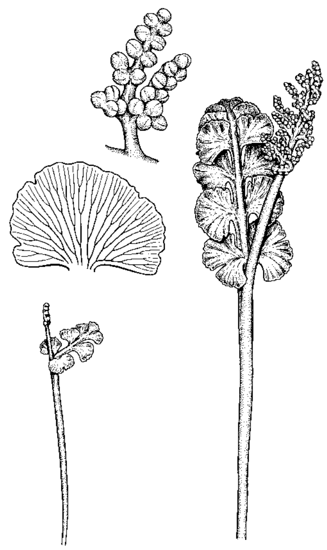
Conservation Assessment

for

Botrychium lunaria (Common Moonwort)

Photo © Steve Mortensen



Drawing provided by USDA Forest Service

USDA Forest Service, Eastern Region

2001

Prepared by Steve Chadde & Greg Kudray

Requisition no. 43-54A7-0-0036 / Project no. Ottawa-00-06

This Conservation Assessment was prepared to compile the published and unpublished information on the subject species or community.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

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Botrychium lunaria is the original moonwort (*Botrychium* subgenus *Botrychium*) described by Linnaeus. Although only several centimeters tall, it is the largest moonwort of the Great Lakes region. *B. lunaria* is local and rare when found, but widely distributed across North America and around the globe. *B. lunaria* is not particularly rare in Michigan, but there are very few known occurrences in Wisconsin and Minnesota. Rangewide, it prefers a generally open habitat, but plants are also found in forested environments. Most details about the biology of *B. lunaria* are generalized from studies of other moonwort species. Much of the life-cycle occurs underground, and populations of aboveground sporophytes fluctuate widely from year-to-year. An individual plant may not appear aboveground every year, complicating attempts to adequately inventory populations. Like other moonworts, *B. lunaria* is dependent on a mycorrhizal relationship; thus species conservation efforts must include consideration of this relationship. Little information is available on managing habitat to maintain the species, but potential threats may include drought, fire, timber harvesting, collecting, herbicides, herbivory, exotic earthworms, and forest succession (USDA Forest Service 2000). Since plants are small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, range, and habitat. Much basic research on *B. lunaria* 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 lunaria*.
2. Provide a summary of the distribution and status of *Botrychium lunaria*, 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.

The genus *Botrychium*, family Ophioglossaceae, are small ferns that are typically divided into three subgenera in North America (Lellinger 1985, Wagner and Wagner 1993a). One subgenus, *Osmundopteris*, is only represented in our area by *B. virginianum*, the rattlesnake fern, which is common around much of the world (Wagner 1998). Subgenus *Sceptridium*, the grapeferns, includes plants which are medium-sized and decidedly evergreen (Lellinger 1985). Subgenus *Botrychium*, the moonworts, are 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 U.S. 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 the traditional 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 occur together 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 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 from the Upper Great Lakes region.

Botrychium lunaria is a small fern (like all of the moonworts), but is one of the larger species in the group (Wagner 1998). It is the original moonwort described by Linnaeus, and the taxon most familiar to Europeans. *B. lunaria* is named for its distinctive half moon-shaped pinnae. Its unique aspect may have encouraged the widespread notion that it has magical powers. In the Middle Ages, plants were gathered by moonlight and used by necromancers in their incantations to raise the dead (Rook 2001). Cody and Britton (1989) state that, according to old herbals, the "seeds" of *B. lunaria* can make a person "invisible" or can "unlock doors."

Rangewide, *B. lunaria* occurs in open field habitats and sometimes in forests, especially in the southern part of its range (Wagner and Wagner 1993a). However, there is little specific information about many aspects of *B. lunaria* life-history and ecology.

NOMENCLATURE AND TAXONOMY

Scientific Name: *Botrychium lunaria* (L.) Sw.

Family: Ophioglossaceae; Adder's-Tongue Family

Common Name: Common Moonwort

Synonymy: *Botrychium lunaria* (L.) Sw. var. *onondagense* (Underwood) House; *Botrychium onondagense* Underwood

Botrychium lunaria has the largest range of any moonwort (*Botrychium* subgenus *Botrychium*). The species occurs across northern and montane North America, and in Australia, New Zealand, northern Europe, Asia, and South America (Wagner and Wagner 1993a). While several subspecies, varieties, or forms have been recognized in the past, *B. lunaria* is now considered to have a notably uniform morphology compared to other moonworts (Wagner and Wagner 1983, 1990, 1993). Shade forms have also been described as separate varieties or species (Lellinger 1985). For example, *B. onondagense* is now considered to be merely a shade form of *B. lunaria* (Wagner and Wagner 1990).

Like many other moonworts, *B. lunaria* will form interspecific hybrids (Wagner et al. 1985). The hybrids are sterile with aborted spores.

DESCRIPTION OF SPECIES

General description and Identification notes

Botrychium lunaria is a succulent fern only a few inches tall. The leaf blade is typically divided into 4–6 pairs of closely spaced fan-shaped pinnae with no midribs. Some plants can be very similar to *B. simplex* (Tryon 1993), but *B. simplex* typically has the lowest pair of pinnae larger than the next pair, compared to the approximately equal sizes of the two lowest pinnae in *B. lunaria*. The leaf blade (trophophore) of *B. lunaria* is also about equal to, or longer than, the stalk of the sporophore; in *B. simplex* it is shorter (Gleason and Cronquist 1991).

