

*Conservation Assessment
for
Net-veined Chain Fern, (Woodwardia areolata (L.) T. Moore)*



Photo credit: Angelina M. Trombley

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This document is undergoing peer review, comments welcome

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EXECUTIVE SUMMARY

Woodwardia areolata is a long-lived perennial fern common to moist habitats of the southeastern United States. It is ranked G5 globally. In the southern tier states in Forest Service Region 9 it occurs as scattered isolated populations. It is ranked S2 in Missouri, Illinois, Indiana, Ohio and Pennsylvania, S1 in West Virginia. Because many of the Region 9 sites have been discovered in recent decades, *W. areolata* has been thought to be actively migrating northward. In 2003 the author studied 15 current and 2 former populations sites in Missouri, Illinois and Indiana recording habitat and population data including colony sizes and growth rates, reproduction and breeding system, and population genetic structure.

Region 9 populations occur in two distinct habitats: on moist sandstone cliffs and on moist acid soils, the latter often associated with seeps. Populations in either habitat may be under complete canopy shade or in open sun. Populations on soil tend to be more or less isodiametric in shape, consisting of dense rhizome mats in which rhizomes extend their apices at a rate of about eight centimeters per year. Populations on sandstone are configured according to available supportive habitat and grow somewhat more slowly, averaging three to five centimeters per year. Most populations produce few or no fertile fronds, the number increasing in more exposed populations.

Evidence of sexual reproduction was detected in only three sites, all on sandstone cliffs and consisting of a few small sporophytes at the base of the cliffs. Spores collected from natural populations germinated readily and gametophyte plants grew rapidly and normally. Both gametophytes in populations and single gametophytes grown in isolation produced sporophytes with no evidence of genetic load that might prevent sporophyte production in self-fertilized gametophyte plants. Thus an isolated spore is theoretically capable of starting a new sporophyte population, adapting the species to efficient long-distance dispersal.

Scarcity of local reproduction via spores may be related to the small number of fertile fronds produced by most populations, and especially to the observation that the indusial tissue that covers sporangia during development fails to open at spore maturity but instead remains tightly covering the sporangia and preventing the release of spores even into subsequent years. [This behavior was also observed in *Woodwardia fimbriata* and may characteristic of the genus.]

Genetic analysis of Region 9 populations and populations from the heart of the species' range in Arkansas and Alabama revealed very low allelic variation. Of 13 scorable loci in 9 enzyme systems, only one displayed variation, that consisting of 2 alleles. All Region 9 populations were invariable, containing only one or the other of the possible alleles at the variable locus (Pgm 2).

The compact physical structure of *Woodwardia areolata* colonies, the absence of sexual reproduction, and the genetic invariability of all populations in Region 9 suggest that most colonies are clones derived from a single founding spore. Assuming they are clones, minimum

ages estimated from average clone expansion rates range up to 50 years with some possibly much older (over 100 years). These ages may correspond to periods of habitat disturbance--many sites are described as in young or successional forests, others are in road ditches, mine drainages and man-made pond drainages. Thus historic disturbance may have been important to site colonization and current colonization may not be as active as has been presumed.

Populations of *Woodwardia areolata* on sandstone cliffs and on stable forest floors appear vigorous and unthreatened by competition or other immediate threats. They are probably most vulnerable to regional disturbance, such as forest clearing, that alter the hydrology of their habitats, interrupting a continuous moisture supply. Plants in roadside ditches and similar temporary habitats are threatened by competition from aggressive roadside vegetation and by roadside management activities, including those that alter the hydrology of the site.

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NOMENCLATURE AND TAXONOMY

Woodwardia areolata (Linnaeus) T. Moore

Synonyms: *Lorinseria areolata* (Linnaeus) Presl
Woodwardia angustifolia Smith
Woodwardia onocleoides Willdenow

Common Name: Net-veined Chain Fern, Netted Chain Fern

The species is sometimes treated in *Lorinseria* and distinguished from *Woodwardia* by its dimorphic leaves, the sori of fertile leaves being produced on much narrowed pinnae. Occasional production of intermediate leaves with sori on broad pinnae renders this distinction insufficient to warrant generic segregation from *Woodwardia*. The name *areolata* is from the Latin *areolatus* (a small space) and refers to the islands of tissue enclosed by the veins. (Lellinger 1985, Tryon and Moran 1997)

DESCRIPTION OF SPECIES

Rhizomes long-creeping, blackish, slightly subterranean; fronds dimorphic; stipes distant, sparsely scaly, the sterile ones (7)10-40 cm long, reddish-brown at the base, straw-colored above the base, often narrowly alate at the apex, the fertile ones 13-60 cm long, dark reddish-brown or purplish-black, not alate at the apex; sterile laminae ovate-lanceolate to oblong, 10-37 cm long, 5.5-20 cm wide, pinnate at the base, pinnatifid above the base, the rachises narrowly to broadly alate, the pinnae and segments narrowly elliptic to oblong, slightly undulate, acute at the apex; fertile laminae oblong, 15-35 cm long, 6-18 cm wide, pinnate throughout, the rachises not alate, the pinnae linear. (Lellinger 1985)

LIFE HISTORY

Reproduction

Sexual reproduction. Like other homosporous ferns, *Woodwardia areolata* has two independent generations, a diploid, spore-producing sporophyte and a haploid, gametophyte-producing gametophyte. Each spore is genetically capable of producing a bisexual gametophyte that theoretically can, by intragametophytic selfing, produce a sporophyte. Such sporophytes are genetically completely homozygous and express all alleles, including deleterious alleles. In species with high genetic loads (high numbers of deleterious alleles) intragametophytic selfing often results in aborted or inviable sporophytes.

