Conservation Assessment

For

Botrychium minganense (Mingan Moonwort)

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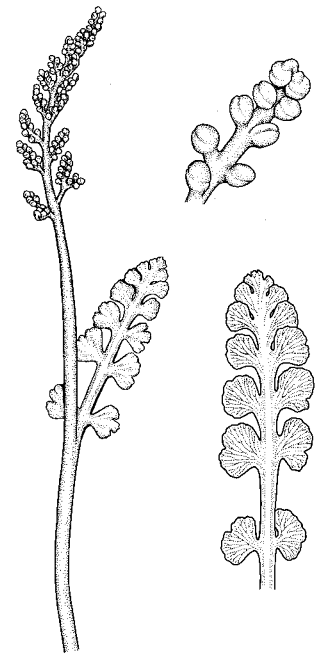

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USDA Forest Service, Eastern Region

2001

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

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EXECUTIVE SUMMARY

Botrychium minganense (Mingan moonwort) is a small moonwort first described in 1927 by Victorin. The species occurs across northern North America, extending southward in the western mountains to southern California and northern Arizona. In the midwest, the species is found in northern portions of Minnesota, Wisconsin, and Michigan. *B. minganense* is listed as a state special concern species in both Minnesota and Wisconsin, but is not presently listed or tracked by the Michigan Natural Features Inventory. It is found in a variety of habitats in the Great Lakes region, including mesic woods, meadows, sand dunes, and riverbanks. In Michigan, the species is often associated with sites underlain by limestone such as those near the Mackinac Straits. Most details about the biology of *B. minganense* are generalized from studies of other moonwort species, although status reports for the species have been completed in Montana and the Pacific Northwest. Much of the life-cycle occurs underground, and populations of aboveground sporophytes fluctuate. An individual plant may not appear aboveground every year, complicating attempts to adequately inventory populations. Like other moonworts, *B. minganense* is dependent on a mycorrhizal relationship; thus species conservation efforts must consider this relationship. Little information is available on managing habitat to maintain the species, but potential threats may include drought, fire, timber-harvesting, collecting, herbivory, trampling, exotic plants, and exotic earthworms (USDA Forest Service 2000). Since plants of Mingan moonwort are small and populations fluctuate, continued inventory efforts are necessary to better refine population demographics, range, and habitat.

INTRODUCTION/OBJECTIVES

One of the conservation practices of the USDA Forest Service is designation of Regional Forester's sensitive species. The Eastern Region (R9) of the Forest Service updated its sensitive species list on February 29, 2000. Part of that process included identification of priority species for conservation assessments and strategies. A group of *Botrychium* species (Ophioglossaceae; Adder's-tongue Family), including *B. minganense*, were one of those priorities.

The objectives of this document are to:

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

The genus *Botrychium*, family Ophioglossaceae, are small ferns that are typically divided into three subgenera in North America (Lellinger 1985, Wagner and Wagner 1993a). One subgenus, *Osmundopteris*, is only represented in our area by *B. virginianum*, the rattlesnake fern, which is common around much of the world (Wagner 1998). Subgenus *Sceptridium*, the grapeferns, includes plants which are medium-sized and decidedly evergreen (Lellinger 1985). Subgenus *Botrychium*, the moonworts, including *B. minganense*, are often rare, local, and very small plants that are difficult to find and positively identify.

North America is a center of diversity for moonworts (Wagner and Wagner 1994) and the upper Great Lakes Region, along with the northwestern U.S. and nearby Canada, are two of the richest areas (Wagner and Wagner 1990, Wagner 1998). Twenty-three species of North American moonworts are now recognized (Wagner and Wagner 1994) compared to the traditional interpretation of only six (Clausen 1938). The problems in distinguishing moonwort species are considerable (Wagner and Wagner 1990), including the tendency for different species of moonworts to occur together at one site, the natural variation in form due to microhabitat variability, their small size, and the difficulty of making good herbarium specimens. However, decades of work, primarily by Dr. Herb Wagner and associates, have clarified the taxonomy of the group, habitat preferences, and the ranges of individual species. Several rare species within subgenus *Botrychium* are now recognized from the Upper Great Lakes region.

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Botrychium minganense was first described as a species in 1927 by Frere Marie Victorin (Victorin 1927). His description, however, was controversial, as some believed it to be very similar to *B. onondagense*, which today is considered merely a deep-shade form of *B. lunaria* (Wagner and Wagner 1990). Others considered *B. minganense* scarcely distinguishable from *B. lunaria*, or have mistakenly identified herbarium specimens as *B. dusenii*, a South American species (Wagner and Wagner 1993a). In 1952, Wagner and Lord (1956) studied the plant and concluded that Victorin had been correct in naming *B. minganense* a distinct species. Those authors identified 14 characters separating the two species, including *B. minganense's* possession of 90 chromosomes, rather than 45 as in *B. lunaria*.

NOMENCLATURE AND TAXONOMY

Scientific Name: *Botrychium minganense* Victorin

Synonymy: *Botrychium lunaria* (L.) Sw. ssp. *minganense* (Victorin) Calder and Taylor; *Botrychium lunaria* (L.) Sw. var. *minganense* (Victorin) Dole

Family: Ophioglossaceae; Adder's-tongue family

Common Name: Mingan moonwort

Botrychium minganense victorin was originally described in 1927 in the proceedings and transcripts of the Royal Society of Canada (Victorin 1927), and is treated as a valid species by Wagner and Wagner (1993) in Flora of North America. In the past this species was often treated as a subspecies or variety of *Botrychium lunaria*.

