Lycopodiella inundata

Northern Bog Club-moss

Lycopodiaceae

Lycopodiella inundata by Peter M. Dziuk, 2012

***Lycopodiella inundata* Rare Plant Profile**

New Jersey Department of Environmental Protection
State Parks, Forests & Historic Sites
Forests & Natural Lands
Office of Natural Lands Management
New Jersey Natural Heritage Program

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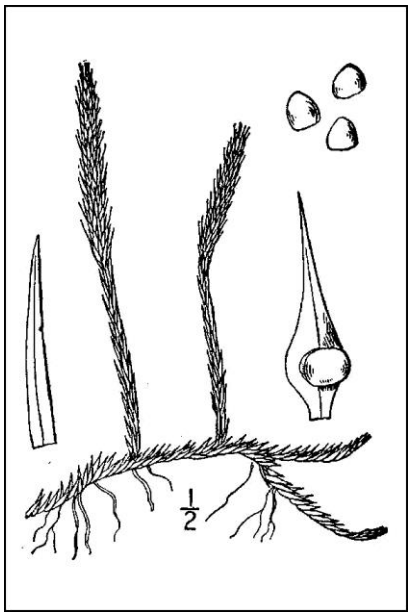
Life History

Like other pteridophytes, *Lycopodiella inundata* (Northern Bog Club-moss) has a life cycle with two independent generations. The spores produced by mature plants first develop into gametophytes, which eventually form structures that generate male and female reproductive cells (gametes). In some club-mosses that process can require 6–15 years for completion. Male gametes (sperm) develop in an antheridium and a female gamete (egg) develops in an archegonium. After fertilization occurs the more recognizable sporophytes appear, initially maintaining an attachment to the gametophytes but eventually becoming independent (Raven 1986).

Lycopodiella inundata spores germinate readily. The gametophytes are green and capable of photosynthesis but they are also mycorrhizal. The body of an *L. inundata* gametophyte is erect and cylindrical with a cluster of lobes at the top and the reproductive organs are situated at the bases of the lobes. The entire structure is 1–5 mm in diameter. Lobes that break off can develop into new gametophytes, and a single *L. inundata* gametophyte may produce more than one sporophyte. The gametophytes can persist for more than one season but they disintegrate as the sporophytes develop (Goebel 1905, Bruce 1972, Lane and Bogle 1974). Detailed illustrations and photographs of gametophytes and developing sporophytes were provided by Goebel (1887) and Bruce (1972), respectively.



Left: Britton and Brown 1913, courtesy USDA NRCS 2024a. Right: Peter M. Dziuk, 2014.

The sporophytes of *Lycopodiella inundata* are perennial and they have leafy horizontal and erect stems. The branching horizontal stems creep along on the ground, producing roots on the underside. Excluding the leaves, they are less than 1 mm in diameter. The unbranched, upright stems are 3–10 cm tall and have spirally arranged leaves that are 5–6 mm in length and have smooth margins. The leaves occupying the upper third to half of the erect stems are similar but larger (10–20 mm long) and they produce sporangia in their axils. The reproductive portion of the stems (strobili) have been likened to 'bushy tails' (Staniforth 2012). Two other *Lycopodiella*

species occur in New Jersey: *L. alopecurioides* and *L. appressa*. They can be distinguished from *L. inundata* by their horizontal stems, which are thicker (1.5–5 mm in diameter) and bear toothed leaves. (See Britton and Brown 1913, Fernald 1950, Gleason and Cronquist 1991, Montgomery and Fairbrothers 1992, Haines 2001, Wagner and Beitel 2024, Weakley et al. 2024). *L. inundata* sporophytes produce numerous secondary compounds, some of which reportedly have medicinal properties (Dvirna et al. 2019).

Different *Lycopodiella* species frequently co-occur and members of the genus hybridize readily (Gillespie 1962, Bruce et al. 1991). Crosses between *L. inundata* and the other two species that grow in New Jersey can produce fertile offspring (Wagner and Beitel 2024). The hybrids are usually found near their parents, and they have intermediate characteristics but they can generally be separated from *L. inundata* by their wider (1–3 mm) horizontal stems. Their erect stems are often taller (up to 20 cm) and some teeth may be present on the leaves (Montgomery and Fairbrothers 1992). In other parts of its range *L. inundata*, which is diploid, has been known to hybridize with some triploid species (*L. margueritae* and *L. subappressa*) but the offspring are sterile (Bruce et al. 1991, Wagner and Beitel 2024).

