Conservation Assessment

for

Appalachian Bristle Fern (Trichomanes boschianum) Sturm

Photo: by Paul G. Davison

USDA Forest Service, Eastern Region

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Steven R. Hill, Ph.D.
Illinois Natural History Survey
Center for Biodiversity
607 East Peabody Drive
Champaign, Illinois 61820

This document is undergoing peer review, comments welcome

This Conservation Assessment was prepared to compile the published and unpublished information on the subject taxon or community; or this document was prepared by another organization and provides information to serve as a Conservation Assessment for the Eastern Region of the Forest Service. It does not represent a management decision by the U.S. Forest Service. Though the best scientific information available was used and subject experts were consulted in preparation of this document, it is expected that new information will arise. In the spirit of continuous learning and adaptive management, if you have information that will assist in conserving the subject taxon, please contact the Eastern Region of the Forest Service - Threatened and Endangered Species Program at 310 Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203.

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EXECUTIVE SUMMARY

This Conservation Assessment is a review of the distribution, habitat, ecology, and population biology of the Appalachian bristle fern, *Trichomanes boschianum* Sturm, throughout the United States, and in the U.S.D.A. Forest Service lands, Eastern Region (Region 9), in particular. This document also serves to update knowledge about the status, potential threats, and conservation efforts regarding the Appalachian bristle fern to date. The Appalachian bristle fern is a small, filmy-leaved, creeping rhizomatous evergreen fern that is found in parts of the eastern United States, and it has a small disjunct population in Chihuahua, Mexico. In the United States it is known to occur historically in thirteen states, namely, AL, AR, GA, IL, IN, KY, MS, NC, OH, SC, TN, VA, and WV. It is one of the few members of the primarily tropical fern family Hymenophyllaceae, the Filmy fern family, in North America north of Mexico. It is found loosely rooted on the surfaces of somewhat acidic rock outcrops, particularly within heavily shaded, constantly moist and humid, sheltered grottoes, where it is often pendant from rock ceilings. The populations are isolated partly because of infrequent suitable habitat and the colonies are usually small. Globally, its ranking is G4 (apparently secure world-wide, but factors exist to cause some concern). Though not truly common anywhere, the Appalachian bristle fern is most often found in the southern Appalachian region and northern Alabama, and, in Illinois and Indiana it is found primarily within the Shawnee and Hoosier National Forests. The species has been included on the Regional Forester Sensitive Species list (RFSS) for both the Shawnee National Forest and the Hoosier National Forest. It is vulnerable to critically imperiled throughout its range, and it is considered imperiled in Illinois where it is listed as Endangered,

and it has also been listed as Endangered in Indiana and Ohio, and as Threatened in Arkansas, North Carolina and Tennessee. It is being tracked in most states where it occurs. This rare fern faces several risks that could result in its extirpation here and throughout its range if it is not properly protected.

In additional to species listed as endangered or threatened under the Endangered Species Act (ESA), or species of Concern by U.S. Fish and Wildlife Service, the Forest Service lists species that are Sensitive within each region (RFSS). The National Forest Management Act and U.S. Forest Service policy require that National Forest System land be managed to maintain viable populations of all native plant and animal species. A viable population is one that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its range within a given planning area.

The objectives of this document are to:

-Provide an overview of the current scientific knowledge on the species.

-Provide a summary of the distribution and status on the species range-wide and within the Eastern Region of the Forest Service, in particular.

-Provide the available background information needed to prepare a subsequent Conservation Approach.

NOMENCLATURE AND TAXONOMY

Scientific Name:	*Trichomanes boschianum* Sturm (1861)
Common Names:	Appalachian bristle fern; Appalachian filmy fern; Appalachian filmy-fern; Filmy fern; Bristle-fern
Synonymy:	none
Class:	Filicopsida (Ferns)
Family:	Hymenophyllaceae (the Filmy fern family)
Plants Code:	TRBO (USDA NRCS plant database, W-2) http://plants.usda.gov/cgi_bin/topics.cgi

There are eight species of bristle fern (*Trichomanes*) in North America north of Mexico (Farrar 1993). Most members of the family and genus live in wet areas of the tropics. This species is similar to the tropical *Trichomanes radicans* Sw., but it is not similar to any other species in the United States. It is the largest of the filmy ferns in the United States. It is a true fern, a vascular plant that typically reproduces by spores.

This fern was named in honor of R. B. van den Bosch, a nineteenth-century botanist who wrote about the filmy fern (Snyder & Bruce 1986).

DESCRIPTION OF SPECIES

Trichomanes boschianum is a rather small, filmy-leaved, creeping rhizomatous evergreen fern, a perennial herb. It can be found locally in sparse or dense colonies, and individual stems can be long, perhaps 1 m under ideal conditions. Its widely spaced leaves (fronds) are 4-20 cm long and 1-4 cm wide, with green somewhat flattened and winged petioles 1-5 cm long that are shorter than the blades. The stems are slender and long-creeping and are covered with small dark gland-tipped hairs and branched or unbranched rhizoid-like hairs, and they are sparsely rooted. The leaf blades (laminae) are only one cell thick between the veins and they lack stomata; they are lanceolate in shape, often pendulous, shiny dark emerald green and translucent when fresh, 1-2-pinnate-pinnatifid, slightly narrowed at the base if at all, and often long-acuminate at the apex; the 6-10 pairs of pinnae have 2-4 pairs of pinnules that are deeply divided into narrow lobes; the sori are terminal on lateral veins at the base of lobes, conic in shape, about 3 times longer than wide, and with an extended receptacle (bristle) to which the sporangia are attached. The sporangia and spores are eventually shed by growth of this bristle from its base (description primarily from Gleason & Cronquist 1991, Lellinger 1985, Farrar 1993). Reported chromosome numbers include 2*n* = 72, 108, 144 (Farrar 1993).

HABITAT AND ECOLOGY

Trichomanes boschianum is normally found in a very distinctive and limited habitat. Typically, the plants grow loosely rooted on the surfaces of vertical or horizontal rock outcrops, usually moist, well-weathered sandstone cliffs under overhangs or in shallow caves in deep shade. The plants are often on the undersides of the overhangs and the fronds are then pendulous. These areas are often near or within formations called rock shelters or rock houses (Francis *et al.* 1993) because people have used the more protected sites within these areas to escape from the weather since prehistoric times. While the members of the Filmy fern family are able to survive occasional drying and freezing, they have a delicate structure that requires deeply sheltered habitats with nearly continuous high moisture and humidity (Farrar 1993) much like their tropical relatives. The rock outcrops where *Trichomanes boschianum* grows are generally exposed to nearly continuous moisture from seepage or spray from waterfalls. Several of the largest colonies are known from natural grottos behind waterfalls along the Blue Ridge escarpment of North and South Carolina.

