Muhlenbergia torreyana

Pine Barren Smoke Grass

Poaceae

Muhlenbergia Torreyana by Bob Cunningham, 2016

***Muhlenbergia torreyana* Rare Plant Profile**

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

501 E. State St.
PO Box 420
Trenton, NJ 08625-0420

Prepared by:
Jill S. Dodds
jsdodds@biostarassociates.com

July, 2022

For:
New Jersey Department of Environmental Protection
Office of Natural Lands Management
New Jersey Natural Heritage Program
natlands@dep.nj.gov

This report should be cited as follows: Dodds, Jill S. 2022. *Muhlenbergia torreyana* Rare Plant Profile. New Jersey Department of Environmental Protection, State Parks, Forests & Historic Sites, State Forest Fire Service & Forestry, Office of Natural Lands Management, New Jersey Natural Heritage Program, Trenton, NJ. 21 pp.

Life History

Muhlenbergia torreyana (Pine Barren Smoke Grass) is a perennial grass that spreads via scaly, horizontal rhizomes. The grass grows in clumps because the rhizomes are relatively short. The flowering stems (culms) are 30–70 cm high, smooth, and strongly flattened, especially at the base. The base of a culm is surrounded by erect leaves that are 6–20 cm long and 1–3.5 mm wide. The leaves are folded along the midribs, rough on both surfaces, and sharply pointed at the tips. Ligules at the base of the leaf sheaths consist of a zone of short hairs. The inflorescence is an open, diffuse panicle that is somewhat oblong or cylindrical in shape, typically between 10–28 cm long and 4–8 cm wide. Spikelets usually have a single floret, although occasional spikelets may include a second one. The florets are grayish-green to purple in color. The pedicels are usually longer than the florets and may be up to 9 mm in length. Each floret has a pair of unawned, pointed glumes that are roughly equal to the lemma in length (~1–2 mm) and remain on the inflorescence after the mature spikelet falls off. (See Britton and Brown 1913, Fernald 1950, Hitchcock 1950, Boyd 1991, Gleason and Cronquist 1991, Chamberlain 2018, Peterson 2021).

Left: Hitchcock 1950, courtesy USDA NRCS 2022a. Center: dogtooth77, 2015. Right: Britton and Brown 1913, courtesy USDA NRCS 2022b.

In New Jersey, *M. torreyana* flowers and fruits from early August through October (Hough 1983). Clonal patches of nonflowering plants may be recognized by the evenly-spaced tufts of upright, blue-green leaves. Each tuft has a flattened stem bearing 5–10 stiff, folded leaves. At the top of each leaf sheath is a thickening that can be easily detected by running the stem from base to tip between thumb and forefinger (Weakley 2015).

Muhlenbergia torreyana is the sole known host plant for a recently discovered leafhopper, *Flexamia whitcombi*, which has only been found in New Jersey to date (Hicks 2015). Many leafhoppers are host-specific (Milne and Milne 1980), and members of the genus *Flexamia* are almost exclusively associated with native grasslands (Bess and Hamilton 1999). An entire

branch of *Flexamia* apparently developed as specialists on various species of *Muhlenbergia*, and ongoing searches of habitats where perennial grasses are dominant have resulted in the detection of a number of previously unknown leafhoppers (Whitcomb and Hicks 1988). Hicks (2015) noted that about a quarter (27%) of all known *Flexamia* species feed exclusively on some type of *Muhlenbergia*. Leafhopper damage to host plants is usually limited to some leaf spotting or wilting and rarely results in serious injury (Missouri Botanical Garden, undated). Although certain leafhoppers can transmit diseases to plants (Milne and Milne 1980), *Flexamia* has been described as a non-vector genus (Hicks 2015).

Pollinator Dynamics

Wind is the primary means of pollination for plants in the Poaceae (Garcia-Mozo 2017). Some characteristics that facilitate wind pollination in the family include smooth, round pollen grains, a reduced perianth, and a limited number of ovules (Geisler 1945, Friedman and Barrett 2009). In species like *Muhlenbergia torreyana* that have diffuse inflorescences, culm movement in the wind may play a role in both dispersal and receipt of pollen (Friedman and Harder 2004). Even for grass species that also utilize insects as pollinators, wind is the most important mechanism for cross-fertilization (Schulze-Albuquerque et al. 2019).

Flowers on large clonal plants are more likely to be the recipients of pollen from genetically similar individuals (Handel 1985), but the capacity for self-fertilization in *Muhlenbergia torreyana* has not been investigated. Self-incompatibility is frequent in the grass family (Friedman and Barrett 2009) although sometimes it is partial, reducing but not eliminating the production of viable seeds (Connor 1979). However, self-compatibility has been documented in the genus *Muhlenbergia* (Mitchell and Pohl 1966) and at least one species (*M. microsperma*) is known to produce cleistogamous flowers (Chase 1918).

Seed Dispersal

The fruit of *Muhlenbergia torreyana* is a single-seeded grain that is spindle-shaped, brownish, and approximately 1 mm long (Peterson 2021). The propagules have no special adaptations for dispersal but are likely to be distributed in multiple ways. The majority of seeds fall near their parent plants (Collins and Uno 1985), but both wind and post-ingestion dispersal are common in grasses (Cheplick 1998). Smooth, hard seeds are likely to be consumed by birds, and winter bird populations often rely on grains for a significant part of their diet (Cheplick 1998, Collins and Uno 1985). Orlowski et al. (2016) determined that when birds consumed high volumes of seeds they were more likely to excrete some propagules that were undigested and therefore viable, and they suggested that the effectiveness of avian dispersal had been underestimated. Flaherty et al. (2017) found that 42% of wetland plant seeds dispersed by White-tailed Deer (*Odocoileus virginianus*) were graminoid species, so post-consumption dispersal by deer is also a possibility.

No information was found regarding seed longevity or germination in Pine Barren Smoke Grass, although seed banking has been reported in other species of *Muhlenbergia* (e.g. Keddy and Reznicek 1982, Middleton 2003). The seeds of many plants that inhabit intermittent ponds on

the coastal plain can remain in the ground for years and germinate when conditions are favorable (Johnson and Walz 2013). It is also possible that *M. torreyana* relies heavily on vegetative reproduction for population maintenance, as Weakley (2015) indicated that the species rarely flowers except following fire.

