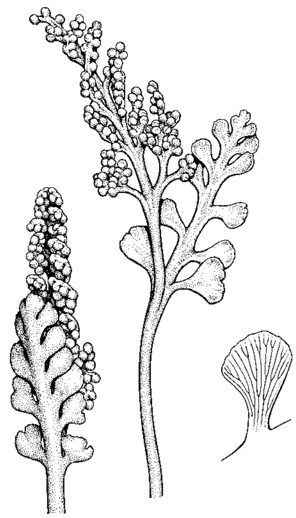
Conservation Assessment

For

Spoon-leaf Moonwort (Botrychium spathulatum)



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This Conservation Assessment was prepared to compile the published and unpublished information and serves as a Conservation Assessment for the Eastern Region of the Forest Service. 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 community, please contact the Eastern Region of the Forest Service - *Threatened and Endangered Species Program at 310 Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203.*

Table of Contents

EXECUTIVE SUMMARY

Botrychium spathulatum is a newly described (1990) small moonwort found at scattered locations in northern North America, including the Great Lakes region. The species is similar to the more common *B. lunaria* and very similar to *B. minganense*, with which it often occurs. *Botrychium spathulatum* occurs in a variety of habitats, most of which are open or partially open, and often where soils are sandy. Typical habitats reported from the Great Lakes include grassy fields, sand dunes, tailings piles, and along railroads and roadsides. As the species is newly described, most details about the biology of *B. spathulatum* are generalized from studies of other moonwort species. Much of the life-cycle occurs underground, and populations of aboveground sporophytes fluctuate from year-to-year. Like other moonworts, *B. spathulatum* is dependent on a mycorrhizal relationship; thus concerns about species conservation and management must include consideration of this relationship. Due to the newness of the species and its relatively few occurrences, little information is available on specifically managing habitat to maintain the species. Potential threats are not well understood; disturbance may stimulate plant establishment in some habitats. Natural plant succession may be a threat in open habitats, but no information is available on the response of *B. spathulatum* to site changes. Since plants are small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, range, and habitat.

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:

1. Provide an overview of current scientific knowledge for *Botrychium spathulatum*.
2. Provide a summary of the distribution and status of *Botrychium spathulatum*, both rangewide and within the Eastern Region of the USDA Forest Service.
3. Provide the available background information needed to prepare a subsequent Conservation Strategy.

In North America, the genus *Botrychium*, family Ophioglossaceae, is comprised of three subgenera (Lellinger 1985, Wagner and Wagner 1993). One subgenus, *Osmundopteris*, is only represented in our area by *B. virginianum*, the rattlesnake fern, which is common around much of the world (Wagner 1998). Subgenus *Sceptridium* are the grapeferns, medium-sized plants and decidedly evergreen (Lellinger 1985). Subgenus *Botrychium*, the moonworts, include numerous species of often rare, local, and very small plants that are difficult to find and 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 nearby 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 the traditional interpretation of only six (Clausen 1938).

The problems in distinguishing moonwort species are considerable (Wagner and Wagner 1990a), including the habit of different species of moonworts growing at one site, the natural variation in form due to microhabitat variability, their small size, and the difficulty of making good herbarium specimens. However, decades of work, primarily by the late Dr. Herb Wagner and 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.

NOMENCLATURE AND TAXONOMY

- Scientific Name: *Botrychium spathulatum* W.H. Wagner
- Synonymy: (none)
- Family: Ophioglossaceae; Adder's-Tongue Family
- Common Name: Spoon-Leaf Moonwort; Spatulate Moonwort; botryche à segments spatulés.

DESCRIPTION OF SPECIES

General description and identification notes

Botrychium spathulatum, along with *B. pallidum,* was first described in 1990 (Wagner and Wagner 1990). *B. spathulatum* is similar to *B. minganense* (present in the Great Lakes region), and *B. ascendens* and *B. crenulatum* (primarily western North American species absent from Great Lakes region). These three species have oval to fan-shaped pinnae in contrast to the spoon-shaped pinnae in *B. spathulatum*. *B. lunaria* is also similar but in this species the pinnae are closely adjacent rather than widely separated as in *B. spathulatum*. Earlier studies considered this group of species to be minor variants of the more common *B. lunaria* (Hauk and Haufler 1999).