In North Carolina, this fern is considered to be an element of both the Spray Cliff and Montane Acidic Cliff Communities (Gaddy 2002, Pittillo 1994, Schafale & Weakley 1990). One of the best indicator species for the possible presence of this plant is *Heuchera parviflora,* which has a slightly greater tolerance to exposure than does this fern. In the Ozarks and Interior Low Plateau region of the midwestern and southeastern United States *Trichomanes boschianum* is considered to be a member of the Midwest Sandstone Moist Cliff Community (Faber-Langendoen & Snow 2000) within which its associates can include the flowering plants *Dicentra canadensis, Dodecatheon frenchii, Heuchera parviflora, Hypericum walteri, Mitchella repens, Mitella diphylla* and the other ferns *Athyrium filix-femina, Cystopteris bulbifera, Osmunda cinnamomea,* and *Osmunda regalis.* In North and South Carolina, where it typically grows on decomposing gneissic metamorphic rock outcrops near waterfalls, the immediate associates are few, and generally include *Heuchera parviflora* and *Selaginella apoda* along with the other filmy fern

Trichomanes petersii and several bryophytes (personal observations). Because of the low light conditions, few other vascular plants are able to survive with this fern. Instead, most immediate associates are lichens, liverworts, and mosses as well as fern gametophytes. The Appalachian bristle fern does not grow on ledges or other microsites where other plants could overwhelm it, nor does it normally grow in direct sun. However, at least one colony in South Carolina was observed to receive direct sun but only in winter (personal observations). The community where it grows is classified as a Primary community. Skorepa (1973) suggested that while the general aspect of the lichen, moss, and vascular plant vegetation on the sandstone outcrops could lead one to believe that succession is taking place, the lichens and mosses on the exposed rocks actually represent a stable climax. Winterringer and Vestal (1956) likewise saw little evidence of succession on sandstone bluffs in southern Illinois.

Mesic upland forest communities generally surround the outcrops, though the tops of some bluffs above may be forested with dry upland forest species tolerant of drought conditions (White & Madany 1978). The habitat exposure varies, but the plants cannot grow where direct sunlight is likely to cause them to dry, or where ice can accumulate and damage or destroy the plants. The surrounding forests help to protect the ferns from those effects and to prevent soil erosion from above; they may also add small amounts of nutrient and organic material to the sand caught in the crevices or on ledges where the ferns grow, though most accumulated soil appears to be from decomposition of the rock itself and little material is contributed from outside of the grottoes. The soil pH is thought to be acidic because soils normally formed from such outcrops are typically so. The fern does not appear to tolerate limestone. The sparse soils on which the plants grow, then, are composed of sandy residuum from the weathered rock face as well as organic materials from decomposing plant materials, mostly from the old fronds of the fern itself as well as from surrounding lichens and bryophytes.

The roots of *Trichomanes boschianum* and many (but not all) other filmy ferns are very weak, and appear to function mostly as root hairs to gather moisture and nutrients; they do not anchor the plant strongly, and, instead, the narrow string-like stems tend to secure the plant by wedging it within narrow crevices when these are available. Sometimes the plant grows simply as a loose mat on a moist ledge and the plants are not at all attached to rock. Filmy ferns in general absorb much of the moisture that they need directly into their leaves from water in the air (in the form of fog, dew, and water spray) and they have little vascular tissue in their fronds. While not amphibious, they need constant moisture and saturated air to survive and prosper. Because they are in habitats that are occasional or often wet, this fern has been included on lists of wetland plants as FACW, OBL (W-2).

The species is thought to be a relict from the southern latitudes (see below). This fern does not appear to compete well with other plants. Its habitat type is not common and so occurrences of the species are also very few. It is difficult to cultivate, requiring a closed terrarium and careful control of incoming light and nutrients, and this supports its designation as a specialist species with narrow habitat tolerances.

DISTRIBUTION AND ABUNDANCE

Trichomanes boschianum is limited in range to an area south of the glacial boundary and it is found in the midwestern and southeastern United States; it also has a small disjunct population in

Chihuahua, Mexico. In the United States it is known to occur historically in thirteen states, namely, AL, AR, GA, IL, IN, KY, MS, NC, OH, SC, TN, VA, and WV (W-2, W-3, Farrar 1993). According to Weakley (W-4) the documentation for the report of this species in Virginia was unknown. However, one recent collection has been made in Russell County, Virginia (Tom Wieboldt, pers. comm.) verifying its presence there. Its distribution is not continuous, but is quite spotty or discontinuous, with notable disjunctions. Additional details on the distribution of the Appalachian bristle fern can be found in Chester *et al.* (1993), Cranfill (1980), Farrar (1993), Mohlenbrock (1959, 1986), Mohlenbrock and Ladd (1978), Kartesz and Meacham (1999), and Smith (1988) as well as from several Internet sites (*e.g.*, W-2, W-3).

Farrar (1993) suggested, and it is generally accepted, that the filmy ferns in southeastern North America are rare because of their delicate nature that requires that they grow in deeply sheltered habitats with almost continuous high moisture and humidity, and that they are currently restricted from a more widespread pre-glaciation distribution. He also suggested that they have persisted only because of their ability to propagate vegetatively by either the sporophyte or gametophyte generation. In fact, at least one species, *Trichomanes intricatum* Farrar, exists only as a gametophyte, and several others are found more often as gametophytes then sporophytes (Farrar 1967, 1985, 1990, 1992, 1993; Stokey 1940).

Most native plants have reached the limit to which they can travel under present conditions of climate (that is, temperature and rainfall), substrate, dispersal mechanism, and other pertinent factors. In other words, species are in balance with their environment as long as the environment is stable. In many biological simulations, ecological extremes are more important than the means in controlling plant distribution (Webb *et al.* 1975). An obvious example is that of frost tolerance (temperature extremes). A plant species completely intolerant of freezing can persist in a site indefinitely until the first time extreme temperatures cause it to freeze. One such freeze in a century may be enough to eliminate a species entirely from a wide area of its range, and changes in climate historically have caused the greatest changes in plant distributions.

In the case of *Trichomanes boschianum*, current distribution appears to be dependent primarily on historical factors (lack of glaciation within its current range, resulting in a 'relict' distribution), substrate and bedrock type, and the age of the surrounding forest (as measured by the degree of disturbance) rather than from temperature extremes alone (though temperature has adversely affected populations; see W-5). With limited opportunity for spore dispersal, it may also be unable to increase its range very quickly. The need for nearly continuous moisture appears to be crucial for this fern, as it is for the filmy-ferns worldwide, along with a stability of substrate and a lack of competition. Under natural conditions, these habitats are stable, but if the habitat becomes too dry, if nutrient and soil accumulation changes, or if human traffic increases, the fragile habitat balance can be destroyed and the populations can be lost.