Based on work in the Pacific Northwest, Wagner (1994) suggested that what is being called *Botrychium minganense* may in fact be four distinct species. However, this assessment treats *B. minganense* as a single species. If changes in taxonomy become accepted, then revisions to portions of this assessment may be necessary.

DESCRIPTION OF SPECIES

General description and identification notes

The aboveground parts of *Botrychium minganense* consist of a single upright stem arising from the ground and terminating in a cluster of tiny ball-like structures that resemble a bunch of grapes (hence one of the common names for the genus of ‘grapefern’). These globular structures (the sporangia) contain the spores necessary for sexual reproduction. Branching from the main stem is the sterile, fern-like leaf blade (the trophophore). In *Botrychium*, the portion of the stem below this juncture of the sterile blade with the main stem is referred to as the common stalk, and the portion supporting the sporangia is called the fertile stalk (sporophore). At the base of the common stalk, but just below the ground, *Botrychium* species have several layers of leaf primordia that are the preformed buds of plants that will emerge in future years.

Botrychium minganense is a small, herbaceous, perennial fern. The sterile blade is dull-green in color, narrowly oblong to linear in overall outline, about 10cm long x 2.5 cm wide. The sterile blade is once-pinnate, with up to 10 pairs of pinnae (segments). In general the segments are well developed, wedge-shaped, and spaced separately from each other along the rachis. The margins of the segments are entire to shallowly crenate. The lowest segments are narrowly fan-shaped.

Botrychium minganense can be confused with other moonworts having fan-shaped leaflets: *B. lunaria, B. pallidum*, and *B. spathulatum*. *Botrychium lunaria* differs in that the leaf segments in *B. lunaria* are much more broadly fan-shaped and the pinnae pairs are arranged closely enough to overlap (Wagner and Wagner 1990). *B. pallidum* is a pale, glaucous green color and smaller than *B. minganense*, and the blade of the sterile segment is trough-shaped instead of flat. *B. spathulatum* has a more leathery textured, deltate-shaped sterile blade, and is much less widely distributed in North America than *Botrychium minganense*.

Each year the sporophyte produces a single dull-green, somewhat fleshy frond divided into two parts, a sterile trophophore and a fertile sporophore. The frond is usually less than 6 inches (15 cm) tall (and often much smaller). The trophophore is pinnatifid with as many as ten pairs of non-overlapping pinnae. The pinnae are variable but they are usually narrowly fan-shaped and have nearly entire margins. The fertile leaf-segment is longer than the sterile segment when mature and bears grape-like sporangia which, upon maturity, release thousands of yellow dust-like spores. The small gametophyte grows underground and is rarely seen or studied.

There are a number of useful references for identifying members of this genus. The treatment in Volume 2 of the Flora of North America (Wagner and Wagner 1993) is the most current published guide to all but the most recently described species (for example, since the release of Volume 2, a new species, *Botrychium lineare*, has been described by Wagner and Wagner [1994]). Lellinger (1985) includes descriptions and color photographs of many moonwort species.

Cody and Britton (1989) provide descriptions and distribution maps of *Botrychium* species known to that time in Canada.

Technical description

"Trophophore stalk 0-2 cm, 0 to 1/5 length of trophophore rachis; blade dull-green, oblong to linear, 1-pinnate, to 10 x 2.5 cm, firm to herbaceous. Pinnae to 10 pairs, horizontal to slightly spreading, approximate to remote, distance between first and second pinnae not or slightly more than between second and third pairs, basal pinna pair approximately equal in size and cutting to adjacent pair, occasionally basal pinnae and/or some distal pinnae elongate, lobed to tip, nearly circular, fan-shaped or ovate, sides somewhat concave, margins nearly entire, shallowly crenate, occasionally pinnately lobed or divided, apex rounded, venation like ribs of a fan with short midrib. Sporophores 1-pinnate, 2-pinnate in very large, robust plants, 1.5-2.5 times length of trophophore. 2n = 180" (from Wagner and Wagner 1993a).

LIFE HISTORY

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

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

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

Vegetative reproduction was not thought to occur in *Botrychium* (Wagner et al. 1985), but Farrar and Johnson-Groh (1990) have documented underground gemmae in a few species of moonwort, including *B. minganense*. They speculated that asexual reproduction may have evolved as an adaptation to dry habitats.

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

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

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

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

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

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

Gametophytes and young sporophytes may exist underground for many years before an aboveground plant develops (Campbell 1922, Muller 1993). Mortality may be high during this period (Peck et al. 1990). The gametophyte produces male and female gametangia, and fertilization of eggs occurs via free-swimming sperm under wet conditions (Lesica and Ahlenslager 1996). Most fertilizations are likely due to inbreeding, since the antheridia and archegonia are nearby and enzyme electrophoresis indicates a lack of genetic variability (McCauley et al. 1985, Soltis and Soltis 1986, Farrar and Wendel 1996a). However, there is no reason that cross-fertilization should not occur (Wagner et al. 1985), especially in consideration of the existence of interspecific hybrids (Wagner et al. 1985, Wagner 1998). McCauley et al. (1985) calculated that *B. dissectum* outcrosses about 5% of the time. Extremely high levels of inbreeding were also found in *B. virginianum* although there was evidence for some outcrossing (Soltis and Soltis 1986).

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

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

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

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

HABITAT

Throughout its range *Botrychium minganense* grows in a broad variety of usually moist or mesic habitats. It was often reported growing with a suite of other *Botrychium* species including: *B. echo*, *B. hesperium*, *B. lanceolatum*, *B. lunaria*, *B. matricariifolium*, *B. montanum*, *B. mormo, B. paradoxum,* and *B. pinnatum* (Wagner and Wagner 1983).

