores landed within 3 m of the source if the plant was above the herbaceous layer, but much less when the sporophore was within the herbaceous layer. While most spores could be expected to land near the parent, some may travel considerable distances (Wagner and Smith 1993, Briggs and Walters 1997).

The succulent nature of the plant, the questionable spore dispersal mechanism, and the very thick spore walls that could help that spores to pass through an animal’s gut, have suggested to some that herbivores such as small mammals may be involved in dispersal (Wagner 1998, Wagner et al. 1985, Wagner and Wagner 1993a). The sporangia may also simply rot in the ground, thereby dispersing their spores (NatureServe 2001). It is uncertain how long Botrychium spores remain viable (Lesica and Ahlenslager 1996).

After spores are released they infiltrate into the soil and may germinate. Infiltration and subsequent germination may take up to 5 years, although some germinate immediately (Casson et al. 1998). Spore germination requires darkness (Whittier 1972, Whittier 1973, Wagner et al. 1985), a requirement that is not surprising given the subterranean habitat of the gametophyte and the need for the gametophyte to be infected by an endophytic fungus in an obligate association (Whittier 1973). Details of this host/fungus interaction can be found in Schmid and Oberwinkler (1994). It has been suggested that Botrychium gametophytes may even delay growth until they are infected with the fungus (Campbell 1911, Whittier 1973, Whittier 1996). Essentially the Botrychium gametophyte becomes a parasite of the mycorrhizal fungus (Casson et al. 1998, Whittier 2000). The underground gametophyte (subg. Sceptridium) is generally less than 0.3 cm in longest diameter, cylindrical or cushion shaped, moderately hairy, and light to dark brown-brown (Wagner et al. 1985).

All Botrychium species are believed to be obligately dependent on mycorrhizal relationships in both the gametophyte (Bower 1926, Campbell 1922, Gifford and Foster 1989, Scagel et al. 1966, Schmid and Oberwinkler 1994) and sporophyte generations (Bower 1926, Gifford and Foster 1989, Wagner and Wagner 1981). The gametophyte is subterranean and achlorophyllous, depending on an endophytic fungus for carbohydrate nutrition, while the roots of the sporophyte lack root hairs and probably depend on the fungus for absorption of water and minerals (Gifford and Foster 1989). Botrychium gametophytes were formerly considered saprophytic (Bower 1926), but are now thought to obtain carbohydrates fixed by neighboring plants and transported by shared mycorrhizal fungi (Camacho 1996); they are thus better classified as myco-heterotrophic (Leake 1994).

A fungal associate is present within the plant at the earliest stages of development of the gametophyte and sporophyte (Bower 1926). There are no reports of successful completion of the lifecycle by Botrychium species without fungal infection, however, the degree of infection may vary between species and age of plants (Bower 1926, Campbell 1922). Little is known about the mycorrhizal fungi associated with Botrychium species other than their presence within the gametophyte and roots of the sporophyte (Camacho 1996). Botrychium mycorrhizae have been described as the vesicular-arbuscular (VAM) type by Berch and Kendrick (1982) and Schmid and Oberwinkler (1994).

The mycotrophic condition is important to the ecology of Botrychium species in several ways. Nutrition supplied through a fungal symbiont may allow the ferns to withstand repeated herbivory, prolonged dormancy, or growth in dense shade (Kelly 1994, Montgomery 1990). The fungal/fern relationship has implications for the occurrence of genus communities, the distribution of the species across the landscape, and associations with particular vascular plants. Mycorrhizal links may explain the often observed close associations between certain moonworts and strawberries (Fragaria spp.; Zika 1992, 1994) and between grapeferns (Botrychium subgenus Sceptridium) and Rosaceous fruit trees (Lellinger 1985). Due to the occurrence of heterotrophic life-stages, moonworts share many of the morphological and habitat characteristics of myco-heterotrophic plants such as orchids (reviewed by Leake 1994) and in many respects behave much like mushrooms (Zika 1994).

Gametophytes and young sporophytes may exist underground for many years before an aboveground plant develops (Campbell 1911, Muller 1993). Mortality may be high during this period (Peck et al. 1990). The gametophyte produces male and female gametangia, fertilization of eggs occurs via free-swimming sperm under wet conditions (Lesica and Ahlenslager 1996). Most fertilizations are likely due to inbreeding, since the antheridia and archegonia are nearby and enzyme electrophoresis indicates a lack of genetic variability (McCauley et al. 1985, Soltis and Soltis 1986, Farrar and Wendel 1996a). However, there is no reason that cross-fertilization should not occur (Wagner et al. 1985), especially in consideration of the existence of interspecific hybrids (Wagner et al. 1985, Wagner 1998). McCauley et al. (1985) calculated that B. dissectum outcrosses about 5% of the time. Extremely high levels of inbreeding were also found in B. virginianum although there was evidence for some outcrossing (Soltis and Soltis 1986).

Sporophytes develop on the gametophyte, forming roots and a single leaf each season from a short rhizome (Foster and Gifford 1974). Root development occurs before any leaf development (Casson et al. 1998). The roots must also be colonized by the mycorrhizal fungi for a nutrient source (Farrar and Johnson-Groh 1990, Wagner 1998, Johnson-Groh 1998). The fungus involved is believed to be a vesicular arbuscular mycorrhizae (Berch and Kendrick 1982), which penetrates inside the plant cells of both the roots and the gametophytes in the case of Botrychium spp. The species of mycorrhizae fungus involved with Botrychium is unknown (Casson et al. 2000). In a comparison of ferns and mycorrhizae colonization, the two Botrychium species surveyed had more extensively colonized roots than the 37 other species of ferns studied (Berch and Kendrick 1982).

