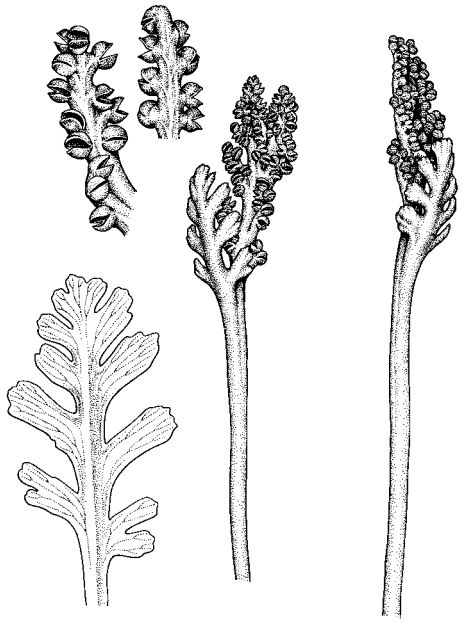
Conservation Assessment
for
Iowa Moonwort (*Botrychium campestre*)



Botrychium campestre. Drawing provided by USDA Forest Service

USDA Forest Service, Eastern Region
2001

Prepared by:
Steve Chadde & Greg Kudray
for
USDA Forest Service, Region 9

This Conservation Assessment was prepared to compile the published and unpublished information on the subject taxon or community; or this document was prepared by another organization and provides information to serve as a Conservation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 taxon, please contact the Eastern Region of the Forest Service Threatened and Endangered Species Program at 310 Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203.

Table of Contents

EXECUTIVE SUMMARY

Botrychium campestre is a small moonwort that was first described as a unique species in 1986. The species ranges across the northern Great Plains, from Iowa and Minnesota on the east, to Alberta and Montana on the west. Populations are also known from Michigan and Wisconsin (mostly near Lakes Michigan and Superior) and in Ontario (near Lake Superior). *B. campestre* habitat is typically sandy prairies, railroad right-of-ways, grassy roadsides, sand dunes near the Great Lakes, and disturbed areas such as tailings piles or old fields. The largest threat to the species may be natural succession toward shaded, forest environments. In addition, populations on sandy sites near Great Lakes shorelines may be threatened by recreational. Much of the plant's life-cycle occurs underground; populations of aboveground sporophytes fluctuate from year-to-year, and individual plants may not appear every year. Like other moonworts, *B. campestre* is dependent on a mycorrhizal relationship and species conservation efforts should consider this relationship. Since the species is small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, species range, and habitat preferences.

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) were one of those priorities.

The objectives of this document are to:

1. Provide an overview of current scientific knowledge for *Botrychium campestre* (Iowa Moonwort).
2. Provide a summary of the distribution and status of *Botrychium campestre*, 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.

Moonworts comprise the subgenus *Botrychium* within the genus *Botrychium* in the Ophioglossaceae or Adder's-Tongue Family, a family of primitive ferns sometimes considered fern-allies (Lellinger 1985, Wagner and Wagner 1993). The family consists of three genera: *Botrychium*, *Ophioglossum*, and *Helminthostachys*, the first two of which occur in North America. The genus *Botrychium* is further divided into three subgenera: *Botrychium* (the moonworts, including *B. campestre*), *Sceptridium* (grapeferns; evergreen plants), and *Osmundopteri*s (represented by rattlesnake fern, *B. virginianum*) (Lellinger 1985).

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).

In North America, thirty species of *Botrychium* are recognized (Wagner and Wagner 1993). Worldwide, it is estimated that 30-50 species exist. Within subgenus *Botrychium*, 23 species were recognized by Wagner and Wagner (1994), compared to an earlier interpretation of only six species (Clausen 1938).

The problems in distinguishing valid moonwort species are considerable (Wagner and Wagner 1990), including the tendency for different species of *Botrychium* to occur together at one site, variation in appearance caused by microhabitat differences, small size, and the difficulty of preserving good herbarium specimens. However, decades of work, primarily by the late Dr. Herb Wagner and his associates, have clarified the taxonomy of the group, their habitat preferences, and the ranges of individual species. Several rare species within subgenus *Botrychium* are now recognized in the Upper Great Lakes region.

Botrychium campestre was discovered in 1982, when it was found simultaneously in Iowa by Theodore Van Bruggen and Lawrence Eilers, and in Michigan by J. M. Beitel during early summer surveys (Wagner and Wagner 1990). Plants found on sand dunes in northern Michigan were first thought to represent a different species or possibly a subspecies of the new taxon, owing to morphological differences in some of the early collections. Eventually, plants of the Great Lakes region and those of Iowa were determined to be the same. However, Wagner and Wagner (1990) concluded that "*B. campestre* is morphologically one of the most variable of moonworts."

NOMENCLATURE AND TAXONOMY

- Scientific Name: *Botrychium campestre* W.H. Wagner and Farrar
- Synonymy: (none)
- Family: Ophioglossaceae; Adder's-Tongue Family
- Common names: Iowa moonwort; prairie moonwort; prairie dunewort; botryche champètre
- Sources: Kartesz 1999, NatureServe 2001, Wagner and Wagner 1993

DESCRIPTION OF SPECIES

General description and identification notes: Botrychium campestre is a small perennial with a single aboveground frond. The frond is divided into two segments that share a common stalk; the common stalk is usually 5-10 cm long. The sterile segment is dull, whitish-green, fleshy, usually widest above the middle, and with usually less than 6 pairs of widely spaced upswept pinnae. The pinnae are linear to spatula-shaped; the largest are often bifid or cleft at the tip, with the upper division being larger than the lower. The fertile segment is stubby, about as long as, or somewhat longer, than the

sterile segment, and is branched, with fleshy, somewhat flattened branches bearing grape-like clusters of sporangia. The leaves appear in early spring (April-May), and turn brown and mostly die by mid- to late- June (Wagner and Wagner 1986). This early withering distinguishes *B. campestre* from other North American moonworts.

