Conservation Assessment
For
Pale Moonwort (Botrychium pallidum)

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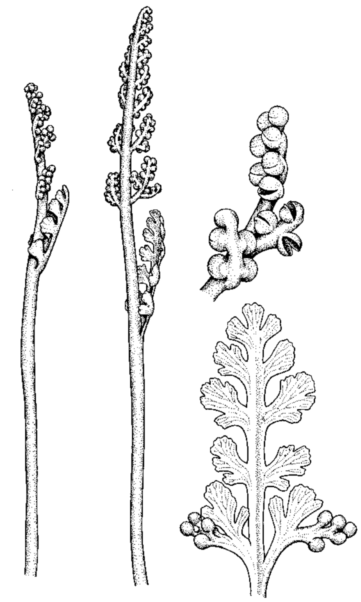

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Prepared by Steve Chadde & Greg Kudray

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This Conservation Assessment was prepared to compile the published and unpublished information and serves as a Conservation Assessment for the Eastern Region of the Forest Service.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.*

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EXECUTIVE SUMMARY

Botrychium pallidum is a tiny fern first described as a unique species in 1990. It is extremely rare and local when found, and across its range of Quebec to Saskatchewan and south to Maine, Michigan, and Colorado, it occurs at widely separated locations. Its habitat is extremely variable, occurring mostly in open areas, but sometimes where shaded. Many of the habitats have regular disturbance regimes. The largest threat to the species may be natural succession toward shaded, forest environments. Details about the biology of *B. pallidum* are generalized from studies of other moonwort species. Much of the life-cycle occurs underground. Populations of aboveground sporophytes appear to fluctuate from year-to-year, and individual plants may not appear every year, complicating attempts to adequately inventory populations. Like other moonworts, *B. pallidum* is dependent on a mycorrhizal relationship; thus species conservation efforts must include consideration of this relationship. No specific information is available on managing habitats to maintain the species. Since plants are small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, species range, and habitat preferences. Much basic research on *B. pallidum* 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:

1. Provide an overview of current scientific knowledge for *Botrychium pallidum*.
2. Provide a summary of the distribution and status of *Botrychium pallidum*, 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 the world (Wagner 1998). Subgenus *Sceptridium* are the grapeferns, medium sized and decidedly evergreen (Lellinger 1985). Subgenus *Botrychium*, the moonworts (including *B. pallidum*), includes numerous species of often rare, local, and very small plants that are difficult to find 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 United States and nearby Canada, are two of the richest areas (Wagner and Wagner 1990, Wagner 1998). Twenty-three species of North American moonworts are now recognized (Wagner and Wagner 1994) compared to an earlier interpretation of only six (Clausen 1938). The problems in distinguishing moonwort species are considerable (Wagner and Wagner 1990), including the tendency for different species of moonworts to co-occur at one site, the natural variation in plant-form due to microhabitat variability, their small size, and the difficulty of making good herbarium specimens. However, decades of work, primarily by Dr. Herb Wagner and associates, have clarified the taxonomy of the group, habitat preferences, and the ranges of individual species. Several rare species of subgenus *Botrychium* are now recognized in the Upper Great Lakes region.

B. pallidum was first described as a new species in 1990 by Wagner and Wagner (1990). Older specimens were typically identified as *Botrychium minganense*, and *B. pallidum* looks like a very pale, dwarf form of that species. *B. pallidum* is widely distributed across northern North America but is exceedingly rare and local (Wagner and Wagner 1990). The species' habitat preferences appear to be quite general, with populations known from forests, fields, and roadsides.

There is little specific information about many aspects of *B. pallidum* life history and ecology.

NOMENCLATURE AND TAXONOMY

- Scientific Name: *Botrychium pallidum* W.H. Wagner
- Family: Ophioglossaceae; Adder's-Tongue Family
- Common Name: Pale Moonwort
- Synonymy: (none)

DESCRIPTION OF SPECIES

General Description And Identification Notes

Botrychium pallidum is a small perennial fern less than 10 cm tall that produces a leaf (the trophophore) with a waxy-appearing, pale-green to whitish blade that is more-or-less folded longitudinally. There are up to 5 pair of pinnae, each tending to form two lobes, the upper one cleft and larger than the lower. A longer, spore-bearing spike (the sporophore) arises from the common stalk. Leaves appear in late spring to early summer. *B. pallidum* can be distinguished from forms of open-grown (in sunlight) *B. minganense* by its smaller size, dull pale (glaucous) color, and a folded trophophore blade compared to the flat trophophore blade of *B. minganense*. The pinnae of *B. pallidum* are also strongly concave and only 2–3 mm long, compared to the 4–6 mm length of the straight *B. minganense* pinnae.