To avoid the problem of intragametophytic selfing, many fern species have a physiological system that prevents simultaneous production of male and female gametangia on the same gametophyte. This is accomplished by a hormone (or pheromone) called antheridiogen that fast-growing gametophytes secrete into the environment. The antheridiogen chemical causes slower-growing gametophytes in the population to become male while the fast-growing gametophytes become female. Male and female gametangia mature simultaneously, promoting cross fertilization, heterozygosity, and avoidance of inbreeding depression. In a modified version of this pattern, fast-growing gametophytes may initially become female, then, if cross fertilization is not achieved, become bisexual. Initially male gametophytes may also eventually become female or bisexual in some species.

A number of fern species have been shown to regularly become bisexual and undergo intragametophytic selfing. These species are often exceptionally good colonizers of distant habitats because of the ability of an isolated spore (the condition generally resulting from long-distance dispersal) to produce a sporophyte. Such species have essentially purged themselves of deleterious alleles, but as a consequence, often have very low genetic variability.

Woodwardia areolata was examined genetically via starch-gel enzyme electrophoresis to assess its genetic variability. Eight leaves were sampled from the periphery of each of two populations in Indiana, 4 populations in Illinois and 4 populations in Missouri. An additional leaf from each of two small populations in Indiana was sampled. Of 13 scorable loci in 9 enzyme systems, genetic variability was found at only one locus. This single variant allele (a fast allele

for PhosphoGlucoMutase locus 2) was present in all plants of the three southernmost Missouri populations sampled (Holly Ridge, Pump Hollow and FS Road 3878). All other populations, including a population from Iron County in Missouri shared the same genotype, a genotype also identical to that of a population sampled from Central Arkansas in the heart of the species range. In a sampling of three populations from southern Alabama where *Woodwardia aerolata* is common the PGM locus was again the only variable locus. The southern Missouri variant allele was present in each Alabama population in about 25% of the plants. Thus the extremely low genetic variability observed in *Woodwardia aerolata* in Region 9 appears to be characteristic of the species across its range and not a consequence of founder effect or genetic drift in small populations

The extremely low genetic variability of *Woodwardia areolata* plus its isolated occurrences throughout the northern extremities of its range suggests that the species is capable of intragametophytic selfing. To further test this hypothesis, gametophytes were grown in culture from spores obtained from a population in Indiana (EO # 11). Uncrowded gametophytes grown in population cultures initially became female (in about 1 month) whereas crowded gametophytes (> 10/cm²) became male and/or female. Gametophytes grown in isolation all became female over the same time period.

To test for the production of a chemical antheridiogen by mature female gametophytes, new spores were sown among the mature gametophytes. Three weeks from sowing, these new gametophytes produced numerous antheridia without first becoming female. This strongly indicates operation of an antheridiogen system in *Woodwardia areolata*.

After six weeks, large female gametophytes were examined microscopically for presence of antheridia. A few antheridia were found and swimming sperm seen. At this time both population cultures and isolated gametophytes were watered to facilitate fertilization. Within two weeks most (63%) of the isolated gametophytes had produced sporophytes and sporophytes were numerous in the population cultures. Sporophytes from both isolated and population cultures appeared normal and healthy after six months in culture.

In the field, evidence of sexual reproduction (gametophytes with small sporophytes) was observed at three sites, all on moist sandstone cliffs (German Ridge in Indiana; Jackson Hollow and Dixon Springs in Illinois). In each case fewer than 20 juvenile sporophytes were present.

From these experiments, it appears that *Woodwardia areolata*, through its antheridiogen system, has a breeding system adapted to promote cross-fertilization when gametophytes occur in dense populations, but is also capable of intragametophytic self-fertilization. The latter permits sporophyte production by gametophytes occurring in isolation following long-distance dispersal (but see discussion of spore production and release under **Dispersal**). The latter is consistent with the species' occurrence patterns in Region 9 and with the observed homogeneity of all populations tested..

Asexual reproduction. As discussed above, the extremely low genetic variability found in *Woodwardia areolata* is apparently characteristic of the species throughout its range. Nevertheless, the variability present at the PGM locus would be expected to be present within

some populations if they were founded by multiple spores. That is not the case in Region 9 *Woodwardia areolata* where all colonies examined from Indiana and Illinois and Missouri were homozygous for one or the other allele. This result would be expected if each of the colonies was founded by a single spore.

Another factor that leads to low genetic variability within populations is heavy reliance on vegetative reproduction. Colonies of long-lived perennial plants become progressively less diverse over time as different clones compete or are passively selected through fluctuations in population size, eventually resulting in persistence of a single clone. If this clone is also capable of dispersal, either vegetatively or by spores (intragametophytic selfing is genetically equivalent to vegetative reproduction since sperm and egg are derived from the same initial haploid cell, the spore), this effect of vegetative reproduction (reduced genetic variability) can spread throughout the species range.

Woodwardia areolata is capable of several means of vegetative reproduction. The rhizomes (horizontally creeping stems) extend annually (about 8 cm) and periodically fork to produce additional apices. An actively growing clone thus extends its periphery by about 8 cm per year. Internally the clone also maintains branching rhizomes so that the clone exists as a dense mat. When healthy, the mat is sufficiently dense to exclude growth of other vegetation.

Though not directly witnessed, *Woodwardia areolata* is undoubtedly also capable of dispersing vegetatively over some distance. In two of the observed populations growing along small streams, vigorous leaf-bearing but unrooted rhizomes on the stream side were extending into the flowing water. Under conditions of high flow these rhizomes could be broken off and deposited at suitable locations downstream. At Holly Springs in Missouri, four separate colonies have been reported within ½ mile along the same stream system.

One common habitat of *Woodwardia areolata* is roadside ditches. It is conceivable that roadwork could distribute rhizomes from one site to another.