The Appalachian bristle fern is at its southern limits of range in the Cumberland Plateau and southern Appalachian Mountains in Alabama, Georgia, and South Carolina (where it also reaches its eastern limit). Its western limit is in Arkansas and some sites are within the Ozark National Forest. In the interior, it reaches southeastern Illinois and Indiana in the somewhat isolated Shawnee Hills and plateau and it is more frequent in Kentucky, then it continues east to the Appalachians and foothills of the western Virginias, eastern Tennessee, and western North Carolina. At its northern limit of range in Ohio, it is in Hocking County where it is known only

from a single drainage system (W-5). Label information suggests that this fern was locally frequent in northern Alabama in the 1940's - 1950's (Haynes & Ginzbarg, pers. comm.) and it is still locally common in that region (Davison, Farrar, pers. comm.). Representative specimens of this rare fern have been listed in Appendix 1. A summary of the distribution of the Appalachian bristle fern has been presented in Appendix 2.

Within the U.S. Forest Service Eastern Region (Region 9) *Trichomanes boschianum* has been confirmed to be present within the Shawnee National Forest in Illinois and in the Hoosier National Forest in Indiana. It is known in several National Forest areas of the southeast, including the William B. Bankhead National Forest in Alabama, the Daniel Boone National Forest in Kentucky (Campbell *et al.* 1993), the Monongahela National Forest in West Virginia, the Cherokee National Forest in Tennessee, the Pisgah and Nantahala National Forests in North Carolina, the Chattahoochee National Forest in Georgia, and the Sumter National Forest in South Carolina.

In Indiana, where it is listed as Endangered, the species has been reported historically in Crawford, Martin, and Perry Counties (W- 6) primarily within the Hoosier National Forest in the vicinity of sites where high quality sandstone cliff communities have also been reported. It had not yet been reported for the state by 1940 (Deam 1940).

In Illinois, where it is also listed as Endangered, the species has been reported historically in Hardin, Johnson, and Pope Counties (Herkert *et al.* 1994, Illinois Endangered Species Protection Board 1999, Mohlenbrock and Snider 1967, Mohlenbrock & Voight 1959). These sites fall within the Greater Shawnee Hills Section of the Shawnee Hill Natural Division of Illinois (Schwegman *et al.* 1973) just south of the glacial boundary. Currently, the Illinois Natural Heritage Database records only three extant populations, in Johnson and Pope Counties. However, Shawnee National Forest records indicate that it still occurs in four Ecological Areas (Double Branch Hole, Bulge Hole, Jackson Hollow, Little Grand Canyon/Horseshoe Bluff; Shimp 2001). In the Illinois Natural History Survey herbarium in Champaign (ILLS), additional collections of *Trichomanes* gametophytes from Gallatin and Union Counties were found, but these may actually be gametophytes of *Trichomanes intricatum* Farrar, which has been reported from Jackson and Pope Counties (Farrar 1992). This has not yet been confirmed.

George Yatskievych (pers. comm.) has searched very intensively for the Appalachian bristle fern in several apparently very suitable habitats in Missouri, but it has not yet been found in the state.

It is not known how many individual plants occur at a given site. This is primarily because the rhizomes are difficult to separate from one another due to their tendency to interweave. The rhizomes also break easily, and the individual divisions continue to grow into new plants. Thus, it may be impossible to get an accurate reading on the number of individuals in a colony in this way. Instead, a population is usually measured in terms of area covered. The entire colony or population can vary from 100 cm^2 or less up to over 100 m^2 (personal observations). The plants are generally very concentrated rather then spread out over the substrate. Furthermore, the populations are isolated from one another because of its specific requirements for an uncommon and discrete habitat and intolerance of competition. In terms of numbers of individuals, it is possible that the entire number of genetically different individuals currently alive may be in the low thousands or even considerably less globally. There is little specific data in this regard other

than the data available in state Natural Heritage databases, which suggests these low remaining numbers. It could as easily be surmised that the species was never common because of limited habitat. Certainly, individual colonies have been very significantly reduced in size during the last half-century and the species is considered to be in decline (Farrar 1993).

PROTECTION STATUS

The Nature Conservancy ranking for *Trichomanes boschianum* is G4 (apparently secure world-wide, but factors exist to cause some concern; W-3, Appendix 3). In the United States the species is given the National Heritage status rank of N4 with a similar meaning. It has been designated as Endangered in Illinois, Indiana, and Ohio, and it has been listed as Threatened in Arkansas, North Carolina, and Tennessee. In South Carolina it is considered to be of Regional Concern. In West Virginia it has been included on the Rare Species List but it is not listed as threatened or endangered. Apparently, only one population is currently known in Virginia, and it will probably be listed as Endangered there during a future species review.

Trichomanes boschianum is listed as sensitive on the U.S. Forest Service's Regional Forester Sensitive Species (RFSS) list in the Shawnee National Forest and the Hoosier National Forest, Region 9.

The Appalachian bristle fern was not listed as threatened or endangered in Illinois until 1994, when it was added to the listing as Threatened (Herkert *et al.* 1991, 1994). At the time it was added, Herkert *et al.* (1994) stated: "Populations of this species in Illinois are showing signs of decline. Presently there are believed to be only about 10 extant populations in the state". In 1999 its status in Illinois was upgraded to Endangered because of continued decline, and currently only three extant populations are listed in the Illinois Heritage database, though more actually appear to be extant.

Protection for this fern and other plants with relatively inconspicuous individuals is currently more dependent on habitat protection, and so its survival will probably depend more on this than on species protection. *Trichomanes boschianum* is to be restricted to a specialized and scarce habitat and high quality examples of this habitat (Sandstone overhang, Sandstone cliff) have been given a priority for protection in some states including Indiana (see W-6).

