BIOLOGY OF HERBACEOUS PLANTS IN INDIANA DUNES NATIONAL LAKESHORE: SPECIES PROJECTED TO ADAPT OR BE RESISTANT TO CLIMATE CHANGE

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BACKGROUND

Climate change is affecting ecosystems at both a local and global scale. Projections of increased temperatures, drought, and extreme precipitation events are already happening and are likely to become the norm during the next 100 years. The warmer the climate gets, the faster the climate zones where existing plants and animals live are shifting. This could make it harder for plants and animals to adjust to rapidly changing conditions. In the future species will have less time to adapt to shifting climate zones, which will increase the risk of extinction for some. Information on whether species will be resilient or decline is largely lacking, but is necessary to guide management (Moritz and Agudo 2013).

Northwest Indiana and Indiana Dunes National Lakeshore (INDU) will likely be affected by these changes. More information is needed of the flora and fauna that can adapt to these novel conditions, especially for ecological restoration purposes. Information based on projected climate change scenarios and the likelihood of resilience of native flora and fauna to projected changes is necessary to develop regional climate change adaptation strategies (Galatowitsch et al. 2009). The goal here was to conduct a survey that includes plant species that exhibit wide climate tolerances and are locally present in the region.

OBJECTIVES

The goal for this project was to conduct a survey of flora, particularly herbaceous plants (angiosperms), which are projected to be resilient to climate change, by investigating information through literature and website reviews.

The objectives include selection of three habitat types found in INDU: dunes, interdunal wetlands, and mesic prairies, which are the focus of habitat restoration in the park. For each habitat 10 keystone plant species were selected, based on literature and website reviews, that will be potentially resilient to climate change events.

The results of the project will be used to inform managers at INDU, the state park, and other partner organizations of plants species that are likely to persist during the next 80-100 years in the selected habitats. The information can be used to guide informed decision making regarding restoration of the selected habitat types.

PROJECTED CLIMATE CHANGES FOR INDIANA

Anthropogenic climate change is projected to cause substantial changes in the temperature, precipitation, and weather events in the United States, including in Indiana. According to the Union of Concerned Scientists and the Ecological Society of America (2003), by 2030 Indiana is projected to experience summers like Missouri and winters like southern Ohio. More specifically, summer temperatures are projected to increase by 2°C and winter temperatures by 1°C. Precipitation changes are projected to decrease by 15% in the summer and not change in the winter. Although, in a global climate change risk analysis for the world's ecosystems, freshwater run-off was predicted to decrease in the eastern United States (Scholze et al. 2006). At the end of the century (2095), Indiana is projected to experience Oklahoma summers and Virginia winters (UCS 2003). Temperatures are expected to increase 4-6°C in the summer months and 3-4°C in the winter. Mean precipitation may not change, but overall Indiana will likely become drier because of increased evaporation via transpiration due to increased temperatures. Soil may become drier and droughts may increase. Indeed water levels of the Great Lakes and other inland water bodies are projected to decrease due to droughts and high

evaporation due to temperature increases of 2-4 °C, with the greatest increases likely to occur in the summer months (Mishra et al. 2010). By 2095 summer precipitation is projected to decrease by 10-15%; winter precipitation is project to increase by 5-10% (UCS 2003). A model by Mishra et al. (2010) suggested that average monthly precipitation would increase in winter and spring, but generally decrease in summer and autumn. They also suggested that water runoff is likely to increase. Indiana is likely to experience more extreme storm events with increases in heavy rain storms. There will be an increase in the growing season and increased atmospheric CO_2 and nitrogen deposition. A recent model by Villarini et al. (2013) suggested that there may be an increase in the number of heavy storm days in the northern region of the central US, which will be correlated with higher temperature. These changes will impact Indiana wildlife, plants, agriculture, and human populations, as well as an increase in disease and pest prevalence.

HABITAT DESCRIPTIONS AND PROJECTED CLIMATE CHANGES

Sand Dunes Habitat

Sand dunes are unique habitats found along the coasts of large bodies of water in the Great Lakes region. Strong wind and wave action causes the buildup of sand as ridges along coastal beaches and the eventual creation of sand dunes (MNFI 2010). Glacial sediment provided the sand source for the sand dunes along the Laurentian Great Lakes and is less than 16,000 years old. There are several habitat types found within the open sand dunes, including the beach, fore dune, open dune, and forested dunes. Many of the plants found in the sand dunes must be able to withstand frequent disturbance, sand burial, low nutrient content, low moisture, and heavy winds. This distinctive habitat provides a home for unique flora, including but not limited to *Ammophila breviligulata*, *Artemisia campestris*, *Cakile edentula*, *Calamovilfa longifolia*, *Cirsium pitcher*, *Juniperus horizontalis*, *Prunus pumila*, and *Solidago simplex* (MNFI 2010).