When the sporophyte eventually emerges, a sterile leafy blade (trophophore) and a fertile segment (sporophore) will develop. Botrychium plants may go dormant some years and not produce an aerial sporophyte (Wagner and Wagner 1981, Muller 1993). B. mormo plants do not produce aboveground sporophytes more than two consecutive years (Johnson-Groh 1998) and there may be gaps as long as 6 years, although 1–3 years is more typical (Johnson-Groh 1998, Tans and Watermolen 1997). Botrychium, with the exception of B. mormo, will not produce more than one sporophyte from a gametophyte within one growing season (Casson et al. 1998).

Several factors likely determine the size of the plant and how many spores it is capable of producing (Casson et al. 1998). These include the health of the plant and the associated fungi, climatic conditions, plant age, predators, and other factors. In discussing B. mormo, Casson et al. (1998) estimated that about 5–10 percent of aboveground plants would develop into larger plants with 20–50 sporangia (spore-bearing tissues) each.

B. hesperium plants emerge from the ground in midspring, and typically die-back in early fall (Wagner and Wagner 1993b). The loss of plants to herbivory, fire, and removal by collection did not affect the return of moonworts in later years (Johnson-Groh and Farrar 1996a, b). Botrychium may depend little on photosynthesis, and mycorrhizae alone may supply a significant amount of the plant's nutrients and energy (Johnson-Groh 1999, Casson et al. 2000). However, it has been suggested that that photosynthesis may be important and that indiscriminate collecting could threaten Botrychium populations (USDA Forest Service, Eastern Region 1999).

Numerous hybrids between different species of moonworts have been found (Wagner et al. 1985; Wagner 1991, 1993). The hybrids possess abortive spores and are intermediate in characteristics between the presumed parents (Wagner 1993). All 23 species of moonwort (Botrychium subgenus Botrychium) have chromosome numbers based on 45, half the members are tetraploids, and one is a hexaploid (Wagner 1993). Chromosome number has been useful in recognizing the distinctness of a new species; additionally, some species may have arisen through allopolyploids of interspecific hybrids (Wagner 1993). Farrar and Wendel (1996a, b) have applied enzyme electrophoresis to the genetic relationships of eastern moonworts, including B. hesperium, and have also suggested some relationships for moonwort species and hybrids. B. hesperium hybridizes readily with B. paradoxum

(Wagner and Wagner 1983). Sterile hybrids have also been detected with B. echo (Wagner and Wagner 1983).

HABITAT

Lellinger (1985) described the North American habitat of B. hesperium as exposed, dry fields, and on roadsides. Western North American plants often occur at high-elevations. Grassy mountain slopes, snow-fields, roadside ditches with willows, and sand dunes comprise another habitat description (Wagner and Wagner 1993b). Reported elevations range from 200–2800 m. In the Rocky Mountains B. hesperium often grows with B. echo, and in the Lake Superior region, with B. acuminatum and B. matricariifolium (Wagner and Wagner 1993b).

B. hesperium occurs primarily in early successional habitats and other habitats subject to periodic disturbance (NatureServe 2001). NatureServe (2000) also lists mature, mesic northern hardwood forests as habitat in the eastern portion of the range along with sand dunes, moist shrubby jack pine forest in dune swales, along grassy roadsides, and in fields.

Rocky Mountain habitats often had rocky soils. Reportedly the easiest way to find the species was to drive along roads at the proper altitudes and to search within roadside ditches having gravelly soil and scattered shrubby vegetation (Wagner and Wagner 1983). Plants were sometimes even present in the gravel of the road shoulder.

In Minnesota, B. hesperium appears to prefer open disturbed habitats. Element occurrence records (Appendix A) list habitats as tailings ponds, gravel pits, ditches, an old log landing, and along a weedy roadside. B. hesperium was sometimes found with other Botrychium species in Minnesota including B. matricariifolium and B. pallidum. One site supported seven additional species of Botrychium.

The two Ottawa National Forest sites with habitat data reported plants as occurring in an open area of woods on rocky soil, or in rich hardwoods (Appendix A). Hiawatha National Forest records listing habitat data included an abandoned hiking trail in a dune area and along the shoulder of a gravel road. The habitats of other northern Michigan and adjacent Canadian specimens listed by Wagner and Wagner (1990b) included sand dunes, railroad sidings, fields, and woods. They reported that B. hesperium occurred with B. lunaria, B. matricariifolium, B. minganense, B. multifidum, B. acuminatum, B. pseudopinnatum, and B. simplex in this area.

DISTRIBUTION, ABUNDANCE, AND STATUS

B. hesperium can occur as single plants, sometimes with larger populations of other Botrychium spp., or it can occur in pure stands, sometimes in large numbers (Wagner and Wagner 1990b). The species is found in the Lake Superior region, and also in southern Saskatchewan, Alberta, and British Columbia, south in the Rocky Mountains to northern Arizona.

North American range of Botrychium hesperium (Wagner and Wagner 1993).

Listed below are state, national, and global conservation rankings. See Appendix C for a definition of ranking codes.

United States Distribution
Arizona, Colorado, Michigan, Minnesota, Montana, Oregon, Utah, Washington, Wyoming.

State status:
Arizona (SR), Colorado (S2), Michigan (S1S2), Minnesota (none), Montana (S2), Oregon (S?), Utah (S1), Washington (S1), Wyoming (SR).

United States National Conservation Status Rank: N2 (29 Jan. 1997)

Canadian Distribution
Alberta, British Columbia, Ontario, Saskatchewan.

Province status:
Alberta (S1), British Columbia (S1?), Ontario (S1), Saskatchewan (S1).

Canada Conservation Status Rank: N2 (22 Mar. 1989)

Global Heritage Status Rank: G3 (07 Feb. 1992)
Rounded Global Heritage Status Rank: G3
Global Heritage Status Rank Reasons: Botrychium hesperium occurs infrequently, in localized areas, and with small population sizes.