Habitat

Muhlenbergia torreyana typically grows at elevations of 0–150 meters in sites that are wet or moist year-round, many of which are seasonally inundated (Peterson 2021). The Tennessee occurrence, which is situated on the eastern side of the Highland Rim, may be somewhat higher in elevation (DeSelm et al. 1994). *M. torreyana* habitats usually have a relatively open canopy (Morse et al. 2009). In New Jersey the characteristic trees are generally Pitch Pine (*Pinus rigida*) or Atlantic White Cedar (*Chamaecyparis thyoides*) (Breden et al. 2001), but more southern occurrences may be associated with Longleaf Pine (*Pinus palustris*), Pond Pine (*P. serotina*), Pond Cypress (*Taxodium ascendens*), or oak (*Quercus*) barrens (Walker 1993, Sorrie et al. 1997, Edwards and Weakley 2001, Gray 2001, Morse et al. 2009, Thornhill et al. 2014, Weakley 2015).

Callazza and Fairbrothers (1980) summarized *Muhlenbergia torreyana*'s habitats in the New Jersey Pinelands as peaty or damp sandy soil in swamps, marshes, bogs, forest depressions, and roadside ditches that are continuously wet and have a layer of organic matter. Available habitat notes from 94 extant and historical occurrences in the New Jersey Pine Barrens (NJNHP 2022) provided more specific information regarding the community types in which *M. torreyana* is likely to occur. Of the 72 populations found in natural communities, 39% occurred in some type of intermittent pond and 25% in savannas. Other habitats were categorized more generally as spung (11%), bog (10%), wet swale or meadow (10%), river bank (3%) or intermittent stream bed (3%). Nearly a quarter of the 94 sites (23%) had a history of disturbances including ditches, old clay or gravel pits, abandoned cranberry bogs, or low clearings associated with old roadways, railroads or utility right-of-ways. The majority of disturbed habitats resembled the natural plant communities favored by Pine Barren Smoke Grass. Under the right circumstances, manmade ponds in the Pine Barrens can become functionally equivalent to natural coastal plain ponds with the passage of time (Zampella and Laidig 2003).

Coastal Plain Intermittent Ponds are rare throughout their range (Johnson and Walz 2013). The ponds are usually shallow and have seasonally variable hydrology, alternately holding water and drying out at different times of year. In such habitats, *Muhlenbergia torreyana* is likely to be found in an herbaceous zone on the sloping sides or borders of the pools (NJNHP 2022). Twenty-one kinds of Coastal Plain Intermittent Pondshore communities occur in New Jersey (Walz et al. 2006). Pine Barren Smoke Grass is a defining species of the Pine Barrens Coastal Plain Muhly Pondshore association (*Muhlenbergia torreyana—Rhynchospora fusca* marsh), a community that is critically imperiled globally (G1) and is only known from New Jersey where it is also critically imperiled (S1). The association develops on the higher, outer margins of sandy basins and it is fire-dependent (Walz et al. 2006, NatureServe 2022).

Pine Barrens Savanna communities are globally imperiled (G2) and imperiled or critically imperiled (S1S2) in New Jersey. The habitat type is usually found along old stream channels

which are separated from the associated river by a well-developed levee, and the sites are influenced by periodic flooding or groundwater seepage from adjacent cedar swamps (Breden et al. 2001). Six ecological associations have been identified within New Jersey's savanna habitats, and *Muhlenbergia torreyana* is particularly abundant in Pine Barrens Streamside Muhly Savanna (*Muhlenbergia torreyana—Lobelia canbyi—Rhynchospora alba* fen), a graminoid-dominated community on shallow muck over sand or bog iron substrate (Walz 2004). The association is imperiled globally (G2) and locally (S2). The open nature of the community is maintained by periodic disturbances that include fire, flooding, and deer browse, and soil chemistry may also play a role in retarding succession (Walz 2004). In this setting fire can engender a monoculture of *Muhlenbergia torreyana* (NatureServe 2022).

Muhlenbergia torreyana occurrences in New Jersey that are not in coastal plain ponds or savannas are usually associated with Pitch Pine Lowland (*Pinus rigida*/*Gaylussacia dumosa*/*Calamovilfa brevipilis* woodland), a community type that is critically imperiled both locally (S1) and globally (G1). The association is characterized by an open canopy (10–50% cover) of Pitch Pine with a scattered shrub layer dominated by mixed ericaceous species and *Ilex glabra*. Pine-barren Sand-reed (*Calamovilfa brevipilis*) is the dominant herb (Breden et al. 2001). In Pitch Pine Lowlands, *M. torreyana* is usually found in low, wet areas where the canopy has been opened up by a natural or anthropogenic disturbance (NJNHP 2022).

Aside from the previously noted differences in the dominant woody species, habitats for other occurrences throughout the range of *Muhlenbergia torreyana* are similar to those described for New Jersey. Two Georgia sites were characterized as moist Pine Barrens (Harper 1900) and the margins of a Pine Barrens pond (Harper 1903). The Maryland occurrence was described as a small population of mostly nonflowering plants in wet, often flooded, open woods (Hirst 1983). *M. torreyana* has been recorded in coastal plain ponds in New York (Zaremba and Lamont 1993) and North Carolina (Sorrie et al. 2006), and seasonal ponds were also identified as the most likely habitat for one historical Delaware occurrence (McAvoy and Wilson 2014). Additional North Carolina occurrences are known from savanna and blackwater river meander communities (LeGrand et al. 2022). The extant Tennessee occurrence is located in a wet grassland community situated in a powerline right-of-way which passes through a swampy hardwood forest that developed in what was once a hydric oak savanna (Ciafré et al. 2022).

In locations that have not been altered by human activity, the open habitats utilized by *Muhlenbergia torreyana* are maintained by natural disturbances such as floods and fires (Morse et al. 2009). Periodic inundation, which is a feature of many of the communities described above, restricts canopy development. Intermittent desiccation can make sites more susceptible to burning, which also inhibits woody plant succession. In Maryland, *M. torreyana* was characterized as a species of fire-prone coastal depressions (MDWHS 2021) and its habitats in North Carolina are also subject to sporadic fires (Sorrie et al. 1997, Sorrie et al. 2006). Fire has been noted as contributing to habitat conditions for a number of *M. torreyana* occurrences in New Jersey (NJNHP 2022) and the plant associations in which Pine Barren Smoke Grass is dominant are maintained by episodic burns (Walz 2004, Walz et al. 2006). Unlike some fire-adapted species that rapidly move between patches of habitat in a landscape matrix, *Muhlenbergia torreyana* is more likely to rely on large population sizes in order to persist at sites where it has already become established (Gray 2001).

Wetland Indicator Status

Muhlenbergia torreyana is a facultative wetland species, meaning that it usually occurs in wetlands but may occur in nonwetlands (U. S. Army Corps of Engineers 2020).