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 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 dark-green, oblong, once-pinnate, to 10 × 4 cm, thick, fleshy. Pinnae to 9 pairs, spreading, mostly overlapping except in shaded forest forms, 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, broadly fan-shaped, undivided to tip, margins mainly entire or undulate, rarely dentate, apical lobe usually cuneate to spatulate, notched, approximate to adjacent lobes, apex rounded; venation like ribs of fan, midribs absent. Sporophores 1–2-pinnate, 0.8–2 times length of trophophore. 2n =90 (after Wagner and Wagner 1993a).

LIFE HISTORY

B. lunaria belongs to subgenus *Botrychium* (moonworts) within the genus *Botrychium*. In North America there are also subgenus *Osmundopteris* (rattlesnake fern) and subgenus *Sceptridium* (grapeferns) (Lellinger 1985, Wagner and Wagner 1993a). The life-cycle of all three subgenera is similar (Lesica and Ahlenslager 1996). Moonworts are generally smaller than rattlesnake ferns and grapeferns. The plants have both a trophophore (vegetative segment) and a sporophore (fertile segment). 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. lunaria* has not been fully researched and there may be life- history details specific to *B. lunaria* that do not follow these general patterns for the genus. Lack of specific information on the life history of *B. lunaria* is a serious 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 in a few species of moonwort. They speculated that asexual reproduction may have evolved as an adaptation to the dry habitat that some of these moonwort species were found in. They also examined *B. lunaria*, but found no evidence of gemma production, indicating that the primary mode of reproduction would be sexually through spores.

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

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

After the spores are released, in May or June for *B. lunaria* (Rook 2001), they infiltrate into the soil and may germinate. Infiltration and subsequent germination may take up to 5 years, although some germinate immediately (Casson et al. 1998). Spore germination requires darkness (Whittier 1972, Whittier 1973, Wagner et al. 1985), a requirement that is not surprising given the subterranean habitat of the gametophyte and the need for the gametophyte to be infected by an endophytic fungus in an obligate association (Whittier 1973). Details of this host/fungus interaction can be found in Schmid and Oberwinkler (1994). It has been suggested that *Botrychium* gametophytes may even delay growth until they are infected with the fungus (Campbell 1911, Whittier 1973, Whittier 1996). Essentially the *Botrychium* gametophyte becomes a parasite of the mycorrhizal fungus (Casson et al. 1998, Whittier 2000). The underground gametophyte (subg. *Sceptridium*) is generally less than 0.3 cm in longest diameter, cylindrical or cushion shaped, moderately hairy, and light to dark brown-brown (Wagner et al. 1985).

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

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

The mycotrophic condition is important to the ecology of *Botrychium* species in several ways. Nutrition supplied through a fungal symbiont may allow the ferns to withstand repeated herbivory, prolonged dormancy, or growth in dense shade (Kelly 1994, Montgomery 1990). The fungal/fern relationship has implications for the occurrence of genus communities, the distribution of the species across the landscape, and associations with particular vascular plants. Mycorrhizal links may explain the often observed close associations between certain moonworts and strawberries (*Fragaria* spp.; Zika 1992, 1994) and between grapeferns *(Botrychium* subgenus *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 1921, Muller 1993). Mortality may be high during this period (Peck et al. 1990). The gametophyte produces male and female gametangia, fertilization of eggs occurs via free-swimming sperm under wet conditions (Lesica and Ahlenslager 1996). Most fertilizations are likely due to inbreeding, since the antheridia and archegonia are nearby and enzyme electrophoresis indicates a lack of genetic variability (McCauley et al. 1985, Soltis and Soltis 1986, Farrar and Wendel 1996a). However, there is no reason that cross-fertilization should not occur (Wagner et al. 1985), especially in consideration of the existence of interspecific hybrids (Wagner et al. 1985, Wagner 1998). McCauley et al. (1985) calculated that *B. dissectum* outcrosses about 5% of the time. Extremely high levels of inbreeding were also found in *B. virginianum* although there was evidence for some outcrossing (Soltis and Soltis 1986).

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

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

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

B. lunaria plants emerge from the ground in spring, dying in the later half of summer (Wagner and Wagner 1993a). 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).

Numerous hybrids between different species of moonworts have been found (Wagner et al. 1985; Wagner 1991, 1993). The hybrids possessed abortive spores and were 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

Lellinger (1985) described the North American habitat of *Botrychium lunaria* as grassy or mossy meadows and sandy or gravelly riverbanks, in acid to circumneutral soils. In the Great Lakes region, open fields, and less often forests, are described as typical habitats (Wagner and Wagner 1993a). The National Plant Data Center (USDA, NRCS 1999) listed a number of habitat characteristics for *B. lunaria* including soil tolerances (no fine-textured soils), soil pH range (5.8 to 7.2), and minimum and maximum precipitation range (14 to 55 inches). A Forest Service database (USDA Forest Service 2000) reported the habitat as cool/moist conditions, along forest roads and trails, in open areas, lakeshores (sand dunes), and occasionally in forests; plants were also reported from sandy soils of old log landings in jack and red pine woods.

In Wisconsin, *B. lunaria* typically occurs on cool, moist sandy soils, under a boreal or northern hardwood forest cover (Wisconsin DNR 2001). Another Wisconsin source (Wisconsin DNR 1982) reported that *B. lunaria* needs shade and may be found in cool, calcareous conditions in moist, mossy wooded streambanks and ravines near Lakes Michigan and Superior. Judziewicz (1993) reported an occurrence of *B. lunaria* on sandstone cliffs in the Apostle Islands.