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.

Botrychium campestre is one of four moonwort species that commonly produce dense clusters of minute, spherical gemmae (bud-like structures) on the lower stem (Farrar and Johnson-Groh 1990). Unusual forms of *B. campestre* with coalescent pinnae are found on dunes in the vicinity of Lake Michigan (Wagner and Wagner 1993).

This species emerges early in comparison to other moonworts. In the midwestern U.S., the best period to search for dunewort is early-May through early June, although if the season is warm, plants may die-back earlier. Plants may also be visible through June and into early July (albeit brown and withered) in northern portions of its range. Because of its relatively early appearance in the growing season and its small size, this species is easily overlooked during field surveys.

Wagner and Wagner (1990) noted that Iowa moonwort can be distinguished from all other moonworts by the following combination of characters:

- occurrence in open prairie or dune habitats;
- very early appearance in the spring;
- the masses of small round gemmae (vegetative propagules) on the lower stem;
- the usually sessile or subsessile leaves divided into more or less deeply incised, narrowly and asymmetrically flabellate (fan-shaped) segments.

Botrychium campestre is similar to the more widespread *B. minganense* (mingan moonwort), with which it sometimes occurs. *Botrychium minganense* can be distinguished by its generally larger size, its flat (as opposed to longitudinally infolded) leaves with unlobed basal pinnae (lateral division of leaf) (Wagner and Wagner 1990).

In general, survey and field determination of moonworts is complicated by their species ecology. A species often occurs with a number of other *Botrychium* in the same apparent habitat, a phenomenon termed “genus communities” (Wagner and Wagner 1983). Species cannot be identified with certainty in their immature stages, and fronds may emerge from the ground over a several month span during favorable growing seasons. Conversely, plants may not appear at all during unfavorable seasons. In addition, moonworts are small and difficult to find even where they are relatively common. The ecology of moonworts

and the vulnerability of their populations to management activities are not well understood. Some species of *Botrychium* occupy a diversity of habitats across their range, raising questions about habitat specificity. In addition, *Botrychium* have been documented at sites of natural or man-made disturbance, raising questions whether at least some moonworts are adapted to disturbance and early successional habitats (Wagner and Wagner 1993, Lellinger 1985, Lesica and Ahlenslager 1996).

The tendency for species of *Botrychium* to grow together within the same habitat is a natural "common garden" experiment. For example, if taxa growing together maintain consistent morphological differences and do not form fertile hybrids, then they may be considered legitimate species. Hybrids between species of moonworts are apparently rare, but when found, have been determined to have abortive spores (Wagner and Wagner 1983, 1986; Wagner et al. 1984).

Reliable field determination of most species of *Botrychium* depends on the use of technical keys, comparison with silhouette outlines and verified specimens, and field-experience on the part of the researcher. Distinctions between moonworts are based mostly on the lobing of the trophophore, the color, luster, and texture of the plants, and, to a lesser extent, features of the sporophore.

Technical Description. In *Botrychium campestre,* "the trophophore stalk is usually absent but sometimes broadly tapered to 10 mm in forms with coalesced proximal pinnae; the blade is glaucescent, oblong, longitudinally folded when alive, 1-pinnate, to 4 cm long × 1.3 cm wide, and very fleshy. Pinnae to 5- (sometimes to 9-) pairs, spreading, usually remote, separated 1–3 times the pinna width; in some populations irregularly and extensively fused with considerable webbing along rachis; distance between first and second pinnae not, or slightly more than, that between the second and third pairs; basal pinna pair approximately equal in size and cutting to the adjacent pair, mostly linear to linear-spatulate, undivided to tip, margins crenulate to dentate, usually notched or cleft into 2 or several segments, apex rounded to acute; venation ribbed and fan-like, midrib absent. Sporophores 1- (or rarely 2-) pinnate, 1–1.5 times the length of the trophophore. 2n =90" (from Wagner and Wagner 1993).

LIFE HISTORY

Moonworts are primitive ferns with some of the highest chromosome numbers in the plant kingdom. They are characterized by a simple morphology but an often confusing taxonomy. The sporophyte (the conspicuous spore-producing generation of the plant) is small, arising from a simple underground stem. The roots lack root-hairs. The plants generally produce one aboveground leaf, or frond, per year, with successive primordia enclosed in a sheath at their base. The frond is divided into two parts which share a common stalk, a usually sterile segment (the trophophore), and a fertile segment (the sporophore). The trophophore is usually pinnatifid and features of its lobing are one of the primary characters which distinguish the species. The sporophore bears grape-like sporangia where spores are produced. Spores germinate and develop into tiny

underground gametophytes which are rarely observed. Both generations of the fern are associated with mycorrhizal fungi (see below).

Farrar and Johnson-Groh (1990) reported the presence of subterranean gemmae in *B. campestre* and three other *Botrychium* species, the first documentation of such structures in any fern. According to the authors, the ecological significance of gemmae may be related to the advantage conveyed by asexual reproduction in habitats that are often very dry. Across its range, Iowa moonwort is a spring species, with aerial shoots typically withering by early to mid-summer. Similarly, leaves of *B. campestre* are fully developed 1-3 weeks before other associated species of *Botrychium*, most of which are just emerging from the ground at that time (Wagner and Wagner 1990).

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.