There are a number of useful references for identifying members of this genus. 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 linear*e, 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 blade longitudinally more or less folded and trough-like when alive, narrowly oblong, up to 4 x 1 cm, once-pinnate, the pinnae approximate, up to 5 pairs, small, to 6 mm long, flabellate, the basal or both sides deeply concave, broadly attached, the larger ones ascending and strongly asymmetrical, tending toward two lobes, the upper one cleft and larger than the lower; outer margins entire to irregularly crenulate-denticulate; lamina herbaceous, glaucous pale green; lower sporophore pinnae with a large or small branch; spore diameter 23–28 μm; chromosomes n=45 (after Wagner and Wagner 1990).

LIFE HISTORY

Botrychium pallidum 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 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. Reproduction in *B. pallidum* has not been researched and there may be life history details specific to *B. pallidum* that do not follow these general patterns for the genus. Lack of specific information on the life history of *B. pallidum* is a significant management concern.

Vegetative reproduction was not thought to occur in *Botrychium* (Wagner et al. 1985), but Farrar and Johnson-Groh (1990) have documented underground gemmae (bud-like structures) in a few species of moonwort. They speculated that asexual reproduction may have evolved as an adaptation to the dry habitats that some of these moonwort species were found in. *B. pallidum* is one of four moonwort species that commonly produce dense clusters of minute, spherical gemmae at the root bases (Wagner and Wagner 1993).

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, 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 *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 1996a, 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). However, grapeferns (subgenus *Sceptridium*), may appear more regularly than moonworts (subgenus *Botrychium*) (Johnson-Groh, reported in USDA Forest Service, Eastern Region 1999). 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% of aboveground plants will develop into larger plants with 20 to 50 sporangia (spore-bearing tissues) each.

B. pallidum plants emerge from the ground in late spring or early summer (Wagner and Wagner 1993). 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. Mycorrhizae alone may supply a significant amount of the plant's nutrients and energy (Johnson-Groh 1999, Casson et al. 2000).

Available information (Montgomery 1990, Muller 1993, Kelly 1994, Lesica and Ahlenslager 1996) indicates that members of subgenus *Botrychium* (moonworts) are short-lived perennials while subgenus *Sceptridium* (grapeferns) are more long-lived. Estimated half-life times for various grapeferns were 43.2 years (Montgomery 1990) and 11.2 years (Kelly 1994), while moonwort half-lives were 1.3 years (Muller 1993) and 3 years or less (Lesica and Ahlenslager 1996).

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 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) have applied enzyme electrophoresis to the genetic relationships of eastern moonworts and have also suggested some relationships for moonwort species and hybrids.

HABITAT

In the initial description of the species (Wagner and Wagner 1990), specimens of *B. pallidum* were reported from a wide variety of habitats including:

- sand dunes,
- open meadows and fields,
- sandy roadbanks,
- grassy ditches,
- shrubby second-growth fields,
- mixed hardwood forests.

A later report (Wagner and Wagner 1993) added that the species was found mainly in open fields but was also known to occur in shaded places. *B. pallidum* may be limited primarily to areas kept open by a regular disturbance regime (NatureServe 2001), similar to reports of other moonworts associated with light to moderate disturbances (Lesica and Ahlenslager 1996).

In the Great Lakes region, the species' habitat is likewise diverse. In Minnesota, reported habitats included maple/basswood forests, red and jack pine forests, a sandy ridge between a bog and an old gravel pit, wetlands, ephemeral ponds, pine needles, oak leaves, a housing development lot with weedy species, open fields, a log landing, a narrow bench beside a small stream, and open tailings ponds (Mulligan 1999). Disturbance seems to be a consistent trend (Mulligan 1999).