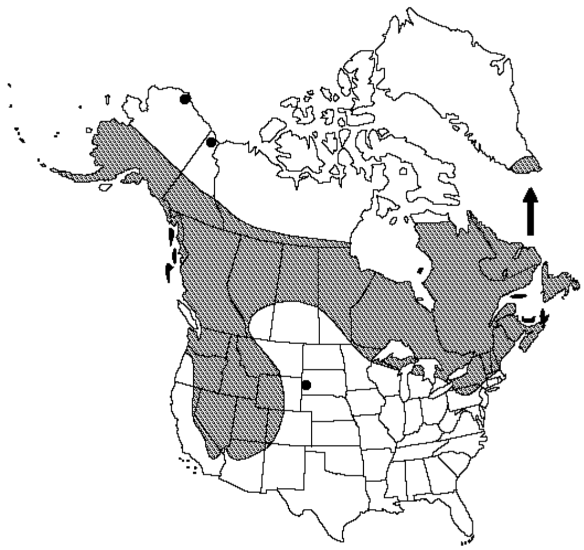
In Minnesota *B. lunaria* appears to prefer open habitats, such as gravelly banks, rocky ledges, and talus, but there are less than 10 occurrences reported for the state (Coffin and Pfanmuller 1988). Associated species for two element occurrence records on the Superior National Forest included *B. matricariifolium, B. hesperium, B. minganense, B. multifidum, Achillea millefolium, 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,* and *Melampyrum lineare* (USDA Forest Service, Eastern Region 1999).

In Michigan, Hagenah (1966) reported that most *B. lunaria* occurrences were in areas with limestone and dolomite close to the surface. He also stated that large colonies had been found in old fields.

DISTRIBUTION, ABUNDANCE, AND STATUS

Although widely distributed, *B. lunaria* is often rare or local. There are also likely to be undiscovered populations due to the plant's small size. A summary of element occurrence records for Wisconsin (Wisconsin DNR 1982, Appendix A) list 6 sites supporting about 100 plants. There are no known occurrences on the Chequamegon-Nicolet National Forest (USDA Forest Service 2000). Only one verified site is reported from the Superior National Forest in Minnesota (USDA Forest Service 2000). Statewide, Minnesota element occurrence records list three sites, last visited in 1906, 1993, and 1998 (USDA Forest Service, Eastern Region 1999), although Coffin and Pfanmuller list eight records (1988). In 1984 *B. lunaria* was listed as special concern in Minnesota because it was thought to be simply overlooked (Minnesota DNR 1995). However, after surveys conducted for *B. mormo* in areas where *B. lunaria* had been found in the past, no new *B. lunaria* sites were found, prompting a change to threatened status because the species might be rarer than previously thought (USDA Forest Service, Eastern Region 1999). *B. lunaria* is not considered rare in Michigan (USDA Forest Service 2000).

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 C.



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

Global Conservation Status Rank: G5 (1995)
Rounded Global Conservation Status Rank: G5

United States: National Conservation Status Rank: N4? (1995)
Canada: National Conservation Status Rank: N? (1993)

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

United States
Alaska (SR), Arizona (S1), California (S2?), Colorado (S2S3), Idaho (S1), Maine (S1), Massachusetts (SR), Michigan (S?), Minnesota (S2, state threatened), Montana (SR), Nevada (SR), New Mexico (SR), New York (S1), North Dakota (SR), Oregon (S2), Pennsylvania (SR), South Dakota (SH), Utah (S1), Vermont (SH), Washington (S3), Wisconsin (S1, state endangered), Wyoming (S2)

Canada
Alberta (S4S5), British Columbia (SR), Labrador (Newfoundland) (S4), Manitoba (S4), Newfoundland (S3), Newfoundland Island (Newfoundland) (SR), Northwest Territories (SR), Nova Scotia (S1), Nunavut (SR), Ontario (S4S5), Prince Edward Island (SU), Quebec (SR), Saskatchewan (S1), Yukon Territory (SR)

EO SUMMARY

GREAT LAKES STATES – NUMBER OF ELEMENT OCCURRENCES

State	No. of EOs	State Rank	Status	Comments
Minnesota	4	S2	T	
Wisconsin	6	S1	E	
Michigan	na	S4	none	Not tracked in state
Total	na			

STATE and NATIONAL FORESTS - SUMMARY OF ELEMENT OCCURRENCES

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

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. lunaria*. 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). Her study reported that populations fluctuated independently among plots at any given site, and some populations may be increasing while others are decreasing (Johnson-Groh 1999). These variations reflected microsite differences such as soil moisture, herbivory, or mycorrhizae (Johnson-Groh 1999), although populations of moonworts are known to fluctuate widely 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 large part, in accordance with mycorrhizal health due to their obligate relationship with the fungi (Johnson-Groh 1998). 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). 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. She recovered up to 7000 gametophytes and 250 non-emergent sporophytes per square meter of soil, 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 suggests 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 a 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. lunaria* may respond similarly.

Many species of *Botrychium* are associated with slight to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993a, Lesica and Ahlenslager 1996). *B. lunaria* may benefit from disturbances like logging (Grover 2000), although no research has been reported. A species like *B. lunaria* that is often found in open areas with a regular disturbance regime may have a metapopulation structure where 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

Identified threats to *Botrychium lunaria* include drought, fire, timber harvesting, collecting, herbicide application, herbivory, exotic earthworms, and forest succession (USDA Forest Service 2000). An underlying constraint to effective management is the lack of information available on the species. Some of these threats will have their direct effect on the aboveground sporophyte and may be less serious, since the belowground part of the life-cycle is so important (see Sections C and F above).