Sporophytes of some species, including *B. campestre*, *B. minganense,* and *B. montanum*, can develop vegetatively from underground propagules called gemmae, explaining the high plant densities often seen in populations of these species (Farrar and Johnson-Groh 1990). Mature moonwort sporophytes generally produce a single aboveground, photosynthetic, fertile frond per growing season, but prolonged dormancy has been documented for several species (Johnson-Groh and Farrar 1993, Lesica and Ahlenslager 1996). Mature sporophytes of moonworts (*Botrychium* subgenus *Botrychium*) whose demography has been studied have been shown to be short-lived perennials, but longevity varies between species (Lesica and Ahlenslager 1996) and has not been determined for most species. In contrast, grapeferns *(Botrychium* subgenus *Sceptridium*) may be quite long-lived (Kelly 1994, Montgomery 1990).

The sporangia is the site of meiosis; each large eusporangium of *Botrychium* species produces thousands of haploid (1N) spores (Gifford and Foster 1989). Spores are small and lightweight enough to be carried by air currents. While most spores may land near the parent plant, some may travel considerable distances (Wagner and Smith 1993, Briggs and Walters 1997), and even under a closed forest canopy on a calm day, when a mature sporophyte is flicked, a small cloud of yellow dust can be seen rising in the air. The effectiveness of long distance dispersal by spores may help to explain the broad and often disjunct distributional patterns often typical of moonworts (Barrington 1993, Peck et al. 1990). However, other studies report dispersal distances to be much less. Hoefferle (1999) and Casson et al. (1998) reported spores of *Botrychium* to disperse by wind about one meter or even less from the parent plant. 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.

Dispersal of moonwort spores by droppings of small mammals has also been suggested (Zika 1992) and is consistent with observations of browsed sporophores of some species. This method of dispersal may explain the tendency of moonworts to grow in patches and may be especially important for dispersal in forest environments with little wind movement.

Research on a number of ferns (but not including *Botrychium*) determined that spores remained viable for at least as long as one year, and spores on herbarium sheets germinated after over 50 years, demonstrating potential for a 'spore bank' in the soil (Dyer and Lindsay 1992). In nature, *Botrychium* spores germinate underground, and development of the haploid, non-photosynthetic gametophyte is dependent on early infection by an endophytic fungus (Bower 1926, Gifford and Foster 1989). The gametophyte, with its fungal associate, is thought to nourish the young embryonic sporophyte (Camacho 1996). Spore germination requires variable periods of darkness depending on the species (Whittier 1981). Gametophytes of *Botrychium* species can be grown in sterile culture without a fungal symbiont if a suitable source of soluble sugars is supplied (Whittier 1984).

Botrychium gametophytes are bisexual with the antheridia positioned above the archegonia (Bower 1926, Campbell 1922, Gifford and Foster 1989), facilitating self-fertilization, an advantage for colonizing new sites following long distance spore dispersal (Peck et al. 1990). Self-fertilization may be the norm due to limited range of the flagellated sperm in the soil (Barrington 1993) and high levels of inbreeding have been demonstrated for some *Botrychium* species based on electrophoretic evidence (Soltis and Soltis 1986). The longevity of gametophytes and their fate following maturation of an associated sporophyte have not been studied.

Mycorrhizal relations. After the spores are released, they infiltrate into the soil and germinate. Infiltration and subsequent germination may require up to 5 years, although some spores may germinate immediately (Casson et al. 1998). Spore germination requires darkness (Whittier 1972, 1973; Wagner et al. 1985), a requirement that is not surprising in view of the subterranean habitat 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 described in detail by 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).

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).

HABITAT

Botrychium campestre is reported as “extremely inconspicuous in prairies, dunes, grassy railroad sidings, and fields over limestone” by Wagner and Wagner (1993). *B. campestre* is found in the midwest in native grasslands, in sand dunes, and along railroads (Nekola and Schlicht 1997; Wagner and Wagner 1986, 1990). These habitats are similar to those of a number of western North America species of moonwort which occur in grass-dominated mountain meadows. *B. campestre* appears to have several adaptations to dry habitats including its early spring growth habit and its reproduction, in part, by underground gemmae.

In Michigan, prairie dunewort occurs principally on perched sand dunes near Lake Michigan, and also near Lake Superior at the Grand Sable Dunes in Pictured Rocks National Lakeshore (Higman and Penskar 1999). Associated species include *Artemisia campestre* (wormwood), *Arctostaphylos uva-ursi* (bearberry), dune grasses *(Ammophila breviligulata* and *Calamovilfa longifolia*), and *Arabis lyrata* (lyre-leaved rock cress).

Notable is the common association with several other species of *Botrychium*, including *B. hesperium, B. lunaria, B. matricariifolium, B. minganense, B. acuminatum* and *B. simplex* (Wagner and Wagner 1990). Wagner and Wagner (1983) termed these situations "genus communities," where several species of *Botrychium* occur together in the same habitat. He also reported that of this group of *Botrychium* species, *B. campestre* was the first to yellow, dry, and die, usually by mid-June, or earlier if the season was hot and dry. Non-dune habitats in Michigan include old fields and under deciduous trees on limestone outcrops.

In Minnesota, North Dakota, and Iowa, *B. campestre* occurs in open grassland prairies, especially on sandy soils (Nekola and Schlicht 1997, Coffin and Pfanmuller 1988). Sites are sometimes disturbed (such as iron-ore tailings piles and railroad right-of-ways). Associated species include prairie species such as *Schizachyrium scoparium, Poa pratensis, Stipa spartea, Bouteloua curtipendula, Lithospermum canescens, Symphoricarpos occidentalis, Sorghastrum nutans,* and *Sporobolus heterolepis*.

In Wisconsin, a single population is reported from sand dunes at Kohler Park Dunes in Sheboygan County along Lake Michigan. However, it is unknown if this population is still extant as recent surveys have been unable to find any plants.