Table 1 lists the official state rank assigned by each state's Natural Heritage program according to the Nature Conservancy at their Internet site (W-3). Appendix 3 explains the meanings of the acronyms used (W-7). A summary of the current official protection status for the Appalachian bristle fern follows:

U.S. Fish and Wildlife Service:	Not listed (None)
U.S. Forest Service:	Region 9, Sensitive
Global Heritage Status Rank:	G4
U.S. National Heritage Status Rank:	N4

Table 1: S-ranks for *Trichomanes boschianum* [Heritage identifier PPHYM02040]

State	Heritage S-rank	State	Heritage S-rank
Alabama	S3	North Carolina	S1
Arkansas	S2S3	Ohio	S1
Georgia	S1	South Carolina	S1
Illinois	S2	Tennessee	S1S2
Indiana	S1	Virginia	S1
Kentucky	S3S4	West Virginia	S1
Mississippi	S1		

LIFE HISTORY

Trichomanes boschianum is a delicate, filmy-leaved, creeping rhizomatous evergreen fern, a perennial herb that can be found locally in sparse or dense colonies and individual stems can be long, perhaps 1 m under ideal conditions. Its average life span is not known, but growth is known to be generally very slow and some individuals with very long rhizomes may be very long-lived. It is possible that individual colonies are made of individuals with a single genotype, though there is only some data in this regard. Farrar (pers. comm.) has indicated that he found no variation in allozymes among or between *Trichomanes boschianum* plants from any of the sites that he studied. He also suspects that in most sites each population is a clone.

The sporophyte's rhizomes break easily, and each division can continue growing, making a distinction between plants difficult, if not impossible, to interpret. This means of propagation has undoubtedly helped this fern to persist at specific sites, but not to spread to other sites very far distant. Plant growth and size is limited by characteristics of its immediate habitat (microhabitat) including such factors as available space, degree of exposure, and soil and nutrient availability, and there may be long periods of dormancy of individual plants in some populations in dry, hot, or cold periods. When one examines a colony of the Appalachian bristle fern, one notices that as the plants approach the more exposed areas of the habitat, the fronds appear progressively more damaged, and the plants and/or fronds at the very margins of the colony are usually dead or senescent (personal observations). Those plants in the moister pockets within the grottoes appear robust in comparison, helping to demonstrate the extreme sensitivity of this plant.

Plants (sporophytes) apparently begin growth in mid to late spring but they can probably photosynthesize all year. Individual leaves appear to persist for a very long time in this environment, and even old rhizomes normally bear fronds. According to Farrar (1993) most populations suffer heavy mortality from sporadic droughts, the plants are very slow to regrow, and many populations are currently only a fraction of their recorded size of 20 years ago. In Ohio, this fern is said to be fertile July - September (W-5). Weakley (W-4) stated that the species is fertile June-September, but it has been seen and collected with fertile fronds in South Carolina in May and December as well (personal observations). One would expect that it might be fertile all year because it has evergreen, long-lived leaves and because the sporangia and spores are gradually released as the sorus bristle grows. It is not infrequently found with

sporangia in the Carolinas, and probably elsewhere.

The ferns can reproduce in several ways, including by division (fragmentation) as stated above. They can reproduce by means of spores that are produced in sporangia (spore cases) that are borne inside and protected within the base of a sorus resembling a cylindrical tube or funnel that is formed by a covering called an indusium (Lellinger 1985). A specialized bristle-like structure protrudes from the sorus from the middle of this tube, and sporangia are produced at its base. The bristle grows by means of cells produced at its base (intercalary growth) much like a lawn grass, and the sporangia, still attached or rupturing, are gradually carried to the opening of the tube where the spores are released. The dust like spores are dispersed into the air when mature, and they may be present and shed all year because the leaves are evergreen in this species. Because of the normally very still air in its habitat, the spores are unlikely to be carried far unless the colonies are in areas of waterfalls or water spray. Spores of filmy ferns probably do not survive or persist for long after being shed.

The spores grow into a gametophyte that is quite unlike the heart-shaped gametophytes of many other ferns; it is thread-like and resembles a tuft of green algae. According to Farrar (1985, 1993) these gametophytes seldom show evidence of sexual reproduction but they can be found in the vicinity of fertile sporophytes. Sterile triploid hybrids ($2n = 108$) have been found between the western diploid ($2n = 72$) and eastern tetraploid ($2n = 144$) cytotypes or 'races' demonstrating the presence of sexual reproduction. A case could be made that two cryptic reproductively isolated species are actually involved, but this has not been proposed. New spore-producing fern plants (sporophytes) are produced only if eggs on these gametophytes are fertilized by free-swimming sperm cells whereupon they can grow into a new rooted plant. The eggs can only be fertilized when there is a film of water available on the gametophyte in which a sperm can swim. Therefore, the spore must first disperse to a suitable moist or wet area on the rock and it must remain moist for the young sporophyte of this species to survive. These fertilization events and sheltered conditions are rare and so the colonies and, hypothetically, the individual plants are rare.

Still another important manner in which the fern reproduces is asexual reproduction by means of the production of gemmae, which are minute, readily detached propagules produced by the gametophytes (Lellinger 1985). These deciduous structures can grow into new gametophytes identical to the parent, and the species can be maintained exclusively as gametophytes with sporophytes rarely or never produced. This further supports the hypothesis that some or most of the existing populations of this fern are genetically identical clones that may be of great age like those of the Sword moss (*Bryoxiphium norvegicum*), perhaps, that has similarly isolated populations and reproductive problems in similar habitats (Hill 2002a). In cultivation, new sporophytes have also been observed to grow from asexual proliferation of the fronds (in this species, and certainly in *Trichomanes membranaceum* L., personal observations).

POPULATION BIOLOGY AND VIABILITY

In the previous section, some variations in the life history of *Trichomanes boschianum* were briefly presented. While mature individuals appear to be persistent and long-lived, the success of establishment and growth of new individuals to maturity is very difficult and can depend on local conditions and on suitable years. It is likely that some sporophytes may never produce additional plants by sexual means (Farrar 1993). It is not known how far the spores can travel, but the few

colonies extant and their local nature as well as the generally still air within the rock shelters and grottoes suggests that they cannot travel long distances or that there is little additional suitable habitat available for the species even if they can. The establishment of new colonies has never been demonstrated in the wild. This fern has a narrowly defined habitat in which it cannot develop large populations, and this can be demonstrated by the die-off of stems that grow to the exposed margins of the colonies. Therefore, its viability depends entirely upon its persistence at its currently known sites and the protection of its habitat.

It is unlikely that the species would be able to re-establish itself at a site from which it has been extirpated even though fern spores are light and can probably disperse in air. The distances between populations are too great, and the numbers of reproductive individuals are too small. Despite this, the species has been given a relatively secure rank of G4 because, historically and based upon herbarium collections, a significant number of populations have been found over a large part of the country. However, some of these populations are now gone or reduced in size, and the loss of a few populations can eliminate the fern from an entire state at the edge of its range. The species is considered to be somewhat stable and still viable in some parts of its range at this time, and many of the populations are protected within conservation areas or national forests (see Appendices 1 and 2). It is thought that recreational activities and over-collecting have eliminated or decimated some populations of the plant, and that this may continue.