Botrychium spathulatum produces a single erect frond, up to 12 cm (5 in) high divided into a sterile (trophophore) and a fertile (sporophore) section. The trophophore has a stalk, less than 1 mm long, and a narrowly triangular blade pinnately divided into 2-8 pairs of spoon-shaped, widely spaced, entire to lobed leaflets (pinnae). The sporophore is 1-2 times the length of the trophophore and 1-2 times pinnately divided into linear segments that bear the spores (NatureServe 2001).

A key to all *Botrychium* species is provided in Wagner and Wagner (1993), but the difficulty of accurately identifying subtly different species of *Botrychium* often requires expert verification. The treatment in Volume 2 of the Flora of North America (Wagner and Wagner 1993) is the most current published guide to all but the most recently described species (for example, since the release of Volume 2, a new species, *Botrychium lineare*, has been described by Wagner and Wagner [1994]). 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

Trophophore stalk 0–1 mm long; blade shiny yellow-green, narrowly deltate, flat, 1-pinnate, to 8 × 2.5 cm, thick, leathery. Pinnae to 8 pairs, ascending, remote, distance between first and second pinnae not or slightly more than between second and third pairs, basal pinna pair approximately equal in size and cutting to adjacent pair, mostly narrowly spatulate to linear-spatulate and rounded or ±2-cleft, lobed to unlobed to tip, margins mainly entire or occasionally irregularly and shallowly incised, apex rounded-notched, venation like ribs of fan, midrib absent. Sporophores 1-2 times pinnate, 1.2–2 times length of trophophore. 2n=180 (after Wagner and Wagner 1993).

Botrychium spathulatum has long been confused with the somewhat more common *B. minganense*, with which it often grows in the Lake Superior region. The leaves typically appear later in *B. spathulatum* than in *B. minganense*. However, Wagner and Wagner (1990) cautioned that positively identifying young, poorly developed, or badly pressed specimens may be difficult. A detailed table of differences between the two species is provided in Table 1.

TABLE 1. Comparison of mature plants of *B. minganense* and *B. spathulatum* (after Wagner and Wagner 1990).

Character	*B. minganense*	*B. spathulatum*
Distribution	Canada south in western U.S. to Arizona; frequent	Mostly Canada and Alaska; rare
Usual habitat	Woods, second-growth	Open fields, dune shrubby fields slopes
Common stalk 1 cm below trophophore (diam., dried)	2.5-4.0 mm	4-6 mm
Luster and color (alive)	Dull green	Shiny yellow-green
Trophophore attachment	Sessile to well developed stalk	Sessile or nearly so
Trophophore internodes	Straight-sided or nearly so	Shallowly concave
Trophophore outline	Narrowly oblong	Narrowly deltate

Trophophore apex	Gradually reduced to minute lobes	Abruptly reduced to lobes	coarse
Lowest pinnae	Smaller or equals those above	Larger than those above	
Supramedial pinnae	Enlarged or conform	Conform	
Blade folding	Not folded, flat or forming shallow trough over rachis	Basal pinnae commonly folded	
Pinna pairs (avg.)	5.7(3-8)	4.6(2-7)	
Pinna spacing	Separated to overlapping (especially in exposed places)	Mostly well separated, and sometimes remote	
Pinna orientation	Only slightly ascending or not at all	Ascending, the lower pinnae strongly oblique	
Pinna shape	Semi-orbicular to flabellate, usually widest in middle	Spatulate to flabellate. widest usually at or below apex	
Anterior pinna margins		Convex	Concave
Angularity of lower pinnae	Usually rounded	Usually with angular corners	
Pinna attachment	Narrowly adnate, 1/4-1/3 of pinna width	Broadly adnate, 1/3-1/2 of pinna width	
Pinna outer margin	Coarsely crenulate to undulate	Mainly entire, but may be coarsely dentate or lobed	
Vein endings (median pinnae)	8-18	16-24	
Sinuses (if present)	Mostly narrow or closed (lower pinnae not commonly cleft)	Sinuses mostly wide (lower pinnae commonly cleft)	
Sporophore/ trophophore length	1.5-2.2	1.2-1.8	