The growth form of most of the colonies observed in this study suggests that they are single clones. Characteristics indicative of clonal growth include:

1. Most colonies are composed of a continuous dense mat of rhizomes.
2. When not limited by habitat change, colonies are more or less isodiametric and display a vigorously growing “front” around their periphery.
3. Isolated plants do not exist even where the habitat extends well beyond the colony. An exception exists where large colonies extend over heterogeneous sandstone cliffs. In this habitat, plants may be isolated in favorable pockets and crevices. However, in Jackson Hollow in Illinois, this is the documented result of a previously continuous colony sloughing rhizome mats from more or less smooth surfaces between favorable pockets and crevices. [In 2000 the colony was observed as a continuous mat. In 2003 isolated fragments remained on the cliff with dead rhizome mats at the cliff base.]

Ecology

Woodwardia areolata is a long-lived perennial. Assuming a single introduction followed by clonal growth from the center out was at an average rate of 8 cm per year, minimum ages of the colonies observed in this study ranged up to 50 years. A clone in Jackson Hollow, Illinois first recorded as a single rhizome in 1965 had a maximum width of 2.3 M in 2003. Average actual clonal expansion determined for this clone was 3 cm per year in each direction. Applying this figure for average annual rhizome extension yields a minimum age of 133 years for the largest observed colony where sexual reproduction was not present. This age is consistent with ages determined for other clonal ferns (direct determinations up to 300 yr; indirect determinations of several thousand years).

Woodwardia areolata occurs in both mature woodlands under closed canopy and in open habitats such as cliffs and in roadside ditches. In the latter habitat it displays evidence of an ability to colonize recently disturbed habitats. It is limited to acidic, non-calcareous substrates supplying more or less continuous moisture. Its westernmost distribution in Texas and Oklahoma may be limited by absence of such sites. Its maximum extension inland from the coast (including Region 9 occurrences) has been reported to correspond with a winter minimum mean temperature of -4.5°C (Cranfill 1983).

Cranfill (1983) suggested that the occurrence of *Woodwardia areolata* on sandstone cliffs in the northern part of its range may reflect lower competitive ability of the species in northern seeps and bogs and higher competitive ability on sparsely vegetated cliffs. This interpretation is not consistent with observations of this study in Region 9. Colonies of *Woodwardia areolata* in seep and bog habitats under closed canopy appear to have very little competition. Furthermore, they are growing vigorously and appear to have grown over and eliminated any competing vegetation. Only one colony was observed to be suffering from competition, that in a roadside ditch where an introduced annual grass (*Microstegium vimineum*) and introduced Japanese honeysuckle (*Lonicera japonica*) appeared to have overgrown and killed much of the colony.

On sandstone sites, initial colonization by *Woodwardia areolata* must be accomplished by the gametophyte generation, thus it can occur only where adequate moisture is present. Such sites in crevices and pockets are occupied by a large number of bryophyte, pteridophyte and angiosperm species, but the gametophyte of most ferns has an advantage in these habitats in its ability to grow in deep dark crevices, taking advantage of very small microsites. Once established, sporophytes of *Woodwardia areolata* can vegetatively grow out over the sandstone cliff by rhizome extension. The Pennsylvanian sandstones of southern Illinois and Indiana are acidic, non-calcareous, and extremely stable. Because these sandstones are also porous, they retain a reservoir of moisture. Cliff exposures with appropriate aspect and bedding plane slope can supply constant moisture to *Woodwardia areolata* colonies much the same as soil seeps and permanent streams (Farrar 1998).

Dispersal/Migration

Dispersal. Dispersal of propagules in ferns is typically by production and release of spores from sporophyte fronds. Spore numbers are prodigious. For a fertile frond the size of

those produced by *Woodwardia areolata*, the number is usually in excess of 100,000. Usually spores are released during the growing season, but several species, including *Woodwardia areolata* have extended spore release over the winter season and into the following year. When spores are released, their distribution follows a leptokurtic pattern whereby most spores are deposited within a few meters of the parent sporophyte. Therefore only nearby habitats (e.g. within 10 meters of the source) can safely be assumed to receive large numbers of spores. However, if only one percent becomes airborne on wind currents, then 1000 spores per frond may leave the immediate habitat. Frequent observation of plants of some species established many miles distant from any source population attest to the high dispersal capability of fern species (Peck et. al 1990).

Spore dispersal is not equivalent to migration for all species. Many species appear to be incapable of migrating long distances. This is due to two primary factors. First, the spore must land in a microsite suitable for germination, gametophyte growth and subsequent sporophyte growth. Second, a spore dispersed out of the local habitat is likely to grow in effective isolation from others of its species. Thus it is necessary for the isolated gametophyte to become bisexual and, if bisexuality is accomplished, to be sufficiently free of deleterious alleles to withstand the level of inbreeding depression associated with intragametophytic selfing (Dassler and Farrar 2001, Chiou et al.1998).

Fern species also vary as to the efficiency of spore release from their spore-producing fronds. For reasons unknown, some species fail to shed the indusial cover (vegetative structure that covers the sporangia during development) that encloses their sporangia. This is the case in *Woodwardia areolata* where a thick indusium remains tightly wrapped around the sorus (group of sporangia) indefinitely. Fertile fronds produced in 2002 still contained unopened indusia in October of 2003. Spores from these fronds germinated readily upon sowing in culture. Likely they would be viable and could germinate when the fertile frond eventually falls and rots, but as a dispersal mechanism, this could be effective only on steep cliffs or if the remains of the frond are transported by water.

The permanently closed indusium in *Woodwardia areolata* does not seem to be an effect of growing in an unfavorable habitat. James Peck (personal communication) reports similar behavior of *Woodwardia areolata* in Central Arkansas in the heart of its range. Plants of *Woodwardia fimbriata* in California also failed to open or shed their indusia when dried. [To obtain spores for culture studies of these two species it was necessary to slit the indusia with a razor blade.]