Mature sporangia may be found on *Lycopodiella inundata* from July through October (Hough 1983, Weakley et al. 2024). The sporophytes can also reproduce clonally and they sometimes form dense stands (Wagner 1963, Ivanova et al. 2016). A population in Poland was estimated to have more than 800 stems per square meter (Kiedrzyński et al. 2015). During the winter months aboveground portions of *L. inundata* die back but sections of the horizontal stems persist and produce new growth in the spring(Wagner 1963).

Pollinator Dynamics

Lycopodiella inundata is a non-flowering plant so pollination does not take place. Fertilization is dependent on water, which allows the movement of biflagellate sperm cells toward a receptive egg cell (Raven 1986). Cross-fertilization in pteridophytes requires sperm from the gametophyte of one sporophyte to fertilize the egg of a gametophyte from a different sporophyte. The sexual union of gametes originating from a single gametophyte, or of gametes produced by two different gametophytes that were derived from the same sporophyte parent, are both forms of self-fertilization (Haufler 2002).

The gametophytes of *L. inundata* are bisexual, producing both antheridia and archegonia (Goebel 1905). Consequently, frequent self-fertilization might be expected but that does not seem to be the case. A study of several other club-mosses by Soltis and Soltis (1988) found that the rates of self-fertilization between gametes from the same gametophyte were extremely low, although the mechanism for achieving inter-gamete fertilization was unknown. In fact, outcrossing appears to be prevalent among pteridophytes in general, and a number of ecological, developmental, chemical, and genetic factors that may contribute to the high rates of cross-fertilization have been identified (Haufler 2002, Haufler et al. 2016).

Seed Dispersal and Establishment

Dispersal in *Lycopodiella inundata* is carried out by spores rather than seeds. Mature plants release a copious amount of sulphur-colored spores that are flammable due to their high oil content (Britton and Brown 1913, Fernald 1950). *L. inundata* spores are slightly wrinkled on the surface (Staniforth and Brunton 2022). The dust-like propagules are transported by wind and may be deposited locally or thousands of kilometers away (Kessler 2010). *L. inundata* gametophytes have typically been documented growing in relatively close proximity to established sporophytes (Bruce 1972, Lane and Bogle 1974), but observations could be biased because they are quite difficult to detect and identify when there are no mature plants nearby.

When *Lycopodiella inundata* spores land in a suitable location they can germinate and form a small cluster of cells, but further growth and development cannot occur without a fungal partner (Bruce 1972, Hoysted et al. 2021). Mycorrhizae have been found in *L. inundata* during all of its life stages (Harley and Harley 1987). The fungi associated with Northern Bog Club-moss are fine root endophytes belonging to a broad subdivision identified as Mucoromycotina. After facilitating the development of *L. inundata* gametophytes the fungi remain attached, permitting the mutually beneficial exchange of nutrients when the sporophytes mature. The fungi also associate with other plant species in the same habitat, which might allow further sharing of resources (Hoysted et al. 2019, 2021). Kowal et al. (2020) found seasonal variation in the colonization of *L. inundata* roots, with the highest levels occurring in the fall, and they also documented differences between populations that aligned with local climactic conditions.

Under the right circumstances, dispersal of *Lycopodiella inundata* might result from the relocation of vegetative material. Wagner (1963) observed that the clubmoss was capable of regenerating from stem fragments, and other *Lycopodiella* species have been propagated from cuttings (Benca 2014).

Habitat

Lycopodiella inundata can grow in a variety of wet habitats at elevations of 0–2000 meters above sea level. It has been found on moist streambanks or lakeshores and in seepage areas, wet swales, bogs, and marshes (Jennings 1918, Wagner and Beitel 2024, Weakley et al. 2024). The substrate is typically sandy or peaty and the sites are often acidic (Fernald 1942, Gillespie 1962, Rasmussen and Lawesson 2002, Rhoads and Block 2007, van Geel et al. 2017, McCullough 2022, Staniforth and Brunton 2022). However, there is evidence that *L. inundata* can tolerate a wide range of soil pH and moisture levels (Rasmussen and Lawesson 2002) and the gametophytes have been known to establish in microsites with an assortment of substrate types, hydrological conditions, and light availability (Bruce 1972). In general, *L. inundata* favors open sites with a high exposure to sunlight and fares poorly when shaded (Rasmussen and Lawesson 2002, Weakley et al. 2024). It is often found growing with other *Lycopodiella* species and additional associates may include *Sphagnum* spp., *Drosera* spp., and assorted graminoids (Burnham 1913, Gillespie 1962, Bruce et al. 1991, Staniforth and Brunton 2022). In the northeastern United States *L. inundata* sometimes frequents cranberry bogs (Bell 1941, Martin 1959, Breden et al. 2001).