USDA Plants Code (USDA, NRCS 2022c)

MUTO

Coefficient of Conservatism (Walz et al. 2018)

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 worldwide range of *Muhlenbergia torreyana* is restricted to the eastern United States (POWO 2022). The map in Figure 1 depicts the global extent of Pine Barren Smoke Grass. The vast majority of extant populations of *M. torreyana* are located in New Jersey (Morse et al. 2009). The map shows that the distribution of *Muhlenbergia torreyana* is somewhat scattered within its range. Sorrie and Weakley (2001) observed that a notable number of species which were primarily found on the coastal plain also had disjunct occurrences in the Eastern Highland Rim and Cumberland Plateau regions of central Tennessee and/or Kentucky, estimating that 57 additional plant species displayed a similar distribution pattern.

The USDA PLANTS Database (2022c) shows records of *Muhlenbergia torreyana* in seven New Jersey counties: Atlantic, Burlington, Camden, Cape May, Cumberland, Gloucester, and Ocean (Figure 2). The data include historic observations and do not reflect the current distribution of the grass.

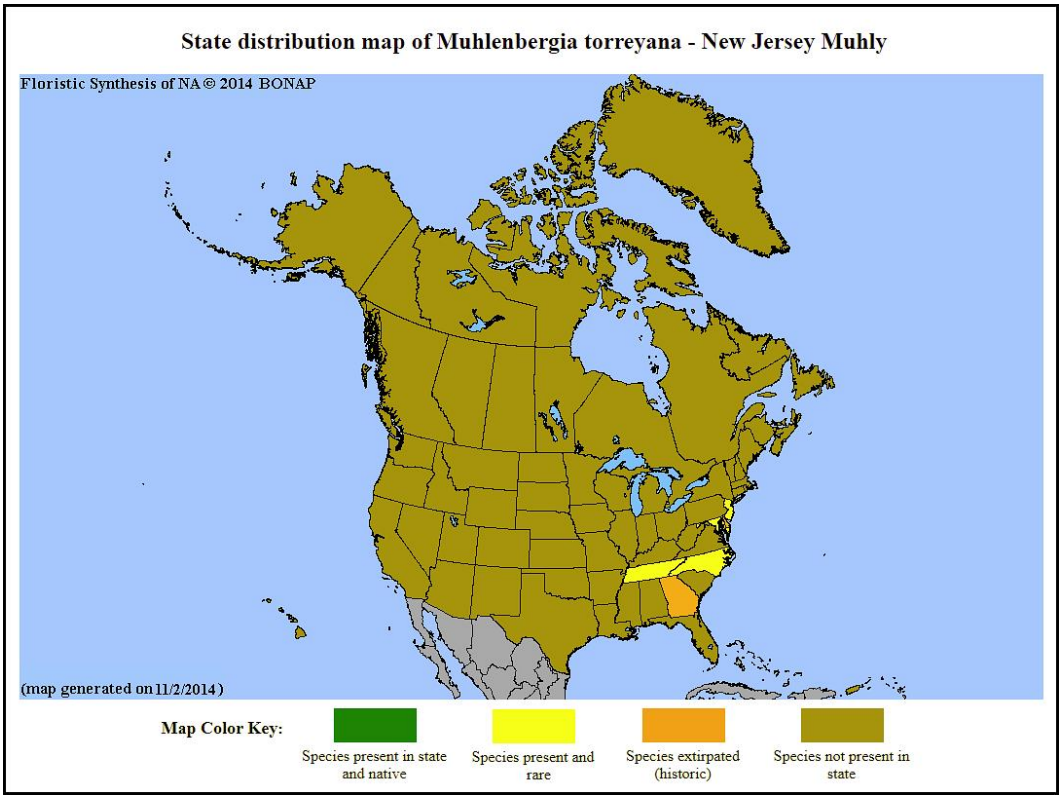

Figure 1. Distribution of M. torreyana in North America, adapted from BONAP (Kartesz 2015).

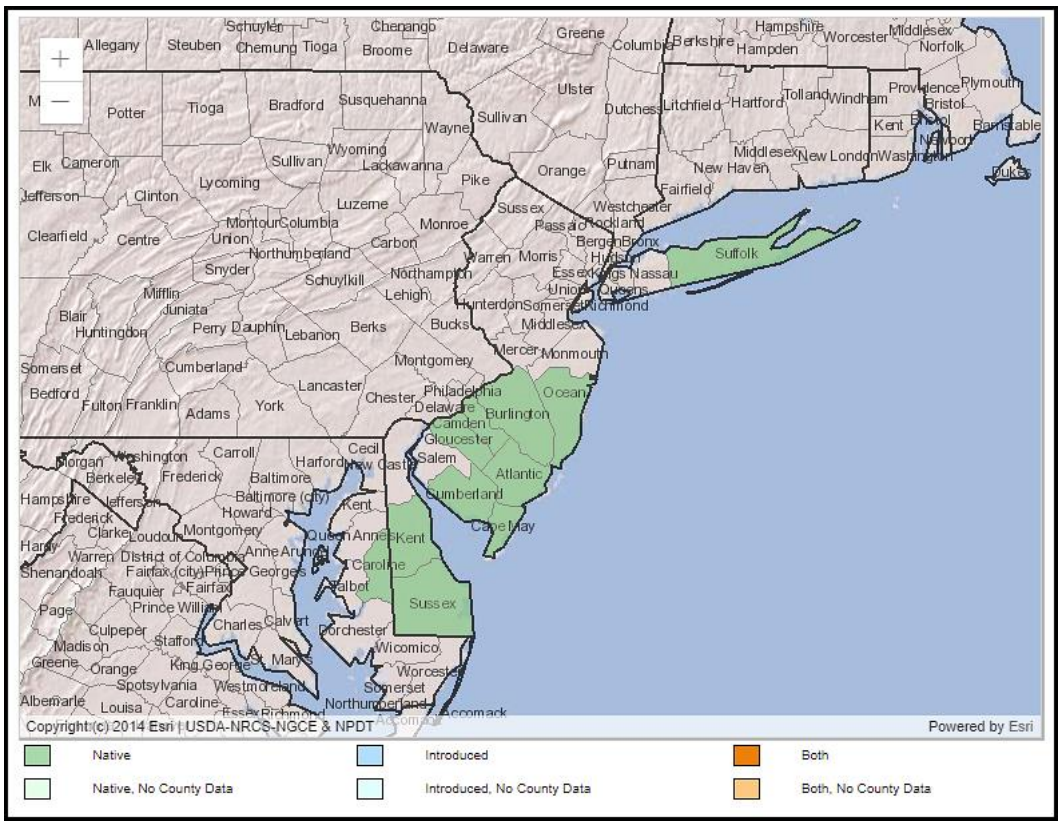

Figure 2. County records of M. torreyana in New Jersey and vicinity (USDA NRCS 2022c).