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	Status	Comments
Minnesota	9	--	Not ranked
Wisconsin	0	--	Not present
Michigan	7	S1S2	State threatened
Total	16		

GREAT LAKE STATES and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	9
Chippewa National Forest	0
Superior National Forest	2
Michigan	7
Ottawa National Forest	3
Hiawatha National Forest	2
Huron-Manistee National Forest	0
Wisconsin	0
Chequamegon-Nicolet National Forest	0
Total State EOs	16
Total National Forest EOs	7
NF as % of EOs in MN, WI, MI	44%

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of B. hesperium. Population studies on other species of moonworts have documented considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh and Farrar 1996a, Johnson-Groh 1999). Typically, populations fluctuated independently among plots at any given site, with some populations increasing while others were decreasing (Johnson-Groh

1999). These variations reflected microsite differences such as soil moisture, herbivory, or mycorrhizae (Johnson-Groh 1999), although populations of moonworts often fluctuate wildly from year-to-year without any apparent cause (Johnson-Groh 1999), and individual plants may not emerge every year (Muller 1993, Johnson-Groh and Farrar 1996a, Johnson-Groh 1998).

Botrychium plants probably appear or disappear, at least in part, due to the health of the mycorrhizae fungi because of their obligate relationship with the fungi (Johnson-Groh 1998). Johnson-Groh (1999) concluded that mycorrhizae were the most important limiting factor for Botrychium establishment, distribution, and abundance. Environmental factors that may affect mycorrhizae, like reductions in water availability, were also likely to have significant impacts on moonworts, whereas the repeated removal of leaf tissue may have little effect (Johnson-Groh 1999). Standard assumptions about the population biology of other, more ‘typical’ plants may be irrelevant to Botrychium because of this obligate relationship (Johnson-Groh 1999).

Since there is considerable variation in the numbers of aboveground sporophytes, a field measurement of only sporophytes does not completely indicate population numbers. Johnson-Groh (1998) developed a method to extract Botrychium gametophytes and belowground sporophytes from soil samples. Up to 7000 gametophytes and 250 non-emergent sporophytes per square meter of soil have been recovered, although an unknown number of these may be from the common B. virginianum (Johnson-Groh 1998). In another report Johnson-Groh et al. (2000) found gametophyte populations ranging up to 2000 gametophytes/m^2 for some moonwort species; other moonwort species had a much lower density. Bierhorst (1958) reported finding 20 to 50 gametophytes of B. dissectum beneath each surface square foot with a predominance of younger gametophytes versus older ones with attached sporophytes. These findings suggest that discovery of even a single emergent sporophyte may indicate a self-sustaining population at that site (Casson et al. 1998).

A spore bank that consists of all ungerminated spores, including unopened sporangia, is present within the litter, duff, and soil (Casson et al. 1998). The spores persist in the soil for several years and, along with underground gametophytes and developing sporophytes, form a highly buffered population that can rebound from unfavorable years (Johnson-Groh et al. 1998, Johnson-Groh 1999). However, events that destroy the sporophytes may have an effect several years later (Johnson-Groh 1999). These underground stages have been compared to seed banks in angiosperms and could play an important role in population dynamics (Kalisz and McPeek 1992).

A population model for Botrychium mormo has been developed by a working group within the Population and Habitat Viability Assessment effort (Berlin et al. 1998) and Johnson-Groh et al. (1998). This model uses a variety of input variables such as number of spores in the soil, number of soil gametophytes, frequency of catastrophes, etc. They concluded that populations subjected to increased levels of annual environmental variation are at greater risk of population decline and extinction, although a single catastrophic year has relatively little effect on simulated populations. The population is likely more stable than would be predicted from monitoring only aboveground plants due to the large proportion of the population in underground stages. B. hesperium may respond similarly.

Many species of Botrychium are associated with light to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993a, Lesica and Ahlenslager 1996). A species like B. hesperium that is often found in open and disturbed areas may have a metapopulation structure whereby local populations are founded then go extinct as succession proceeds toward a closed climax community (Menges and Gawler 1986, Parsons and Browne 1982). The high variability in aboveground plant numbers found in some moonworts suggests a high probability of local extinction (Johnson-Groh et al. 1998). This kind of species may then depend on a regime of natural disturbances that creates a shifting mosaic of seral communities (Pickett and Thompson 1978).

Most moonworts, including B. hesperium, are highly variable due to genetic and habitat differences (Wagner and Wagner 1990b). Forms of B. hesperium in the Lake Superior region range from small, compact sun-forms found in open dunes and sandy fields, to very lax shade-forms of moist, shrubby jack pine forests in dune valleys (Wagner and Wagner 1990b).

POTENTIAL THREATS AND MONITORING

Threats to B. hesperium are not well understood (NatureServe 2001), and a serious impediment to management is the lack of information available on the species. Because this species occurs in both naturally and artificially (human-caused) disturbed sites, threats include natural plant succession as well as the same human activities (recreation, road and trail maintenance activities, grazing) that also apparently resulted in creating the initial suitable habitat (NatureServe 2001). Agriculture and forestry activities may also threaten this species in some areas (NatureServe 2001). Some threats will have their direct effect on the aboveground sporophyte and may be less serious, since the belowground part of the life-cycle is of such importance (see Sections C and F above).

Simple removal of leaf tissue may be inconsequential to the ability of moonworts to survive, although removing sporulating individuals may eventually have an effect (Johnson-Groh 1999). Wagner and Wagner (1993a) also stated that taking many samples will have little effect on the population as long as the underground shoots and roots are left intact. However, Hoefferle (1999) found that if the aboveground plant was removed after spore release, the trophophore the following year was significantly smaller in size. Removal before sporulation had no effect. (It should be noted that this was a one-year study and weather conditions could have had a significant impact). Longer-term studies have indicated that the removal of leaves has no effect on subsequent leaf size or vigor (Johnson-Groh and Farrar 1996a, b). However, it has been suggested that that photosynthesis may be important and that indiscriminate collecting could threaten Botrychium populations (USDA Forest Service, Eastern Region 1999); thus leaf removal may have negative impacts on a population.