In Illinois and Indiana, suitable habitat for the species occurs only along a narrow band in the sandstone areas of the Shawnee Hills where there appears to be additional suitable habitat for the plant available. While it is thought that most significant sized populations have been found because the habitat is a very popular one among hikers (and botanists to some extent), additional searches are suggested. With proper habitat management, the current populations should persist.

POTENTIAL THREATS

Overall, the Appalachian bristle fern is considered secure because of the breadth of its distribution and the fact that quite a few populations are in protected areas. However, its habitat is not common and this fern cannot stand some types of disturbance. An obvious and rarely stated threat to the species is from the quarrying or strip mining of its habitat, particularly in the Cumberland Plateau region of Kentucky and Tennessee. Any construction on the bluffs immediately above the ferns would likely create a very definite threat to their survival. For this plant and others in its habitat, protection for the upland and surrounding forest is necessary to buffer sites from the effects of erosion and drying and to preserve conditions which may influence long-term viability (W-5). The other threats to the species include physical damage from trampling by rock climbers, from over-zealous collecting, and from additional and subtler degradation of the environment. Pollutants and herbicides applied on or at the top of cliffs could eliminate the species from toxic runoff and from direct toxicity. The elimination of vegetation cover on the bluffs above may also reduce the soil and nutrients available to the plants in the sheltered habitats below decreasing reproductive potential. These plants are dependent on a continuous moisture regime. Factors affecting water availability, including the drilling of wells, the diverting of water, or the damming of rivers and streams could eliminate entire populations. Many of the populations are dependent upon the water vapor and spray produced by waterfalls and cataracts of fast-moving streams, and these are areas often looked upon as desirable for hydroelectric facilities. If prolonged drought occurs, the populations would also be expected to decline or even disappear.

While reasons for the fern's decline in Illinois were not stated by Herkert *et al.* (1994), in Kentucky, and most likely at many of its sites, one of the greatest threats to this species appears to be from rock climbing enthusiasts. According to Wilson Francis (2001), president of the Kentucky Native Plant Society, the plants of the sandstone cliffs have been relatively out of reach from the impacts of recreational users until now. Today, much of the climbing is being done by means of the setting of steel bolts into drilled holes in the sandstone cliffs and the laying out of vertical climbing routes. Portable drills have resulted in the creation of thousands of rock climbing routes on these cliffs, most of which have been made without permission on National Forest lands. Plant communities have been trampled around the bases of the cliffs (and in areas where climbers take shelter such as the fragile rockhouses). Climbers have scraped soil out of crevices for a better grip. According to Francis (2001) "One climbing guidebook advocates "cleaning" the rock with herbicide, bleach, and wire brushes. The cliffline plant community is under assault by a recreational user group that seems to consider the [sandstone cliffs] an outdoor climbing gym." This appears to state the case succinctly. For this and other rare plants of the sandstone cliffs and rockhouses to survive, this activity must be prevented where these plants occur.

There is also no doubt but that excess collection by botanists has assisted in the decline of this species. I have been told a story of a collector who tore off and collected large sheets of the extremely rare and related Tunbridge fern (*Hymenophyllum tunbrigense* (L.) Smith), as well as *Trichomanes* itself, under the horrified gaze of colleagues at a professionally-sponsored field trip to the only known North American site for that fern in a deep gorge in South Carolina. Farrar (1993) stated "About two dozen small populations of *Hymenophyllum tunbrigense* exist in a single river gorge in Pickens County, South Carolina. It is slow to recover from disturbance, and its numbers have been substantially reduced by collecting since its initial discovery in 1936." Other botanists, researchers, enthusiasts, and educators have been similarly carried away by interest over these tropical ferns in their relict habitats. Moreover, because it is evergreen, botanists tend to collect it when they see it. In the Illinois Natural History Survey herbarium (ILLS) there are at least eleven herbarium sheets of *Trichomanes boschianum* that were collected at a single site over a period of years, and many sheets, collected from the few known localities in Illinois, are also housed at the Southern Illinois University herbarium. This sort of collecting is not only unnecessary but, today, it can be devastating to the remaining populations. Specimens should be made, but only sparingly, from newly discovered colonies as a means of scientific documentation. Some of the generally used guidelines for plant collecting were presented by Hill (1995).

The use of fire as a management tool does not appear to be beneficial to this species; on the contrary, the cliffs actually provide protection from natural fires and a combustible component is not part of its immediate environment. Fires set by campers and others within the shelters where this fern grows have greatly damaged the colonies. At one site in South Carolina, for example, a large group of illegal alcohol stills were set up at one time under a sizeable ledge where the fern grows, and the sterile, blackened ceiling and walls of the rock shelter at this site clearly show the effect that this had on the plants (personal observations). This site at "Moonshine Falls" was large enough that the ferns still persist nearby, and an investigation into its reestablishment within the interior might be possible, provided that fires are no longer set. Certainly, Native Americans used these shelters as well, and they may or may not have caused some damage to the colonies. Burning of the surrounding forest or the forest on the bluffs above also might be

detrimental by increasing drying and erosion, but hard data is lacking. It is just as likely that a burned forest at some distance could add nutrient to its microhabitat.

It is generally accepted by biologists that habitat fragmentation can have profound effects on the success and persistence of local populations. Any activities that result in barriers to dispersal, such as developments, clearcuts, road/utility line corridors, and strip-mined areas limit the possibility of population expansion and genetic exchange in many species. Deleterious effects of fragmentation could possibly go unnoticed for a long period of time, making the short-term effects on species viability less apparent. Over time, as populations become increasingly more isolated, the effects of fragmentation can potentially be observed at the molecular level by reduced genetic frequencies caused by random drift (Barrett & Kohn 1991). When one is considering populations that are already naturally isolated, as in the case of the Appalachian bristle fern, random genetic drift may have already occurred. In fact, this may have been a driving force in its evolution as a distinct species, and the distinct eastern and western cytotypes with different chromosome numbers may indicate a nearly complete split into two new species because of isolation effects.

As suggested above, some of the best-known colonies of this fern occur near well-used and accessible trails and this has had negative effects on them. Restricted access to the current sites, relocation of the trails, and elimination of rock climbing where it grows would be indicated as a means to ensure the species' survival and viability, as in the case of other species with a similar habitat (Shawnee National Forest 2001, W-3). Not only campers and rock climbers use these shelters, but relic hunters have done considerable damage to them in the past, and they continue to damage these fragile sites by moving or removing the sediment from these shelters in an attempt to find what was left by the early Americans, destroying or decimating these ferns and other rock shelter species. These activities are currently illegal where this species grows in the Shawnee National Forest, and increased enforcement of these protective laws is probably necessary.