Conservation Status

Muhlenbergia torreyana is globally vulnerable. The G3 rank means the species has a moderate risk of extinction or collapse due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors (NatureServe 2022). In North America, *M. torreyana* has also been identified as a plant species of highest conservation priority for the North Atlantic region, which includes four Canadian provinces and twelve U. S. states. The species has a regional rank of R2 (imperiled), signifying a high risk of extinction (Frances 2017). The map below (Figure 3) illustrates the conservation status of *M. torreyana* throughout its range. The grass is vulnerable (moderate risk of extinction) in New Jersey, imperiled (high risk of extinction) in North Carolina, and critically imperiled (very high risk of extinction) in Maryland and Tennessee. *M. torreyana* is possibly extirpated in Georgia and presumed extirpated in Delaware and New York.

In the mid-1970s Pine Barren Smoke Grass was included on a list of plants for which a federal status review was initiated (USFWS 1975) but it was subsequently classified as a 3C taxon, signifying that the species was more abundant than previously thought and/or not subject to any identifiable threat (USFWS 1980). *M. torreyana* was one of the original plants identified as being in need of protection by the New Jersey Pinelands Commission (1980), which recommended that the species be included on the national list of threatened and endangered plants. Despite its tenuous status throughout its range, *Muhlenbergia torreyana* is not currently eligible for protection at the federal level (USFWS 2022).

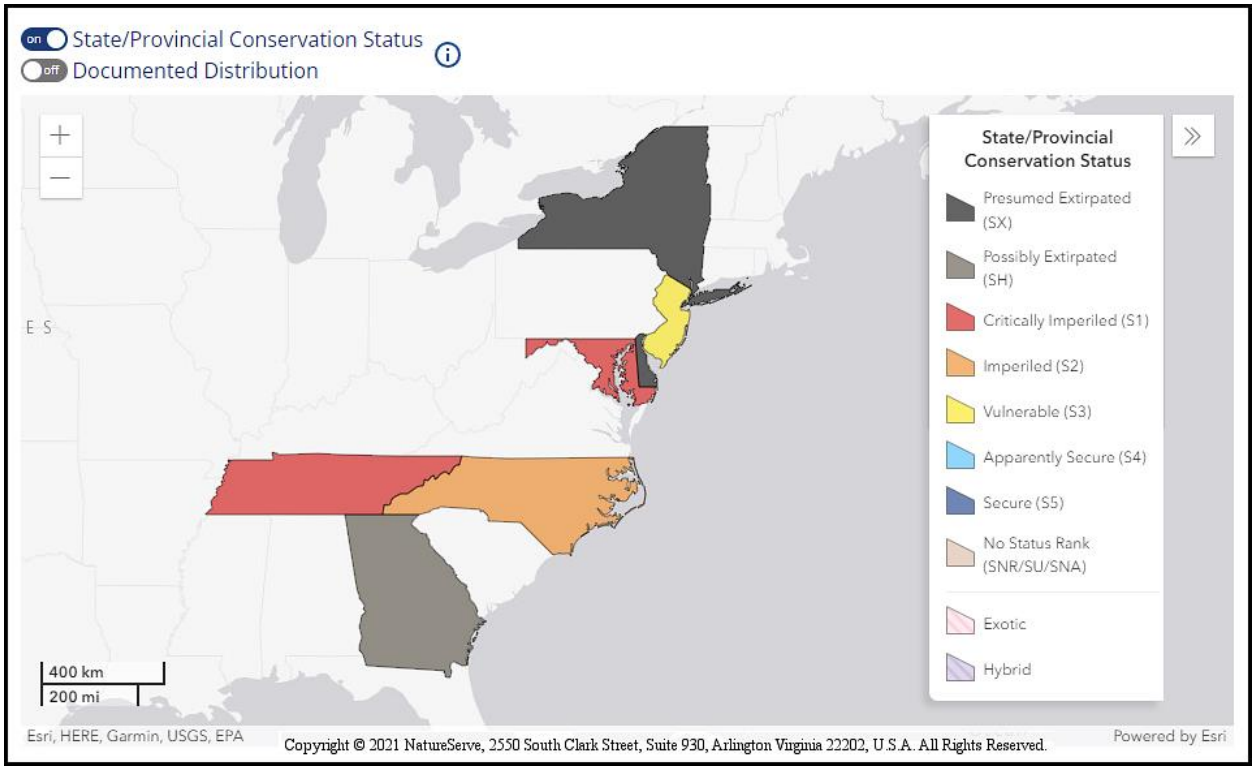

Figure 3. Conservation status of M. torreyana in North America (NatureServe 2022).

Muhlenbergia torreyana is ranked S3 in New Jersey (NJNHP 2022). A rank of S3 may indicate a species that is widely distributed throughout the state but in small populations, or one that is found in a limited number of locations but may be locally abundant where it occurs. Additional regional status codes assigned to the plant signify that the species is eligible for protection under the jurisdictions of the Highlands Preservation Area (HL) and the New Jersey Pinelands (LP) (NJNHP 2010).

Muhlenbergia torreyana was first described from a specimen that originated in southern New Jersey, where it was known since the early part of the 1800s (Torrey 1819, Fairbrothers 1979). The grass was reported as frequent in the bogs of the Pine Barrens by Britton (1881) and Stone (1911). In New York, Pine Barren Smoke Grass was found on Long Island some time during the mid-1800s: The species was not included in Torrey's 1843 state flora of New York but Zaremba and Lamont (1993) indicated that it was last seen in 1883. *M. torreyana* was also found at a limited number of sites in Delaware beginning around 1873 (Clancy 1993). The next place it turned up was in Georgia, where two populations were discovered in 1900 and 1901 (Harper 1901, 1903). A number of collections were subsequently made from a single county in Tennessee, dating back to sometime around the 1930s (Mid-Atlantic Herbaria 2022). Hitchcock (1950) included Kentucky in the species distribution notes, but no specimens documenting its presence in that state have been located (Peterson 2021). In the 1970s *M. torreyana* was reported as threatened in Delaware, Georgia, Kentucky and Tennessee (Fairbrothers 1979), but the species was not discovered in Maryland or North Carolina until the 1980s (Hirst 1983, Weakley 2015). *Muhlenbergia torreyana* was recently documented in South Carolina for the first time by a 2016 specimen that resides at the University of North Carolina in Asheville (Mid-Atlantic Herbaria 2022).

In addition to the newly reported occurrence in South Carolina, *M. torreyana* is only known to be currently extant outside of New Jersey at a single site in Maryland (MDWHS 2021), one remaining site in Tennessee (Ciafré et al. 2022), and 13 sites in North Carolina (LeGrand et al. 2022). In New Jersey, 87 occurrences are tracked as extant (NJNHP 2022) and species was recently found at two additional sites in a county where it was previously thought to be historical (Moore 1989, Moore et al. 2016).