Lycopodiella inundata can make use of anthropogenic sites that offer conditions comparable to those of its natural habitats. For example, it has colonized damp depressions associated with abandoned excavation sites and road edges (Burnham 1913, Bruce 1972, Lane and Bogle 1974, Pickering and Wigston 1990, Wagner and Beitel 2024). In New Jersey *L. inundata* has been documented in an assortment of both natural and artificial habitats similar to those reported throughout its range. One record that appears to be unique to the state was an occurrence which established on log that was floating in shallow water near the shore of a lake (NJNHP 2024).

Wetland Indicator Status

Lycopodiella inundata is an obligate wetland species, meaning that it almost always occurs in wetlands (U. S. Army Corps of Engineers 2020).

USDA Plants Code (USDA, NRCS 2024b)

LYIN2

Coefficient of Conservancy (Walz et al. 2020)

CoC = 8. Criteria for a value of 6 to 8: Native with a narrow range of ecological tolerances and typically associated with a stable community (Faber-Langendoen 2018).

Distribution and Range

The native range of *Lycopodiella inundata* extends throughout the northern hemisphere, including parts of North America, Europe, and Asia (POWO 2024). The map in Figure 1 depicts the extent of the clubmoss in the United States and Canada.

The USDA PLANTS Database (2024b) shows records of *Lycopodiella inundata* in 17 New Jersey counties: Atlantic, Bergen, Burlington, Camden, Cape May, Cumberland, Gloucester, Mercer, Middlesex, Monmouth, Morris, Ocean, Passaic, Salem, Sussex, Union, and Warren (Figure 2). The data include historic reports and do not reflect the current distribution of the species.

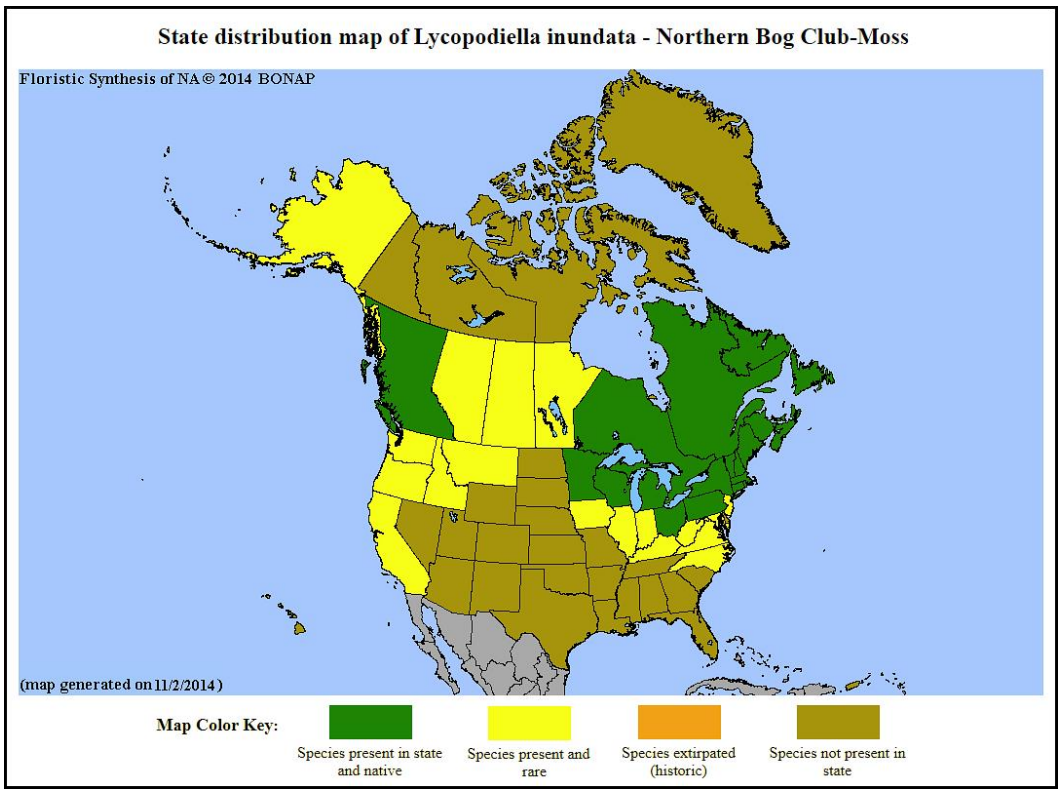


Figure 1. Distribution of L. inundata in North America, adapted from BONAP (Kartesz 2015).