Time of sporangial maturation (est.)	10 days earlier	10 days later
Sporangium diameter	(0.8-) 1-1.1 (-1.3) mm	(1-) 1.2-1.4 (-1.7) mm

LIFE HISTORY

B. spathulatum belongs to subgenus *Botrychium* (moonworts) within the genus *Botrychium*. In North America there is also subgenus *Osmundopteris* (rattlesnake fern) and subgenus *Sceptridium* (grapeferns) (Lellinger 1985, Wagner and Wagner 1993). The life-cycle of all three subgenera is generally 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). Grapefern trophophores are present during the winter, while moonwort and rattlesnake fern leaves die back by winter.

Like all ferns, moonworts are characterized by alternation of generations between sporophytes and gametophytes. The sporophyte, the diploid (2N) generation of the plant, begins its life after fertilization of an egg by a sperm within the archegonium of the gametophyte. Embryology of moonwort species has been little studied due to the difficulty of obtaining suitable material (Gifford and Foster 1989, Mason and Farrar 1989). Early morphological studies (e.g., Campbell 1922) described a diversity of patterns of embryo development among moonworts. For example, *Botrychium simplex* has a relatively large cotyledon and rapid development, perhaps capable of maturing a small aboveground fertile frond in its first year, while *B. lunaria* has a relatively small cotyledon, and may take as much as seven years to produce an emergent frond.

The following information is from research with a variety of *Botrychium* species. Because it is only recently described as a species and is known from relatively few locations, specific life-history features of *B. spathulatum* have not been studied in detail. There may be aspects specific to *B. spathulatum* that do not follow the general patterns for the genus. Lack of specific information on the life history of *B. spathulatum* is a significant detriment to successful management and conservation.

Vegetative reproduction was not thought to occur in *Botrychium* (Wagner et al. 1985), but Farrar and Johnson-Groh (1990) documented underground gemmae in a few species of moonwort, including the closely related *B. minganense*. They speculated that asexual reproduction may have evolved as an adaptation to the dry habitat that some of these moonwort species were found in. *B. spathulatum* was not specifically examined in their study.

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). In most species the sporangial opening to release the spores 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 potentially travel much less, perhaps only a few centimeters from the parent (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 plant, 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 (Wagner 1998) that could help the spores to pass through an animal's gut, have suggested to some that herbivores, such as small mammals, may be involved in dispersal (Wagner et al. 1985, Wagner and Wagner 1993). The sporangia may also simply rot in the ground, thereby dispersing their spores (NatureServe 2001). It is uncertain how long *Botrychium* spores will remain viable (Lesica and Ahlenslager 1996).

After the spores are released, they infiltrate into the soil and may germinate. Infiltration and subsequent germination may take up to 5 years, although some may germinate immediately (Casson et al. 1998). Spore germination requires darkness, (Whittier 1972, Whittier 1973, Wagner et al. 1985), a requirement that is not surprising in view of the subterranean habitat of the gametophyte and the need for the resultant gametophyte to be infected by an endophytic fungus in an obligate association (Whittier 1973). Details of this host/fungus interaction are provided 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).

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 *Sceptridiu*m) 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 1996, Farrar 1998). 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), and 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 fungus may be transferring carbohydrates from other photosynthesizing plants in the vicinity, possibly species of herbaceous flowering plants (Farrar 1998). 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 37 other species of ferns (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). For example, *B. mormo* plants apparently do not produce aboveground sporophytes more than two consecutive years and there may be gaps as long as 6 years, although 1–3 years is more typical (Johnson-Groh 1998, Tans and Watermolen 1997). Species of *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. spathulatum leaves typically appear later than those of *B. minganense*. In general, in open droughty areas plants appear and mature earlier, while woodland plants emerge and persist later in the season (Hagenah 1966). The loss of plants to herbivory, fire, and 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 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).