Factors that influence the rarity of a plant species include its geographic range, habitat specificity, and local population size (Rabinowitz 1981). While both the range and the habitat requirements of *Muhlenbergia torreyana* are narrow, the grass may be locally abundant—at least in New Jersey—where it can sometimes form a turf and dominate large areas that occasionally span several acres (Morse et al. 2009, NJNHP 2022). On one occasion, the density of *M. torreyana* was cited as a possible threat to another endangered species (Peters 1993).

Expansive stand of *M. torreyana* in southern New Jersey by dogtooth77, 2014.

Threats

Pine Barren Smoke Grass is restricted to a limited number of community types, all of which are relatively rare. Consequently, habitat loss or degradation is the most significant threat to *Muhlenbergia torreyana* throughout its range. In the past, hundreds of coastal plain ponds were degraded or destroyed by ditching for agriculture and by timber harvesting practices (McAvoy and Bowman 2002). Ongoing threats to the sensitive intermittent pond habitats include hydrologic modifications that alter natural patterns of filling and drying as well as the introduction of pollutants that change water quality or chemistry (Johnson and Walz 2013). Other wetland habitats, both in the Pine Barrens and outside of New Jersey, face similar threats. Gordon (2009) noted the absence of *M. torreyana* from a former site that had been heavily impacted by agriculture, and habitat losses resulting from logging, plowing, or changes in hydrology continue to threaten the species throughout its range (Morse et al. 2005). Zampella and Laidig (1997) found that characteristics frequently associated with degraded habitat in the Pine Barrens included a high proportion of agricultural or developed land in the watershed, elevated pH, elevated conductivity in surface waters, an abundance of channel sediment, and dense woody cover. Their study of Pinelands species in relation to those variables identified 29 plants as indicators of degraded habitats but showed that *Muhlenbergia torreyana* was unlikely to co-occur with those, instead being positioned on the opposite side of the spectrum.

Imminent threats to *Muhlenbergia torreyana* populations in New Jersey are minimal. Threats from off-road vehicles were noted for a few occurrences, but many locations are remote and inaccessible and thus protected from vehicular traffic (NJNHP 2022). Loss of habitat to natural successional processes was noted as a concern at several sites, and that has the greatest potential to pose a significant long-term threat to the species. While conducting a study of Pine Barrens savanna communities, Smith (2012) found that over 70% of savanna habitat in the area examined had been lost between 1940 and 2002. While some savanna habitats maintained a fairly steady graminoid cover, others occurred within a shifting mosaic of community types which was perpetuated by ongoing disturbances that opened new gaps to compensate for those lost to succession. However, even the more persistent open patches showed signs of slow decline due to the incursion of Atlantic White Cedar. The overall decline appeared to be driven by the alteration of natural disturbance regimes (Smith 2012). To a lesser extent, suppression of natural fire regimes can also impact coastal plain ponds (Johnson and Walz 2013).

Referencing Doust's (1981) discussion of phalanx and guerilla growth forms, Edwards and Weakley (2001) placed *Muhlenbergia torreyana* in the former category, noting that rhizomatous species with a phalanx growth form are less likely to experience competition and more likely to encounter microhabitat conditions comparable to those in which they are already established. The authors raised the possibility that utilization of a phalanx growth strategy could indicate that a species is a poor competitor. While *M. torreyana* is able to dominate a habitat under favorable circumstances, competition with other species may play a more significant role when habitat conditions are altered. As the climate continues to warm, New Jersey is expected to experience higher temperatures as well as more extreme events that result in both floods and droughts (Hill et al. 2020). The combination could disrupt the hydrologic cycles of intermittent wetlands and alter the trajectory of succession and patterns of dominance in sensitive Pine Barren communities.

Management Summary and Recommendations

Muhlenbergia torreyana should be a priority for conservation in New Jersey because the state is a stronghold for the globally vulnerable species. The natural habitats utilized by Pine Barren Smoke Grass are also rare, so preservation of the grass will depend on protecting the fragile communities where it thrives.

The key to managing the communities that support *M. torreyana* appears to be the maintenance of natural hydrological patterns and water quality. Management of those habitats will require a watershed-wide perspective, as plant communities on protected and buffered land can still be affected by activities off-site that draw down the water table or introduce silt and nutrients into the waterways. That presents an enormous challenge which is likely to be further complicated by climate change.

Approximately a quarter of New Jersey's *M. torreyana* populations are located in Pine Barren savannas, which may need an additional level of effort to manage the rate of successional processes. In small, relatively stable sites selective removal of cedar trees could help to maintain the open canopy, but that would not be practical at sites that are larger or changing rapidly.

Management studies of the Pine Barren Gentian (*Gentiana autumnalis*), a fall-flowering species that sometimes shares habitat with *M. torreyana*, showed that either mowing or burning just prior to the growing season increased plant density, flowering, and seed set (Rebozo et al. 2019). Similar techniques are likely to benefit Pine Barren Smoke Grass, particularly where it occurs within communities that are known to be fire-dependent, although further investigation would be required to establish the appropriate disturbance frequency, intensity, and timing. Site-specific plans would be needed in order to determine which tool might be best suited to a particular location, and also to consider the needs and tolerances of all species present as many other rare plants and animals can co-occur with *M. torreyana*.

Studies of *Muhlenbergia torreyana* were conducted by Pizzolato (1995, 1996) but the research was primarily focused on anatomy, particularly on procambial development in floral parts. Additional investigations are needed to increase knowledge regarding the species' life history. Topics worthy of further exploration include the relative importance of sexual and vegetative reproduction to population persistence, the conditions that facilitate flowering, the requirements for germination and establishment, and the factors that restrict the species to certain habitat types. Many grasses form mycorrhizal associations, including at least one species of *Muhlenbergia* (Wang and Qiu 2006), but it would be good to know if this occurs in *M. torreyana* and—if so— the extent to which it is significant to any aspect of the plant's establishment or survival.

Synonyms

The accepted botanical name of the species is *Muhlenbergia torreyana* (Schult.) Hitchc. Orthographic variants, synonyms, and common names are listed below (ITIS 2021, USDA NRCS 2022c, POWO 2022).

Botanical Synonyms	Common Names
Sporobolus torreyanus (Schult.) Nash	Pine Barren Smoke Grass
Sporobolus compressus (Torr.) Kunth	New Jersey Muhly
Agrostis compressa Torr.	Flat-stemmed Dropseed
Agrostis torreyana Schult.	Torrey's Dropseed
Colpodium compressum Trin.	Torrey's Muhly
Muehlenbergia torreyana (Schult.) Hitchc.	
Vilfa compressa Trin.	

References

Bess, James A. and K. G. A. Hamilton. 1999. A new *Flexamia* (Homoptera: Cicadellidae: Deltocephalinae) from southern Michigan. The Great Lakes Entomologist 32(1&2): 9–14.