Simple removal of leaf tissue may be inconsequential to the ability of moonworts to survive although removing sporulating individuals may eventually have an effect (Johnson-Groh 1999). Wagner and Wagner (1993) 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) concluded that if the aboveground plant was removed after spore release, the trophophore the following year was significantly smaller. 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 had little effect on subsequent leaf-size or plant vigor (Johnson-Groh and Farrar 1996a, b). Collection by herbalists due to the plant's perceived medicinal powers may also pose a threat (USDA Forest Service, Eastern Region 1999).

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

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). A similar effect may occur in the open habitats often favored by *B. lunaria*. 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). However, the disturbed areas sometimes favored by *B. lunaria* likely would have less organic material; typical earthworm activity cycling organic material may not be a serious threat to *B. lunaria* habitat there. It should also be noted that *B. lunaria* occurs with some regularity in forested environments in our area, these areas could be impacted by worms, so the potential of the threat is uncertain.

Threat from exotic earthworms

Native earthworms were eliminated from the Lake States during the last ice age. Natural recolonization from the unglaciated south has been extremely slow, for example, less than 100 miles in the several thousand years since the glacial retreat (James 1990, Berlinger 2000, Conover 2000). European earthworms were introduced into North America with European settlement and then spread through the use of earthworms for fishing bait, gardening, and inadvertent human transport (Kalisz and Wood 1995, Berlinger 2000). Logging machinery and other forest vehicles can transport cocoons and hatchlings, thereby dispersing earthworms widely into forests (Marinissen and van den Bosch

1992, Dymond et al. 1997). More remote forests in our region still lack earthworms, but as humans move through the landscape the probability of colonization increases (Casson et al. 2000).

In general, earthworms have been considered to have a very positive influence on soil structure, litter decomposition, and mineralization and cycling of nutrients (review in Lee 1985), but since regional ecosystems have evolved in the absence of earthworms (James 1990), their recent introduction is having serious consequences.

One of the earliest studies of non-native earthworms in forested habitats documented a disappearance of the organic surface horizon, an increase in the depth and character of the A layer, and a decrease in the B horizon (Langmaid 1964). Another study stated that worms "eliminated the forest floor" (Groffman et al. 2000). Alban and Berry (1994) provided the first detailed documentation of earthworm effects in Minnesota forest soils where they dramatically reduced the litter and duff layers, eliminated the E-layer, and increased the A horizon. Worms also can make the soil more permeable to water (Peterson and Dixon 1971), potentially altering water relations, especially near the surface.

Leaf litter can be completely broken-down in as little as 4 weeks by worms (Knollenberg et al. 1985), in a natural forest system it has been estimated that it might take 3–5 years for decomposition (Mortensen and Mortensen 1998). Earthworms introduced to mine spoil banks have been seen to have dramatic effects on the litter layer, burying or consuming 5 metric tons of leaf letter/ha within 2 years (Vimmerstedd and Finney 1973).

The evidence suggests that the several species of exotic earthworms now colonizing the Lake States region will have considerable impact on native plants including at least one moonwort species (*B. mormo*). A comparison of 6 plots with earthworms compared to 6 plots without worms (albeit a small sample size) on the Chippewa NF found that 70% of the plant species were adversely affected by worms and 25 species, or about 50% of all the species present in the undisturbed plots (and including *B. mormo*), were apparently eliminated by the worms (Almendinger 1998). Others have also reported decreased diversity in the herbaceous understory (Nielsen and Hole 1963 and 1964, Nixon 1995, Cothrel et al. 1997). It has been suggested that European earthworms may be incompatible with the survival of many North American hardwood understory species (Hale et al. 1999), although some species have been reported to increase in numbers after worm invasion (Almendinger 1998, Berlinger 2000).

In an ongoing *B. mormo* monitoring effort on the Chippewa National Forest (Johnson-Groh 1999), plots impacted by worms exhibited significant negative effects on *B. mormo* populations. However, she cautioned that, while the worms likely had fatally affected the plants, other, 'worm-free' populations also showed decreases during that dry period. She also observed that it is normal for moonwort populations to fluctuate widely and that population declines may be due to a population exceeding the carrying capacity of a site. Another monitoring study in the same area also observed negative effects on soil properties and a dramatic reduction in the *B. mormo* population following exotic earthworm invasion (Casson et al. 2000).

The loss of the soil organic layer may affect moonworts through their obligate association with mycorrhizal fungi. The fungi may perish with the loss of the forest floor (Nixon 1995) or may also be eaten by sowbugs, which, in at least one instance appear to be invading sites with exotic earthworms (Wolff et al. 1997).

Stewardship overview and population viability concerns

Often it is difficult to determine what factor or combination of factors is impacting *Botrychium* populations (USDA Forest Service, Eastern Region 1999). Populations are inherently variable (Johnson-Groh 1999) but maintaining the health of the mycorrhizae seems to be an underlying necessity. Moisture relations are critical, and activities which act to dry the habitat may have deleterious effects on the population. One *B. lunaria* site in Minnesota has been burned for opening maintenance (USDA Forest Service 2000). Given the general preference of the species for open sites (Lellinger 1985), some kind of opening management may be a feasible management tool, although no information is available on the response of *B. lunaria* populations to management of any kind.

Since *B. lunaria* often exists in a habitat that is early successional due to disturbance, it may be prone to local extinctions, thus population viability may rely on a shifting mosaic of suitable habitats opening up for colonization (see Section F). Land protection should take into account the immediate area surrounding the *B. lunaria* 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 all *Botrychium*, *B. lunaria* is small, inconspicuous, and difficult to find. The fluctuating population of moonworts also creates difficulties; plants may go dormant some years and not appear aboveground. There are almost certainly undiscovered sites for *B. lunaria*, inventories for the plant should continue. While some research data has been developed about population fluctuations for certain species of *Botrychium* (Johnson-Groh 1999), specific information for *B. lunaria* population biology is lacking.