The number of fertile fronds produced is also unusually low in R9 colonies of *Woodwardia areolata* (Table 1). Whereas the ratio of fertile fronds to stem apices in most ferns exceeds 1, this ratio in *Woodwardia areolata* was generally less than 0.1 with five of 13 colonies having produced no fertile fronds in 2003. Two colonies with somewhat higher ratios (.26 and .40) grew in more or less open habitats, suggesting that light intensity and therefore total carbon accumulation may influence the ability of *Woodwardia areolata* to produce fertile fronds.

The low production of fertile fronds combined with a general failure of *Woodwardia areolata* to release spores from fertile fronds may explain, in part, the absence of additional

sexually produced plants in the immediate vicinity of most of the colonies examined in this study.

Migration. Most of the sites for *Woodwardia areolata* in FS Region 9 have been discovered within the last few decades. This has understandably led to the assumption that *Woodwardia areolata* is has recently become established and continues to expand its R9 occurrences. Estimated ages of existing colonies, based on the assumption that they are clones resulting from a single founding event, indicate that many of these colonies are much older than assumed. For example, the colony in Iron County Missouri, the second most northerly site for *Woodwardia areolata* known in the state has an estimated minimum age of 50 years (assuming the clone expanded from the center to the margins at a rate of 16 centimeters per year) and could be considerably older if years of poor growth occurred. Considering this possible age together with the known ability of *Woodwardia areolata* to colonize disturbed areas, it is conceivable that this site may have been colonized following clearcutting of the site in the mid 1900's. In Indiana most non-FS sites are in moist "flat woods" described as being young regrowth. The average diameter of these colonies was 1-3 meters with a minimum estimated age, assuming they are clones, of 6-18 years when discovered mostly 15 to 20 years ago. Possibly these also became established following timber harvest in the sites. Estimated ages of Illinois, Missouri and Ohio colonies give similar results (Table 2). Viewed in this perspective, *Woodwardia areolata* may not be increasing in abundance in Region 9, but rather in an equilibrium state, or possibly even less abundant than it may have been following periods of more frequent disturbance in these areas.

The above scenario rests on an assumption of a clonal nature of existing colonies. Colony characteristics discussed above (under Asexual Reproduction) are consistent with this interpretation. Genetic evidence for clonal structure has been obtained for some ferns through starch-gel enzyme electrophoresis. It is of some significance that the Iron Co. colony discussed above is genetically uniform and differs from the other three Missouri colonies tested. Unfortunately, the absence of genetic variation within and among most colonies precludes this being a strong source of evidence for the clonal nature of *Woodwardia areolata*.

Obligate Associations

No obligate associations are known for *Woodwardia areolata*.

HABITAT

Range-wide

Range-wide, *Woodwardia areolata* is typically associated with three types of habitat—moist to mucky acid soils of natural seeps, soils at the edge of small permanent streams flowing over acidic substrates, and acidic sandstone outcrops (Cranfill 1983). In addition to natural occurrences, supportive habitats of both types may be associated with man-made disturbance. Roadside ditches and shoulders often provide suitable soil substrate, as do seeps from artificial ponds, especially those formed in coal strip-mine debris. Occasionally plants occur on road and

railroad cuts through sandstone rock. In southern Illinois several populations are known on the sides of canyon-like railroad cuts leading to tunnel entrances. Supportive habitats may be under closed-canopy deciduous forests or in open sunlight so long as the moisture supply is relatively continuous.

National Forests

In Region 9 National Forests *Woodwardia areolata* occurs in all the habitat types described above. Information below was obtained from databases maintained by the Natural Heritage Programs of Indiana, Missouri, Ohio and West Virginia, the Illinois Plant Information Network, The MarkTwain, Shawnee, Hoosier, *Woodwardia aerolatayne* and Monongahela National Forests, and from personal observations of *Woodwardia areolata* populations in Missouri, Illinois and Indiana.

Indiana

In Indiana most NF sites are on natural outcrops of Pennsylvanian sandstone, occurring under the canopy of mature deciduous forests. One historic site (now extirpated) was in a roadside ditch that now appears relatively dry and no longer contains any plants. A vigorous colony near Indian Lake in Perry County grows at the base of a small (1 M) sandstone outcrop on the road shoulder that extends to the base of the roadside ditch where the colony grows on soil as well. Fourteen additional sites are listed in the Indiana Natural Heritage Database, occurring in Harrison, Jefferson, Jennings, Perry, Porter and Ripley Counties. All of these non-National Forest sites are in wet to moist flat woods, mostly in young successional forests, most colonies occupying 1-5 yd². One site is in acid mine drainage.

Illinois

In Illinois the largest NF colonies grow on moist sandstone cliffs of natural exposures and on canyon-like railroad cuts in these sandstones near the entrances to tunnels. Smaller colonies also occur in roadside ditches. Data was not obtained for non-National Forest sites. *Woodwardia areolata* likely also occurs in young moist flatwoods and acid mine seeps as it does in Indiana and Ohio.

Missouri

In Missouri all NF sites are on soil, either on the edge of small permanent streams or in boggy acid seeps in bottomland. In one of the latter, MO EO 9, *Woodwardia areolata* grows with *Sphagnum angustifolium*, also a FS sensitive species. We did not find *Woodwardia areolata* at a historic site (MO E0 5) in the drainage from a small man-made pond of unknown age. This occurrence was recorded in 1987. This site may have become too dry as the drainage has breached a small debris dam below the main dam that may have initially retained seepage water. Below dam seepage from other ponds in the area maintain continuously saturated soil supporting *Cephalanthus occidentalis* and other wetland plants. These other ponds were present when acquired by the Forest Service in 1936 (personal communication from Angelina Trombley,

Wildlife biologist for the Mark Twain NF in Poplar Bluff). No information on the age of the pond supporting *Woodwardia areolata* was available.