Like many moonworts, *B. pallidum* is often found growing in the company of other moonworts, a phenomenon called "genus communities" (Wagner and Wagner 1983). *B. pallidum* has been found with various combinations of nine other species of moonworts, and, at the time of their report, had not been found without other species of *Botrychium* nearby. (Wagner and Wagner 1990).

DISTRIBUTION, ABUNDANCE, AND STATUS

B. pallidum is an exceedingly rare and local plant (Wagner and Wagner 1990). This recently described species has a widespread but disjunct range, and it is possible that gaps in the range will be filled with new occurrences. Wagner observed that where it occurred, the species was usually present in only small numbers but that occasionally sizeable colonies were found (reported in Mulligan 1999). Currently, no populations have been discovered in Wisconsin, but additional inventories may locate this species in the state (Mulligan 1999). There are 26 sites in Minnesota (Appendix A). Most of the Minnesota sites are in the northeastern counties and in Polk County in the northwest (Mulligan 1999). In Michigan, three sites are reported from the Hiawatha National Forest.

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

Global and state rankings were obtained from NatureServe (www.natureserve.org), a comprehensive online database of information on plants, plant communities, and animals. Conservation status ranks are defined in Appendix A.

Global Conservation Status Rank: G2G3 (1997)
Rounded Global Conservation Status Rank: G2

Global Conservation Status Rank Reasons:
This species has a broad but disjunct range and is very local in its distribution. This small, inconspicuous species has likely been overlooked, and its range may be more continuous than our present knowledge indicates.

United States: National Conservation Status Rank: N2N3 (2000)
Canada: National Conservation Status Rank: N1 (1994)

U.S. and Canada State/Province Conservation Status Ranks

United States: Colorado (S2), Maine (SR), Michigan (S3), Minnesota (S1), Montana (S1).
Canada: Manitoba (S1), Ontario (S1), Quebec (S1), Saskatchewan (S?).

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	State Rank	Status	Comments
Minnesota	26	S1	E	State endangered
Wisconsin	0	--	--	--
Michigan	3	S3	SC	State special concern
Total	29			

STATE and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

National Forest	No. of EOs
Minnesota	26
Chippewa National Forest	12
Superior National Forest	0
Michigan	3
Ottawa National Forest	0
Hiawatha National Forest	3
Huron-Manistee National Forest	0
Wisconsin	0
Chequamegon-Nicolet National Forest	0
Total State EOs	29
Total National Forest EOs	15
NF as % of EOs in MN, WI, MI	52%

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. pallidum*. Population studies on other species of moonworts have shown considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). Populations fluctuated independently among plots at any given site, some populations may be increasing while others are decreasing (Johnson-Groh 1999). These variations reflect microsite differences such as soil moisture, herbivory, or mycorrhizae (Johnson-Groh 1999), although populations of moonworts are known to fluctuate wildly without any apparent cause (Johnson-Groh 1999). Individual plants may not emerge every year (Muller 1993, Johnson-Groh 1998).

Botrychium probably appear or disappear in accordance with mycorrhizal health (Johnson-Groh 1998) due to their obligate relationship with the fungi. Johnson-Groh (1999) concluded that mycorrhizae are the most limiting factor for *Botrychium* establishment, distribution and abundance. Environmental factors that may affect mycorrhizae, like reduction in water availability, are then also likely to have significant impacts on moonworts, whereas the repeated removal of leaf tissue may have little effect (Johnson-Groh 1999). Wagner and Wagner (1993) also concluded that taking many samples will have little effect on the population as long as the underground shoots and roots are left intact. 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 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 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 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 moonwort population that can rebound from unfavorable years (Johnson-Groh et al. 1998, Johnson-Groh 1999). However, events that destroy the sporophytes, like an herbicide application, may have an effect several years later (Johnson-Groh 1999). These underground stages have been compared to seed-banks in angiosperms and likely play an important role in population dynamics (Kalisz and McPeek 1992).

A population model for the moonwort *B. 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. pallidum* may respond similarly.