Lellinger (1985) described the North American habitat of *B. minganense* as meadows, prairies, woods, sand dunes, and riverbanks. Wagner and Wagner (1990) described the typical habitat as "woods and second-growth shrubby fields." In the Great Lakes region, maple-basswood forests, grassy skid-trails, and meadows and clearings are typical habitats (Wagner and Lord 1956; see Appendix A).

In Minnesota, *B. minganense* is most commonly found in maple-basswood forests. Associated species include species typical of rich mesic woods such as *Actaea rubra, Dirca palustris, Uvularia grandiflora, Aralia nudicaulis,* and *B. virginianum, Aralia racemosa, B. multifidum,* and *Carex pensylvanica. Botrychium mormo* was reported nearby at several sites, including one site where exotic earthworms were present. Several Minnesota populations were located in transition areas between upland and wetland habitats, along fluctuating sandy shorelines, or in moist-wet woods under *Thuja occidentalis*. *B. minganense* was also found in dry-mesic woods. Northern red oak, basswood, bigtooth aspen, and paper birch were common overstory trees.

In old fields and clearings, associated species were shrubs such as *Vaccinium angustifolium, Cornus stolonifera, Salix humilis,* and *Arctostaphylos uva-ursi.* Herbaceous species included *Danthonia spicatum, Anaphalis margaritacea, Fragaria virginiana, Achillea millefolium, Melampyrum lineare*, and a suite of other *Botrychium* species, including *B. matricariifolium, B. lunaria, B. hesperium, B. multifidum* and *B. spathulatum.*

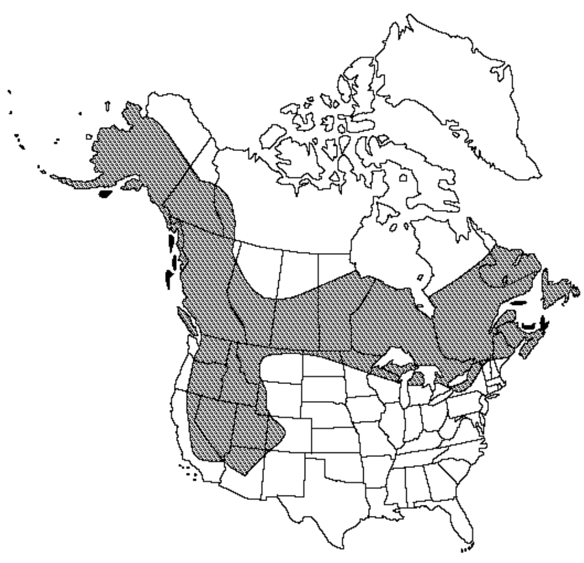
In Wisconsin, habitat preferences included woods dominated by sugar maple and basswood, sandy open lakeshores, old clearings, and along grassy logging roads (Wisconsin DNR 2001).

In Michigan, Hagenah (1966) reported that *B. minganense* was most common in areas near the Mackinac Straits underlain by limestone and dolomite bedrock. In general, habitats were similar to those associated with *B. lunaria*. It usually occurred in second-growth deciduous forests (Wagner and Lord 1956).

In the northwestern United States, *B. minganense* is reported from a wide range of habitats and elevations (Vanderhorst 1997). In Idaho the species is reported from western red cedar, hemlock, grand fir, and lodgepole pine forest habitat types as well as from alder thickets. In Washington it is found mostly in riparian areas with western red cedar or mixed conifers, but is also reported from rocky subalpine and alpine habitats. In Montana it is known from rocky alpine areas, montane grasslands, mossy lakeshores, alder thickets, and both conifer and deciduous forests. Most occurrences were in mature stands of western red cedar (*Thuja plicata*) or western hemlock (*Tsuga heterophylla*).

DISTRIBUTION, ABUNDANCE, AND STATUS

Botrychium minganense is widespread and transcontinental across northern North America, extending south in the western mountains to southern California and northern Arizona. Populations in northern portions of Minnesota, Wisconsin, and Michigan occur at the southern edge of the species' range.



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

Unlike *B. lunaria* which is circumboreal and also found in the southern hemisphere, *B. minganense* is endemic to North America (Wagner and Wagner 1990).

In Canada, the species is reported from Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland, Northwest Territories, Nova Scotia, Ontario, Prince Edward Island, Quebec, Saskatchewan, and the Yukon.

In the United States, *B. minganense* occurs in Alaska, Arizona, California, Colorado, Idaho, Maine, Michigan, Minnesota, Montana, Nevada, New Hampshire, New York, North Dakota, Oregon, Utah, Vermont, Wisconsin, Wyoming (Wagner and Wagner 1993a).

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

Global Conservation Status Rank: G4 (1998)
Rounded Global Conservation Status Rank: G4

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

United States: National Conservation Status Rank: N? (1993)
United States: Status by State
Alaska (SR), Arizona (SR), California (S1.3), Colorado (S1), Idaho (S3), Maine (SR), Michigan (S?), Minnesota (S3, state special concern), Montana (S3), Nevada (SR), New Hampshire (SR), New York (S1), North Dakota (S1), Oregon (S2), Utah (S1), Vermont (SR), Washington (S3), Wisconsin (S2, state special concern), Wyoming (S1).

Canada: National Conservation Status Rank: N? (1993)
Canada: Status by Province
Alberta (S2), British Columbia (SR), Labrador (Newfoundland) (SU), Manitoba (S1S2), New Brunswick (S1), Newfoundland (SU), Newfoundland Island (Newfoundland) (SR), Northwest Territories (SR), Nova Scotia (SU), Ontario (S4), Prince Edward Island (SU), Quebec (S?), Saskatchewan (S1).