At the current time, the populations of *Trichomanes boschianum* in the Shawnee National Forest may be immediately threatened with elimination because of the factors presented above. In the absence of future management of the forest and sandstone shelters for this species, it could decrease or be eliminated.

RESEARCH AND MONITORING

There has been a considerable amount of research on the genetics of this and related or similar species thanks to the work of Farrar (1967, 1985, 1990, 1992) and Farrar, Parks, and McAlpin (1982) who primarily studied isozymes and allozymes of the gametophyte generation. There has not been as much published research on the genetics (specifically, the nucleic acids) of the sporophytes of this species particularly within colonies or between proximate colonies. Also, little published literature exists on the establishment, viability, and population dynamics of the species. The techniques for these and other aspects of monitoring and studying rare plant species are explained well in Collins *et al.* (2001), Philippi *et al.* (2001), and Imm *et al.* (2001).

The Appalachian bristle fern is being monitored by some botanists working on behalf of the state Natural Heritage programs and other organizations in the areas where it is listed as rare, threatened, or of special concern (W-2, W-3). However, there is neither sufficient funding nor

are there enough botanists available to survey the immense area that needs to be covered in the monitoring of the large numbers of sensitive plants, including this one (Hill 2002). There is the potential of additional suitable habitat in extreme southern Illinois as well as in southern Indiana where *Trichomanes boschianum* could exist, and continued searches for the species should be conducted. It is important not to collect an entire plant, and only rarely should leaves be taken (see above). Photographs are a less damaging means to document this species, but the species must be positively identified for any data to be of use and so vouchers may be required. Of course, its habitat is generally very dark and this needs to be taken into consideration.

The Hoosier National Forest has instituted an agreement with the Indiana Department of Natural Resources, Division of Nature Preserves, to conduct surveys of rare and exotic plants in special areas (Day 2000). The populations of rare plants are to be documented, former sites revisited, new sites are to be found, and plot information collected, and each exact location is to be noted with Global Positioning System technology. As of 2000, *Trichomanes boschianum* had been assessed at one known site within the National Forest. This careful documentation should be encouraged at sites in all of the states where this scarce plant occurs.

Research is needed concerning the re-establishment of this plant. While this plant can be propagated with success from divisions and from gametophytes in culture, the subsequent acclimation and introduction of these young plants into a natural environment may or may not be possible. As far as known, it has not been attempted on a large scale (see next section).

Of particular importance is the monitoring of the known populations over time to determine population dynamics and survival trends. More research is needed particularly on the longevity of individuals and the establishment of sporophytes. Particular care must be shown to avoid invasive monitoring (trampling, scraping, removal of soil, breaking of substrate) within the sites. It might be useful to enclose some colonies within a newly devised, protective, gated, and locked fencing similar to that used to protect bat hibernacula to investigate the effectiveness of this kind of protection and that would still allow periodic monitoring. Enforced protection of the cliff shelter and grotto habitat within which *Trichomanes boschianum* lives from the several types of imminent threats that exist is the primary management need.

RESTORATION

The recovery potential for *Trichomanes boschianum* is probably poor (W-5) at most sites.

There are no known restoration efforts being conducted on *Trichomanes boschianum* anywhere in its range. Most research on the species has been conducted to determine its genetic relationships. This matter appears to have been settled, and some limited monitoring has been instituted only in relatively recent times. More data is needed on this species and its listing in the RFSS list should help in this regard. The National Forests are, clearly, one of the greatest hopes for the protection of this rather narrowly distributed and isolated near-endemic plant.

This species of fern is not commercially available, and it is not generally cultivated (Lellinger 1985). Restorations of any native plant species are recommended using only nursery propagated material grown from native, local populations to avoid interbreeding with genotypes not adapted to the local conditions and to avoid compromising the local gene pool. If this rule is not followed, the result is generally the loss of plants because they are not competitive under local

conditions or the result could be the success of a plant or plants that cannot be considered truly native (considered by some to be a plant community 'reconstruction' rather than a 'restoration'). Research has already demonstrated that this species has two distinct cytotypes or 'genetic races' found at the eastern and western ends of its range (Farrar 1993) and these genetically distinct populations probably should be kept separate. The propagation of the Appalachian bristle fern in Illinois from unknown sources would not be encouraged in a restoration effort. Local plants should, instead, be propagated for introduction in such an effort, should it be undertaken. Ferns are rather easily grown from spores under controlled conditions, and this one can be rather easily grown from cuttings under controlled conditions. However, it is yet to be determined if the Appalachian bristle fern can be successfully grown and restored to its habitat in this way.

SUMMARY

The Appalachian bristle fern is a small, filmy-leaved, creeping rhizomatous evergreen fern that is found in parts of the eastern United States, and it has a small disjunct population in Chihuahua, Mexico. In the United States it is known to occur historically in thirteen states. It is one of the few members of the primarily tropical fern family Hymenophyllaceae, the Filmy fern family, in North America north of Mexico. It is found loosely rooted on the surfaces of non-calcareous (somewhat acidic) rock outcrops, particularly within heavily shaded, constantly moist and humid, sheltered grottoes, where it is often pendant from rock ceilings. The populations are isolated partly because of infrequent suitable habitat and the colonies are usually small. Globally, its ranking is G4 (apparently secure world-wide, but factors exist to cause some concern). Though not truly common anywhere, the Appalachian bristle fern is most often found in the southern Appalachian region and northern Alabama, and, in Illinois and Indiana it is found primarily within the Shawnee and Hoosier National Forests. The species has been included on the Regional Forester Sensitive Species list (RFSS) for both the Shawnee and the Hoosier National Forests. It is vulnerable to critically imperiled throughout its range, and it is considered imperiled in Illinois and Indiana where it is listed as Endangered, and it has also been listed as Endangered in Ohio, and as Threatened in Arkansas, North Carolina and Tennessee. It is being tracked in most states where it occurs.

This rare fern faces several risks that could result in its extirpation throughout its range if it is not properly protected. These risks include quarrying and mining, changes in regional hydrology, recreational rock climbing, over-collecting, and other activities that may increase drying and erosion from modification of the surrounding habitat. Casual access to the vicinity of the populations should be limited. Continued population monitoring is needed and searches should be conducted for additional populations in far southern parts of both Illinois and Indiana in suitable habitat. Strong enforcement of limited access laws already in place and strong management through increased protection of its habitat including possible exclosures may be needed for it to persist at its present locations, which are currently thought to be rather insecure and vulnerable.