Almost no information is available on *B. lunaria* 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. lunaria* 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. lunaria* life history is needed including its important relationship with mycorrhizal fungi and its belowground ecology in general. Data on spore dispersal is also lacking.

Exotic earthworms are a serious threat to some moonwort species, particularly *B. mormo* (Sather et al. 1998). It is unclear how *B. lunaria* may be affected by exotic earthworm activity.

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; 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* spp. at www.natureserve.org (NatureServe 2001).

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

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

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

LITERATURE CITED AND REFERENCES

Alban, D. H. and E. C. Berry. 1994. Effects of earthworm invasion on morphology, carbon, and nitrogen of a forest soil. Applied Soil Ecology 1:243-249.

Almendinger, J. 1998. Unpublished. Frequency of vascular plants with regard to significant earthworm activity. Minnesota Department of Natural Resources. Grand Rapids, Minnesota.

Berch, S. M. and B. Kendrick. 1982. Vesicular-arbuscular mycorrhizae of southern Ontario ferns and fern-allies. Mycologia 74: 769-776.

Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). 1998. Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Berlinger, N. 2000. A bad case of worms. Minneapolis-St. Paul Star Tribune. 21 August 2000. page A-l.

Bierhorst, D. W. 1958. Observations on the gametophytes of *Botrychium virginianum* and *B. dissectum*. Amer. J. of Bot. 45: 1-9.

Bower, F. O. 1926. The ferns (Filicales), volume 2. Cambridge University Press. 344 pp.

Briggs, D. and S. M. Walters. 1997. Plant variation and evolution. Cambridge University Press. New York.

Camacho, F. J. 1996. Mycorrhizal fungi of *Botrychium* genus communities in Montana. Unpublished proposal to the Montana Natural Heritage Program. Oregon State University, Corvallis, OR. 6 pp.

Campbell, D. H. 1911. The eusporangiate. Carnegie Inst. Wash. Publ. No. 140.

Campbell, D. H. 1922. The gametophyte and embryo of *Botrychium simplex*, Hitchcock. Annals of Botany 36:441-456.

Casson, J., J. Dobberpuhl, D. Farrar, A. Hoefferle, C. Johnson-Groh, H. Peters, H. Wagner, F. Wagner, C. Westfield, and P. Miller. 1998. Population life history and viability working group report. In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Casson, J., I. Shackleford, L. Parker, and J. Schultz. 2000. Conservation Strategy for the Goblin fern, *Botrychium mormo* W. H. Wagner. USDA Forest Service, Eastern Region. 27 October, 2000 draft.

Clausen, R. T. 1938. A monograph of the Ophioglossaceae. Memoirs of the Torrey Botanical Club 19(2): 1-177.

Cody, W. J., D. M. Britton. 1989. Ferns and Fern Allies of Canada. Research Branch Agriculture Canada Public. 1829/E.

Coffin, B., and L. Pfanmuller (eds.). 1988. Minnesota's Endangered Flora and Fauna. Univ. of Minnesota Press, Minneapolis.

Conover, A. 2000. Foreign worm alert. Smithsonian, August 2000. Smithsonian Institution.

Cothrel, S. R., J. P. Vimmerstedt, and D. A. Kost. 1997. *In situ* recycling of urban deciduous litter. Soil Biol. Biochem. 29: 3/4: 295-298.

Dymond, P., S. Scheu, and D. Parkinson. 1997. Density and distribution of *Dendrobaena octaodra* (Lumbricidae) in aspen and pine forests in the Canadian Rocky Mountains (Alberta). Soil Biol. Biochem. 29:3/4: 265-273.

Farrar, D. R. 1998. Population genetics of moonwort populations. In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Farrar, D. R. and C. L. Johnson-Groh. 1990. Subterranean sporophytic gemmae in moonwort ferns, *Botrychium* subgenus *Botrychium.* American Journal of Botany 77: 1168-1175.

Farrar, D. R. and J. F. Wendel. 1996a. Eastern moonworts: Genetics and relationships. (Abstract). Am. J. Botany 83(Suppl.): 124.

Farrar, D. R. and J. F. Wendel. 1996b. On the origins and relationships of the *Botrychium matricariifolium* complex in eastern North America. (Abstract). Am. J. Botany 83(Suppl.): 125.

Foster, A. S., and E. M. Gifford. 1974. Comparative morphology of vascular plants. W. H. Freeman, San Francisco.

Gifford, E. M. and A. S. Foster. 1989. Morphology and evolution of vascular plants, third edition. W. H. Freeman and Co., New York, NY. 626 pp.

Gleason, H. A. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Second edition. The New York Botanical Garden, Bronx, New York.

Groffman, P. M., P. J. Bohlen, T. J. Fahey, and M. C. Fisk. 2000. Invasion of north temperate forest soils by exotic earthworms. Research Report. Institute of Ecosystem Studies. www.ecostudies.org/research/reportstgrofrep2.html

Grover, M. 2000. Rocky Road Environmental Assessment. USDA Forest Service, Superior National Forest.
http://snf.toofarnorth.org/resources/2000/21_appen_j.htm

Hagenah, D. J. 1966. Notes on Michigan Pteridophytes, II. Distribution of the Ophioglossaceae. Amer. Fern J. 56: 150-163.