Boyd, H. H. 1991. A Field Guide to the Pine Barrens of New Jersey: Its Flora, Fauna, Ecology and Historic Sites. Plexus Publishing, Inc., Medford, NJ. 423 pp.

Breden, Thomas F., Yvette R. Alger, Kathleen Strakosch Walz, and Andrew G. Windisch. 2001. Classification of Vegetation Communities of New Jersey: Second iteration. Association for Biodiversity Information and New Jersey Natural Heritage Program, Office of Natural Lands Management, Division of Parks and Forestry, NJ Department of Environmental Protection, Trenton, NJ. 230 pp.

Britton, N. L. 1881. A preliminary catalogue of the flora of New Jersey. Geological Survey of New Jersey, Office of the Survey, Rutgers College, New Brunswick, NJ. 233 pp.

Britton, N. L. and A. Brown. 1913. An Illustrated Flora of the Northern United States and Canada in three volumes: Volume I (Ferns to Buckwheat). Second Edition. Reissued (unabridged and unaltered) in 1970 by Dover Publications, New York, NY. 680 pp.

Calazza, Nicholas and David E. Fairbrothers. 1980. Threatened and endangered vascular plant species of the New Jersey Pinelands and their habitats. Report prepared for the New Jersey Pinelands Commission, New Lisbon, NJ. 38 pp.

Chamberlain, S. 2018. Field Guide to Grasses of the Mid-Atlantic. The Pennsylvania State University Press, University Park, PA. 167 pp.

Chase, Agnes. 1918. Axillary cleistogenes in some American grasses. American Journal of Botany 5(5): 254–258.

Cheplick, Gregory P. 1998. Seed dispersal and seedling establishment in grass populations. In G. F. Cheplick (ed.). Population Biology of Grasses. Cambridge University Press, Cambridge, United Kingdom. 412 pp.

Ciafré, Clair M. and L. Dwayne Estes. 2022. Two coastal plain *Dichanthelium* (Poaceae: Paniceae) disjunct in Tennessee grasslands and their conservation. Castanea 87(1): 121-128.

Clancy, Keith. 1993. Selected rare and historical plants of Delaware. Bartonia 57 Supplement: 75–92.

Collins, Scott L. and Gordon E. Uno. 1985. Seed predation, seed dispersal, and disturbance in grasslands: A comment. American Naturalist 125(6): 866–872.

Connor, H. E. 1979. Breeding systems in the grasses: A survey. New Zealand Journal of Botany 17: 547–574.

Cunningham, Bob. 2016. Cover photo of *Muhlenbergia torreyana*. Used with permission.

DeSelm, H. R., B. E. Wofford, R. Kral and E. W. Chester. 1994. An annotated list of grasses (Poaceae, Graminae) of Tennessee. Castanea 59(4): 338–353.

dogtooth77. 2014. *Muhlenbergia torreyana* at Belleplain. Licensed under CC BY-NC-SA 2.0 via Creative Commons.

dogtooth77. 2015. *Muhlenbergia torreyana* inflorescence. Licensed under CC BY-NC-SA 2.0 via Creative Commons.

Doust, Lesley Lovett. 1981. Population dynamics and local specialization in a clonal perennial (*Ranunculus repens*): I. The dynamics of ramets in contrasting habitats. Journal of Ecology 69(3): 743–755.

Edwards, Adrienne L. and Alan S. Weakley. 2001. Population biology and management of rare plants in depression wetlands of the southeastern coastal plain, USA. Natural Areas Journal 21: 12–35.

Faber-Langendoen, D. 2018. Northeast Regional Floristic Quality Assessment Tools for Wetland Assessments. NatureServe, Arlington, VA. 52 pp.

Fairbrothers, David E. 1979. Endangered, threatened, and rare vascular plants of the Pine Barrens and their biogeography. In Richard T. T. Forman (ed.). Pine Barrens Ecosystem and Landscape. Rutgers University Press, New Brunswick, NJ. 601 pp.

Fernald, M. L. 1950. Gray's Manual of Botany. Dioscorides Press, Portland, OR. 1632 pp.

Flaherty, Kelley A., James S. Rentch, and James T. Anderson. 2017. Wetland seed dispersal by white-tailed deer in a large freshwater wetland complex. AoB PLANTS 10(1): doi: 10.1093/aobpla/plx074

Frances, Anne (Principal Investigator). 2017. Prioritization and Conservation Status of Rare Plants in the North Atlantic - Final Report. Report prepared for NatureServe by the North Atlantic Landscape Conservation Cooperative, Hadley, MA. Available at https://www.natureserve.org/publications/prioritization-and-conservation-status-rare-plants-north-atlantic-final-report

Friedman, Jannice and Lawrence D. Harder. 2004. Inflorescence architecture and wind pollination in six grass species. Functional Ecology 18: 851–860.

Friedman, Jannice and Spencer C. H. Barrett. 2009. Winds of change: New insights on the ecology and evolution of pollination and mating in wind-pollinated plants. Annals of Botany 103(9): 1515–1527.

García-Mozo, H. 2017. Poaceae pollen as the leading aeroallergen worldwide: A review. Allergy 72: 1849–1858.

Geisler, Florence. 1945. A pollen study of thirty-two species of grasses. Butler University Botanical Studies 7(6): 65–73.

Gleason, H. A. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. Second Edition. The New York Botanical Garden, Bronx, NY. 910 pp.

Gordon, Ted. 2009. 2005-2006 field trips. Bartonia 64: 55–76.

Gray, Janet Bracey. 2001. Rare vascular flora of the Longleaf Pine-Wiregrass ecosystem: Temporal responses to fire frequency and population size. Master's Thesis, North Carolina State University, Raleigh, NC. 48 pp.

Handel, Steven N. 1985. The intrusion of clonal growth patterns on plant breeding systems. The American Naturalist 125(3): 367–384.

Harper, Roland M. 1900. Biodiversity occurrence data published by Missouri Botanical Garden. Accessed July 10, 2022 through Mid-Atlantic Herbarium Consortium at https://midatlanticherbaria.org/portal/index.php.

Harper, R. M. 1901. On a collection of plants made in Georgia in the summer of 1900. Bulletin of the Torrey Botanical Club 28: 454–484.

Harper, R. M. 1903. Botanical explorations in Georgia during the summer of 1901 - II. Noteworthy Species. Bulletin of the Torrey Botanical Club 30(6): 319–342.

Hicks, Andrew. 2015. In the shadow of a megalopolis, a new *Flexamia* from a threatened grass species in the New Jersey Pine Barrens (Hemiptera, Cicadellidae, Deltocephalinae, Paralimnini). ZooKeys 511: 69–79.