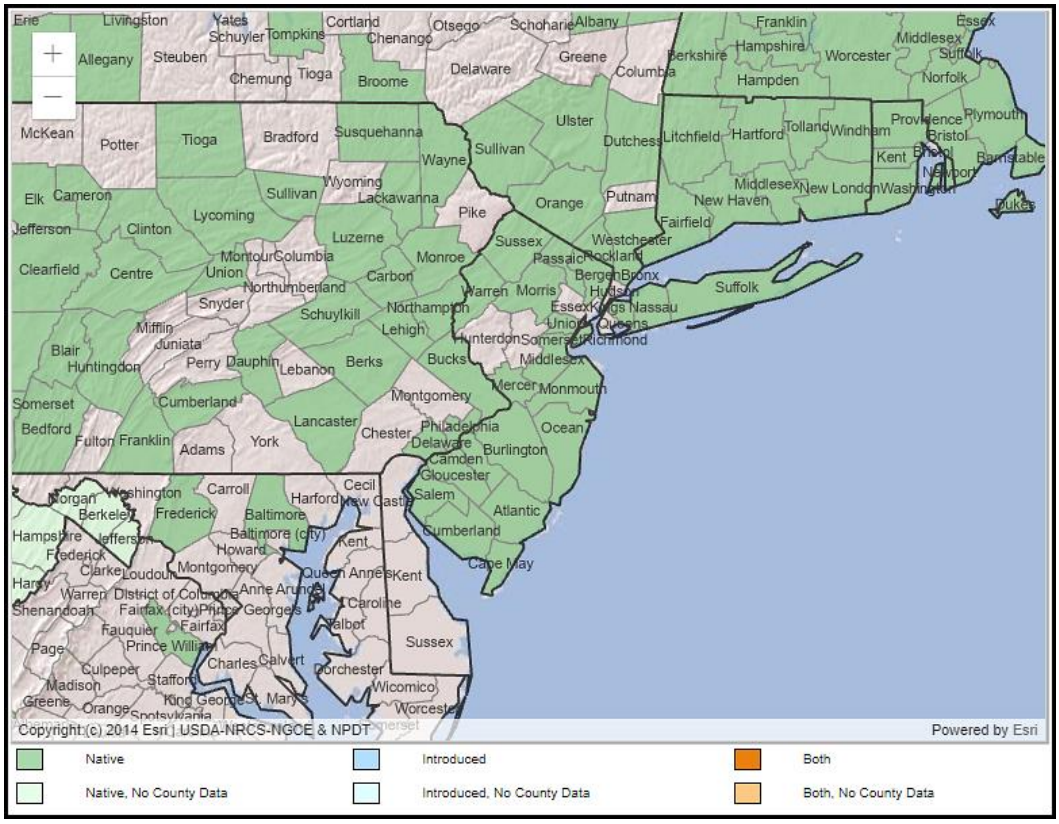


Figure 2. County records of L. inundata in New Jersey and vicinity (USDA NRCS 2024b).

Conservation Status

Lycopodiella inundata is considered globally secure. The G5 rank means the species has a very low risk of extinction or collapse due to a very extensive range, abundant populations or occurrences, and little to no concern from declines or threats (NatureServe 2024). The map below (Figure 3) illustrates the conservation status of Bog Clubmoss in North America. *L. inundata* is vulnerable (moderate risk of extinction) in one state and one province, imperiled (high risk of extinction) in six states and one province, critically imperiled (very high risk of extinction) in ten states and two provinces, and possibly extirpated in Illinois. *L. inundata* is secure, apparently secure, or unranked in other North American districts where it occurs.