Hale, C., L. Frelich and P. Reich. 1999. Unpublished. Research proposal concerning earthworms and population dynamics and diversity of native plant species. University of Minnesota. St. Paul, Minnesota.

Hoefferle, A. M. 1999. Impacts of aerial leaf removal on leaf size of the daisy leaf moonwort (*Botrychium matricariifolium*) and the triangle moonwort (*Botrychium lanceolatum* var. *angustisegmentum*) in the subsequent year (master's thesis). Houghton, (MI): Michigan Technological University. 42 pp.

James, S. W. 1990. Oligochaeta: Megascolecidae and other earthworms from southern and Midwestern North America. p. 370-386. In: Dinal, D. L. (ed.) *Soil Biology Guide.* John Wiley and Sons, New York.

Johnson-Groh, C. 1998. Population demographics, underground ecology and phenology of *Botrychium mormo.* In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report. CBSG, Apple Valley, MN.

Johnson-Groh, C. 1999. Population ecology of *Botrychium* (moonworts), status report on Minnesota *Botrychium* permanent plot monitoring. Dept. of Biology, Gustavus Adolphus College, St. Peter, MN.

Johnson-Groh, C. L., D. R. Farrar. 1996a. Effects of leaf loss on moonwort ferns, *Botrychium* subgenus *Botrychium*. Am. J. Botany 83(Supple.): 127.

Johnson-Groh, C. L., D. R. Farrar. 1996b. The effects of fire on prairie moonworts (*Botrychium* subgenus *Botrychium)*. Am. J. Botany 83(Supple.): 134.

Johnson-Groh, C. L., D. R. Farrar, P. Miller. 1998. [Abstract] Modeling extinction probabilities for moonwort (*Botrychium*) populations. Amer. J. Bot. Supplement 85: 95.

Johnson-Groh, C. L., L. Schoessler, C. Riedel, K. Skogen. 2000. Underground distribution and abundance of *Botrychium* gametophytes and juvenile sporophytes. http://www.botany2000.org/sympos5/abstracts/8.shtml

Judziewicz, E. J. 1993. Flora of the Apostle Islands. Mich. Bot 32: 43-189.

Kalisz, S., and M. A. McPeek. 1992. Demography of an age-structured annual: resampled projection matrices, elasticity analysis, and seed bank effects. Ecology 73: 1082– 1093.

Kalisz, P. J. and H. B. Wood. 1995. Native and exotic earthworms in wildland ecosystems. In: Hendrix, P. F. 1995. Earthworm ecology and biogeography. Lewis Publishers. Boca Raton, Florida.

Kelly, D. 1994. Demography and conservation of *Botrychium australe*, a peculiar sparse mycorrhizal fern. N.Z. J. Bot. 32: 393-400.

Knollenberg, W. G., R. W. Merritt, and D. L. Lawson. 1985. Consumption of leaf litter by *Lumbricus* terrestris (Oligochaeta) on a Michigan Woodland Floodplain. American Midland Naturalist 113: 1-6.

Langmaid, K. K. 1964. Some effects of earthworm invasion in virgin podzols. Canadian Journal of Soil Science 44: 34-37.

Leake, J. R. 1994. The biology of myco-heterotrophic plants. New Phytologist 127: 171-216.
Lee, K. E. 1985. Earthworms, Their Ecology and Relationship with Soils and Land Use. Academic Press.

Lellinger, D. B. 1985. A field manual of the ferns and fern-allies of the United States and Canada. Smithsonian Institution Press. Washington, D. C.

Lesica, P., and K. Ahlenslager. 1996. Demography and life history of three sympatric species of *Botrychium* subg. *Botrychium* in Waterton Lakes National Park, Alberta. Can J. Bot. 74: 538-543.

Marinissen, J. C. Y., and F. van den Bosch. 1992 Colonization of new habitats by earthworms. Oecologia 91: 371-376.

McCauley, D. E., Whittier D. P., Reilly L. M. 1985. Inbreeding and the rate of self-fertilization in a grape fern, *Botrychium dissectum*. Amer. J. Bot. 72: 1978-1981.

Menges, E. S., and S. C. Gawler. 1986. Four-year changes in population size of the endemic, Furbish's lousewort: implications for endangerment and management. Natural Areas Journal 6: 6-17.

Minnesota DNR. 1995. Proposed Amendment of MN Rules, Chapter 6134: Endangered and Threatened Species Statement of Need and Reasonableness. p 180.

Montgomery, J. D. 1990. Survivorship and predation changes in five populations of *Botrychium dissectum* in eastern Pennsylvania. Am. Fern J. 80: 173-182.

Mortensen, S. and C. Mortensen. 1998. A new angle on earthworms. The Minnesota Volunteer, Jul-Aug., 1998. Minn. Dept. Nat. Res., St. Paul, MN.

Muller, S. 1992. The impact of drought in spring on the sporulation of *Botrychium matricariifolium* (Retz) A. Br. in the Bitcherland (Northern Vosges, France). Acta. Oecol. 13:335-43.

Muller, S. 1993. Population dynamics in *Botrychium matricariifolium* in Bitcherland (Northern Vosges Mountains, France). Belg. J. Bot. 126: 13-19.

NatureServe: An online encyclopedia of life [web application]. 2001. Version 1.0. Arlington (VA): Association for Biodiversity Information. Available: http://www.natureserve.org/. (Accessed: January 21, 2001).

Nielsen, G. A. and F. D. Hole. 1963. A study of the natural processes of incorporation of organic matter into soil in the University of Wisconsin Arboretum. Wisconsin Academy of Sciences, Arts and Letters 52: 213-227.