Hill, Rebecca, Megan M. Rutkowski, Lori A. Lester, Heather Genievich, and Nicholas A. Procopio (eds.). 2020. New Jersey Scientific Report on Climate Change, Version 1.0. New Jersey Department of Environmental Protection, Trenton, NJ. 184 pp.

Hirst, Frank. 1983. Field report on the Delmarva flora, I. Bartonia 49: 59–68.

Hitchcock, A. S. 1950. Manual of the Grasses of the United States. Two Volumes. Second Edition. Dover Publications, New York. 1051 pp.

Hough, Mary Y. 1983. New Jersey Wild Plants. Harmony Press, Harmony, NJ. 414 pp.

ITIS (Integrated Taxonomic Information System). Accessed November 13, 2021 at http://www.itis.gov

Johnson, Elizabeth A. and Kathleen Strakosch Walz. 2013. Integrated Management Guidelines for Four Habitats and Associated State Endangered Plants and Wildlife Species of Greatest Conservation Need in the Skylands and Pinelands Landscape Conservation Zones of the New Jersey State Wildlife Action Plan. Report prepared for NatureServe #DDCF-0F-001a, Arlington, VA. 140 pp.

Kartesz, J. T. 2015. The Biota of North America Program (BONAP). Taxonomic Data Center. (http://www.bonap.net/tdc). Chapel Hill, NC. [Maps generated from Kartesz, J. T. 2015.

Floristic Synthesis of North America, Version 1.0. Biota of North America Program (BONAP) (in press)].

Keddy, P.A. and A. A. Reznicek. 1982. The role of seed banks in the persistence of Ontario's coastal plain flora. American Journal of Botany 69(1): 13–22.

LeGrand, H., B. Sorrie, and T. Howard. 2022. *Muhlenbergia torreyana*. Vascular Plants of North Carolina, North Carolina Biodiversity Project and North Carolina State Parks, Raleigh, NC. Accessed July 19, 2022 at https://auth1.dpr.ncparks.gov/flora/species_account.php?nrid_sciName=Muhlenbergia%20torreyana

McAvoy, William A. and Peter Bowman. 2002. The flora of coastal plain pond communities on the Delmarva Peninsula. Bartonia 61: 81–91.

McAvoy, William A. and Ronald M. Wilson. 2014. Rediscovery of *Lobelia boykinii* (Campanulaceae) in Delaware. Phytoneuron 23: 1–4.

MDWHS (Maryland Wildlife and Heritage Service). 2021. Rare, Threatened and Endangered Plants of Maryland. Maryland Department of Natural Resources. 231 pp.

Mid-Atlantic Herbaria. 2022. https://midatlanticherbaria.org/portal/index.php. Accessed on July 14, 2022.

Middleton, Beth. 2003. Soil seed banks and the potential restoration of forested wetlands after farming. Journal of Applied Ecology 40: 1025–1034.

Milne, Lorus and Margery Milne. 1980. The Audubon Society Field Guide to North American Insects and Spiders. Alfred A. Knopf, New York.

Missouri Botanical Garden. Undated. Leafhoppers and Planthoppers. Accessed July 13, 2022 at https://www.missouribotanicalgarden.org/gardens-gardening/your-garden/help-for-the-home-gardener/advice-tips-resources/pests-and-problems/insects/hoppers-and-leafhoppers/leafhoppers-and-planthoppers.aspx

Mitchell, William W. and Richard W. Pohl. 1966. Variation and aneuploidy in *Muhlenbergia glomerata*. The American Midland Naturalist 76(1): 211–221.

Moore, Gerry. 1989. A checklist of the vascular plants of Cumberland County, New Jersey. Bartonia 55: 25–39.

Moore, Gerry, Renee Brecht, and Dale Schweitzer. 2016. Additions and corrections to the checklist of vascular plants of Cumberland County, New Jersey. Bartonia 68: 1–59.

Morse, L., D. Snyder, and K. Gravuer. 2009. *Muhlenbergia torreyana* conservation status factors. NatureServe, Arlington, VA. Accessed July 10, 2022 at https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.146912/Muhlenbergia_torreyana

NatureServe. 2022. NatureServe Explorer [web application]. NatureServe, Arlington, VA. Accessed July 26, 2022 at https://explorer.natureserve.org/

New Jersey Pinelands Commission. 1980. Comprehensive Management Plan for the Pinelands National Reserve (National Parks and Recreation Act, 1978) and Pinelands Area (New Jersey Pinelands Protection Act, 1979). Adopted November 1, 1980, New Jersey Pinelands Commission, New Lisbon, NJ. 439 pp.

NJNHP (New Jersey Natural Heritage Program). 2010. Special Plants of NJ - Appendix I - Categories & Definitions. Site updated March 22, 2010. Available at https://nj.gov/dep/parksandforests/natural/docs/nhpcodes_2010.pdf

NJNHP (New Jersey Natural Heritage Program). 2022. Biotics 5 Database. NatureServe, Arlington, VA. Accessed February 1, 2022.

Orłowski, Grzegorz, Joanna Czarnecka, Artur Goławski, Jerzy Karg, and Marek Panek. 2016. The effectiveness of endozoochory in three avian seed predators. Journal of Ornithology 157: 61–73.

Peters, Dana. 1993. Knieskern's Beaked-rush (*Rhynchospora kneiskernii*) Recovery Plan. Report prepared for U. S. Fish and Wildlife Service, Region Five, Hadley, MA. 36 pp.

Peterson, Paul M. Page updated May 11, 2021. *Muhlenbergia torreyana* (Schult.) Hitchc. In: Flora of North America Editorial Committee, eds. 1993+. Flora of North America North of Mexico [Online]. 22+ vols. New York and Oxford. Accessed July 12, 2022 at http://floranorthamerica.org/Muhlenbergia_torreyana

Pizzolato, Thompson Demetrio. 1995. Patterns of procambial development in rachilla and floret of *Muhlenbergia torreyana* (Gramineae, Chloridoideae). International Journal of Plant Sciences 156(5): 604–614.

Pizzolato, Thompson Demetrio. 1996. Gynobasic procambial initiation in the pistil of *Muhlenbergia torreyana* (Gramineae, Chloridoideae) in contrast to the gynomedian pattern. Bulletin of the Torrey Botanical Club 123(2): 126–134.

POWO. 2022. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. Retrieved July 10, 2022 from http://www.plantsoftheworldonline.org/

Rabinowitz, Deborah. 1981. Seven forms of rarity. In H. Synge (ed.) The Biological Aspects of Rare Plant Conservation. John Wiley & Sons Ltd., New York, NY.

Rebozo, Ryan R., Lena Struwe, and Walter F. Bien. 2019. The demography of *Gentiana autumnalis* in populations under varying management regimes in New Jersey. Castanea 84(2): 238–254.