Populations in New York and eastern Canada have been reported (Wagner and Wagner 1990) and represent outliers from the species' main range to the west. In New York, the species occurs on dry limestone outcrops and cliffs.

DISTRIBUTION, ABUNDANCE, AND STATUS

Botrychium campestre is concentrated in the upper Great Lakes region, western Iowa, and western Minnesota, ranging westward into Nebraska, North Dakota (one occurrence), Saskatchewan, and Alberta, with isolated disjunct occurrences known in New York and eastern Canada (Wagner and Wagner 1990).

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

In Michigan, Iowa dunewort occurs principally on perched sand dunes near Lake Michigan, and also near Lake Superior at the Grand Sable Dunes in Pictured Rocks National Lakeshore (Higman and Penskar 1999). Populations are also known from Benzie County, Leelanau County (including North and South Manitou Islands, Fox Island, and Sleeping Bear Dunes National Lakeshore). Inland populations are reported from Camp Grayling Military Reservation in Crawford County (Higman and Penskar 1999).

In Wisconsin, a single population is reported from Kohler Park Dunes in Sheboygan County along Lake Michigan. However, the current status of this occurrence is unknown.

In Minnesota, *B. campestre* is reported from 30 sites, primarily from western portions of the state. It is found in sandy prairies, roadsides, and on mine tailings resulting from iron ore mining.

A single population is known from a sandy prairie site in North Dakota; three populations are known from grasslands in Iowa.

Based on our current knowledge of the species' range, populations near Lakes Superior and Michigan, and in New York represent outliers from the main species range of the central prairies and Great Plains.

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

- Global Conservation Status Rank: G3
- Reasons: *Botrychium campestre* occurs over a fairly broad range. Because it is inconspicuous and difficult to locate, population numbers are small. However, ongoing surveys are discovering additional populations.
- United States - National Conservation Status Rank: N3
- Canada - National Conservation Status Rank: N1

United States and Canadian Occurrences:
United States
Colorado (S1)
Idaho (S1)
Iowa (S2)
Michigan (State threatened, S2)
Minnesota (S3)
Montana (S1)
Nebraska (S1)
New York (SH)
North Dakota (S1)
Oregon (S1)
South Dakota (SR)
Washington (S1)

Wisconsin (S1)
Wyoming (S1)

Canada
Alberta (S1)
New Brunswick (S1)
Ontario (S1)
Quebec (S1)
Saskatchewan (S1)

EO SUMMARY

Great Lakes states – number of element occurrences

State	No. of EOs	Status	Comments
Minnesota	30	S3	State special concern
Wisconsin	1	S1	State endangered; plants not observed since 1985.
Michigan	11	S2	State threatened
Total	42		

State and National Forests - Summary of element occurrences

National Forest	No. of EOs
Minnesota	30
Chippewa National Forest	0
Superior National Forest	0
Michigan	11
Ottawa National Forest	0
Hiawatha National Forest Rapid River Ranger District - 1 St. Ignace Ranger District - 1	2
Huron-Manistee National Forest	0
Wisconsin	1
Chequamegon-Nicolet National Forest	0
Total State EOs	42
Total National Forest EOs	2
NF as % of EOs in MN, WI, MI	5%

POPULATION BIOLOGY AND VIABILITY

Little specific information exists on the biology and ecology of *B. campestre*. The most thorough overviews are presented in Wagner and Wagner (1986), Wagner and Wagner (1990), Farrar and Johnson-Groh (1986), Nekola and Schlicht (1997), and Johnson-Groh (1999). Open dune habitats are somewhat unstable due to shifting sand, and maintaining natural processes is likely important. In prairie environments, fire or grazing may be useful management tools for maintaining the species, although they have not been extensively studied (Johnson-Groh and Farrar 1996a). Based on known locations of *B. campestre*, some degree of disturbance which results in more open conditions may be desirable. For example, populations are known from tailings piles, roadsides, and along railroads.

Population studies on other species of moonworts (*Botrychium* subgenus *Botrychium*) have shown that there is considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). Populations often fluctuate independently among plots at any given site, and while some populations may be increasing, others are decreasing. These variations reflect microsite differences such as soil moisture, herbivory, and mycorrhizae, although numbers of aboveground plants may fluctuate widely without any apparent cause, and individual plants may not emerge every year (Muller 1993, Johnson-Groh 1998, 1999).

Botrychium may appear or disappear in accordance with mycorrhizal health (Johnson-Groh 1998) due to their obligate relationship with the fungi. In general, Johnson-Groh (1999) concluded that mycorrhizae were the most limiting factor for *Botrychium* establishment, distribution and abundance. Environmental factors that may affect mycorrhizae, like reductions in soil moisture, then also likely have significant impacts on moonworts, whereas the repeated removal of leaf tissue may have little effect (Johnson-Groh and Farrar 1996b). Wagner and Wagner (1993) also believed that taking many samples would have little effect on the population as long as the underground shoots and roots were left intact. Standard assumptions about the population biology of other more ‘normal’ plants may be irrelevant to *Botrychium* because of the obligate mycorrhizal 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 per square meter 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

discovering a single emergent sporophyte may indicate a self-sustaining population at a given 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. These underground stages have been compared to seed banks in angiosperms and could play an important role in the population dynamics of *Botrychium* (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, while a single catastrophic year had relatively little effect on simulated populations. Populations are likely more stable than would be predicted from monitoring only aboveground plants due to the large proportion of the population in underground stages. *B. campestre* may respond in a similar fashion.