Nielsen, G.A. and F. D. Hole. 1964. Earthworms and the development of coprogeneous A1 horizons on forest soils of Wisconsin. Soil Science Society of America Proceedings 28: 426-430.

Nixon, W. 1995. As the worm turns. American Forests. Autumn 1995: 34-36.

Parsons, R. F., and J. H. Browne. 1982. Causes of plant species rarity in semi-arid southern Australia. Biol. Conserv. 24: 183-192.

Peck, J. H. 1980. Discovery of the goblin fern in Wisconsin. Bull. Bot. Club of Wi. 12(2): 2-4.

Peck, J. H., C. J. Peck, and D. F. Farrar. 1990. Influence of life history attributes on formation of local and distant fern populations. Am. Fern J. 80: 126-142.

Peterson, A. E., and R.M. Dixon. 1971. Water movement in large soil pores: validity and utility of the channel concept, College of Agr. and Life Sci., Univ. of Wisconsin Res. Rep. 75.

Pickett, S. T. A., and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biol. Conserv. 13: 27-37.

Read, D. J. 1994. Plant-microbe mutualisms and community structure. In: Schulze, E.D. and H.A. Mooney (eds.) Biodiversity and ecosystem function, Springer-Verlag, New York.

Rook, E. J. S. 2001. *Botrychium lunaria*.
http://www.rook.org/earl/bwca/nature/ferns/botrylun.html

Sather, N., C. Kjos, C. Mortensen, J. Gallagher, S. Mortensen, C. Leibl, B. Wolff, S. Trull, and O. Byers. Threats and Risk Working Group Report. 1998. In: Berlin, N., P. Miller, J. Borovansky, U. S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern *(Botrychium mormo):* Final Report. CBSG, Apple Valley, MN.

Scagel, R. F., R. J. Bandoni, G. L. Rouse, W. B. Schofield, J. R. Stein, and T. M. Taylor. 1966. An evolutionary survey of the plant kingdom. Wadsworth Publishing Co., Belmont, CA. 658 pp.

Schmid, E., and F. Oberwinkler. 1994. Light and electron microscopy of the host-fungus interaction in the achlorophyllous gametophyte of *Botrychium lunaria.* Can. J. Bot. 72: 182-188.

Soltis, D. E., and P. S. Soltis. 1986. Electrophoretic evidence for inbreeding in the fern *Botrychium virginianum* (Ophioglossaceae). Amer. J. Bot. 73: 588-592.

Tans, W. E. and D. X. Watermolen. 1997. Distribution, current population status, growth and habitat of goblin fern *(Botrychium mormo)* in Wisconsin. Wisconsin Endangered Resources Report #115. Bureau of Endangered Resources, Wisconsin Department of Natural Resources. Madison, Wisconsin.

Tryon, R. M. 1993. Ferns of Minnesota. University of Minnesota Press. Minneapolis, Minnesota.

USDA, NRCS. 1999. The PLANTS database (http://plants.usda.gov/plants). National Plant Data Center, Baton Rouge, LA 70874-4490 USA

USDA Forest Service, Eastern Region. 1999. Draft Species Data Collection Forms prepared under contract for population viability analyses on the Wisconsin and Minnesota National Forests. Unpublished reports, Eastern Region, Milwaukee, WI.

USDA Forest Service. 2000. Population Viability Assessment Database. USDA Forest Service, Eastern Region, Milwaukee, WI.

Vimmerstedt, J. P. and J. H. Finney. 1973. Impact of earthworm introduction on litter burial and nutrient distribution in Ohio strip-mine spoil banks. Soil Sci. Soc. Am. Proc., 37: 388-391.

Wagner, W. H. 1991. New examples of the moonwort hybrid, *Botrychium matricariifolium* X *simplex* (Ophioglossaceae). Can. Field Nat. 105(1): 91-94.

Wagner, W. H. 1998. A Background for the Study of Moonworts. In: Berlin, N., P. Miller, J. Borovansky, U.S. Seal, and O. Byers (eds.). Population and Habitat Viability Assessment Workshop for the Goblin Fern *(Botrychium mormo):* Final Report. CBSG, Apple Valley, MN.

Wagner, W. H., and A. R. Smith. 1993. In: Flora of North America North of Mexico, Volume 1. Flora of North America Editorial Committee (ed.). Oxford University Press. New York.

Wagner, W. H., and F. S. Wagner. 1981. New species of moonworts, *Botrychium* subg. *Botrychium* (Ophioglossaceae), from North America. American Fern Journal 71(l): 26.

Wagner, W. H., and F. S. Wagner. 1983. Genus communities as a systematic tool in the study of new world *Botrychium* (Ophioglossaceae). Taxon 32(1): 51-63.

Wagner, W. H., and F. S. Wagner. 1988. Detecting *Botrychium* hybrids in the Lake Superior region. Mich. Bot. 27: 75-80.

Wagner W. H., and F. S. Wagner. 1990. Notes on the fan-leaflet group of moonworts in North America with descriptions of two new members. Amer. Fern J. 80: 73-81.

Wagner, W. H., and F. S. Wagner. 1993a. Ophioglossaceae. In Morin, N. R. Flora of North America North of Mexico, Volume 2, Pteridophytes and Gymnosperms. Oxford University Press. New York.

Wagner, W. H., and F. S. Wagner. 1993b. Three new species of moonworts (*Botrychium* subg. *Botrychium*) endemic in western North America. American Fern Journal 76(2): 33-47.