Schulze-Albuquerque, Isadora, Ana Carolina Galindo Da Costa, Paulo Milet-Pinheiro, Daniela Maria Do Amaral Ferraz Navarro, William Wayt Thomas, and Isabel Cristina Machado. 2019. Visual and olfactory floral cues related to ambophilous pollination systems in Poaceae. Botanical Journal of the Linnean Society 192(1): 242–257.

Smith, David C. 2012. Succession dynamics of Pine-Barrens riverside savannas: A landscape survey approach. Master's Thesis, Rutgers University, New Brunswick, NJ. 69 pp.

Sorrie, B. A., Brian Van Eerden, and Mary J. Russo. 1997. Noteworthy plants from Fort Bragg and Camp MacKall, North Carolina. Castanea 62(4): 239–259.

Sorrie, Bruce A., and Alan S. Weakley. 2001. Coastal Plain vascular plant endemics: Phytogeographic patterns. Castanea 66(1-2): 50–82.

Sorrie, Bruce A., Janet Bracey Gray, and Philip. J. Crutchfield. 2006. The vascular flora of the Longleaf Pine ecosystem of Fort Bragg and Weymouth Woods, North Carolina. Castanea 71(2): 127–159.

Stone, Whitmer. 1911. The Plants of Southern New Jersey. Quarterman Publications, Boston, MA. 828 pp.

Thornhill, Robert, Alexander Krings, David Lindbo, and Jon Stucky. 2014. Guide to the vascular flora of the savannas and flatwoods of Shaken Creek Preserve and vicinity (Pender & Onslow Counties, North Carolina, U.S.A.). Biodiversity Data Journal 2: e1099, doi: 10.3897/BDJ.2.e1099.

Torrey, John. 1819. A Catalogue of Plants Growing Spontaneously Within Thirty Miles of the City of New York. Lyceum of Natural History of New York. 100 pp.

Torrey, John. 1843. A Flora of the State of New York. Vol. II. Carroll and Cook, Albany, NY. 572 pp.

U. S. Army Corps of Engineers. 2020. National Wetland Plant List, version 3.5. https://cwbi-app.sec.usace.army.mil/nwpl_static/v34/home/home.html U. S. Army Corps of Engineers Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH.

USDA, NRCS (U. S. Dept. of Agriculture, Natural Resources Conservation Service). 2022a. *Muhlenbergia torreyana* illustration from Hitchcock, A. S., 1950, Manual of the Grasses of the United States, 2 vols., Second Edition, Dover Publications, New York, Scanned By Omnitek Inc. Image courtesy of The PLANTS Database (http://plants.usda.gov). National Plant Data Team, Greensboro, NC.

USDA, NRCS (U. S. Dept. of Agriculture, Natural Resources Conservation Service). 2022b. *Muhlenbergia torreyana* illustration from Britton, N. L. and A. Brown, 1913, An illustrated flora of the northern United States, Canada and the British Possessions, 3 vols., Kentucky Native Plant

Society, New York, Scanned By Omnitek Inc. Image courtesy of The PLANTS Database (http://plants.usda.gov). National Plant Data Team, Greensboro, NC.

USDA, NRCS (U. S. Dept. of Agriculture, Natural Resources Conservation Service). 2022c. PLANTS profile for *Muhlenbergia torreyana* (New Jersey Muhly). The PLANTS Database, National Plant Data Team, Greensboro, NC. Accessed July 10, 2022 at http://plants.usda.gov

USFWS (U. S. Fish and Wildlife Service). 1975. Endangered and threatened wildlife and plants: Review of status of over 3000 vascular plants and determination of "Critical Habitat". Federal Register 40(127): 27824–27924.

USFWS (U. S. Fish and Wildlife Service). 1980. Endangered and threatened wildlife and plants: Review of plant taxa for listing as endangered or threatened species. Federal Register 45(242): 82480–82569.

USFWS (U. S. Fish and Wildlife Service). 2022. *Muhlenbergia torreyana* entry on ECOS (Environmental Conservation Online System). Accessed July 10, 2022 at https://ecos.fws.gov/ecp/species/1250

Walker, Joan. 1993. Rare vascular plant taxa associated with the Longleaf Pine ecosystems: Patterns in taxonomy and ecology. In Sharon M. Hermann (ed.). Proceedings of the Tall Timbers Fire Ecology Conference No. 18, The Longleaf Pine Ecosystem: Ecology, restoration and management. Tall Timbers Research Station, Tallahassee, FL.

Walz, Kathleen Strakosch. 2004. Vegetation of Pine Barren Riverside Savannas in New Jersey: Ecological Community Classification. New Jersey Department of Environmental Protection, Division of Parks and Forestry, Office of Natural Lands Management, Natural Heritage Program, Trenton, NJ. 41 pp.

Walz, Kathleen Strakosch, Scott Stanford, Nancy Lee Adamson, Linda Kelly, Karl Anderson, Kim Laidig, and John Bonnell. 2006. Coastal Plain Intermittent Pondshore Communities of New Jersey. New Jersey Department of Environmental Protection, Division of Parks and Forestry, Office of Natural Lands Management, Natural Heritage Program, Trenton, NJ. 50 pp.

Walz, Kathleen S., Linda Kelly, Karl Anderson and Jason L. Hafstad. 2018. Floristic Quality Assessment Index for Vascular Plants of New Jersey: Coefficient of Conservativism (CoC) Values for Species and Genera. New Jersey Department of Environmental Protection, New Jersey Forest Service, Office of Natural Lands Management, Trenton, NJ. Submitted to United States Environmental Protection Agency, Region 2, for State Wetlands Protection Development Grant, Section 104(B)(3); CFDA No. 66.461, CD97225809.

Wang, B., and Y. L. Qiu. 2006. Phylogenetic distribution and evolution of mycorrhizas in land plants. Mycorrhiza 16(5): 299–363.

Weakley, A. S. 2015. Flora of the southern and mid-Atlantic states, working draft of May 2015. University of North Carolina Herbarium, North Carolina Botanical Garden, Chapel Hill, NC.

Whitcomb, Robert F. and Andrew L. Hicks. 1988. Genus *Flexamia*: New species, phylogeny, and ecology. Great Basin Naturalist Memoirs 12: 224–323.

Zampella, R. A. and K. J. Laidig. 1997. Effect of watershed disturbance on Pinelands stream vegetation. Journal of the Torrey Botanical Society 124(1): 52–66.

Zampella, Robert A. and Kim J. Laidig. 2003. Functional equivalency of natural and excavated coastal plain ponds. Wetlands 23(4): 860-876.

Zaremba, Robert E. and Eric E. Lamont. 1993. The status of the coastal plain pondshore community in New York. Bulletin of the Torrey Botanical Club 120(2): 180–187.