Many species of *Botrychium* are associated with light to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993). Habitat reports for *B. pallidum* are often in disturbed areas (Wagner and Wagner 1990, Mulligan 1999, NatureServe 2001). A species like *B. pallidum* that apparently requires open areas with a regular disturbance regime may have a metapopulation structure where local populations are founded, then become extinct as succession proceeds toward a closed-canopy forest 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

The primary threat to *B. pallidum* appears to be the loss of its typical open, grassy habitat to successional overgrowth (NatureServe 2001). Habitat encroachment due to development, agriculture, and recreation are also threats to *B. pallidum* and its habitat (USDA Forest Service 2000).

Simple removal of leaf tissue may be inconsequential to the ability of moonworts to survive, although removing sporulating individuals may eventually have a negative 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) reported that if the aboveground shoot was removed after spore release, the trophophore the following year was significantly smaller; removal before sporulation had no effect. However, it should be noted that this was a one-year study and weather conditions could have had an impact (Hoefferle 1999). Longer-term studies have indicated that removal of leaves had no effect on subsequent leaf size or vigor (Johnson-Groh and Farrar 1996a, b).

In a French study (Muller 1992), drought-like conditions wilted a *Botrychium* sp. sporophyte before 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 anything that affects mycorrhizae negatively 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 and 1964, Cothrel et al. 1997, Nixon 1995). Since most mycorrhizal activity occurs in the interface between the O and A horizons (Read 1994), the concurrent action of exotic earthworms in the same area may have significant effects. The exotic earthworms have their largest impact on the organic surface layer present in some soils (Langmaid 1964). Some suggest earthworms may be a possible threat to *B. pallidum* (Mulligan 1999, USDA Forest Service 2000), although no research has indicated that the worms are a threat to species of *Botrychium* other than *B. mormo*, which occurs in the habitats most likely to be affected (Mulligan 1999). The soils preferred by *B. pallidum* would probably not have thick organic surface layers due to their disturbed nature, although some of the forest environments supporting this species may be impacted.

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 soil mycorrhizae seems to be an underlying necessity. Given the general preference of the species for open, somewhat disturbed sites (NatureServe 2001), management activities that open the canopy somewhat may be a desirable management tool. However, no specific information is available on the response of *B. pallidum* populations to management of any kind.

Since *B. pallidum* often exists in a habitat that is early successional due to disturbance, it may be prone to local extinctions. Population viability may therefore rely on a shifting mosaic of suitable habitats opening for colonization (see Section F). Land protection efforts should take into account the immediate area surrounding the *B. pallidum* populations to ensure that an adequate buffer to fully protect the population from potential threats and to allow for expansion is available (NatureServe 2001).

RESEARCH AND MONITORING REQUIREMENTS

Like most species of *Botrychium*, *B. pallidum* is small, inconspicuous, and difficult to find. The fluctuating population sizes of moonworts also creates difficulties; plants may not appear aboveground in a given year. Given these characteristics and the only recent recognition of this species (Wagner and Wagner 1990), it is very likely that there are undiscovered sites for *B. pallidum*. Inventories for the plant should continue. While some research data have been developed about population fluctuations for certain species of *Botrychium* (Johnson-Groh 1999), specific information for *B. pallidum* population biology is lacking.

Almost no information is available on *B. pallidum* 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. Succession has been considered a threat (USDA Forest Service 2000), but it is unclear how *B. pallidum* reacts to site changes over time.

Life history information for moonworts is mostly generalized from studies on various species within the group. Specific information on *B. pallidum* life history is needed including its important relationship with mycorrhizal fungi and its belowground ecology in general. Data on spore dispersal are also lacking.

Exotic earthworms are a serious threat to some moonwort species, particularly *B. mormo* (Sather et al. 1998). It is unknown if exotic earthworms threaten *B. pallidum* populations or habitats.

Berlin et al. (1998) make a number of specific research and monitoring recommendations for *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 generally apply to most rare *Botrychium* species 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 may be monitored through a randomized, permanent plot methodology. Individuals within each plot can 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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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 – ELEMENT OCCURRENCE RECORDS, *BOTRYCHIUM PALLIDUM*

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	3
Minnesota	27
Wisconsin	0

MICHIGAN

Location: Michigan, Chippewa County
Ownership: Forest Service
Abundance: no information
Habitat: no information
Comments:
Source of information: Hiawatha National Forest occurrence record