EO SUMMARY

Great Lakes States – Number Of Element Occurrences

State	No. of EOs	State Rank	Status	Comments
Minnesota	33	S3	SC	state special concern
Wisconsin	16	S2	SC	state special concern
Michigan	na	S?	none	Not tracked in state
Total	na			

Great Lakes National Forests - Summary Of Element Occurrences

National Forest	No. of EOs
Minnesota (statewide)	33
Chippewa National Forest	14
Superior National Forest	4
Michigan (statewide)	na
Ottawa National Forest	-
Hiawatha National Forest	-
Huron-Manistee National Forest	-
Wisconsin (statewide)	16
Chequamegon-Nicolet National Forest	4
Total State EOs (MN and WIS only)	49
Total National Forest EOs (MN and WIS only)	22
NF as % of EOs in MN and WI	45%

POPULATION BIOLOGY AND VIABILITY

Little information is available about the population biology of *B. minganense*. Population studies on other species of moonworts have shown that there can be considerable annual variation in the number of aboveground plants at a given site (Johnson-Groh 1999). These variations reflect microsite differences such as soil moisture, herbivory, or mycorrhizae, although populations of moonworts are known to fluctuate widely without any apparent cause (Johnson-Groh 1999), and individual plants may not emerge every year (Muller 1993, Johnson-Groh 1998).

Botrychium species are terrestrial ferns that reproduce by means of microscopic spores (Lellinger 1985). When the spore germinates, it develops into a tiny underground structure (gametophyte) that produces the gametes (egg and sperm). When the sperm is mature it is released from one part of the gametophyte and swims via a thin film of water to the egg. The fertilized zygote then develops roots, stem, and the aboveground structure seen as the fern (sporophyte). The sporophyte produces the spores by the thousands in round sacs (sporangia) borne in clusters at the top of the fertile stalk.

In *Botrychium minganense*, asexual reproduction is sometimes accomplished via gemmae, which are spherical units produced on the underground stem and which are capable of developing into sporophytes (Farrar and Johnson-Groh 1990).

Botrychium apparently appear or disappear, at least in part, in accordance with mycorrhizal health due to their obligate relationship with the fungi (Johnson-Groh 1998). Johnson-Groh (1999) concluded that mycorrhizae are the most limiting factor for *Botrychium* establishment, distribution, and abundance. Environmental factors that may affect mycorrhizae, like reductions in water availability, are then also likely to have significant impacts on moonworts, in contrast to the repeated removal of leaf tissue which may have little negative effect (Johnson-Groh 1999). Standard assumptions about the population biology of non-mycorrhizal plants may be irrelevant to *Botrychium* because of this obligate relationship (Johnson-Groh 1999).

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

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

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

Many species of *Botrychium* are associated with slight to moderate disturbances (Lellinger 1985, Wagner and Wagner 1993a, Lesica and Ahlenslager 1996). *B. minganense* may benefit from disturbances such as partial timber removal (Grover 2000), although no research has been reported. A species like *B. minganense* that is sometimes found in open areas with a regular disturbance regime may have a metapopulation structure where local populations are founded then go extinct as succession proceeds toward a closed climax community (Menges and Gawler 1986, Parsons and Browne 1982). The high variability in aboveground plant numbers found in some moonworts suggests a high probability of local extinction (Johnson-Groh et al. 1998). This kind of species may then depend on a regime of natural disturbances that creates a shifting mosaic of seral communities (Pickett and Thompson 1978).

Much remains a mystery about the reproductive biology of this entire genus because traditional ways of observing genetic and reproductive traits of a species, such as through reciprocal transplants or common garden experiments, have been difficult to conduct with this genus, presumably because of their requisite mycorrhizal relationships (Wagner and Wagner 1983). The growth rate is so slow that ordinarily only a single leaf is produced per year. In addition, many *Botrychium* species apparently undergo periods of dormancy, where plants will not appear aboveground for one to several years, and then re-emerge in the general vicinity (Gehring and Potash 1995; Montgomery 1990).

POTENTIAL THREATS AND MONITORING

The major viability considerations for *Botrychium minganense* are loss of populations due to management actions that change the habitat (canopy coverage, summer temperature, and soil moisture), disturb the mycorrhizal association, or loss of populations through direct impact caused by trampling, soil disturbance, or invasion by exotic plants. Climate change has the potential to affect this species if occupied sites become much warmer and drier, since almost all of the known sites are relatively cool and moist.

Botrychium minganense may respond poorly to fire, especially where surface duff is removed. However, the plant's response is unknown at the current time.

Livestock such as cattle and horses may have an adverse impact on *Botrychium minganense* for several reasons. While there is evidence that *Botrychium* species are grazed by deer and small mammals such as rodents and rabbits (Zika 1992), the impacts from these animals are not equivalent to domestic stock because the latter weigh significantly more and crop plants to ground level. Small mammals have been reported to more selectively browse clusters of sporangia, leaving the trophophore intact, which may play a role in spore dispersal (Zika 1992). Additional impacts from livestock include trampling, soil compaction, and the introduction of exotic weeds.