Many species of *Botrychium* are associated with light to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993). Habitat reports for *B. campestre* are often from disturbed areas (Wagner and Wagner 1990; see Appendix A). A species like *B. campestre* that seems to require

open areas with a regular disturbance regime may have a metapopulation structure where local populations become established, then become locally extinct if succession proceeds toward a closed-canopy forest (Menges and Gawler 1986, Parsons and Browne 1982). The high variability in aboveground plant numbers found in some moonworts may lead to 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

In the midwest, the primary threat to *B. campestre* may be the loss of its typical open, grassy habitat due to succession towards more closed-canopy conditions. Recreation and associated trampling impacts may also be a threat, especially for populations located near Great Lakes shorelines. In prairie habitats such as those associated with the species in Minnesota, direct habitat loss due to development and agriculture are likely important.

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 had little effect on a population if the underground shoots and roots were left intact. However, Hoefferle (1999) reported that if aboveground plants were removed after spore release, trophophores the following year were significantly smaller (removal before sporulation had no effect). She cautioned, however, that her research was a one-year study only, and weather conditions could have had an impact (Hoefferle 1999). Longer-term studies have indicated that the removal of leaves had no effect on subsequent leaf size or vigor (Johnson-Groh and Farrar 1996a).

In a French study (Muller 1992), drought-like conditions wilted a sporophyte of *Botrychium matricariifolium* before plants had an opportunity to produce spores. The work of Johnson-Groh (1999) also emphasized the importance of water-relations to moonworts and their supporting mycorrhizae. Mycorrhizae are likely the most limiting factor to *Botrychium* establishment, distribution, and abundance (Johnson-Groh 1999); therefore anything negatively affecting mycorrhizae may be expected to also have deleterious effects on *Botrychium*.

Large decreases in mycorrhizal fungi have occurred following earthworm invasion in deciduous hardwood forests (Nielsen and Hole 1963, 1964; Cothrel et al. 1997; Nixon 1995). Since 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). While earthworms may be a possible threat to *B. campestre,* no research has indicated that the worms are a threat to species of *Botrychium* other than *B. mormo*, which occurs in the forested habitats likely to be most affected. Grassland, sand dune, and disturbed sites occupied by this species do not have thick organic surface layers developed under a canopy of deciduous trees.

Stewardship Overview and Population Viability Concerns. Often it is difficult to determine what factor or combination of factors is impacting *Botrychium* populations. 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, management activities that open the canopy somewhat or reduce the herbaceous cover may be appropriate management tools. However, little specific information is available on the response of *B. campestre* to these types of management practices.

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

Research and Monitoring Requirements : Like most species of *Botrychium*, *B. campestre* is small, inconspicuous, and difficult to find. In addition, the plant's tendency

to fluctuate in aboveground numbers (or in unfavorable years, failing to appear aboveground at all), and early-season growth habit make finding this plant difficult. Given these factors, plus the only recent recognition of this species (Wagner and Wagner 1990), and the taxonomic difficulties of the genus, it is very likely that there are undiscovered sites for *B. campestre*, and 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 on the population biology of *B. campestre* is largely lacking.

Within the genus, exotic earthworms are a serious threat to at least *B. mormo* (Sather et al. 1998). It is unknown if exotic earthworms threaten *B. campestre* populations or their prairie or dune 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 (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.

Perhaps the easiest and most effective way of monitoring habitat would be through the use of 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

Barrington, D. S. 1993. Ecological and historical factors in fern biogeography. Journal of Biogeography 20: 275-280.

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.

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. 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.

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

Cody, W. J., and 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.

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.

Dyer, A. F. and S. Lindsay. 1992. Soil spore banks of temperate ferns. American Fern Journal 82: 89-122.

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.

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.

Higman, P. J., and M. R. Penskar. 1999. Special plant abstract for *Botrychium campestre* (prairie dunewort). Michigan Natural Features Inventory, Lansing, MI. 2 pp. Funding for abstract provided by Michigan Department of Environmental Quality - Land and Water Management Division, Coastal Zone Management Program and Michigan Department of Natural Resources - Wildlife Division, Non-Game Program.

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.

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., and D. R. Farrar. 1996a. The effects of fire on prairie moonworts (*Botrychium* subgenus *Botrychium).* American J. Botany 83(Supple.): 134.

Johnson-Groh, C. L., and D. R. Farrar. 1996b. Effects of leaf loss on moonwort ferns, *Botrychium*

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

Johnson-Groh, C. L., and D. R. Farrar. 1993. Population dynamics of prairie moonworts (*Botrychium* subgenus *Botrychium*) in Iowa and Minnesota (abstract). American Journal of Botany 80 (supplement): 109.

Johnson-Groh, C. L., L. Schoessler, C. Riedel, and K. Skogen. 2000. [Abstract] Underground distribution and abundance of *Botrychium* gametophytes and juvenile sporophytes. American J. Bot. Supplement.

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.

Kartesz, J. T. 1999. A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland. First Edition. In: Kartesz, J.T., and C.A. Meacham. Synthesis of the North American Flora, Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC.

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

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.

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.

Mason, N. A. and D. R. Farrar. 1989. Recovery of *Botrychium* gametophytes, gemmae, and immature sporophytes by centrifugation. American Fern Journal 79: 143-145.

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.

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

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).

Nekola, J. C. and D. W. Schlicht. 1997. Ecology of *Botrychium campestre* on northeastern Iowa glades. The Prairie Naturalist. 28:77-89. (Description of ecological range of *B. campestre* on northeastern Iowa glade communities.)

Nekola, J. C. (date?) Distribution of *Botrychium campestre* in northeastern Iowa. American Fern Journal. (Range extension of *B. campestre* to northeastern Iowa)

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., 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.

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.

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.