Hybrids between different species of moonworts have been found (Wagner et al. 1985; Wagner 1991, 1993; Wagner and Wagner 1988). The hybrids possess abortive spores and are intermediate in characteristics between the presumed parents (Wagner 1993). Wagner and Wagner (1990) reported hybrids between *B. spathulatum* and *B. minganense* from Ontario, with plants present which were intermediate in character between the two parents.

All 23 taxa of moonworts 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) applied enzyme electrophoresis to the genetic relationships of eastern moonworts, and suggested some relationships for moonwort species and hybrids.

HABITAT

The general North American habitat of *B. spathulatum* was described as sand dunes, old fields, and grassy railroad sidings by Wagner and Wagner (1993). In Ontario, plants occurred along railroad tracks, where the species was growing with *B. campestre*, *B. minganense*, and *B. lunaria*, typical of the "genus communities" often formed by members of this genus (Wagner and Wagner 1983a). Other Ontario populations occurred in old fields and on grassy riverbanks.

In Michigan, *B. spathulatum* is known from sandy roadsides, grassy fields, and on wooded sand dunes near the Great Lakes. Light conditions are reported as open to partially shaded.

In Minnesota, several large populations of *B. spathulatum* were reported from a tailings pond of an iron-ore mine (see Appendix A). Associated species included *Populus balsamifera*, *Achillea millefolium*, *Taraxacum officinale*, and *Verbascum thapsus*. Plants occurred in full sun and in partial shade under trees of balsam poplar and jack pine.

A single occurrence of *Botrychium spathulatum* is reported on the Chippewa National Forest in Minnesota (Ian Shackleford, Chippewa NF, pers. comm. September 2000). No abundance or habitat information were available for this population.

In Wisconsin, *B. spathulatum* is known from a single site in Door County. The habitat is described as an old field, with plants growing in full sun (see Appendix A).

DISTRIBUTION, ABUNDANCE, AND STATUS

Botrychium spathulatum is known from scattered locations from the northern Great Lakes region to James Bay and the Gaspé region. In western North America, the species occurs from western Montana northward to Alaska.

North American range of *Botrychium spathulatum* (Wagner and Wagner 1993).

The species is not listed as endangered, threatened, or special concern in Michigan or Minnesota. It is listed as a species of special concern in Wisconsin. However, the single known Wisconsin population has not been relocated since its initial discovery in 1982, and its current status or presence is unknown.

State and provincial conservation status rankings are listed below (see Appendix C for ranking definitions).

United States
Alaska (S2?), Michigan (S3, no special status), Minnesota (S?, no special status) Montana (S1), Wisconsin (S1, state special concern).

Canada
Alberta (S1S2), British Columbia (S?), Northwest Territories (SR), Nova Scotia (SU), Ontario (S1), Prince Edward Island (SU), Quebec (S1), Yukon Territory (SR)

Global Heritage Status Rank: G3 (11Aug2000)
Rounded Global Heritage Status Rank: G3
Rationale: Species widespread but populations usually small; newly described species that may be more widespread. Somewhat abundant in Michigan; about 24 occurrences elsewhere across a sampling of range.

United States
National Conservation Status Rank: N3 (17Nov1996)
Canada
National Conservation Status Rank: N2N3 (11Aug2000)

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	Status	Comments
Minnesota	4	S?	No special status
Wisconsin	1	S1	State special concern
Michigan	unknown	S3	Not tracked
Total	na		

GREAT LAKE STATES and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	4
Chippewa National Forest	1
Superior National Forest	0
Michigan	na
Ottawa National Forest	0
Hiawatha National Forest	6
Huron-Manistee National Forest	0
Wisconsin	1
Chequamegon-Nicolet National Forest	0
Total State EOs	na
Total National Forest EOs	7
NF as % of EOs	na

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. spathulatum*. Population studies on other species of moonworts have shown that there can be considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). In her studies, populations typically fluctuated independently among plots at any given site, with some populations increasing while others were decreasing (Johnson-Groh 1999). These variations were considered to reflect 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 probably appear or disappear, at least in part, due to the health of 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 a finding 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. spathulatum* may respond similarly.