Threat from exotic earthworms

Native earthworms were eliminated from the Lake States during the last ice age. Natural recolonization from the unglaciated south has been extremely slow, for example, less than 100 miles in the several thousand years since the glacial retreat (James 1990, Berlinger 2000, Conover 2000). European earthworms were introduced into North America with European settlement and then spread through the use of earthworms for fishing bait, gardening, and inadvertent human transport (Kalisz and Wood 1995, Berlinger 2000). Logging machinery and other forest vehicles can transport cocoons and hatchlings, thereby dispersing earthworms widely into forests (Marinissen and van den Bosch 1992, Dymond et al. 1997). More remote forests in our region still lack earthworms, but as humans move through the landscape the probability of colonization increases (Casson et al. 2000).

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

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

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

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

An ongoing *B. mormo* monitoring effort on the Chippewa NF had plots impacted by worms with significant negative effects on *B. mormo* populations (Johnson-Groh 1999). However, the author cautioned that, while the worms likely had fatally affected the plants, all other populations also showed decreases during that dry period. She also observed that it is normal for moonwort populations to fluctuate widely and that population crashes may be due to a population exceeding the carrying capacity of a site. Another monitoring study reported by Casson et al. (2000) in the same area under the direction of biologists with the Leech Lake Reservation Division of Resource Management also show negative effects on soil properties and a dramatic reduction in the *B. mormo* population after exotic earthworm invasion.

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

Stewardship overview and population viability concerns

Often it is difficult to determine what factor or combination of factors is impacting *Botrychium* populations (USDA Forest Service, Eastern Region 1999). Populations are inherently variable (Johnson-Groh 1999) but maintaining the health of the mycorrhizae seems to be an underlying necessity. Moisture relations are critical, as activities that dry the habitat may have deleterious effects on the population. One *B. lunaria* site in Minnesota is burned to maintain its open character (USDA Forest Service 2000). Given the general preference of *B. minganense* for open sites (Lellinger 1985), some kind of opening management may be a feasible management tool, although little information is available on the response of *B. minganense* populations to management of any kind.

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

Research and monitoring requirements

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

Almost no information is available on *B. minganense* life history in relation to disturbance and colonization of new sites. While its habitat is generally considered to be in somewhat open areas, it also occurs in forested habitats. Succession has been considered a threat (USDA Forest Service 2000), but it is unclear how *B. minganense* reacts to site changes over time.

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

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

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

Monitoring for this species is needed over a relatively long time span (at least 5 years), not only to mitigate for year by year variation in environmental conditions but because tagged *Botrychium* species are known to remain belowground, and then reappear after a lapse of one to several years (Montgomery 1990; Gehring and Potash 1995; Zika et al. 1995). In small populations, individual counts of the entire group should be made. In large populations, a representative sample of the population should be monitored through a randomized, permanent plot methodology. Individuals within each plot should be mapped as an aid to tracking, possibly providing detailed information pertaining to life span, dormancy, recruitment, etc.

Habitat monitoring is also a need for the species. Correlations between changes in habitat and reproductive success can give strong recommendations toward future management activities. Such monitoring will also indicate the appropriate time to initiate management activities. Perhaps the easiest and most effective way of monitoring habitat would be through permanent photo-points. Although photo-points may not provide the detailed information pertaining to species composition within a given site, rough changes in habitat should be observable. Photo-point analysis of canopy cover, and shrub and ground layer competition with respect to population trends would provide useful information for possible management procedures. Other more time-intensive procedures designed to statistically track changes in composition of the ground-layer associates at each site may be installed and monitored along with the methodology designed to track population trends, as discussed above.

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UNITED STATES
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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 Minganense* Element Occurrence Records

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

Element occurrence summary:

Michigan	na
Minnesota	33
Wisconsin	16

MINNESOTA

Location: Minnesota, St. Louis County
Ownership: Superior National Forest
Abundance: <20 plants in scattered singles, local, in old field and building site.
Habitat: open, well-drained sand and gravel. Plants mainly in short grass areas. scattered Vaccinium shrub cover.
Comments: Associated spp: *Fragaria virginiana, Trifolium* spp., *Achillea millefolium, Vaccinium angustifolium, Botrychium matricariifolium, B. lunaria, B. hesperium, B. multifidum* and *B. spathulatum*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, St. Louis County
Ownership: unknown
Abundance: unknown
Habitat: growing on trail.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, St. Louis County
Ownership: unknown
Abundance: unknown
Habitat: middle of old logging road.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Beltrami County
Ownership: Chippewa National Forest
Abundance: unknown
Habitat: maple-basswood-cedar stand.
Comments: with *Botrychium mormo*. Earthworms invading western 3/4 of stand.

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

Location: Minnesota, Cass County
Ownership: unknown
Abundance: unknown
Habitat: unknown
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Private
Abundance: infrequent
Habitat: infrequent along the upper edge of a small but fairly steep, bowl-like hollow in a mature, deciduous forest dominated by *Acer saccharum* and *Tilia americana*.
Comments: associated species include: *Actaea rubra, Dirca palustris, Uvularia grandiflora, Aralia nudicaulis,* and *Botrychium mormo*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: unknown
Habitat: mature, deciduous forest dominated by *Acer saccharum* and *Tilia americana*.
Comments: Associated species include *Botrychium mormo, B. virginianum, Aralia racemosa, Uvularia grandiflora,* and *Dirca palustris*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Leech Lake Reservation
Abundance: 4 plants observed
Habitat: plants occur in a second-growth deciduous forest dom by Acer saccharum and Tilia americana. On a plateau above the steep, south shore of Leech Lake.
Comments: Associated species include: *Uvularia grandiflora, Sanguinaria canadensis, Botrychium virginianum, B. Multifidum,* and *Monotropa hypopithys*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: unknown
Abundance: unknown
Habitat: predominantly maple-basswood, with several large cedar in immediate vicinity.
Comments: Associated species: *Carex pensylvanica, Botrychium mormo, B. virginianum, Aralia racemosa, Streptopus roseus*.