Foredune habitat at Indiana Dunes National Lakeshore.
Photo by Alan Clinton

The sand dunes of the Great Lakes have been heavily threatened by human activity, primarily due to development of residential areas and sand mining (MNFI 2010). Off-road vehicles and human traffic area are also concerns for plant disturbance and erosion. Many invasive species are also a concern. Various agencies and institutions work to preserve the Great

Lakes sand dunes, thus strict developmental restrictions have been placed in many of the remaining dunes along the shoreline of the Great Lakes.

Climate change presents additional and unique threats to the Great Lakes dunes ecosystem, including those in northwestern Indiana. Temperatures are projected to increase and precipitation patterns to change. Plants will need to be able to withstand fluctuating water regimes, heat stress, and water stress. The frequency of extreme storms is also projected to increase in Indiana and the Great Lakes, which could result in increased disturbance and erosion of sand dunes. Plants such as *Ammophilia brevilgulata* and *Cakile edentula* may be resistant to such erosion, because of their ability to grow through sand burial. Higher waves and strong winds may change erosion and deposition patterns (NFW&P CC Adaptation Strategy 2012). It may be especially important for plants growing on the beach and foredune habitat to withstand extreme sand burial and disturbance. A reduction in shoreline ice could result in a loss of shoreline protection from winter storms.

Interdunal Wetlands Habitat

Interdunal wetlands are depressions found between freshwater sand dune ridges of the Laurentian Great Lakes (parabolic and perched dunes; narrow swales, pannes, and troughs behind beach or dune ridges) that are characterized by seasonally fluctuating water tables (MNFI 2010) The location of the interdunal wetland within the sand dunes determines the type. Six interdunal wetlands have been documented in Indiana (MNFI 2010). Different types of interdunal wetlands can include pannes (closer to lake) and forested interdunal wetlands and swales further inland (MNFI 2010). Water levels are determined by the water table fluctuations, rainfall, and soil permeability (Ranwell 1959). Flashy, intense storm events projected to increase due to climate change may cause high flooding in interdunal wetlands and could negatively impact plant and animal species. Climatic conditions are strongly influenced by the lake, because water level fluctuates seasonally and synchronously with lake level. Due to the close proximity to the Great Lakes, the interdunal wetlands experience a slightly milder climate and higher precipitation typical of the Midwest due to temperature/precipitation moderation by the Great Lakes. During summer months waters in interdunal wetlands warm quickly. Storm events and strong winds can cause partial burial of wetland depressions.

Interdunal panne at Indiana Dunes National Lakeshore.
Photo by Elizabeth LaRue

The saturated sand and water found in interdunal fens are slightly alkaline and carbonate rich due to upland run-off through limestone bedrock (MNFI 2010). The vegetation of interdunal wetlands must be tolerant to higher concentrations of carbonate. Occasionally springs are found within these fen wetlands and help maintain water levels. Common herbaceous species include *Calamagrostis canadensis, Cladium mariscoides, Eleocharis elliptica, Euthamia graminifolia, Hypericum kalmianum, Juncus balticus, Lobelia kalmia, Potentilla fruticosa, Schoenoplectus pungens, Rhynchospora capillacea*. *Tofieldia glutinosa, Triglochin maritimum,* and *Utricularia cornuata.*

Water levels are projected to decrease in response to climate change (Angel and Kunkel 2010) and changing water levels may threaten interdunal wetlands. Vegetation tolerant of fluctuating water-levels and drought conditions such as *Juncus balticus* and *Cladium mariscoides* may be favored. In dry years plants from adjacent habitats can become established (MNFI 2010), which could result in biodiversity loss of species characteristic of this habitat if drought events become more common in the Great Lakes. Other anthropogenic threats include invasive species, off-road vehicles, development, and heavy human traffic MNFI 2010).

Numerous changes are projected to occur due to climate change over the next century in inland water and coastal ecosystems (NFW&P CC Adaptation Strategy 2012, Erickson et al. In Press). Due to increased temperatures inland waters are projected to experience expansions of warm-water species, depleted O_2 levels, stress on cold-water species, increased pathogen/pest susceptibility, and increased algal blooms. Due to altered temperature, coastal ecosystems are projected to see an increase in forested wetland vegetation and phenology changes. Potential reductions in snowpack may change water run-off and water distribution patterns. A loss of shoreline ice may reduce coastal protection from winter storms. Projected drying conditions and changes in precipitations patterns are predicted to cause changing lake levels, result in lower baseline summer water levels, and loss of intermittent wetlands. Increased and more severe storm events could increase burial threat to nearshore interdunal wetlands due to increased beach erosion. Elevated CO_2 levels have been shown to lead to a 32% increase in carbon absorption, which could help to alleviate increasing atmospheric CO_2 (Erickson et al. In Press). This highlights the importance for conserving wetlands under climate change.