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. 1986. 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. 1988. Detecting *Botrychium* hybrids in the Lake Superior region. Mich. Bot. 27: 75-80.

Wagner, W. H., and F. S. Wagner. 1990. Moonworts *(Botrychium* subg. *Botrychium*) of the upper Great Lakes region, USA and Canada, with descriptions of two new species. Contr. U. of Mich. Herb. 17:313-325.

Wagner, W. H., and F. S. Wagner. 1993. 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. 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, C. Haufler, and J. K. Emerson. 1984. A new nothospecies of moonwort (Ophioglossaceae, *Botrychium*). Canadian Journal of Botany 62: 629-634.

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. 1981. Spore germination and young gametophyte development of *Botrychium* and Ophioglossum in axenic culture. American Fern Journal 71: 13-19.

Whittier, D. P. 1984. The organic nutrition of *Botrychium* gametophytes. American Fern Journal 74: 77-86.

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

Whittier, D. P. 2000. [Abstract] Gametophyte and young sporophyte development in the Ophioglossaceae. American J. Botany (Supplement).

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 campestre* element occurrences.

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 11
Minnesota 30
Wisconsin 1
Michigan (11)

Location: Michigan, Alger County
Ownership: Pictured Rocks National Lakeshore
Abundance: 1985: about 80 individuals over 2 acres.
Habitat: Perched open dunes near Lake Superior (Grand Sable Dunes).
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Benzie County
Ownership: Pictured Rocks National Lakeshore
Abundance: 1985: About 10 plants over less than 0.5 acre.
Habitat: Perched open dune along Lake Michigan
Comments: Associates: *Equisetum hyemale, Arctostaphylos, Artemisia campestris, Lilium philadelphicum, Silene vulgaris, Hieracium pilosum, Senecio, Poa compressa, Melilotus alba, Arabis lyrata*.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Delta County
Ownership: Hiawatha National Forest
Abundance: (no data).
Habitat: On steep, sparsely vegetated hillside.
Comments: In proposed campsite.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore
Abundance: About 75 plants were seen in 1984; 20 plants reported from <0.5 acre in 1985.
Habitat: north-facing dune hollow.
Comments: Assoc.: Beachgrass, *Fragaria, Equisetum*.

Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore
Abundance: 1984: 20-30 plants; 1985: 20 plants over about 0.5 acre.

Abundance: About 75 plants were seen in 1984; 20 plants reported from <0.5 acre in 1985.
Habitat: north-facing dune hollow.
Comments: Assoc.: Beachgrass, *Fragaria, Equisetum*.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore
Abundance: 1984: 20-30 plants; 1985: 20 plants over about 0.5 acre.
Habitat: Large, open and stabilized dunes near Lake Michigan.
Comments: Assoc.: Beachgrass, *Fragaria, Equisetum, Senecio plattensis*.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore
Abundance: 1985: 33 plants seen in 2 areas within 2 acres.
Habitat: A perched open dune.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore
Abundance: 1985: 105 plants counted in <0.5 acre.
Habitat: Open dunes perched on eroding moraine.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore (South Manitou Island)
Abundance: 1985: 41 plants in 1 acre.
Habitat: Perched dunes.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Sleeping Bear Dunes National Lakeshore (North Manitou Island)
Abundance: 1985: 12 plants in less 0.5 acre.
Habitat: Perched open dunes.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Leelanau County
Ownership: Beaver Islands State Wildlife Research Area
Abundance: 1985: 2 plants found, highly probable that more exist.
Habitat: Perched open dune along Lake Michigan

Comments: South Fox Island
Source of information: Michigan Natural Features Inventory database report 2000.
Habitat: Large, open and stabilized dunes near Lake Michigan.
Comments: Assoc.: Beachgrass, *Fragaria, Equisetum, Senecio plattensis*.
Source of information: Michigan Natural Features Inventory database report 2000.

Location: Michigan, Mackinac County
Ownership: Hiawatha National Forest
Abundance: (no data).
Habitat: (no data).
Source of information: Hiawatha National Forest.

Minnesota (30)

Location: Minnesota, Big Stone County
Ownership: State of Minnesota
Abundance: 5 plants in woods on edge of prairie on north-facing slope. Fewer plants in 1988 than found in 1987, presumed due to a spring prairie burn.
Habitat: Bluffs facing lake.
Comments: associated species are *Fraxinus pensylvanica, Symphoricarpos occidentalis, Rhus radicans, Ulmus americana, Rhus glabra, Oxalis violacea, Carex blanda, Poa pratensis.*

Source of information: MN DNR, Natural Heritage and Nongame Research

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Big Stone County
Ownership: unknown
Abundance: one plant
Habitat: on west-facing prairie.
Comments: associated species: *Poa pratensis, Stipa spartea, Schizachyrium scoparium, Anemone patens, Aster sericeus, Solidago rigida, Oxalis violacea, Bouteloua curtipendula, Lithospermum canescens, Symphoricarpos occidentalis, Viola pedatifida.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Big Stone County
Ownership: unknown
Abundance: one clump of 2 plants
Habitat: in woods on the edge of prairie, south-west-facing slope.
Comments: associated species: *Fraxinus pensylvanica, Quercus macrocarpa, Poa pratensis, Solidago canadensis, Symphoricarpos occidentalis*. Slope above plants dominated by *Schizachyrium scoparium*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Big Stone County
Ownership: private
Abundance: 12 plants in area of about 15 sq meters.
Habitat: on west-facing slope.
Comments: associated species: *Sorghastrum nutans, Poa pratensis, Bouteloua curtipendula, Aster sericeus, Anemone patens, Psoralea esculenta, Sporobolus heterolepis, Oxalis violacea, Thalictrum dasycarpum, Antennaria* sp.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clay County
Ownership: private
Abundance: 3 plants of *Botrychium campestre* mixed with 4 plants of *B. simplex* in area of 10 sq meters.
Habitat: west-facing slope.
Comments: *Poa pratensis, Stipa spartea, Amorpha canescens, Anemone patens, Poa compressa, Comandra umbellata, Antennaria* sp.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clay County
Ownership: unknown
Abundance: 1 plant.
Habitat: on northeast aspect in prairie.
Comments: *Poa pratensis, Schizachyrium scoparium, Stipa spartea, Heuchera richardsonii, Koeleria cristata, Anemone patens, Psoralea esculenta, Comandra umbellata, Bouteloua curtipendula.*