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CONTACTS

Shawnee National Forest; 50 Highway 145 South, Harrisburg, IL 62946

Elizabeth L. Shimp	(618) 253-7114; e-mail: eshimp@fs.fed.us
Steve Widowski	(618) 658-2111; e-mail: swidowski@fs.fed.us

Hoosier National Forest; 811 Constitution Avenue, Bedford, IN 47421 (812) 275-5987

Steven D. Olson (719) 553-1400; e-mail: solson01@fs.fed.us
currently: Pike-San Isabel National Forests,
Cimarron-Comanche National Grasslands,
Kachina Drive, Pueblo, CO 81008

Illinois Natural History Survey; 607 E. Peabody Drive, Champaign, IL 61820

Dr. Steven R. Hill (217) 244-8452; e-mail: srhill@mail.inhs.uiuc.edu
Dr. L. Richard Phillippe (217) 244-2181; e-mail: rickp@mail.inhs.uiuc.edu
Dr. John B. Taft (217) 244-5046; e-mail: taft@mail.inhs.uiuc.edu

Illinois Endangered Species Board

Dr. John E. Ebinger (217) 345-3815; e-mail: cfjee@eiu.edu

Biological Consultant

John E. Schwegman (618) 543-9429; e-mail: botany@midwest.net

Ohio Department of Conservation, Natural Heritage Program

Marilyn Ortt (614) 373-3372

Iowa State University

Dr. Donald R. Farrar e-mail: dfarrar@iastate.edu

University of North Alabama, Department of Biology , UNA Box 5232, Florence, AL 35632

Dr. Paul G. Davison Phone (256) 765-4434; e-mail: Pdavison@unanov.una.edu

APPENDICES

APPENDIX 1

Representative specimens of *Trichomanes boschianum* examined or cited in the literature

Herbaria: CLEMS = Clemson University, Clemson, SC. CONN = University of Connecticut, Storrs. GH = Gray Herbarium of Harvard University, Cambridge, MA. ILLS = Illinois Natural History Survey Herbarium, Champaign. MICH = University of Michigan Herbarium, Ann Arbor. NCU = University of North Carolina herbarium, Chapel Hill. NY = New York Botanical Garden herbarium, Bronx. TENN = University of Tennessee herbarium, Knoxville. UNA = University of Alabama herbarium, Tuscaloosa. VDB = Vanderbilt University Herbarium, now at Botanical Research Institute of Texas, Fort Worth. VPI = Virginia Polytechnic Institute and State University, Blacksburg. VT = University of Vermont herbarium, Burlington. WCUH = Western Carolina University herbarium, Cullowhee.

ALABAMA: COLBERT CO., Spring Creek, 2.7 mi from Littleville, 29 Jun 1941, *Shaw s.n.* (UNA); FRANKLIN CO., The Dismals near Phil Campbell, 7 Sep 1953, *Chermock & Segars s.n.* (UNA); HALE CO., E side Havana glen, 22 Feb 1949, *Harper 4101* (UNA); JACKSON CO., below falls, Long Island Gulf, fertile, Jan - Mar 1915, *Graves 18* (UNA); LAMAR CO., Stucks Springs, NE corner of county, 7 Sep 1952, *Chermock & Segars s.n.* (UNA); LAWRENCE CO., King Cove ca. 5 mi E of SW corner of county, 22 Aug 1940, *Segars & Harvill 163* (UNA); MARION CO., Williams Creek ca. 2 mi NNW of Hamilton, 11 Jul 1969, *Kral 35432* (UNA); MORGAN CO., West Flint Creek near Walden Chapel, 2 Aug 1953, *White s.n.* (UNA); WALKER CO., West Fork Sipsey River on Winston County line ca. 5 mi N of Curry, 10 Jul 1949, *Segars & Harvill 54* (UNA); WINSTON CO., 5 mi ENE of Double Springs at Natural Bridge, 22 May 1949, *Harvill 5025* (UNA);

ILLINOIS: GALLATIN CO., The Pounds, SW of Gibsonia, sandstone cliffs, (gametophyte only), 23 Apr 1963, *Evers 75794* (ILLS); High Knob, SW of Gibsonia. sandstone cliff, (gametophyte only), 24 Apr 1963, *Evers 75758* (ILLS); Thacher Hollow, W of Pounds Hollow, sandstone cliff, (gametophyte only), 17 Apr 1969, *Evers 98608* (ILLS); HARDIN CO., Brown's Hole, SE of Lamb, 11 Apr 1972, *Evers & White 107376* (ILLS); JOHNSON CO., Benson's Bluff, SE of Goreville, (gametophyte only), 8 Apr 1970, *Evers 101848* (ILLS); Benson's Bluff, SE of Goreville, 11 Jun 1968, *Evers 94965* (ILLS); N of Scout Cave, SE of Goreville, 2 Feb 1969, *Schwegman s.n.* (ILLS); 2 mi S of Ozark, 9 Dec 1959, *Evers 63236* (ILLS); Cedar Falls, 2 mi SE of Ozark, Shawnee National Forest, 24 Jul 1984, *McKnight 3894* (ILLS) ; along Ozark Creek, 2 mi S of Ozark, 28 Mar 1961, *Evers 61375* (ILLS); St. Mary's Grotto, 2 mi S of Ozark, (gametophyte only), 14 May 1963, *Evers 75979* (ILLS); POPE CO., Jackson Hollow (north section), SW of McCormick, 13 Mar 1959, *Evers 59776* (ILLS); along Bay Creek, S of Belle Smith Springs, SE of McCormick, 12 Mar 1959, *Evers 59775* (ILLS); Hayes Creek Canyon, N of Eddyville, 26 Feb 1958, *Evers 55831* (ILLS); 3.5 mi W of Eddyville, 3 Apr 1958, *Evers 55861* (ILLS) ;Wallace School, N of Robbs, 13 Nov 1958, *Evers 59774* (ILLS); UNION CO., Panther Den area, N of Lick Creek, (gametophyte only), 15 Sep 1964, *Evers 81487* (ILLS)

MISSISSIPPI: TISHOMINGO CO., Cave Spring, sandstone grotto, Natchez Trace Parkway, 8 Dec 1984, *Webb 5071* (TENN, VDB).