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

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: 6+ plants found in hardwoods,
Habitat: maple-basswood with cedar component.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: unknown
Abundance: infrequent
Habitat: plants growing in a deciduous forest dominated by *Acer saccharum* and *Tilia americana.*
Comments: associated with *Botrychium matricariifolium, B. virginianum, Uvularia grandiflora, Athyrium filix-femina.*
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: unknown
Habitat: deciduous forest
Comments: associated species include sugar maple, basswood, ash, ironwood and quaking aspen.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: 1 plant
Habitat: upland deciduous mix of maple-basswood type with sporadic balsam fir and aspen. Open overstory, damp soil with moderate plant cover.
Comments: associated species include *Aralia nudicaulis*, *Acer saccharum* seedlings, *Sanguinaria canadensis*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: 1 plant
Habitat: maple/basswood
Comments: large population of *B. matricariifolium* present at site.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County

Ownership: Chippewa National Forest
Abundance: 2 plants
Habitat: at edge of vernal pools in maple-basswood forest; moist soil with a rich organic layer.
Comments: associated with populations of *Botrychium matricariifolium* with *B. virginianum,* trillium, ash, ladyferns and lily-of-the-valley.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: three plants
Habitat: mature maple-basswood forest with aspen and large yellow birch.
Comments: understory mostly open. Found with *B. mormo*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cass County
Ownership: Chippewa National Forest
Abundance: unknown
Habitat: mesic deciduous forest dominated by *Acer saccharum* and *Tilia americana*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clearwater County
Ownership: Itasca State Park
Abundance: unknown
Habitat: under *Thuja*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Clearwater County
Ownership: Itasca State Park
Abundance: infrequent.
Habitat: hardwood forest
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Cook County
Ownership: Superior National Forest
Abundance: 2 plants
Habitat: in open field, sandy soil, of an old logging landing and sawmill in jack pine and red pine association. Evidence of recent fire.
Comments: Associated spp: *Danthonia spicata, Fragaria virginiana, Anaphalis margaritacea, Schizachne purpurescens, Oryzopsis asperifolia, Antennaria neglecta, Viola adunca, Poa compressa, Trifolium* spp., *Cornus stolonifera, Salix humilis, Arctostaphylos uva-ursi, Vaccinium angustifolium, Melampyrum lineare*. Seven other species of *Botrychium* at same site.

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

Location: Minnesota, Crow Wing County
Ownership: unknown
Abundance: two plants
Habitat: base of a mossy hillside on a narrow bench just above a beach, near the edge of a small pool in an old-growth maple-basswood forest
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: Chippewa National Forest
Abundance: unknown
Habitat: deciduously forested south shore of pigeon dam lake
Comments: 100+ plants plus additional *Botrychium* plants observed including *B. matricariifolium*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: Chippewa National Forest
Abundance: two plants
Habitat: *Acer-Tilia* stand on ridge. 90% canopy, shrubs <10%.
Comments: Associated spp: *Acer* seedlings, also *Ulmus, Acer spicatum, Prunus virginiana, Lonicera canadensis, Botrychium mormo.*
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: Chippewa National Forest
Abundance: one plant.
Habitat: base of a west-facing slope; plants occur in the transition from maple-basswood forest to marshy shoreline.
Comments: *Botrychium mormo* and *B. matricariifolium* also present.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: Chippewa National Forest
Abundance: 20 plants.
Habitat: plants occur along the edge of a low area in a deciduous forest with *Acer saccharum* and *Populus grandidentata*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Itasca County
Ownership: Chippewa National Forest
Abundance: 3 plants
Habitat: in tire tracks of an old logging road. habitat was a maple/ basswood/ birch mix. very little forb cover. compacted soil.
Comments: *B. matricariifolium* also present at site.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Kanabec County
Ownership: Private
Abundance: three plants
Habitat: mid-age oak forest dominated by multi-stem *Quercus rubra* and *Tilia americana. Populus grandidentata* in patches, *Acer saccharum* understory.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lake County
Ownership: Superior National Forest
Abundance: <20 plants
Habitat: on and near logging road which is not highly traveled. plants growing along crown of old logging road and in small adjacent clearing.
Comments: Associated spp: *Trifolium* sp., *Achillea millefolium,* short grasses, *Botrychium matricariifolium, B. lanceolatum* subsp. *lanceolatum, B. simplex, B. spathulatum*, *B. hesperium* and *B. multifidum.*
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lake County
Ownership: Superior National Forest
Abundance: <20 plants in scattered singles in an area currently used as a camp site and historically used as a log landing and/or home site.
Habitat: plants growing in areas of shorter grasses in full sun and under small pine clump in clearing.
Comments: Associated spp: *Trifolium* spp., *Achillea millefolium,* short grasses, *Botrychium simplex, B. matricariifolium, B. multifidum, B. rugulosum, B. dissectum* and *B. hesperium*.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lake County
Ownership: unknown
Abundance: unknown
Habitat: deep shade on a damp mossy ledge.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lake Of The Woods County
Ownership: unknown
Abundance: unknown
Habitat: unknown
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Lake Of The Woods County
Ownership: unknown
Abundance: 2-3 plants
Habitat: balsam-fir stand.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

Location: Minnesota, Norman County
Ownership: unknown
Abundance: unknown
Habitat: unknown
Comments: collected as *B. lunaria*, annotated by W.H. Wagner to *B. minganense* in 1970.
Source of information: Minnesota DNR, Natural Heritage and Nongame Research Program database report 2000.