In a French study (Muller 1992), drought-like conditions resulted in wilting a sporophyte of Botrychium matricariifolium prior to sporulation. The work of Johnson-Groh (1999) also emphasized the importance of water-relations to moonworts and their supporting mycorrhizae. Mycorrhizae are probably the most limiting factor for Botrychium establishment, distribution, and abundance (Johnson-Groh 1999); therefore adverse impacts to the mycorrhizae may also be expected to have deleterious effects on Botrychium.

STEWARDSHIP OVERVIEW AND POPULATION VIABILITY CONCERNS

Often it is difficult to determine what factor or combination of factors is impacting Botrychium populations (USDA Forest Service, Eastern Region 1999). Populations are inherently variable (Johnson-Groh 1999) but maintaining the health of the mycorrhizae seems to be an underlying necessity. Moisture relations are critical, and activities which dry the habitat may have deleterious effects on populations, although B. hesperium naturally sometimes occurs on sites with very coarse droughty soils. Given the general preference of the species for open sites, some kind of opening management may be a feasible tool, although no specific information is available on the response of B. hesperium populations to treatments of this kind.

Periodic disturbance is required in certain habitats occupied by B. hesperium, but the specific disturbance regime (e.g. fire, sand movement, blowdowns, road maintenance activities, etc.) is unknown (NatureServe 2001). Excessive foot traffic should be prevented in dune habitats. Invasion of exotic species needs to be addressed.

Since B. hesperium often exists in a habitat that is early successional due to disturbance, it may be prone to local extinctions. Thus population viability may rely on a shifting mosaic of suitable habitats opening up for colonization (see Section F). Land management should consider the immediate area surrounding known populations of B. hesperium to ensure that an adequate buffer to fully protect the population from potential threats is present and room for expansion is available.

RESEARCH AND MONITORING REQUIREMENTS

Like all Botrychium, B. hesperium is small, inconspicuous, and relatively difficult to find. The fluctuating populations also creates difficulties; plants may go dormant some years and not appear aboveground. There are almost certainly undiscovered sites for B. hesperium, and inventories for the plant should continue. While some research data have been developed about population fluctuations for certain species of Botrychium (Johnson-Groh and Farrar 1996a, Johnson-Groh 1999), specific information for B. hesperium population biology is lacking.

Almost no information is available on B. hesperium life-history in relation to disturbance and colonization of new sites. While its habitat is generally considered to be open areas, it also occurs in forested habitats. The specific habitat requirements of B. hesperium and the sensitivity of this species to disturbance need to be determined (NatureServe 2001).

Succession toward closed-canopy conditions may be a threat, as many of the preferred habitats are sites that are continually disturbed and kept open, such as roadsides, ditches, and sand dunes. It is unclear how B. hesperium reacts to site changes over time. Long-term monitoring is necessary to determine life-history characteristics, population stability, and dynamics over time (NatureServe 2001). Data on spore dispersal are also lacking.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for goblin moonwort, B. mormo. Many of their suggestions apply to other Botrychium species; that source should be consulted for detailed recommendations about Botrychium monitoring and research. There are also a number of specific suggestions about habitat and population monitoring for B. rugulosum that may generally apply to most rare Botrychium spp. at www.natureserve.org (NatureServe 2001).

Habitat monitoring is also a need for the species. Correlations between changes in habitat and reproductive success can give strong recommendations toward future management activities. Such monitoring will also indicate the appropriate time to initiate management activities.

In small populations, individual counts of the entire group should be made. In large populations, a representative sample of the population should be monitored through a randomized, permanent plot methodology. Individuals within each plot should be mapped as an aid to tracking, possibly providing detailed information pertaining to life span, dormancy, recruitment, etc.

Habitat monitoring should also be considered at selected sites. Perhaps the easiest and most effective way of monitoring habitat would be through permanent photo-points. Although photo-points may not provide the detailed information pertaining to species composition within a given site, rough changes in habitat should be observable. Photo-point analysis of canopy cover, and shrub and ground layer competition with respect to population trends would provide useful information for possible management procedures. Other more time-intensive procedures designed to statistically track changes in composition of the ground-layer associates at each site may be installed and monitored along with the methodology designed to track population trends, as discussed above.

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CANADA
Ontario: http://www.mnr.gov.on.ca/MNR/nhic/nhic.html
Quebec: http://www.menv.gouv.qc.ca/biodiversite/centre.htm

APPENDICES

Appendix A. Botrychium Hesperium Element Occurrence Records.

The following information was obtained from natural heritage programs in Michigan, Minnesota, Wisconsin, and adjacent states (U.S.) and provinces (Canada). National Forests within the Great Lakes region also provided survey data on species occurrences within each Forest.