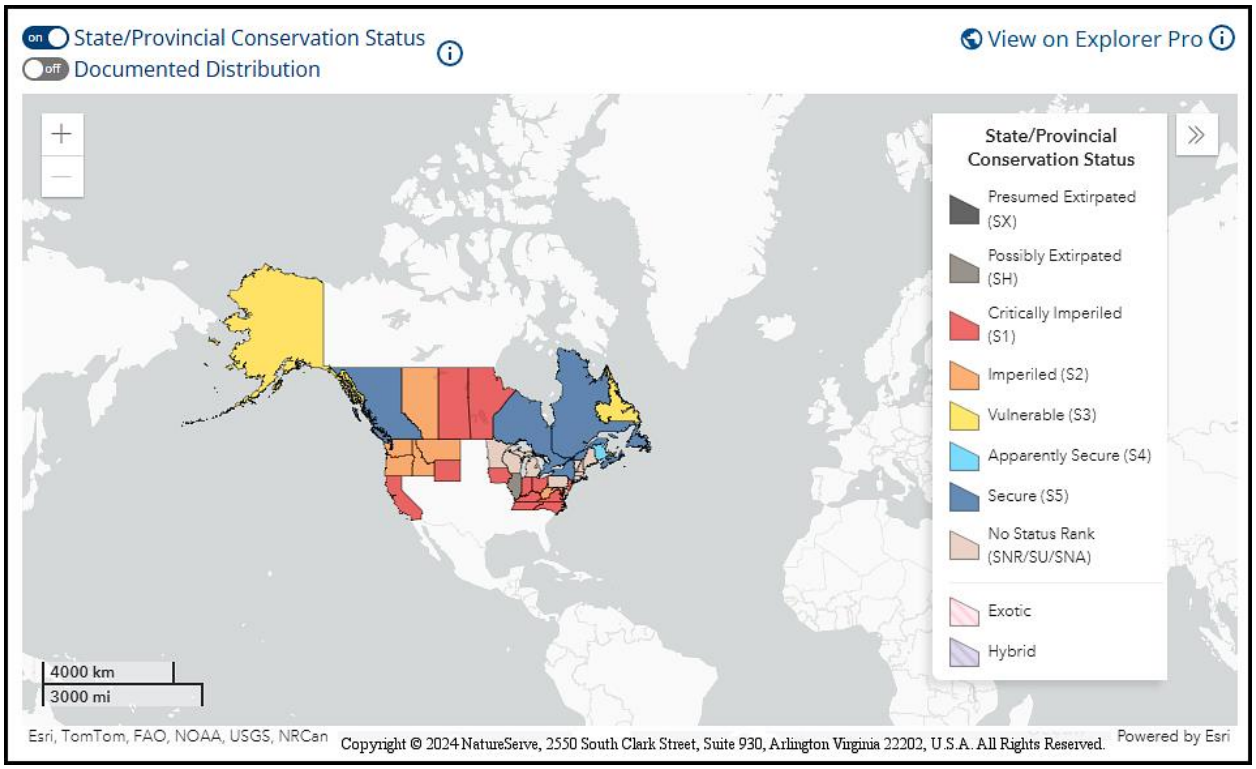


Figure 3. Conservation status of L. inundata in North America (NatureServe 2024).

Lycopodiella inundata is critically imperiled (S1) in New Jersey (NJNHP 2024). The rank signifies five or fewer occurrences in the state. A species with an S1 rank is typically either restricted to specialized habitats, geographically limited to a small area of the state, or significantly reduced in number from its previous status. *L. inundata* has also been assigned a regional status code of HL, signifying that the species is eligible for protection under the jurisdiction of the Highlands Preservation Area (NJNHP 2010).

It is difficult to determine the historic distribution of Northern Bog Club-moss in New Jersey. Inconsistencies in reporting occurred because some early records included taxa that were initially viewed as varieties of *Lycopodiella inundata* but have since been determined to be a separate species (*L. appressa*) or hybrids. (See Britton 1889, Stone 1911, Taylor 1915, Fernald 1946 & 1950, Wagner 1972, Hough 1983, Haines 2002). Montgomery and Fairbrothers (1992) only

showed records of *L. inundata* in seven counties (Bergen, Camden, Gloucester, Middlesex, Morris, Ocean, and Sussex). A general pattern of decline was noted by Montgomery (1982) and *L. inundata* was listed as an S2 species through the beginning of the current century (NJNHP 2001). Just two of the fourteen occurrences tracked by the Natural Heritage Program are thought to be extant today and both are located in Sussex County (NJNHP 2024).