Many species of *Botrychium* are associated with light to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993, Lesica and Ahlenslager 1996). A species like *B. spathulatum* 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).

POTENTIAL THREATS AND MONITORING

Threats to *B. spathulatum* are not well understood but a serious underlying threat is the lack of information available on the species. Johnson-Groh and Farrar (1996a) documented population declines to several moonworts (including *B. simplex* and *B. campestre*) due to the combined effect of drought and fire. Because *B. spathulatum* often occurs in more or less open sites, and sometimes where previously disturbed (e.g., roadsides, tailings piles), threats may include natural plant succession toward closed-canopy conditions. Some threats will have their direct effect on the aboveground sporophyte and may be less significant, since the belowground part of the life-cycle is so important (see Sections C and F above).

Simple removal of leaf tissue may be relatively inconsequential to the ability of moonworts to survive, although removing sporulating individuals may eventually have an effect (Johnson-Groh 1999). Wagner and Wagner (1993) 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) did find 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 a species of *Botrychium* prior to sporulation. The work of Johnson-Groh (1999) also emphasized the importance of water-relations to moonworts and their supporting mycorrhizae. Mycorrhizae are the most limiting factor for *Botrychium* establishment, distribution, and abundance (Johnson-Groh 1999); therefore adverse impacts to the mycorrhizae may be expected to also have deleterious effects on *Botrychium*.

Large decreases in mycorrhizal fungi have occurred following earthworm invasion in deciduous hardwood forests (Nielsen and Hole 1963, 1964; Cothrel et al. 1997; Nixon 1995). Since this is not a habitat associated with *B. spathulatum*, exotic earthworms are unlikely to pose a significant threat to this species. In addition, soils of the disturbed areas often favored by *B. spathulatum* typically have less organic material than forest soils, making these sites less favorable to earthworm activity.

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, activities that dry the habitat may have deleterious effects on the population. As *B. spathulatum* occurs in a variety of habitats, a number of techniques may be necessary to encourage the establishment and maintenance of the species. At present, no information is available on the response of *B. spathulatum* populations to management.

Since *B. spathulatum* often exists in a habitat that is early successional due to disturbance (such as fields, tailings piles, roadsides, etc.), it may be prone to local extinction as succession occurs. Maintaining viable populations may rely on a shifting mosaic of suitable habitats opening up for colonization (see Section F). Species protection efforts should account for the immediate area surrounding *B. spathulatum* populations to ensure that an adequate buffer is present to protect the population from potential threats. A buffer also allows for expansion of the population.

RESEARCH AND MONITORING REQUIREMENTS

Like other moonworts, *B. spathulatum* is small, inconspicuous, and fairly difficult to find. The fluctuating annual number of aboveground stems also creates difficulties; plants may go dormant some years and not be visible. There are probably undiscovered sites for *B. spathulatum*, and inventories for the plant should continue. While some research data have been developed about population fluctuations for certain species of *Botrychium*, much information about *B. spathulatum* population biology is lacking.

Almost no information is available on *B. spathulatum* life history in relation to disturbance and colonization of new sites. While its habitat is generally considered to be open areas, specific habitat requirements of *B. spathulatum* and the sensitivity of this species to disturbance need to be determined. Succession toward closed-canopy conditions may be a threat, but it is unclear how *B. spathulatum* reacts to site changes over time. Long-term monitoring is necessary to determine life history characteristics, population stability, and dynamics over time.