Mesic Prairie Habitat

Mesic prairies are grassland communities dominated by grasses such as *Andropogen gerardii, Andropogon scoparius,* and *Sorghastrum nutans,* which were historically abundant in the open areas of the southern and western Midwest (MNFI 2010). Vegetation is dense to moderately dense and dominated by grasses with many herbaceous plants. Mesic prairies are found on flat to gently sloping areas with loam, sandy loam or silt loam soils. Soil pH ranges from 4.9 to 7.5 and water retaining capacity ranges from 37 to 106%.

Mesic prairies were favorite locations for European settlers to establish homesteads because of the productive soil and open land (MNFI 2010). Due to the use of mesic prairies as farmlands, the status in many states is bleak. Many of the remaining mesic prairies are small in size and isolated. Furthermore, fire is necessary to maintain prairies and biodiversity, thus prescribed burns are used to manage them. Fire promotes seed germination and regenerates nutrients important for many plants. Invasive species and genetic isolation of native prairie plants are major concerns for management.

Climate change projections are likely to impact grasslands in the United States, including mesic prairies in Indiana and the Midwest. Temperatures are projected to increase by 2-4 °C and precipitation patterns are likely to change by the end of the century in Indiana (UCS 2003). Mesic prairies in northwest Indiana may experience increased precipitation in the winter and decreased precipitation during the growing season. Climatic change may facilitate the spread and establishment of invasive species, change fire patterns especially during droughts, and change hydrology through reduced snowpack and altered precipitation patterns (NFW&P CC Adaptation Strategy 2012).

Atmospheric CO_2 is also likely to increase, which could have a large impact on grassland plants (NFW&P CC Adaptation Strategy 2012). Plants using the C3 photosynthesis pathway may benefit from increased atmospheric CO_2 over the C4 pathway (NFW&P CC Adaptation Strategy 2012), but C4 plants may do better under heat and water stress. Other experiments have shown than C4 plants may do better than C3 plants in a warmer, CO_2 enriched environment. It is likely that increased CO_2, temperature and precipitation changes will impact the community composition of grasslands (NFW&P CC Adaptation Strategy 2012), including mesic prairies.

PLANT TRAITS LIKELY TO CONTRIBUTE TO CLIMATE CHANGE RESISTANCE AND ADAPTATION

The Gran Canaria Declaration II on Climate Change and Plant Conservation (2006) and the National Fish, Wildlife, and Plant Climate Adaptation Strategy (2012) suggest that the following species traits are likely to confer resistance to climate change:

- A species has wide climatic tolerances and larger ranges
- A species is not trapped in a habitat or ecosystem (e.g. edge of continent or peninsula)
- A species is common, populations not already declining or small, or having low genetic diversity
- Short generation times in the life history of a species (e.g. annuals, shorter perennials, reproduce quickly)
- Good water use efficiency (WUE), warm temperature and drought tolerant
- High dispersal capability, long seed bank duration
- Resistance to extreme events such as floods, drought, extreme storm events
- Generalist niche/habitat requirements
- A species does not require coevolved species such as a specialist pollinator for survival
- A species has medium phenotypic plasticity

Table 1. Species from three habitats in Indiana Dunes National Lakeshore predicted to exhibit some resilience to project climate change scenarios.