WISCONSIN

Location: Wisconsin, Price County
Ownership: unknown
Abundance: unknown
Habitat: maple woods.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Chippewa County
Ownership: unknown
Abundance: unknown
Habitat: hemlock-spruce bog adjacent to maple-basswood forest.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Barron County
Ownership: unknown
Abundance: unknown
Habitat: maple-basswood forest.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Ashland County

Ownership: Chequamegon National Forest
Abundance: unknown
Habitat: second-growth maple woods.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Washburn County
Ownership: unknown
Abundance: unknown
Habitat: second-growth maple woods.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Sawyer County
Ownership: unknown
Abundance: unknown
Habitat: second-growth maple woods.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Rusk County
Ownership: unknown
Abundance: unknown
Habitat: Bog edge at maple-basswood forest.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Bayfield County
Ownership: unknown
Abundance: unknown
Habitat: unknown
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Douglas County
Ownership: unknown
Abundance: unknown
Habitat: maple woods.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Sawyer County
Ownership: Chequamegon National Forest
Abundance: 10-15+ fertile stems
Habitat: rich sugar maple forest; 0-2% east-aspect slope; moist, loamy soil with silt cap; low to moderate light levels.

Comments: other moonworts present.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Ashland County
Ownership: Apostle Island National Lakeshore
Abundance: unknown
Habitat: unknown
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Ashland County
Ownership: Apostle Island National Lakeshore
Abundance: "rare."
Habitat: bare eroding clay.
Comments: tentative identification by W.H. Wagner based on poor specimen.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Ashland County
Ownership: Chequamegon National Forest
Abundance: 3 stems
Habitat: Northern hardwood forest dominated by sugar maple-basswood. Undergrowth fairly sparse, with patches of *Carex pensylvanica*. Site has an east-aspect, with less than 5% slope.
Comments:
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Bayfield County
Ownership: Chequamegon National Forest
Abundance: 3 flowering stems.
Habitat: Open, fluctuating shoreline of small pond surrounded by white pine and Corylus cornuta. Soils are moist sands.
Comments: Associated species include *Calamagrostis canadensis, Glyceria canadensis, Rumex acetocella*, and species of *Solidago, Panicum, Viola, Fragaria, Hieracium, Potentilla, Lycopus,* and *Carex. Botrychium matricariifolium* and *B. multifidum* also present.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Door County
Ownership: Newport State Park
Abundance: one plant
Habitat: unknown
Comments: reported near a trail "in scrubby area."
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Location: Wisconsin, Forest County
Ownership: Chequamegon-Nicolet National Forest
Abundance: 2 stems.

Habitat: Sugar maple-basswood-beech forest, in thin organic soil on rock shelf (part of a large shaded rock outcrop).
Comments: *Sambucus pubens* and *Ribes* spp. nearby.
Source of information: Wisconsin Natural Heritage Program Element Occurrence Record, 2000.

Appendix B. *botrychium* Status and threats summary

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

Table 1. *Botrychium* status.

	status			
	minnesota	**michigan**	**wisconsin**	**global/national**
B. campestre	SC (S3)	T (S2)	E (S1)	G3/N3
B. dissectum	(not listed) SU	(not listed) S?	(not listed) SR	G5/N5
B. hesperium (B. michiganense)	(not listed)	T (S1S2)	(absent)	G3/N2
B. lanceolatum var. angustisegmentum	T (SR)	(not listed) S4	(not listed) S3	G5/N4
B. lunaria	T (S2)	(not listed) S?	E (S1)	G5/N4?
B. minganense	SC (S3)	(not listed) S?	SC (S2)	G4/N?
B. mormo	SC (S3)	T (S1S2)	E (S2)	G3/N3
B. oneidense	E (S1)	(not listed) S?	SC (S2)	G4Q/N4
B. pallidum	E (S1)	SC (S3)	(absent)	G2G3/N2N3
B. pseudopinnatum	(not listed) S?	(absent)	(not listed)	G1/N1
B. rugulosum	T (S2)	(not listed) S3	SC (S2)	G3/N3
B. simplex	SC (S3)	(not listed) S?	(not listed) S?	G5/N5
B. spathulatum	(not listed) S?	(not listed) S3	SC (S1)	G3/N3

Key
Status:
E = state endangered
T = state threatened
SC = state special concern
S1 = state rankings (see Appendix B)
absent = taxon not known from state

not listed = taxon not tracked by state natural heritage program.
Global/National – worldwide or United States ranking provided by NatureServe (2001, see Appendix B. for definitions).

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

taxon	range	habitat amplitude	pop trend	habitat integrity	vulnerability
B. campestre	wide, disjunct	intermediate	unknown	fair	medium
B. dissectum	wide	broad	increasing	fair	low
B. hesperium (B. michiganense)	endemic	intermediate	stable	fair	medium
B. lanceolatum var. *angustisegmentum*	wide	intermediate	increasing	fair	low
B. lunaria	wide	broad	stable	fair	medium
B. minganense	wide	broad	increasing	good	low
B. mormo	endemic	narrow	decreasing	fair	high
B. oneidense	wide	intermediate	unknown	fair	medium
B. pallidum	narrow	broad	stable	fair	low
B.pseudopinnatum	endemic	narrow	unknown	poor	high
B. rugulosum	narrow	intermediate	stable	fair	low
B. simplex	wide	broad	increasing	good	low
B. spathulatum	narrow	intermediate	unknown	fair	medium

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

Table 3. Major threats to *Botrychium*.