Life-history information for this species has been generalized from studies on various other species within the *Botrychium* subgenus. Specific information on *B. spathulatum* life-history is needed including its important relationship with mycorrhizal fungi and its belowground ecology in general. Data on spore dispersal are also lacking.

While exotic earthworms are a serious threat to some moonwort species, particularly *B. mormo* (Sather et al. 1998), it is unlikely that earthworms will pose a significant threat to *B. spathulatum* or its habitats.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for the moonwort *B. mormo*. Many of their suggestions apply to other *Botrychium* species also, and 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).

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 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. 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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UNITED STATES
Michigan: http://www.dnr.state.mi.us/wildlife/heritage/mnfi/
Minnesota: http://www.dnr.state.mn.us/ecological_services/nhnrp/index.html
Wisconsin: http://www.dnr.state.wi.us/org/land/er/nhi/nhi.htm
Illinois: http://dnr.state.il.us/
Indiana: http://www.ai.org/dnr/naturepr/index.htm
Iowa: http://www.state.ia.us/dnr/organiza/ppd/nai.htm
Ohio: http://www.dnr.state.oh.us/odnr/dnap/dnap.html
North Dakota: http://www.abi.org/nhp/us/nd/index.html
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 SPATHULATUM* 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	4
Wisconsin	1

MICHIGAN

Location: Michigan, Delta County
Ownership: Hiawatha National Forest
Abundance: Not listed
Habitat: Old revegetated gravel pit.
Comments: Plants on old mounds of pit shaded by adjacent mesic northern forest.
Source of information: Hiawatha National Forest survey form.

Location: Michigan, Schoolcraft County
Ownership: Hiawatha National Forest
Abundance: 3 fronds on herbarium sheet
Habitat: Not listed
Source of information: Hiawatha National Forest survey form.

Location: Michigan, Alger County
Ownership: Pictured Rocks National Lakeshore
Abundance: Not listed
Habitat: Sandy woods and dunes near Lake Superior.
Source of information: Hiawatha National Forest survey form.

Location: Michigan, Chippewa County
Ownership: Hiawatha National Forest
Abundance: Not listed
Habitat: Semi-open, sandy, rocky soil.
Source of information: Hiawatha National Forest survey form.

Location: Michigan, Chippewa County
Ownership: Hiawatha National Forest
Abundance: Not listed
Habitat: Open and semi-open areas along road.
Source of information: Hiawatha National Forest survey form.

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

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

MINNESOTA

Location: Minnesota, Crow Wing County
Ownership: Unknown
Abundance: Not listed
Habitat: plants occur in a tailings pond of a cuyuna iron mine. Associated with *Populus balsamifera, Achillea millefolium, Taraxacum officinale, Verbascum thapsus.*
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Crow Wing County
Ownership: Unknown
Abundance: 100's of plants observed.
Habitat: the site is an old tailings pond in a mine dump area. Plants occur in full sun and in partial shade under balsam poplar and small jack pine. Soil is dark in color, very fine in texture: tailings. Associated with *Fragaria virginiana, Botrychium pallidum, Achillea millefolium, Arabis x divaricarpa, Verbascum thapsus.*
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Crow Wing County
Ownership: Unknown
Abundance: Not listed
Habitat: At the base of a mossy hillside on a narrow bench just above the beach along the northwest shoreline
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in the recently exposed tailings surrounding a receding tailings pond of a mine spoil area on the western-most end of the Mesabi iron range. Associated with *Populus*

balsamifera, Botrychium campestre, Achillea millefolium, Carex aurea.
Comments: 1998.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

WISCONSIN

Location: Wisconsin, Door County
Ownership: Unknown
Abundance: ca. 10-12 plants observed in 1982; plants not seen in 1994 visit.
Habitat: Plants in full sun with sparse grasses in old field habitat.
Comments: Originally identified as *Botrychium lunaria* (with ca. 70 plants reported from this location).
Source of information: Wisconsin 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
B. spathulatum	(not listed) S?	(not listed) S3	SC (S1)	G3/N3

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 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.

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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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)