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clay County
Ownership: unknown
Abundance: unknown
Habitat: on east aspect, gentle slope in an area approx 50 m sq.
Comments: *Poa pratensis, Stipa, Geum, Symphoricarpos, Schizachyrium, Anemone, Sisyrinchium, Artemisia frigida*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clay County
Ownership: unknown
Abundance: unknown
Habitat: hilltops and slightly down slope from hill crest on east aspect

Comments: *Poa pratensis, Stipa, Geum, Symphoricarpos, Schizachyrium, Anemone, Comandra, Pycnanthemum*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clay County
Ownership: unknown
Abundance: unknown
Habitat: flat or slightly undulating prairie.
Comments: *Poa pratensis, Stipa, Schizachyrium, Lithospermum, Botrychium simplex.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Crow Wing County
Ownership: unknown
Abundance: unknown
Habitat: old tailings pond in a mine dump area. Plants occur in full sun and in partial shade under balsam poplar and small jack pine.
Comments: associated with *Fragaria virginiana, Botrychium pallidum, Achillea millefolium, Arabis x divaricarpa, Verbascum thapsus.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Crow Wing County
Ownership: unknown
Abundance: unknown
Habitat: Plants occur in a tailings pond of a cuyuna iron mine. Plants occur in full sun and in partial shade under balsam poplar and small jack pine.
Comments: associated with *Populus balsamifera, Achillea millefolium, Taraxacum officinale, Verbascum thapsus, Botrychium spathulatum*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: unknown
Abundance: unknown
Habitat: Plants occur in the recently exposed tailings surrounding a receding tailings pond of a mine spoil area on the western-most end of the Mesabi iron range.
Comments: Associated with *Populus balsamifera, P. grandidentata, Botrychium spathulatum, Achillea millefolium, Carex aurea*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: unknown
Abundance: unknown

Habitat: Plants occur in a tailings pond in a mine spoil area near the western end of the Mesabi iron range.
Comments: Associated with *Populus balsamifera, Botrychium matricariifolium, Hieracium pilosella, Achillea millefolium, Picea mariana*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Kittson County
Ownership: State of Minnesota (Lake Bronson State Park)
Abundance: 3 plants
Habitat: flat or slightly undulating prairie
Comments: Associated with *Poa pratensis, Andropogon, Stipa, Schizachyrium, Artemisia, Solidago, Euphorbia, Botrychium simplex, B. gallicomontanum*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: unknown
Abundance: 7 plants
Habitat: upper east-facing slope.
Comments: Associated species: *Poa pratensis, Sporobolus heterolepis, Solidago rigida, Stipa spartea, Anemone patens*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Abundance: unknown
Habitat: Plants occur in the recently exposed tailings surrounding a receding tailings pond of a mine spoil area on the western-most end of the Mesabi iron range.
Comments: Associated with *Populus balsamifera, P. grandidentata, Botrychium spathulatum, Achillea millefolium, Carex aurea*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: private
Abundance: a few plants
Habitat: n-facing slopes in prairie
Comments: site dominated by *Schizachyrium scoparium*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: unknown
Abundance: 7 plants
Habitat: upper east-facing slope.

Comments: Associated species: *Poa pratensis, Sporobolus heterolepis, Solidago rigida, Stipa spartea, Anemone patens.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: unknown
Abundance: unknown
Habitat: --
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: private
Abundance: 6 plants in area of 4 sq. meters
Habitat: in dense mulch on west-facing slope.
Comments: *Poa pratensis, Muhlenbergia cuspidata, Aster sericeus, Astragalus lotiflorus, Amorpha canescens, Stipa spartea, Anemone patens, Anemone cylindrica, Ratibida columnifera.*

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lac Qui Parle County
Ownership: U.S. Fish and Wildlife Service (National Wildlife Refuge)
Abundance: 1 plant
Habitat: north-facing slope.
Comments: Associated species: *Muhlenbergia cuspidata, Poa pratensis, Stipa spartea, Amorpha canescens, Bouteloua curtipendula, Aster sericeus, Heuchera richardsonii, Anemone patens, Potentilla arguta.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lincoln County
Ownership: The Nature Conservancy (Hole-in-the-Mountain Prairie)
Abundance: ca. 30 plants
Habitat: mostly along the roadside.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Norman County
Ownership: unknown
Abundance: 5 plants but more reported from earlier surveys, mixed with Botrychium simplex.
Habitat: flat or slightly undulating prairie.
Comments: Associated species: *Stipa spartea, Poa pratensis, Geum triflorum, Potentilla arguta, Psoralea esculenta, Antennaria* sp., *Echinacea angustifolia, Liatris punctata, Oenothera.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Norman County
Ownership: unknown
Abundance: unknown
Habitat: hill crest and gentle slope.
Comments: Associated species: *Poa pratensis, Geum, Anemone, Sisyrinchium, Artemisia frigida, Heuchera.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Pipestone County
Ownership: MN DNR (scientific and natural areas)
Abundance: 5 plants
Habitat: ne-facing prairie slope and e-face of ravine
Comments: with *Schizachyrium scoparium.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Polk County
Ownership: unknown
Abundance: 5 plants
Habitat: ne-facing prairie slope and e-face of ravine
Comments: with *Schizachyrium scoparium.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Polk County
Ownership: unknown
Abundance: unknown
Habitat: sandy roadside bluff above the hill river.
Comments: Associates include *Geum triflorum, Artemisia frigida, Botrychium simplex, Comandra umbellata, Viola pedata*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, St. Louis County
Ownership: unknown