Location: Michigan, Chippewa County
Ownership: Forest Service
Abundance: no information
Habitat: no information
Comments:
Source of information: Hiawatha National Forest occurrence record

Location: Michigan, Chippewa County
Ownership: Forest Service
Abundance: no information
Habitat: no information
Comments:
Source of information: Hiawatha National Forest occurrence record

MINNESOTA

Location: Minnesota, Aitkin County
Ownership: Unknown
Abundance: 1 plant
Habitat: On a narrow bench beside a small stream in a hardwood forest dominated by *Acer Saccharum* and *Tilia americana.*
Comments: 1997
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a deciduous forest dominated by *Acer Saccharum*. Associated with *Botrychium minganense, B. matricariifolium, B. simplex. B. multifidum, B. virginianum*.
Comments: 1993
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: Unknown
Abundance: 1 plant
Habitat: 200m north of pipeline along edge of wet depression near well-defined deer trail. Maple-basswood forest with yellow birch. *Botrychium matricariifolium* also present at site.

Associated spp: Solomon's-seal, young maple, grass spp., wild lily-of-the-valley, jack-in-the-pulpit, ostrich fern and *Equisetum* spp. Wet area with moderate humus content.
Comments: 1997
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 3 plants
Habitat: Along the shoreline of lake. Lakeshore has large white pine and cedar. Habitat also includes red pine, *Poa* spp and hazel. Flat slope. Associated species: sarsaparilla and wild strawberry.
Comments: 1997
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: USFS
Abundance: 2 plants
Habitat: Red pine stand with pine needle ground cover. Open understory with sparse maple saplings. Flat slope. Associated spp.: cinnamon fern and maple.
Comments: 1997
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: native American land
Abundance: not listed
Habitat: Located in lot in tribal housing development. Dominated by weedy species including *Euphorbia esula*. Collected from slight depression area dominated mainly by *Phalaris arundinacea* and associated with *B. matricariifolium* and *B. simplex.*
Comments: 1996
Source of information: Minnesota element occurrence record

Location: Minnesota, Cass County
Ownership: native American land
Abundance: not listed
Habitat: In mesic hardwood forest dominated by *Acer saccharum* and *Tilia americana*. About 20 ft from wetland. Associated with *Aralia racemosa*, occasional *Laportea, Hydrophyllum*, *Arisaema*, *Uvularia grandiflora*, *Equisetum fluviatile*; also in area, *B. virginianum, B. mormo, B. matricariifolium*. Deep leaf litter.
Comments: 1996
Source of information: Minnesota element occurrence record

Location: Minnesota, Cook County
Ownership: Unknown
Abundance: 8 plants
Habitat: In old roadside embankment/ditch/borrow pit. Area open, few shrubs. Associated spp.*: B. michiganense, B. matricariifolium, Fragaria, Achillea, Hieracium, Trifolium*.

Southern exposure, plants on level ground. Portions of area recently brush logged to cut/slash brush.
Comments: 1999
Source of information: Minnesota element occurrence record

Location: Minnesota, Cook County
Ownership: USFS
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. Associated 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*. Seven other spp of *Botrychium* found at same site.
Comments: 1998
Source of information: Minnesota element occurrence record

Location: Minnesota, Cook County
Ownership: USFS
Abundance: 2 plants
Habitat: In campsite area on moose lake in shaded *Thuja/Betula* forest. Duffy soils at mouth of periodically flushed drainage channel. Site appears seasonally flushed/eroded, occasionally more severely eroded/braided. Very unusual site for *Botrychium*. *B. matricariifolium* observed about 150 ft from site.
Comments: 1999
Source of information: Minnesota element occurrence record

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, Botrychium spathulatum.*
Comments: 1998
Source of information: Minnesota element occurrence record

Location: Minnesota, Crow wing County
Ownership: Unknown
Abundance: Not listed
Habitat: On big island in lake, near the edge of a small pool in an old-growth maple-basswood forest.
Comments: 1998
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: USFS