The Missouri Natural Heritage database lists 17 occurrences of *Woodwardia areolata*, 5 of these on National Forest and 1, the Holly Ridge sites, partly on Missouri Department of Conservation land. Privately owned sites are in Barton, Bollinger, Callaway, Lawrence, Ripley and Stoddard counties. All are in acid seeps or along streams except those in Callaway (the northernmost) and Lawrence the westernmost) counties where colonies of *Woodwardia areolata* occur on moist sandstone cliffs.

Ohio

Two National Forest sites occur in Ohio, one in an acidic soil seep, the other on a mesic wooded slope. In addition to these sites in Athens and Hocking counties, the Ohio Natural Heritage database lists non-NF occurrences of *Woodwardia areolata* in Adams, Athens, Gallia, Hocking, Jackson, Meigs and Vinton counties, all in the southern part of the state. The non-NF occurrences (27) are primarily in mesic woods (5), often associated with seeps (7), especially acid seeps associated with mine spoils (10). Occasional occurrences are on sandstone cliffs (2), roadside ditches (2) and along small streams (1).

West Virginia

In the West Virginia National Forest site *Woodwardia areolata* was recorded in Cranberry Glades in Pocahontas County in 1941. It has not been observed there since that time. Presumably this occurrence was in a bog habitat similar to its other Pocahontas site in a mountaintop sphagnum bog on Droop Mountain. The West Virginia Natural Heritage Database lists a total of six sites in Greenbrier, Hancock, Mineral, Pocahontas and Upshur counties. The Upshur County site is thought to be introduced. Occurrences other than in Pocahontas County are in mesic woods. The Hancock County site is owned by the WVDNR.

Site Specific

The following tables summarize the known extant and extirpated records for *Woodwardia areolata* occurrences in FS Region 9. Table 1 includes all sites; Table 2 summarizes detailed information obtained from site visits made by the author in October 2003. Habitat information, except for sites visited, is determined from EO records and maps and may not be precisely correct in all cases. Exact locations can be obtained from State Heritage and Forest Service databases.

Table 1. Occurrence Records of *Woodwardia areolata* on National Forest and State Owned Lands in Forest Service Region 9.

Indiana

Site Name	County	EO #	Largest recorded size	Size in 2003	Habitat	First Observed	Last Observed
Peter Cave Hollow	Perry	002	This study	0.2 M	Sandstone bluff, shaded	2000	2003
Peter Cave Hollow	Perry	New	This study	0.25 M	Sandstone bluff, shaded	2003	2003
Rockhouse Hollow	Perry	003	4 M ² in 1987	extirpated	FS road ditch, partly shaded	1987	1987
Indian Lake	Perry	011	This study	4.3 x 1 M	Road ditch and sandstone ledge, partly sunny	1992	2003
German Ridge	Perry	017	This study	9 x 1 M	Sandstone bluff, shaded	2001	2003
Indian Fork Creek	Perry	018	1.8 M x 0.6 M	Not seen	Sandstone cliff 2.6 M above creek, shaded	2001	2001

Illinois

Site Name	County	EO #	Largest recorded size	Size in 2003	Habitat	First Observed	Last Observed
Cardiz Site	Hardin			Not seen	Along sandstone chute		
Benson's Bluff	Johnson			Not seen	Sandstone chute and few on shaded bluff		
Tunnel Hill	Johnson			Not seen	Sandstone railroad cut		
Mill Spring	Massac		This study	5.0 x 0.6 M	Road shoulder above ditch		2003
Jackson Hollow	Pope			Not seen	Sandstone, head of canyon		
Jackson Hollow	Pope	New	This study	2.3 x 2.0 M	Sandstone, north wall of canyon, trail colony	1965	2003
Jackson Hollow	Pope	New	This study	45.0 x 9 M	Sandstone cliff, north canyon wall, main colony	2000	2003
Jackson Hollow	Pope			Not seen	Sandstone canyon 1 mi south of Jackson Hollow		
Little Bay Creek	Pope			Not seen	Sandstone boulder face		
Little Bay Creek	Pope			Not seen	Railroad cut south of entrance to tunnel		
Bell Smith Springs	Pope			Not seen	Sandstone along Spring Branch		
Dixon Springs	Pope		This study	6.5 x 1.0 M	Sandstone wall of narrow canyon	1977	2003
Massac Tower	Pope			Not seen	Seep springs		
Hayes Creek	Pope			Not seen	Sandstone		

Missouri

Site Name	County	EO #	Largest recorded size	Size in 2003	Habitat	First Observed	Last Observed
Holly Ridge	Stoddard	002	6 plants in 1955	Not seen	Spring branch	1955	1955
Holly Ridge	Stoddard	003	2 M ² in 1992	Not seen	Swampy ground, wooded	1972	1992
Holly Ridge	Stoddard	006	This study	6.0 x 2.6 M	Moist soil at edge of stream, shaded	1988	2003
Holly Ridge	Stoddard	014	Not recorded	Not seen		1981	1981
Ground Cedar Pond	Carter	005	1 M x 1 M in 1987	Extirpated	Pond drainageway, chert soil, shaded	1987	1987
FS Road 3878 (=rd267)	Carter	009	This study	5.4 x 4 M	Deep muck with Sphagnum	1996	2003
Pump Hollow	Carter	010	This study	3.6 x 2.6 M	Moist soil and gravel at edge of stream	1995	2003
Wappapello Training Site	Butler	011	5 M ² in 1994	0.16 M	Bottomland above stream, shaded	1994	2003
Middle Fork, Black River	Iron	017	This study	8.0 x 7.0 M	Mucky soil in bottomland, shaded	2002	2003

Ohio

Site Name	County	EO #	Largest recorded size	Size in 2003	Habitat	First Observed	Last Observed
	Athens		8 x 8 M	Several groups totaling 8 x 8 M	North-facing acidic seep at foot of slope with Sphagnum	2003	2003
	Hocking		7 x 5 M	Not seen	North to northeast facing slope under sugar maple and tulip poplar	2002	2002

West Virginia

Site Name	County	EO #	Largest recorded size	Size in 2003	Habitat	First Observed	Last Observed
Cranberry Glades	Pocahontas		No data	Not seen	Mountaintop Bog ?	1941	1941

Table 2. Forest Service Region 9 sites for *Woodwardia areolata* visited in October 2003.