Element occurrence summary:

Michigan	7
Minnesota	9
Wisconsin	0

MICHIGAN

Location: Michigan, Ontonagon County
Ownership: Ottawa National Forest
Abundance: Not listed
Habitat: Open area of woods on rocky soil
Comments: 1989.
Source of information: Ottawa National Forest record

Location: Michigan, Iron County
Ownership: Ottawa National Forest
Abundance: Not listed
Habitat: In rich hardwoods
Comments: 1992.
Source of information: Ottawa National Forest record

Location: Michigan, Ontonagon County
Ownership: Ottawa National Forest
Abundance: Not listed
Habitat: Not listed
Comments: 1992.
Source of information: Ottawa National Forest record

Location: Michigan, Marquette County
Ownership: Unknown
Abundance: Not listed
Habitat: Not listed
Source of information: Ottawa National Forest record

Location: Michigan, Chippewa County
Ownership: Hiawatha National Forest
Abundance: 15–20 estimated

Habitat: In moister, shadier areas along shoulder of gravel road
Source of information: Hiawatha National Forest record

Location: Michigan, Chippewa County
Ownership: Hiawatha National Forest
Abundance: Not listed
Habitat: Not listed
Source of information: Hiawatha National Forest record

Location: Michigan, Alger County
Ownership: Pictured Rocks National Lakeshore
Abundance: Not listed
Habitat: Grand Sable Dunes along abandoned hiking trail. Sandy woods and dunes influenced by Lake Superior
Source of information: Hiawatha National Forest record

MINNESOTA

(Note: all Minnesota records are listed as Botrychium michiganense).

Location: Minnesota, Cook County
Ownership: Unknown
Abundance: ~10 scattered plants observed
Habitat: Along powerline trail. Associated spp: B. matricariifolium, Fragaria, Hieracium.
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: Unknown
Abundance: Approx. 12 plants observed
Habitat: Old roadside ditch and gravel/ sand borrow area. Plants in ditch and flats of old pit area mixed with B. pallidum and B. matricariifolium. Adjacent areas recently mechanically brush hogged. Moderate-heavy forb component of Fragaria, Aster macrophyllum, Achillea, Hieracium. Several Alnus viridis shrubs nearby, but not shading plants.
Comments: 1998
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: Superior National Forest
Abundance: Approx. 50 plants
Habitat: Open field, sandy soil, of an old logging landing and sawmill in jack pine and red pine association. Evidence of recent fire. Assoc. spp: Danthonia spicata, Fragaria virginiana, Anaphalis margaritacea, Schizachne purpurescens, Oryzopsis asperifolia, Antennaria neglecta, Viola adunca, Poa compressa, Trifolium hybridum, Cornus stolonifera, Salix humilis, Arctostaphylos uva-ursi, Vaccinium angustifolium, Melampyrum lineare. 7 other spp of Botrychium found at same site.

Comments: 1998
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: Unknown
Abundance: 12 plants observed
Habitat: Located at edge of old gravel pit/slash burning area. Plants observed at NE corner of gravel pit, along the north and south sides of access road. With Carex siccata, Fragaria, Salix, Alnus, Prunella vulgaris, Achillea millefolium.
Comments: 1999. Verified by W. H. Wagner.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a tailings pond. Associated with Populus balsamifera, Betula papyrifera, Equisetum hyemale, Prunella vulgaris, Botrychium pallidum.
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake County
Ownership: Superior National Forest
Abundance: 8 fertile fronds
Habitat: Located in weedy area over dirt road. Hard, gravelly soil in full sun. Assoc. spp: Danthonia spicata, Chrysanthemum leucanthemum, Crepis tectorum, Fragaria virginiana, Achillea millefolium, Antennaria neglecta, Poa compressa, Trifolium pratense, Prunella vulgaris, Artemisia campestris, Rumex acetosella
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a 40 acre tailings pond of a mine dump area of the Mesabe iron range. Associated with Populus balsamifera, Carex aurea, Malaxis unifolia, Ophioglossum pusillum, Fragaria virginiana
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a stabilized tailings pond associated with Populus tremuloides, Picea mariana, Carex aurea, Ledum groenlandicum, Vaccinium angustifolium.
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a tailings pond associated with Populus balsamifera, Hieracium aurantiacum, Vaccinium angustifolium, Picea mariana, Alnus incana.
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Appendix B. Botrychium Status And Threats Summary.

Three tables are presented below. Table 1 summarizes the state, national, and global status of each Botrychium taxon. Table 2 summarizes range, population, and habitat features. Table 3 ranks the degree of threat to populations of each taxon from various factors. The assigned rankings are intended as general guidelines based on information presented in each conservation assessment. For many taxa, detailed ecological information is lacking.

Table 1. Botrychium status.

	Status			
	Minnesota	**Michigan**	**Wisconsin**	**Global/National**
B. campestre	SC (S3)	T (S2)	E (S1)	G3/N3
B. dissectum	(not listed) SU	(not listed) S?	(not listed) SR	G5/N5
B. hesperium (B. michiganense)	(not listed)	T (S1S2)	(absent)	G3/N2
B. lanceolatum var. angustisegmentum	T (SR)	(not listed) S4	(not listed) S3	G5/N4
B. lunaria	T (S2)	(not listed) S?	E (S1)	G5/N4?
B. minganense	SC (S3)	(not listed) S?	SC (S2)	G4/N?
B. mormo	SC (S3)	T (S1S2)	E (S2)	G3/N3
B. oneidense	E (S1)	(not listed) S?	SC (S2)	G4Q/N4
B. pallidum	E (S1)	SC (S3)	(absent)	G2G3/N2N3
B. pseudopinnatum	(not listed) S?	(absent)	(not listed)	G1/N1
B. rugulosum	T (S2)	(not listed) S3	SC (S2)	G3/N3
B. simplex	SC (S3)	(not listed) S?	(not listed) S?	G5/N5

Key Status:
E = state endangered
T = state threatened
SC = state special concern
S1 = state rankings (see Appendix B)
absent = taxon not known from state
not listed = taxon not tracked by state natural heritage program.

Global/National – worldwide or United States ranking provided by NatureServe (2001, see Appendix B. for definitions).

Table 2. Botrychium range, population, and habitat features.