	threat					
	exotic earthworms	**exotic plants**	**canopy thinning**	**succession to closed canopy**	**disturbance**	
					major	**minor**
B. campestre	low	medium	low	high	medium	low
B. dissectum	medium	medium	medium	low	high	medium
B. hesperium (B. michiganense)	medium (forested sites) low (other sites)	medium-high	low	low-medium	medium	low
B. lanceolatum var. *angustisegmentum*	high	medium	medium	low	medium	low
B. lunaria	low	medium	low	medium	medium	low
B. minganense	high	medium	medium	low	medium	medium
B. mormo	high	low	high	low	high	medium
B. oneidense	high	medium	medium-high	low	high	medium-high
B. pallidum	low	high	low	high	medium	low
B.pseudopinnatum	low	high	low	high	medium	low
B. rugulosum	low	medium	low	high	high	medium
B. simplex	medium	medium	low	medium	medium	low
B. spathulatum	low	high	low	high	medium	low

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

APPENDIX C. GLOBAL, NATIONAL, AND SUBNATIONAL CONSERVATION STATUS RANKS (FROM NATURESERVE, www.natureserve.org).

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

Global, National, and Subnational Conservation Status Ranks

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

What the Ranks Mean

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

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

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

Rank Definitions

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

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

Assessment Criteria

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

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

For species elements, the following factors are considered in assigning a rank:
total number and condition of occurrences
population size
range extent and area of occupancy
short- and long-term trends in the foregoing factors
threats
fragility.

Secondary factors include the geographic range over which the element occurs, threats to occurrences, and viability of the occurrences. However, it is often necessary to establish

preliminary ranks for communities when information on these factors is not complete. This is particularly true for communities that have not been well described. In practice, a preliminary assessment of a community's range-wide global rank is often based on the following:
geographic range over which the element occurs
long-term trend of the element across this range
short-term trend (i.e., threats)
degree of site/environmental specificity exhibited by the element
rarity across the range as indicated by subnational ranks assigned by Heritage data centers.

Global Heritage Status Rank Definitions

Rank	Definition
GX	Presumed Extinct—Believed to be extinct throughout its range. Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
GH	Possibly Extinct (species)—Known from only historical occurrences, but may nevertheless still be extant; further searching needed.
G1	Critically Imperiled—Critically imperiled globally because of extreme rarity or because of some factor(s) making it especially vulnerable to extinction. Typically 5 or fewer occurrences or very few remaining individuals (<1,000).
G2	Imperiled—Imperiled globally because of rarity or because of some factor(s) making it very vulnerable to extinction or elimination. Typically 6 to 20 occurrences or few remaining individuals (1,000 to 3,000).
G3	Vulnerable—Vulnerable globally either because very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction or elimination. Typically 21 to 100 occurrences or between 3,000 and 10,000 individuals.
G4	Apparently Secure—Uncommon but not rare (although it may be rare in parts of its range, particularly on the periphery), and usually widespread. Apparently not vulnerable in most of its range, but possibly cause for long-term concern. Typically more than 100 occurrences and more than 10,000 individuals.
G5	Secure—Common, widespread, and abundant (although it may be rare in parts of its range, particularly on the periphery). Not vulnerable in most of its range. Typically with considerably more than 100 occurrences and more than 10,000 individuals.

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

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

APPENDIX D. CONTRACTOR QUALIFICATIONS AND EXPERIENCE

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

Contact Information

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Statement of Qualifications – Steve W. Chadde

Recent Experience

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

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

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

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

Education

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

Publications

Chadde, Steve. 2000. Natural Features Survey, Lake Superior Shoreline, Marquette County, Michigan. Contract report prepared for Central Lake Superior Watershed Partnership, Marquette.
Chadde, Steve. 1999. A Forester's Field Guide to the Endangered and Threatened Plants of Michigan's Upper Peninsula. Contract report prepared for Mead Corporation, Champion International Corporation, and Shelter Bay Forests.
Chadde, Steve. 1998. A Great Lakes Wetland Flora - A Complete, Illustrated Guide to the Aquatic and Wetland Plants of the Upper Midwest. PocketFlora Press, Calumet, MI. 584 p.
Chadde, Steve, and others. 1998. Peatlands on National Forests of the Northern Rocky Mountains: Ecology and Conservation. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-11. Ogden, UT.
Chadde, Steve. 1996. Plants of the Copper Country - An Illustrated Guide to the Vascular Plants of Houghton and Keweenaw Counties, Michigan, and Isle Royale National Park. PocketFlora Press, Calumet, MI. 112 p.
Chadde, Steve. 1996. Plants of Pictured Rocks National Lakeshore – A Complete, Illustrated Guide to the Plant's of America's First National Lakeshore. PocketFlora Press, Calumet, MI. 103 p.
Chadde, Steve. 1995. Ecological Evaluation - Findlayson Property, Chippewa County, Michigan. Contract report prepared for Michigan Chapter, The Nature Conservancy.
Chadde, Steve. 1995. Research Natural Areas of the Northern Region: Status and Needs Assessment. USDA Forest Service, Northern Region, Missoula, MT. 164 p.
Rabe, Fred, and Steve Chadde. 1995. Aquatic Features of Research Natural Areas of the Kootenai and Flathead National Forests, Montana. USDA Forest Service, Northern Region, Missoula, MT. 66 p. plus appendices.
Rabe, Fred, and Steve Chadde. 1994. Classification of Aquatic and Semiaquatic Wetland Natural Areas in Idaho and Western Montana. Natural Areas Journal 14(3): 175-187.

Statement of Qualifications – Dr. Greg Kudray

Recent Experience

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

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

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

EDUCATION

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

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

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