Indiana

Site Name	EO #	Size of Colony	# Stem Apices	# Fronds	# Fertile Fronds 2003/2002	Minimum Age in 2003 (estimated)	Minimum Age in 2003 (known)
Peter Cave Hollow	IN 2	0.2 M	3	6	0	2	18
Peter Cave Hollow	New in 2003	0.25 M	4	13	0	2	NA
Rockhouse Hollow	IN 3	0	0	0	0	NA	16
Indian Lake	IN 11	4.3 x 1.0 M	85	340	34	27	11
German Ridge	IN 17	9.0 x 1.0 M	45	180	2	56	2

Illinois

Site Name	County	Size of Colony	# Stem Apices	# Fronds	# Fertile Fronds 2003/2002	Minimum Age in 2003 (estimated)	Minimum Age in 2003 (known)
Jackson Hollow	Pope	45 x 9 M	500-1000	2000-4000	12/?	NA	3
Jackson Hollow	Pope	2.3 x 2.0 M	35	150	9	14	38
Dixon Springs	Massac	6.5 x 1.0 M	55	220	4/7	NA	26
Mill Spring	Massac	5.0 x 0.6 M	27	63	0	31	?

Missouri

Site Name	EO #	Size of Colony	# Stem Apices	# Fronds	# Fertile Fronds 2003/2002	Minimum Age in 2003 (estimated)	Minimum Age in 2003 (known)
Holly Ridge	MO 6	6.0 x 2.6 M	200	800	2/3	37	15
Wappapello Dam	MO 11	0.1 M	1	3	0	40 (from size in 1994)	9
Pump Hollow	MO 10	3.6 x 2.6 M	200	700	0	22	8
FS Rd 3878	MO 9	5.4 x 4.0 M	150	>1200	13/?	32	7
Ground Cedar	MO 5	0	0	0	0	22 (from size in 1987)	16
Black River	MO 17	8.0 x 7.0 M	600	3000	8/4	50	1

DISTRIBUTION AND ABUNDANCE

Range-wide Distribution

Woodwardia areolata is a common species from eastern Texas and Oklahoma eastward to southern New England (Cranfill 1983, Tryon and Moran 1997). Along the northern boundary of its distribution *Woodwardia areolata* occurs as disjunct colonies in Missouri, Illinois, Indiana, Ohio, Pennsylvania, and Massachusetts. In southeastern Maine it is known only from specimens collected in the 1860s (Cranfill 1993, in *Flora North America*, Vol. 2).

Except in southern New England, *Woodwardia areolata* seldom occurs north of the southern boundary of Wisconsin Glaciation. A now extirpated occurrence was recorded in southwestern Michigan; a small colony was still extant in nearby Porter Co. in northwestern Indiana in 1988. A single plant was recorded in Calloway County in central Missouri in 1984.

State and National Forest Distribution

Indiana

Twenty occurrences of *Woodwardia areolata* have been recorded in Indiana, six of these in the Hoosier National Forest. *Woodwardia areolata* has been recorded in Porter Co. in northwestern Indiana and in Harrison, Jefferson, Jennings, Perry and Ripley counties in southeastern Indiana. All of the National Forest occurrences are in Perry County (see Table 1).

Illinois

The total number of recorded occurrences of *Woodwardia areolata* was unavailable. Fourteen occurrences are known in the Shawnee National Forest (see Table 1), all from Hardin, Johnson, Massac and Pope counties in southeastern Illinois (Mohlenbrock and Ladd 1978).

Missouri

Seventeen occurrences of *Woodwardia areolata* have been recorded in Missouri, five of these have been recorded in the Mark Twain National Forest. *Woodwardia areolata* has been recorded in Barton and Lawrence counties in southwestern Missouri, Callaway County in central Missouri, and Bollinger, Butler, Carter, Iron, Ripley, and Stoddard counties in southeastern Missouri. National Forest occurrences are in Butler, Carter and Iron counties. A complex of sites occurs on Missouri Department of Conservation land and surrounding private land in Stoddard County. (see Table 1).

Ohio

Ohio National Forest occurrences of *Woodwardia areolata* are in Athens and Hocking counties (see Table 1). Additional occurrences in Adams, Athens Gallia, Hocking, Jackson, Meigs and Vinton counties are all in the southeastern portion of the state.

West Virginia

In addition to the single occurrence on National Forest land in Pocahontas County, West Virginia has recorded occurrences in Greenbrier, Mineral and Pocahontas counties in the Allegheny Mountains of eastern West Virginia and in Hancock County in the northern tip of the state in Tomlinson Run State Park along the Ohio River.

RANGE WIDE STATUS

Woodwardia areolata is widespread and common throughout much of the southeastern and Atlantic states (Cranfill 1983). It is most abundant on the coastal plain, scattered in the Ouachita and Boston mountains, Ozark and Cumberland plateau, and the Piedmont, but not in the high Appalachians, the heavy gumbo soils of the Mississippi Valley, or the limestone regions of the Interior Low Plateaus (Cranfill 1993, in Flora North America Vol. 2).

A summary of the range wide Heritage Status of *Woodwardia areolata* as compiled by Nature Serve is included below (NatureServe 2003).