Taxon	Range	Habitat Amplitude	Pop Trend	Habitat Integrity	Vulnerability
B. campestre	wide, disjunct	intermediate	unknown	fair	medium
B. dissectum	wide	broad	increasing	fair	low
B. hesperium (B. michiganense)	endemic	intermediate	stable	fair	medium
B. lanceolatum var. angustisegmentum	wide	intermediate	increasing	fair	low
B. lunaria	wide	broad	stable	fair	medium
B. minganense	wide	broad	increasing	good	low
B. mormo	endemic	narrow	decreasing	fair	high
B. oneidense	wide	intermediate	unknown	fair	medium
B. pallidum	narrow	broad	stable	fair	low
B.pseudopinnatum	endemic	narrow	unknown	poor	high
B. rugulosum	narrow	intermediate	stable	fair	low
B. simplex	wide	broad	increasing	good	low
B. spathulatum	narrow	intermediate	unknown	fair	medium

Key
range: wide (occurs across much of North America), narrow (e.g. Lake States), endemic (restricted to Lake States), disjunct (separated from main population).
amplitude: broad (tolerates a variety of habitats and conditions), intermediate, narrow (very specific requirements).
estimated population trend: increasing, stable, decreasing, unknown (insufficient information to estimate trend).
habitat integrity: good (most habitats/sites protected, not commonly impacted by management), fair, poor (most sites degraded, unoccupied habitat subject to numerous impacts), unknown.
vulnerability: high (populations generally not resilient or are intolerant of habitat changes), medium, low (populations resilient and/or resistant to change), unknown.

Table 3. Major threats to Botrychium.

	Threat					
	Exotic Earthworms	Exotic Plants	Canopy Thinning	Succession To Closed Canopy	Disturbance	
					Major	Minor
B. campestre	low	medium	low	high	medium	low
B. dissectum	medium	medium	medium	low	high	medium
B. hesperium (B. michiganense)	medium (forested sites) low (other sites)	medium-high	low	low-medium	medium	low
B. lanceolatum var. angustisegmentum	high	medium	medium	low	medium	low
B. lunaria	low	medium	low	medium	medium	low
B. minganense	high	medium	medium	low	medium	medium
B. mormo	high	low	high	low	high	medium
B. oneidense	high	medium	medium-high	low	high	medium-high
B. pallidum	low	high	low	high	medium	low
B.pseudopinnatum	low	high	low	high	medium	low
B. rugulosum	low	medium	low	high	high	medium
B. simplex	medium	medium	low	medium	medium	low
B. spathulatum	low	high	low	high	medium	low

Key
High, medium, or low are used to indicate the estimated degree of impact of a specific threat to a Botrychium population.

Appendix C. Global, National, And Subnational Conservation Status Ranks (From Natureserve, Www.Natureserve.Org).

NatureServe reports the relative imperilment, or conservation status, of plants, animals, and ecological communities (elements) on a global, national, and subnational (state/provincial) level. Based on the conservation status ranking system developed by The Nature Conservancy and the Natural Heritage Network, conservation status ranks are assigned, reviewed, and revised according to standard criteria. Assessing the conservation status of species and ecological communities is the cornerstone of Natural Heritage work. It allows Natural Heritage programs and their cooperators to target the most at-risk elements for inventory, protection, management, and research.

Global, National, and Subnational Conservation Status Ranks

An element is assigned one global rank (called a G-rank), which applies across its entire range; a national rank (N-rank) for each nation in its range; and a subnational rank (S-rank) for each state, province, or other subnational jurisdiction in its range (e.g. Yukon Territory). In general, Association for Biodiversity Information (ABI) scientists assign global, U.S., and Canadian national ranks. ABI scientists receive guidance from subnational data centers, especially for endemic elements, and from experts on particular taxonomic groups. Local data centers assign subnational ranks for elements in their respective jurisdictions and contribute information for national and global ranks. New information provided by field surveys, monitoring activities, consultation, and literature review, improves accuracy and keeps ranks current. Including an annual data exchange with local data centers, ABI's central databases are updated continually with revisions, corrections, and information on ranked elements.

What the Ranks Mean

The conservation rank of an element known or assumed to exist within a jurisdiction is designated by a whole number from 1 to 5, preceded by a G (Global), N (National), or S (Subnational) as appropriate. The numbers have the following meaning:
1 = critically imperiled
2 = imperiled
3 = vulnerable to extirpation or extinction
4 = apparently secure
5 = demonstrably widespread, abundant, and secure.

G1, for example, indicates critical imperilment on a range-wide basis—that is, a great risk of extinction. S1 indicates critical imperilment within a particular state, province, or other subnational jurisdiction, in other words, a great risk of extirpation of the element from that subnation, regardless of its status elsewhere.

Species known in an area only from historical records are ranked as either H (possibly extirpated/possibly extinct) or X (presumed extirpated/presumed extinct). Other codes, rank variants, and qualifiers are also allowed in order to add information about the element or indicate uncertainty. See the lists of conservation status rank definitions for complete descriptions of ranks and qualifiers.

Rank Definitions

Elements that are imperiled or vulnerable everywhere they occur will have a global rank of G1, G2, or G3 and equally high or higher national and subnational ranks. (The lower the number, the "higher" the rank is in conservation priority.) On the other hand, it is possible for an element to be more vulnerable in a given nation or subnation than it is range-wide. In that case, it might be ranked N1, N2, or N3, or S1, S2, or S3 even though its global rank is G4 or G5. The three levels of the ranking system give a more complete picture of the conservation status of a species or community than either a range-wide or local rank by itself. They also make it easier to set appropriate conservation priorities in different places and at different geographic levels.

In an effort to balance global and local conservation concerns, global as well as national and subnational (provincial or state) ranks are used to select the elements which should receive priority for research and conservation in a jurisdiction. Highest priority should be given to elements that are most vulnerable to extinction—that is, those ranked G1, G2, or G3. And, according to the rules of ranking, these must have equally high or higher national and subnational ranks. Elements vulnerable to national or subnational extirpation (ranks N1, N2, N3, or S1, S2, S3) with global ranks of G4 or G5 should be considered next.