Abundance: Not listed
Habitat: Located along the deciduously forested south shore of a lake. Plants occur in a level area very near the marshy lakeshore as part of a large genus community of several species of *Botrychium*.
Comments: 1994
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: Located along the north shore of a lake. Plants occur in a deciduous forest with *Acer Saccharum* and *Populus grandidentata*. Associated with *Thalictrum dioicum, Botrychium virginianum, B. minganense, B. matricariifolium, Corallorhiza striata*.
Comments: 1994
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: located at the base of the slope on the southeast shore of a lake. Plants occur in red oak litter in transition from shore to forest dominated by *Acer Saccharum* and *Tilia americana*. Associated with *Thalictrum dioicum, Lathyrus venosus, Ostrya virginiana, Equisetum sylvaticum, Botrychium minganense*.
Comments: 1994
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: Not listed
Habitat: Plant occurs in a deciduous forest with *Acer saccharum* and *A. spicatum*. Associated with *Thuja occidentalis, Populus grandidentata, Uvularia grandiflora, Botrychium minganense, B. matricariifolium.*
Comments: 1994
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: Unknown
Abundance: 1 plant
Habitat: Plant occurs along sloping sides of bowl-shaped area in a deciduous forest with sugar maple and basswood. One of largest populations of the many forms of *B. matricariifolium* (large-sized plants) observed on Chippewa National Forest.
Comments: 1994
Source of information: Minnesota element occurrence record

Location: Minnesota, Itasca County
Ownership: Unknown

Abundance: Not listed
Habitat: Plants occur in a tailings pond se of the hill-annex mine on the Mesabe iron range. Associated with *Populus balsamifera, Betula papyrifera, Equisetum hyemale, Prunella vulgaris.*
Comments: 1998
Source of information: Minnesota element occurrence record

Location: Minnesota, Lake County
Ownership: Unknown
Abundance: 6 plants
Habitat: On sand ridge between open sphagnum bog and old gravel pit. Plants growing in leaf litter beneath *Alnus.* No immediate overstory, but jack pine, black spruce and paper birch nearby. Ground cover: *Fragaria*, raspberry, *Abies balsamea* saplings; *B. matricariifolium and B. multifidum*
Comments: 1992
Source of information: Minnesota element occurrence record

Location: Minnesota, Lake County
Ownership: Unknown
Abundance: 12 plants in 2 populations in and adjacent to wildlife opening.
Habitat: On a leveled log landing at the base of a north-facing, sandy, jackpine covered slope. Sandy, rocky soil. Associated with *Hieracium aurantiacum, Fragaria americana, Antennaria neglecta, Botrychium matricariifolium, B. simplex*.
Comments: 1995
Source of information: Minnesota element occurrence record

Location: Minnesota, Polk County
Ownership: USFWS
Abundance: 12 plants in 2 populations in and adjacent to wildlife opening.
Habitat: 40-60 small members of genus, several morphological types, on east side of small ephemeral pond in hydric soils. Probably flooded in spring. Upslope of area in pond with *Onoclea sensibilis*, downslope of typical forest floor. With *B. virginianum, B. matricariifolium, Viola pubescens, Circaea alpina, Osmorhiza claytonii.*
Comments: 1995
Source of information: Minnesota element occurrence record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a stabilized tailings pone associated with *Populus tremuloides, Picea mariana, Carex aurea, Ledum groenlandicum, Vaccinium angustifolium.*
Comments: 1998
Source of information: Minnesota 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 element occurrence record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur in a tailings pond. Associated with *Populus balsamifera, Equisetum arvense, Alnus incana, Rumex acetosa, Hieracium aurantiacum.*
Comments: 1998
Source of information: Minnesota element occurrence record

Location: Minnesota, St Louis County
Ownership: Unknown
Abundance: Not listed
Habitat: Plants occur under young aspens along the edge of a road in an old mine dump. Associated with *Populus tremuloides, P. balsamifera, Antennaria neglecta, Fragaria virginiana, Trifolium pratense.*
Comments: 1998
Source of information: Minnesota 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

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.

Contact Information

Steve W. Chadde
PocketFlora Press
700 Calumet Street, Suite 304
Lake Linden, MI 49945
Tel: (906) 296-0506
Fax: (810) 314-4295
Internet: www.pocketflora.com
E-mail: steve@pocketflora.com

Dr. Greg Kudray
EIA – Ecological Inventory and Analysis
RR1, Box 492
Chassell, MI 49916
Tel: (906) 523-4817
Internet: www.ecologyusa.com
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)