Heritage Status

Global Heritage Status Rank: G5

Rounded Global Heritage Status Rank: G5

Nation: United States

National Heritage Status Rank: N5 (17Dec1994)

Nation: Canada

National Heritage Status Rank: N2 (22Mar1989)

U.S. & Canada State/Province Heritage Status Ranks	
United States	Alabama (SR), Arkansas (SR), Connecticut (SR), Delaware (S5), District of Columbia (S?), Florida (SR), Georgia (SR), Illinois (S2), Indiana (S2), Kentucky (S?), Louisiana (SR), Maine (SH), Maryland (SR), Massachusetts (SR), Michigan (SX), Mississippi (SR), Missouri (S2), New Hampshire (SH), New Jersey (S5), New York (SR), North Carolina (S5), Ohio (S2), Oklahoma (SR), Pennsylvania (S2), Rhode Island (S2), South Carolina (SR), Tennessee (SR), Texas (SR), Virginia (SR), West Virginia (S1)
Canada	Nova Scotia (S2)

Woodwardia areolata is listed as State Endangered in New Hampshire (Tryon and Moran 1997).

In National Forest Region 9 *Woodwardia areolata* is listed as a Regional Forester Sensitive Species in the Mark Twain NF in Missouri, the Hoosier NF in Indiana, and the Monongahela NF in West Virginia.

POPULATION BIOLOGY AND VIABILITY

The disjunct occurrences of *Woodwardia areolata* in FS Region 9 are best considered as populations in a source-sink population model (Pulliam 1988). In this model, sink populations in marginal habitat result from continuing migration events from source populations in good habitat in the heart of the species range. The sink populations may not be viable in the absence of continued migration.

Throughout the heart of its range, *Woodwardia areolata* is sufficiently abundant to maintain a stable equilibrium of populations. The density of local spore rain is probably adequate to overcome the species inherent limitations to spore dispersal. Persistence is augmented by vegetative spread by long-lived clones.

In Region 9 sites, the limited ability of *Woodwardia areolata* to disperse spores and accomplish local migration presents some special considerations. Because viable spores are produced by most populations and gametophytes readily grow and produce sporophytes in culture, it is likely that the species would be much more common in Region 9 if not for the lack of spore release.

Many of the colonies visited in this study were growing vigorously with no indication of limitations to growth imposed by the climate or their local environment. They did display very little capability of spreading locally by spores, even when habitat of the type they were growing in appeared to be much more extensive than the site of the sporophyte colony. In this situation, continued existence is dependent on vegetative reproduction by clonal expansion (and possibly by downstream distribution of rhizome fragments). Because most occurrences are limited to a single dense colony, they may be more susceptible to local disturbance than species regularly reproducing sexually.

Due to the above considerations, individual occurrences of *Woodwardia areolata* in Region 9 are probably not sustainable over evolutionary time (100's of years). However, the calculated ages of existing clones indicate that individual clones may persist for many decades. The probable ages of these clones indicate that migration into this area has been going on for a long time, considerably longer than dates of discovery of "new" occurrences imply. From the latter we receive a distorted impression of a recent increase in migration rate. Migrations are probably continuing, but it is not clear whether the rate is increasing, decreasing, or remaining the same.

If the extremely low genetic variability observed in this study is characteristic of the species, long term adaptability to habitat change may be of concern. However, the extensive geographic and habitat range currently occupied by the species indicate high adaptiveness of the current genotypes. Inbreeding depression is not a concern because the species has and continues to be purged of deleterious genetic alleles through intragametophytic selfing. In culture, sporophytes produced by isolated gametophytes continued to grow normally, exhibiting no morphological abnormalities.

POTENTIAL THREATS

Present or Threatened Risks to Habitat

The Pennsylvanian sandstone cliffs of southern Indiana and Illinois are remarkably stable. Many prominent cliff features have persisted unchanged through recorded history. Rockhouses under the most actively eroding cliffs at the heads of canyon have documented habitation by humans for more than 10,000 years (Adovasio and Carlisle 1988). With this stability of substrate the greatest threat to colonies on sandstone cliffs within the forest is alteration of the hydrology such that these habitats would become too dry to support *Woodwardia areolata*.

Sandstones of the type supporting *Woodwardia areolata* are highly porous and capable of storing large quantities of ground water. Constant moisture supplied from within the sandstone is probably more important to sustaining the cliff colonies than is moisture from direct precipitation and runoff. This is especially true of the gametophyte generation which in most ferns can grow and reproduce only on continuously moist surfaces. Drying of the sandstone habitat could potentially be increased through clearing or other activities that cause more rapid runoff of rainfall in the area above the cliffs where the sandstone moisture is recharged. Clearing of the forest canopy surrounding the sandstone habitats could also reduce moisture availability through increased evaporation due to greater exposure to wind and direct sunlight. However, long persistence of a colony of *Woodwardia areolata* in direct sunlight at Dixon Springs in Illinois indicates that full-sun is not a direct threat.

Soil colonies in seeps are also relatively stable so long as the current hydrology continues and the site is not physically disturbed by logging, road construction, grazing, etc. Colonies along permanent streams are more subject to disturbance. These colonies are dependent upon streamside moisture. A change in the stream course leaving the colony exposed to drought would probably be fatal. Such colonies are also vulnerable to streamside erosion and deposition that could physically remove or bury them. The latter appears to have occurred at the Wappapello training site in southeastern Missouri where we were able to find only a single rhizome that was covered by about five centimeters of sediment. [In undisturbed condition, rhizomes grow on the surface of mineral soil, either exposed or covered only by litter.] The entire area appeared to be frequently flooded.

The most vulnerable colonies of *Woodwardia areolata* are those existing in man-made habitats such as roadside ditches and pond drainages. These are most likely to change in hydrology over time and in vegetation community due to succession and/or invasion by weedy

species. Ditches are also subject to maintenance activities that may eliminate colonies or affect colony health.

We failed to find plants of *Woodwardia areolata* at two historic man-made sites. One of these was the drainageway of a pond in southeast Missouri (EO site # 005). The site was last observed in 1987. Now the site is dry, appearing too much so to support *Woodwardia areolata*. A larger pond a mile distant maintains a seep community in its drainage suggesting that this type of habitat may have existed at the colony site when *Woodwardia areolata* was present.