Assessment Criteria

Use of standard ranking criteria and definitions makes Natural Heritage ranks comparable across element groups—thus G1 has the same basic meaning whether applied to a salamander, a moss, or a forest community. Standardization also makes ranks comparable across jurisdictions, which in turn allows ABI scientists to use the national and subnational ranks assigned by local data centers to determine and refine or reaffirm global ranks.

Ranking is a qualitative process: it takes into account several factors, which function as guidelines rather than arithmetic rules. The ranker's overall knowledge of the element allows him or her to weigh each factor in relation to the others and to consider all pertinent information for a particular element. The factors considered in ranking species and communities are similar, but the relative weight given to the factors differs.

For species elements, the following factors are considered in assigning a rank:
Total Number And Condition Of Occurrences
Population Size
Range Extent And Area Of Occupancy
Short- And Long-Term Trends In The Foregoing Factors
Threats
Fragility

Secondary factors include the geographic range over which the element occurs, threats to occurrences, and viability of the occurrences. However, it is often necessary to establish preliminary ranks for communities when information on these factors is not complete. This is particularly true for communities that have not been well described. In practice, a preliminary assessment of a community's range-wide global rank is often based on the following:

Geographic Range Over Which The Element Occurs
Long-Term Trend Of The Element Across This Range
Short-Term Trend (I.E., Threats)
Degree Of Site/Environmental Specificity Exhibited By The Element
Rarity Across The Range As Indicated By Subnational Ranks Assigned By Heritage Data Centers.

Global Heritage Status Rank Definitions

Rank	Definition
GX	Presumed Extinct—Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species)—Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled—Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
G2	Imperiled—Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
G3	Vulnerable—Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure—Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.

G5	Secure—Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

National (N) and Subnational* (S) Heritage Status Rank Definitions
* Subnational indicates jurisdictions at the state or provincial level (e.g. California, Ontario).

Rank	**Definition**
NX **SX**	Presumed Extirpated—Element is believed to be extirpated from the nation or subnation*. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
NH **SH**	Possibly Extirpated (Historical)—Element occurred historically in the nation or subnation*, and there is some expectation that it may be rediscovered. Its presence may not have been verified in the past 20 years. An element would become NH or SH without such a 20-year delay if the only known occurrences in a nation or subnation were destroyed or if it had been extensively and unsuccessfully looked for. Upon verification of an extant occurrence, NH or SH-ranked elements would typically receive an N1 or S1 rank. The NH or SH rank should be reserved for elements for which some effort has been made to relocate occurrences, rather than simply using this rank for all elements not known from verified extant occurrences.
N1 **S1**	Critically Imperiled—Critically imperiled in the nation or subnation* because of extreme rarity or because of some factor(s) making it especially vulnerable to extirpation from the subnation. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
N2 **S2**	Imperiled—Imperiled in the nation or subnation* because of rarity or because of some factor(s) making it very vulnerable to extirpation from the nation or subnation. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
N3 **S3**	Vulnerable—Vulnerable in the nation or subnation* either because rare and uncommon, or found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extirpation. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
N4 **S4**	Apparently Secure—Uncommon but not rare, and usually widespread in the nation or subnation*. Possible cause of long-term concern. Usually more than 100 occurrences and more than 10,000 individuals.
N5 **S5**	Secure—Common, widespread, and abundant in the nation or subnation*. Essentially ineradicable under present conditions. Typically with

considerably more than 100 occurrences and more than 10,000 individuals.

N? **S?**	Unranked—Nation or subnation* rank not yet assessed.

Appendix D. Contractor Qualifications And Experience

The conservation assessment was prepared by Steve W. Chadde and Dr. Greg Kudray. Mr. Chadde holds an M.S. degree in Plant Ecology from Montana State University and a B.S. degree in Agriculture from the University of Wyoming. He has conducted numerous botanical and ecological surveys and research studies in both the Great Lakes (Michigan, Minnesota, Wisconsin) and Rocky Mountain regions. Mr. Chadde's primary areas of expertise are endangered, threatened, and sensitive plant surveys, plant community characterization studies, natural areas evaluations, and wetlands inventory, delineation, and mapping. Dr. Kudray holds a Ph.D. in Wetland Ecology from Michigan Technological University. He has extensive experience in ecosystem characterization and mapping, vegetation inventory and monitoring, and forest analysis. Additional information for each author is provided below.

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E-mail: greg@ecologyusa.com
Statement of Qualifications – Steve W. Chadde

Recent Experience

Consulting Botanist
Ottawa National Forest, Lake Superior Land Co., Central Lake Superior Watershed Partnership, U.P. Engineers and Architects, Michigan (partial list only).
Conducted field surveys for endangered, threatened, and rare plant species, and various wetland and other ecological studies.

Botanist, USDA Forest Service
Ottawa National Forest and Hiawatha National Forest, Michigan
Conducted field surveys for endangered, threatened, and rare plant species on national forest lands in Michigan's Upper Peninsula.

Biologist, US Geological Survey
Great Lakes Science Center, Ann Arbor, Michigan
Vegetation scientist for a large wetland restoration project at Seney National Wildlife Refuge in Michigan's Upper Peninsula.

Natural Areas Ecologist, USDA Forest Service/The Nature Conservancy
Northern Region USDA Forest Service, Missoula, Montana
Responsible for identifying and establishing research natural areas (RNAs) and botanical areas on national forests in northern Idaho, Montana, and North and South Dakota. Performed field surveys and baseline inventories of wetlands and natural areas. Conducted field surveys for rare plants and plant communities.