Abundance: unknown
Habitat: Plants occur in a 40 acre tailings pond of a mine dump area of the mesabe iron range.
Comments: Associated with *Populus balsamifera, Carex aurea, Malaxis unifolia, Ophioglossum pusillum, Fragaria virginiana*.
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Traverse County
Ownership: unknown
Abundance: one plant
Habitat: north-facing slope of prairie
Comments: Associated species: *Symphoricarpos occidentalis, Stipa spartea, Bouteloua curtipendula, Potentilla arguta, Schizachyrium scoparium, Anemone patens, Anemone cylindrica, Achillea millefolium*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Traverse County
Ownership: unknown
Abundance: 2 plants
Habitat: edge of woods-prairie, north-facing slope.
Comments: Associated species: *Fraxinus pensylvanica, Prunus virginiana, Ulmus americana, Parthenocissus quinquefolia, Symphoricarpos occidentalis, Rhus glabra, Rhus radicans, Botrychium virginianum.*
Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Traverse County
Ownership: unknown
Abundance: 2 plants
Habitat: prairie, north-facing slope.
Comments: Associated species: *Poa pratensis, Stipa spartea, Symphoricarpos occidentalis, Anemone patens, Oxalis violacea, Heuchera richardsonii, Geum triflorum.*

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Winona County
Ownership: MN DNR (wildlife management area – Whitewater WMA)
Abundance: 8 plants
Habitat: bluff. In large bedrock bluff prairie, near nw edge of prairie on lower slope, on 45% slope, sw-aspect.
Comments: Associated species include: *Schizachyrium scoparium, Aster oolentangiensis, Coreopsis palmata, Aster sericeus, Sisyrinchium campestre, Amorpha canescens, Sporobolus heterolepis,* scattered *Rhus glabra*.

Source of information: MN DNR, Natural Heritage and Nongame Research Program database report 2000.

Wisconsin (1)

Location: Wisconsin, Sheboygan County
Ownership: state of Wisconsin (Kohler Park Dunes)
Abundance: 3 or 4 plants
Habitat: in dune complex

Comments: with dunegrass, milkweed, wormwood, baltic rush, and beach pea.
Source of information: WI DNR, Bureau of Endangered Resources database report 2000.

Other
North Dakota (1)
This species was collected by Dr. Dennis Disrud of Minot State College on coal mine spoils in Ward County and is the only known record in North Dakota.
Iowa (3)
Known from three prairie sites in Iowa, one each from Fremont, Monona, and Plymouth Counties.

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 estimaed 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.

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

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).

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:
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.

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

Research and Monitoring Requirements : Like most species of *Botrychium*, *B. campestre* is small, inconspicuous, and difficult to find. In addition, the plant's tendency to fluctuate in aboveground numbers (or in unfavorable years, failing to appear aboveground at all), and early-season growth habit make finding this plant difficult. Given these factors, plus the only recent recognition of this species (Wagner and Wagner 1990), and the taxonomic difficulties of the genus, it is very likely that there are

undiscovered sites for *B. campestre*, and 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 on the population biology of *B. campestre* is largely lacking.

Within the genus, exotic earthworms are a serious threat to at least *B. mormo* (Sather et al. 1998). It is unknown if exotic earthworms threaten *B. campestre* populations or their prairie or dune 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 (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.

Perhaps the easiest and most effective way of monitoring habitat would be through the use of 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.

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)

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.

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.

LITERATURE CITED AND REFERENCES

Barrington, D. S. 1993. Ecological and historical factors in fern biogeography. Journal of Biogeography 20: 275-280.

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.

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. 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.

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

Cody, W. J., and 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.

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.

Dyer, A. F. and S. Lindsay. 1992. Soil spore banks of temperate ferns. American Fern Journal 82: 89-122.

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.

Kartesz, J. T. 1999. A Synonymized Checklist and Atlas with Biological Attributes for the Vascular Flora of the United States, Canada, and Greenland. First Edition. In: Kartesz, J.T., and C.A. Meacham. Synthesis of the North American Flora, Version 1.0. North Carolina Botanical Garden, Chapel Hill, NC.

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

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.

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.

Mason, N. A. and D. R. Farrar. 1989. Recovery of *Botrychium* gametophytes, gemmae, and immature sporophytes by centrifugation. American Fern Journal 79: 143-145.

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.

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

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).

Nekola, J. C. and D. W. Schlicht. 1997. Ecology of *Botrychium campestre* on northeastern Iowa glades. The Prairie Naturalist. 28:77-89. (Description of ecological range of *B. campestre* on northeastern Iowa glade communities.)

Nekola, J. C. (date?) Distribution of *Botrychium campestre* in northeastern Iowa. American Fern Journal. (Range extension of *B. campestre* to northeastern Iowa)

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., 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.

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.

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.

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. 1986. 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. 1988. Detecting *Botrychium* hybrids in the Lake Superior region. Mich. Bot. 27: 75-80.

Wagner, W. H., and F. S. Wagner. 1990. Moonworts *(Botrychium* subg. *Botrychium*) of the upper Great Lakes region, USA and Canada, with descriptions of two new species. Contr. U. of Mich. Herb. 17:313-325.