NORTH CAROLINA: MACON CO., Crow Creek Falls, SW of Gneiss, 18 May 1979 & 29 Jun 1983, *Pittillo & Meyerhoff s.n.* (WCUH)

OHIO: JACKSON CO., Canter Cave area, N of Rt. 35, ca. 8 mi E of Ross County line, sandstone cliffs, in deep shady grottoes and crevices, (gametophyte only), 10 Nov 1962, *Wagner 62368* (ILLS) [note: possibly *Trichomanes intricatum*]

SOUTH CAROLINA: GREENVILLE CO., Moonshine Falls, branch of Matthews Creek, below Caesar's Head, W of Rt. 276, in shaded wet gneissic outcrop crevices behind waterfall, 14 Aug 1998, *Hill & Douglass 30636* (ILLS); Moonshine Falls, branch of Matthews Creek, below Caesar's Head, W of Rt. 276, 14 Dec 1992, *Hill et al. 24601* (CLEMS, GH, NY, VT); OCONEE CO., Tamassee Falls, 5 May 1906, *House s.n.* (CONN); Chauga River gorge N of Westminster, 10 Jun 1987, *Hill & Tobe 18083* (CLEMS, MICH, VT); PICKENS CO., Eastatoe Creek Gorge, 7 Jun 1968, *Leonard & Moore 1620* (NCU, WCUH); Eastatoe Creek Gorge, 22 Jun 1970, *Pittillo & Farrar s.n.* (WCUH)

VIRGINIA: RUSSELL CO., sandstone cliff along Clinch River, 4 May 1999, *Belden et al. 1768* (VPI)

APPENDIX 2.

The Distribution of *Trichomanes boschianum* in the United States.

Information from herbarium specimens and the literature. [Incomplete.]

STATE	COUNTIES	NOTES
Alabama	Colbert, Etowah, *Franklin, Hale, Jackson, Lamar, *Lawrence, Marion, Monroe, Morgan, Walker, *Winston *apparently still common here	includes William B. Bankhead National Forest; information contributed by R. Haynes, S. Ginzbarg, D. Farrar, P. Davison, pers. comm.
Arkansas	Cleburne, Johnson, Madison, Pope	see Smith 1988, W-2; includes Ozark N.F.
Georgia	Rabun	see Snyder & Bruce 1986, W-2; includes Chattahoochee N.F.
Illinois	Hardin, Johnson, Pope; possibly Gallatin, Union	includes Shawnee N.F.
Indiana	Crawford, Martin, Perry	see W-6; includes Hoosier N.F.
Kentucky	20 counties, west-central and eastern areas	see W-2; see Cranfill 1980; includes Daniel Boone N.F.
Mississippi	Tishomingo	see W-2; P. Davison, pers. comm.; Menapace *et al.* 1998
North Carolina	Jackson, Macon, Polk	see W-2, W-8; Radford *et al.* 1968
Ohio	Hocking, Jackson [the latter not confirmed]	see W-5 and Appendix 1
South Carolina	Greenville, Oconee, Pickens	see W-2 and Appendix 1
Tennessee	Fentress, Franklin, Monroe, Morgan, Scott	see Chester *et al.* 1993; includes Cherokee N.F.
Virginia	Russell	see W-2; “It's also within a few hundred yards of the Virginia line in Pike County, Kentucky, but searches nearby in Virginia have failed to turn up any so far.” (T.Wieboldt, pers. comm.)
West Virginia	Kanawha, Pocahontas, Wayne, Webster	see W-2; includes Monongahela N.F.

APPENDIX 3.

Natural Diversity Database Element Ranking System

modified from: http://www.cnpsci.org/html/PlantInfo/Definitions2.htm [W-7]

Global Ranking (G)

G1
Critically imperiled world-wide. Less than 6 viable elements occurrences (populations for species) OR less than 1,000 individuals OR less than 809.4 hectares (ha) (2,000 acres [ac]) known on the planet.

G2
Imperiled world-wide. 6 to 20 element occurrences OR 809.4 to 4,047 ha (2,000 to 10,000 ac) known on the planet.

G3
Vulnerable world-wide. 21 to 100 element occurrences OR 3,000 to 10,000 individuals OR 4,047 to 20,235 ha (10,000 to 50,000 ac) known on the planet.

G4
Apparently secure world-wide. This rank is clearly more secure than **G3** but factors exist to cause some concern (i.e. there is some threat, or somewhat narrow habitat).

G5
Secure globally. Numerous populations exist and there is no danger overall to the security of the element.

GH
All sites are historic. The element has not been seen for at least 20 years, but suitable habitat still exists.

GX
All sites are extirpated. This element is extinct in the wild.

GXC
Extinct in the wild. Exists only in cultivation.

G1Q
Classification uncertain. The element is very rare, but there is a taxonomic question associated with it.

National Heritage Ranking (N)

The rank of an element (species) can be assigned at the national level. The **N-rank** uses the same suffixes (clarifiers) as the global ranking system above.

Subspecies Level Ranking (T)

Subspecies receive a **T-rank** attached to the G-rank. With the subspecies, the G-rank reflects the condition of the entire species, whereas the T-rank reflects the global situation of just the subspecies or variety.

For example: *Chorizanthe robusta* var. *hartwegii*. This plant is ranked **G2T1**. The G-rank refers to the whole species range (*i.e*., *Chorizanthe robusta*, whereas the T-rank refers only to the global condition of var. *hartwegii*. Otherwise, the variations in the clarifiers that can be used match those of the G-rank.

State Ranking (S)

S1
Critically imperiled. Less than 6 element occurrences OR less than 1,000 individuals OR less than 809.4 ha (2,000 ac). **S1.1** = very threatened; **S1.2** = threatened; **S1.3** = no current threats known.

S2
Imperiled. 6 to 20 element occurrences OR 3,000 individuals OR 809.4 to 4,047 ha (2,000 to 10,000 ac). **S2.1** = very threatened; **S2.2** = threatened; **S2.3** = no current threats known.

S3
Vulnerable. 21 to 100 element occurrences OR 3,000 to 10,000 individuals OR 4,047 to 20,235 ha (10,000 to 50,000 ac). **S3.1** = very threatened; **S3.2** = threatened; **S3.3** = no current threats known.

S4
Apparently Secure. This rank is clearly lower than S3 but factors exist to cause some concern (*i.e.*, there is some threat, or somewhat narrow habitat).

S5
Secure. Demonstrably secure to ineradicable in the state.

SH
All state sites are historic; the element has not been seen for at least 20 years, but suitable habitat still exists. Possibly extirpated.
SR
Reported to occur in the state. Otherwise not ranked.

SX
All state sites are extirpated; this element is extinct in the wild. Presumed extirpated.

Notes:

1. Other considerations used when ranking a species or natural community include the pattern of distribution of the element on the landscape, fragmentation of the population/stands, and historical extent as compared to its modern range. It is important to take a bird's eye or aerial view when ranking sensitive elements rather than simply counting element occurrences.

2. Uncertainty about the rank of an element is expressed in two major ways: by expressing the rank as a range of values (*e.g.*, **S2S3** means the rank is somewhere between S2 and S3), and by adding a '?' to the rank (*e.g.* S2?). This represents more certainty than S2S3, but less than S2.