Education

Michigan Technological University—Coursework in the Scientific and Technical Communication program.
M.S. Range Ecology— Montana State University, 1985
B.S. Agriculture (Honors)—University of Wyoming, 1983

Publications

Chadde, Steve. 2000. Natural Features Survey, Lake Superior Shoreline, Marquette County, Michigan. Contract report prepared for Central Lake Superior Watershed Partnership, Marquette.
Chadde, Steve. 1999. A Forester's Field Guide to the Endangered and Threatened Plants of Michigan's Upper Peninsula. Contract report prepared for Mead Corporation, Champion International Corporation, and Shelter Bay Forests.
Chadde, Steve. 1998. A Great Lakes Wetland Flora - A Complete, Illustrated Guide to the Aquatic and Wetland Plants of the Upper Midwest. PocketFlora Press, Calumet, MI. 584 p.
Chadde, Steve, and others. 1998. Peatlands on National Forests of the Northern Rocky Mountains: Ecology and Conservation. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-11. Ogden, UT.
Chadde, Steve. 1996. Plants of the Copper Country - An Illustrated Guide to the Vascular Plants of Houghton and Keweenaw Counties, Michigan, and Isle Royale National Park. PocketFlora Press, Calumet, MI. 112 p.
Chadde, Steve. 1996. Plants of Pictured Rocks National Lakeshore – A Complete, Illustrated Guide to the Plant's of America's First National Lakeshore. PocketFlora Press, Calumet, MI. 103 p.
Chadde, Steve. 1995. Ecological Evaluation - Findlayson Property, Chippewa County, Michigan. Contract report prepared for Michigan Chapter, The Nature Conservancy.
Chadde, Steve. 1995. Research Natural Areas of the Northern Region: Status and Needs Assessment. USDA Forest Service, Northern Region, Missoula, MT. 164 p.
Rabe, Fred, and Steve Chadde. 1995. Aquatic Features of Research Natural Areas of the Kootenai and Flathead National Forests, Montana. USDA Forest Service, Northern Region, Missoula, MT. 66 p. plus appendices.

Rabe, Fred, and Steve Chadde. 1994. Classification of Aquatic and Semiaquatic Wetland Natural Areas in Idaho and Western Montana. Natural Areas Journal 14(3): 175-187.
Statement of Qualifications – Dr. Greg Kudray

Recent Experience

Ecological Inventory and Analysis, Chassell, MI. Established company in June 1999 to conduct ecological consulting work for individuals, corporations, and government agencies. Contracted with the Hiawatha National Forest to do ecosystem mapping, the correlation of ecosystem types to soil types, and the training of Hiawatha personnel in ecosystem inventory and mapping. Contracted with the USGS to do wetland vegetation monitoring in the Seney National Wildlife Refuge. Other experience includes teaching wetland plant workshops, evaluation and mapping of exotic plant infestions, vegetation inventory, bryophyte identification, and aquatic plant monitoring. Six seasonal employees in 1999.

Michigan Technological University, Department of Forestry and Wood Products, Houghton, MI. Employed as a research scientist with primary responsibilities involving ecosystem classification and mapping with related database management and data analysis for the Hiawatha National Forest. Wetland mapping was based on a key and field guide developed during my doctoral research and continually refined through multivariate data analysis. In this position I trained and supervised a seasonal crew of biologists (8 in 1996, 9 in 1995, 3 in 1994) to conduct field mapping integrating vegetation, soil, and hydrological data. I also trained and coordinated four employees from the USDA Natural Resources Conservation Service (former USDA Soil Conservation Service) during the 1995 season and USDA Forest Service personnel throughout the project. Accomplishments include the fine-scale mapping of approximately 300,000 acres in the western half of the Hiawatha National Forest and the development of a database with detailed soil characterizations, hydrological data, and vascular and bryophyte plant information from 4000 plot records. In addition to this work I was an instructor in the 1994 Wetland Ecology course (FW 451), taught a 2 day Clear Lake Conference wetlands plant workshop, and also taught the wetland ecology section during a USFS silvicultural certification workshop offered by our department. (1994 to Nov. 1996)

Michigan Department of Natural Resources, Forest Management Division, Baraga Field Office. Assistant area forester supervising two forest technicians. Primarily responsible for the operations inventory and timber sale programs on the 135,000 acre Baraga area state forest. Conducted and supervised stand exam, type mapping, timber volume estimates, stumpage appraisal, and timber sale contract compliance. Other duties included Commercial Forest Act administration, insect surveys, wildfire suppression, road layout, and forest regeneration activities. Overall performance appraisal rating term for 1989 was "exceptional". Received 1989 DNR District One award for overall excellence. (1984 to 1990)

EDUCATION

Michigan Technological University, Houghton, Michigan. Ph.D. in Wetland Ecology. 1999. Research project involved the development of a ecosystem classification system for the wetlands of the Hiawatha National Forest. Attended University of Michigan Biological Station 1991 summer session with classes in Bryology and Aquatic Plants. Other areas of specialization include soil science, hydrology, forest and landscape ecology, vegetation science, statistics, and remote sensing/GIS applications in land management. Overall GPA of 4.0. (1990 to 1994, Nov. 1996 to June 1999). Published book chapter on the relationship of peatland types and vegetation to water chemistry, other publications in review.

Michigan State University, East Lansing, Michigan. MS specializing in Forest Genetics. 1979. Masters thesis was an evaluation of a spruce hybrid breeding program. Work as a research assistant included controlled pollinations, greenhouse propagation, and plantation establishment. Initiated a computerized record keeping system for a breeding arboretum. Published scientific article based on my research. Overall GPA of 3.6. (1977 to 1979)

Michigan State University, East Lansing, Michigan. BS in Forestry. 1976.
Graduated with high honor including Honors College membership. Also a member of Alpha Zeta, Beta Beta Beta, and Phi Kappa Phi honorary societies. Overall GPA of 3.8. (1972 to 1976)