Wagner, W. H., and F. S. Wagner. 1994. Another widely disjunct, rare and local North American moonwort (Ophioglossaceae: *Botrychium* subg. *Botrychium*). American Fern Journal 84(1): 5-10.

Wagner, W.H., F. S. Wagner, and J. M. Beitel. 1985. Evidence for interspecific hybridization in pteridophytes with subterranean mycoparasitic gametophytes. Proc. Royal Soc. of Edin. 86B: 273-281.

Whittier, D. P. 1972. Gametophytes of *Botrychium dissectum* as grown in sterile culture. Botanical Gazette 133: 336-339.

Whittier, D. P. 1973. The effects of light and other factors on spore germination in *Botrychium dissectum*. Canadian Journal of Botany 51: 1791-1794.

Whittier, D. P. 1996. [Abstract] Delayed gametophyte growth in *Botrychium*. Am. J. Bot. 83(Supple.):133.

Whittier, D. P. 2000. Gametophyte and young sporophyte development in the Ophioglossaceae. Symposium: Biology and Conservation of the Ophioglossaceae-A Tribute to Warren "Herb" Wagner http://www.botany2000.org/sympos5/abstracts/8.shtml

Wisconsin DNR. 1982. Wisconsin's Endangered Flora. Wisconsin Department of Natural Resources. Madison, WI.

Wisconsin DNR. 2001. Moonwort grape-fern (*Botrychium lunaria*). (http://www.dnr.state.wi.us/org/land/er/factsheets/plants/moonwort.htm

Wolff, R. J., C. M. Leibl, S. Mortensen, and A. S. Elwell. 1997. The sowbugs (terrestrial Isopoda) in earthworm impacted forest communities. Unpublished preliminary report.

Zika, P. F. 1992. Draft management guide for rare *Botrychium* species (moonworts and grapeferns) for the Mount Hood National Forest. Unpublished report. Oregon Natural Heritage Program, Portland, OR. 43 pp. plus appendices.

Zika, P. F. 1994. A draft management plan for the moonworts *Botrychium ascendens*, *B. crenulatum*, *B. paradoxum*, and *B. pedunculosum* in the Wallowa-Whitman, Umatilla, and Ochoco National Forests. Unpublished report. Oregon Natural Heritage Program, Portland, OR. 41 pages plus figures, tables, and appendices.

Natural Heritage Program Databases consulted and queried

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 LUNARIA* 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	1 (but not tracked in state)
Minnesota	4
Wisconsin	6

MICHIGAN

Location: Michigan, Chippewa County
Ownership: Forest Service
Abundance: Not listed
Habitat: Not listed
Comments: The Hiawatha NF does not survey for this species, this is an old record (1992).
Source of information: Hiawatha National Forest occurrence record

MINNESOTA

Location: Minnesota, Cook County
Ownership: Private
Abundance: Not listed
Habitat: Not listed
Comments: 1906. Both specimens verified by W.H. Wagner 10/97. Not relocated by K. Lederle in 1982 or 1983.
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Cook County
Ownership: USFS
Abundance: 8 plants
Habitat: Located in 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 species of *Botrychium* found at site.
Comments: 1998
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, Lake of the Woods County
Ownership: Unknown
Abundance: Not listed

Habitat: Not listed
Comments: 1894. Additional voucher contains both *B. lunaria* and *B. minganense.*
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

Location: Minnesota, St Louis County
Ownership: USFS
Abundance: <20 plants in scattered singles
Habitat: In old field and building site. Old building site and surrounding field well drained sand and gravel. Plants mainly in short grass areas. Scattered *Vaccinium* shrub cover. Associated spp: *Fragaria virginiana, Trifolium* sp., *Achillea millefolium, Vaccinium angustifolium, Botrychium matricariifolium, B. hesperium, B. minganense,* and *B. multifidum*.
Comments: 1993
Source of information: Minnesota Natural Heritage Program Element Occurrence Record

WISCONSIN

Location: Wisconsin, Ashland County
Ownership: Other public
Abundance: 1977: not listed 1991 - 1996: No plants found.
Habitat: ENE facing sandstone outcrops above shoreline, Northern mesic woods.
Comments: Verified by W.H. Wagner.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Door County
Ownership: Other public
Abundance: Not listed
Habitat: Sandy soil, hemlock-cedar overstory.
Comments: 1978 listing
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Door County
Ownership: Other public
Abundance: 1985: More than 50 plants in one area, other nearby locations have 8 and 6 additional plants. 1986, 1988: No plants found.
Habitat: Cedar stands on ridge and swale topography.
Comments: Site is heavily used by the public and covered with litter. ID needs verification.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Door County
Ownership: Other public
Abundance: 1985: 12 scattered plants 1986: No plants found.
Habitat: Dense fir and cedar woods under heavy shade.
Comments: Site is used by the public and covered with litter but habitat is fairly isolated. ID needs verification.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Door County
Ownership: Wisconsin DNR
Abundance: 1979: 12 plants 1980: 50 plants 1986: < 10 plants 1988: 19 plants 1997 60 plants estimated
Habitat: 1997: In the sandy duff of a cedar and fir woods, also in woods edge and adjacent bluegrass dominated open field. *B. simplex, B. multifidum,* and *B. matricariifolium* also present.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record

Location: Wisconsin, Sawyer County
Ownership: Unknown
Abundance: 1980: Unknown number of mature, sporulating plants. Also collected in the late 1980s.
Habitat: Mesic northern hardwoods forest along nature trail.
Comments: Verified by W.H. Wagner.
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

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	Presumed Extirpated—Element is believed to be extirpated from the nation or

SX	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)