Threats

No particular concerns were identified for extant populations of *Lycopodiella inundata* in New Jersey, although some time has passed since they were last monitored. Loss of suitable habitat was the likely cause of extirpation for several former occurrences in the state, and one population was eradicated by the spread of *Phragmites australis* ssp. *australis* (NJNHP 2024). Throughout the clubmoss's range, changes in habitat quality appear to be the primary threat. Examples include land conversion, wetland drainage, and shifts in community composition (Benca 2014, Ivanova and Natcheva 2016, McCullough 2022, NatureServe 2024). Pickering and Wigston (1990) noted that the low-growing plants could become buried under deposited material, surviving only if they were regularly washed by flooding. Rasmussen and Lawesson (2002) suggested that eutrophication might be responsible, at least in part, for the species' general decline on the European continent.

The success of *Lycopodiella inundata* in infertile, acidic habitats may be attributable to the fact that the stressful conditions reduce the sites' favorability for other species (Rasmussen and Lawesson 2002, McCullough 2022). Recent studies in Europe have shown that the clubmoss is a poor competitor and is highly sensitive to shading (Rasmussen and Lawesson 2002). Even the unrestrained growth of sphagnum mosses can have a detrimental effect on *L. inundata* (van Geel et al. 2017). The reestablishment of *L. inundata* in a Belgian wetland was enhanced by the removal of surface peat because the process deterred the growth of more competitive grasses (Jacquemart et al. 2003). In Poland, Kiedrzyński et al. (2015) observed that the clubmoss was considerably more abundant in open sites than in shrubby settings. A transplantation experiment in Bulgaria found that *L. inundata* sporophytes developed well for several years but declined after taller plants such as *Carex rostrata* and *Menyanthes trifoliata* became established at the site (Ivanova and Natcheva 2016).

Climate Change Vulnerability

Information from the references cited in this profile was used to evaluate the vulnerability of New Jersey's *Lycopodiella inundata* populations to climate change. The species was assigned a rank from NatureServe's Climate Change Vulnerability Index using the associated tool (Version 3.02) to estimate its exposure, sensitivity, and adaptive capacity to changing climactic conditions in accordance with the guidelines described by Young et al. (2016) and the state climactic computations by Ring et al. (2013). Based on available data *L. inundata* was assessed as Highly Vulnerable, meaning that it is likely to experience a significant decrease in abundance or range extent throughout New Jersey by 2050.

Shifting climactic conditions in New Jersey are resulting in higher temperatures, more frequent and intense precipitation events, and increasing periods of drought (Hill et al. 2020). *L. inundata* is well-adapted to cool, wet conditions: The gametophytes can persist under water and ice during the winter (Bruce 1972) and sporophytes appear to tolerate winter flooding as well (Rasmussen and Lawesson 2002). The limits of the species' ability to withstand high temperatures do not appear to have been studied, but it is imperiled throughout the southernmost portion of its range (Figure 3) which suggests that rising temperatures could be a threat. Although *Lycopodiella inundata* can adjust to varying moisture conditions, including brief periods of desiccation (van Geel et al. 2017), lengthy episodes of drought or inundation are likely to be problematic. Fables (1956) observed a decline in a New Jersey population following an extended dry period and Staniforth (2012) reported the disappearance of the species from a flooded site. While climate change poses a significant threat to *L. inundata* in New Jersey, the species might be able to establish in new locations elsewhere. For example, a habitat suitability model predicted that Northern Bog Club-moss will expand its range in the Pacific Northwest (Link-Perez and Laffan 2018).

Management Summary and Recommendations

No management needs have been identified for New Jersey populations of *Lycopodiella inundata* but updated evaluations are required in order to determine the status of extant occurrences and assess present habitat conditions. To date, efforts to relocate historical occurrences have been unsuccessful although there are a number of sites that could still be searched. Management recommendations for remaining populations would depend on the outcome of monitoring visits. If threats are identified, control of invasive species or moderation of successional changes are likely to emerge as priorities.

Synonyms

The accepted botanical name of the species is *Lycopodiella inundata* (L.) Holub. Some orthographic variants, synonyms, and common names are listed below (ITIS 2024, POWO 2024, USDA NRCS 2024b).

Botanical Synonyms	Common Names
Lepidotis inundata (L.) C. Borner	Northern Bog Club-moss
Lycopodium inundatum L.	Inundated Clubmoss
Lycopodium inundatum f. *funiforme* Noiselle ex Nessel	
Lycopodium inundatum f. *furcatum* Fernald	
Lycopodium inundatum var. *diversifolium* Nessel	
Lycopodium inundatum var. *rigidium* Spring	
Lycopodium inundatum var. *typicum* Wherry	
Lycopodium palustre Lam.	
Plananthus inundatus (L.) P. Beauv.	

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