We failed to find *Woodwardia areolata* at a roadside ditch site in Indiana (EO site # 003) also last observed in 1987. The site now appears too dry to support the species, and it is more densely vegetated than most sites supporting *Woodwardia areolata*. In southern Illinois a road ditch site (Mill Spring) is still suitably moist, but supports only a weak colony of a few isolated rhizomes. Here the principal threat to the colony is a dense growth of the introduced Japanese stilt grass *Microstegium vimineum*. The rapid sprawling growth of this annual grass covers and seems to be shading out the ferns. This is the only sizeable soil colony of *Woodwardia areolata* that we observed that did not have a continuous rhizome mat. Without intervention, this colony is not likely to survive.

Over utilization

Woodwardia areolata is not known to be used for any purpose.

Disease or Predation

No disease or significant predation was observed on any of the 13 occurrences of *Woodwardia areolata* in this study, and none was noted in the literature.

Inadequacy of Existing Regulatory Mechanisms

Plants growing in natural habitats are adequately protected barring activities that would change the current hydrology. Colonies in man-made habitats could be better managed through monitoring and regulation of roadside maintenance activities that might adversely affect them. At sites where change in hydrology, community succession, or required activities threatens colony extirpation, transplantation to more suitable sites in the vicinity may be a viable option.

Other Natural or Human Factors

One of the largest colonies of *Woodwardia areolata* in FS Region 9 occurs on a sandstone cliff in Jackson Hollow in Pope Co., Illinois. In 2000 this colony was observed to form a continuous mat completely covering an area of about 45 x 9 M of cliff surface. In 2003, about 50 small patches, mostly less than 1 M² remained on the cliff. The remainder of the colony lay at the cliff base in a jumble of dead and dying rhizome mats, apparently the result of natural sloughing. We speculate that the colony had clonally spread over the relatively smooth cliff face, rooting only in pockets and crevices. The weight of the mat eventually exceeded the strength of the anchoring rhizomes and the sparsely rooted portions broke free, leaving only patches better

anchored in crevices and on ledges with some soil accumulation. Although such ‘overgrowth’ may constitute a threat to cliff plants, it is a risk that could not easily be managed. Discovered soon enough, the sloughed mats could be appropriate material for transplantation to other sites.

SUMMARY OF LAND OWNERSHIP & EXISTING HABITAT PROTECTION

Site records of *Woodwardia aerolata* on National Forest land are maintained by the Forest Service and all records for states are maintained in state Natural Heritage databases. Critical sites are revisited by state and Forest Service personnel as time permits but systematic monitoring is not performed.

In its Forest and Resource Management Plan the Hoosier National Forest in Indiana requires a protection buffer zone around cliffs of the type that support populations of *Woodwardia aerolata*. The 1991 Plan recommends that the Forest "prohibit vegetation management within a distance of 100 feet from the top and base of large cliffs or overhangs (distances measured horizontally).....For the purposes of this recommendation, large cliffs or overhangs are defined as rock outcrop areas which are 15 feet or more in height and 100 feet or more in length. These rock outcrop habitats are not limited to solid cliffs, and may include discontinuous rock faces." The 2006 Plan continues these recommendations with an exception for “possible salvage of dead and dying trees, or sanitation harvest provided it can be done without harming the plants or their viability.”

SUMMARY OF EXISTING MANAGEMENT ACTIVITIES

See above.

PAST AND CURRENT CONSERVATION ACTIVITIES

See above.

RESEARCH AND MONITORING

Existing Surveys, Monitoring, and Research

There are no current surveys or regular monitoring programs for *Woodwardia areolata*. When *Woodwardia areolata* is encountered in the R9 states, it’s occurrence and habitat is recorded and maintained in Forest Service and State databases for sensitive plants.

Studies initiated for this conservation assessment have revealed unusual and interesting aspects of the reproductive biology of *Woodwardia areolata*. In continuing research, we will more closely examine the breeding system and the genetic load of *Woodwardia areolata*, comparing our findings from plants in FS Region 9 to plants from elsewhere in the range of the

species. Specifically, we will determine whether the low genetic variability and the permanently closed indusium found in R9 plants is characteristic of plants in the heart of the range of *Woodwardia areolata*. We will also compare *Woodwardia areolata* to other species of *Woodwardia* to see if these traits are more broadly characteristic of the genus.

Survey Protocol

If a survey specific to *Woodwardia areolata* was to be conducted in Forest Service Region 9, it would need to be based on detection of appropriate habitats, particularly sandstone cliffs and acid seeps. Still the probability of success may be low. Due to the rarity of *Woodwardia areolata* and its dispersal and migration limitations, it is likely that much more suitable habitat exists than is occupied by the species at the periphery of its range.

Research Priorities

In addition to the research described above, regular monitoring of known populations in each habitat type would add much to the knowledge base regarding colony growth rates and responses to disturbance and climate variability. In such monitoring, colony sizes should be carefully measured (not estimated) as to their extent and shape, the approximate number of leaves, and the number of fertile leaves. In spring, new leaves of *Woodwardia areolata* expand from crosiers formed the preceding fall near the rhizome apex. The rhizome then elongates further over the summer and forms the crosiers of the next year's leaves. If measured in late fall, the average length of rhizome extension beyond the current seasons leaves provides an index of plant vigor. In October of 2003, average rhizome extension of colonies measured was eight centimeters. Assuming growth has been clonal, the average rhizome extension can then be used to estimate clone age.

Experiments with transplantation of rhizome segments from existing colonies to adjacent sites of similar habitat in the immediate vicinity could test the hypothesis that failure to release spores and/or establish gametophytes limits local migration efficiency in *Woodwardia areolata*. Such experiments could also prove valuable in salvaging plants in immediate danger of extirpation.

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