Species	Generation Time	Dispersal Ability	Drought Tolerance	Flood/Disturbance Tolerant
Dune				
Ammophila breviligulata	Perennial	Rhizomatous, few seeds	Medium	Burial resistance
***Asclepias syriaca* (D&MP)**	Perennial	High seed dispersal ability, rhizomes	Yes	NA
Cyperus strigosus	Perennial	Moderate seed, slow vegetative spread rate	Low	Somewhat flood resistant
Juncus canadensis	Perennial	Moderate seed spread rate	Probably low	High flood resistant
Monarda punctata	Annual	NA	Moderate	Disturbance tolerant
Oenothera biennis	Biennial	Moderate seed spread rate	Medium	Not flood tolerant
Panicum capillare	Annual	Tumble weed	Dry soils	NA
***Schizachyrium scoparium* (D&MP)**	Perennial	Moderate seed spread rate	High	Poor flood tolerance
Sphenopholis obtusata	Annual	Slow seed spread rate	Low	Low flood tolerance
Xanthium strumarium	Annual	Animal dispersal or seeds float	Dry soils	Flood tolerant
Interdunal Wetlands				
***Agrostis hyemalis* (IDW&D)**	Perennial	Slow seed, moderate vegetative spread rate	Low	High flood tolerance
Campanula aparinoides	Perennial	Slow seed, slow vegetative spread rate	Low	High flood tolerance
Carex stricta	Perennial	Slow seed spread rate	Low	Moderate flood tolerance
Cladium mariscoides	Perennial	Spread by small animals and water	Low	Flood tolerant
Euthamia graminifolia	Perennial	Aggressive rhizome spread	Moderate	Moderate flood tolerance
Lycopus americanus	Perennial	Moderate seed spread rate	Low	High flood tolerance
Lysimachia terrestris	Perennial	Spread rapidly	NA	NA
Schoenoplectus acutus* var. *acutus	Perennial	Moderate seed, vegetative spread rate	Medium	High flood tolerance
Schoenoplectus pungens	Perennial	Moderate seed, vegetative spread rate	Medium	High flood tolerance
Schoenoplectus tabernamontani	Perennial	Slow seed, rapid vegetative spread rate	Low	High flood tolerance
Mesic Prairies				
Andropogon gerardii	Perennial	Slow seed, vegetative spread rate	High	NA
Euphorbia corollata	Annual	Slow vegetative spread	High, dry soils	NA
Lespedeza capitata	Perennial	Slow seed spread rate	High	NA
Liatris aspera	Perennial	Seeds travel up to 8 m by wind	High	Not flood tolerant
Lithospermum canescens	Perennial	NA	Tolerant	NA
Phlox pilosa	Perennial	Spread rapidly by stolons	Dry soils	NA
Sorghastrum nutans	Perennial	Slow seed, moderate vegetative spread rate	Medium	Some flood tolerance, disturbed soils
Symphyotrichum novae-angliae	Perennial	Wind or water dispersed	Tolerant	Tolerates seasonal flooding
Tradescantia ohiensis	Perennial	Seeds can spread aggressively	Tolerant	Moist soils
Verbena stricta	Annual	50th percentile of seeds traveled 0.54 m by wind	Tolerant	Disturbance

SPECIES PROJECTED TO BE RESILIENT TO CLIMATE CHANGE BY HABITAT

Sand Dunes Habitat

Ammophila breviligulata

Distribution

*Ammophila breviligulata (*American beachgrass, *Poaceae*) is a gramminoid native to the coastal sand dunes (USDA 2013). It is found along the Great Lakes, Atlantic, and Pacific coasts as far south as California and South Carolina and north into Ontario. There are no documented varieties or subspecies of *A. breviligulata*. *A. breviligulata* is found along the Lake Michigan shoreline of Indiana (USDA 2013) and is abundant within the Indiana Dunes National Lakeshore. It is not especially abundant in the southern U.S., but its broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

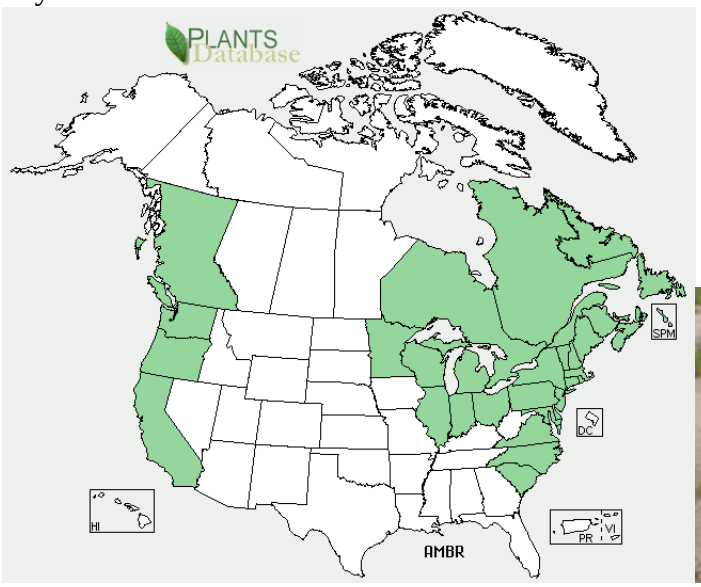

Photo by Elizabeth LaRue

Life history

A. breviligulata is a perennial grass that reproduces primarily by rhizomes (USDA 2013). Seeds are occasionally produced but do not contribute significantly to dispersal potential (Krajnyk and Maun 1982). Due to the low number of seeds produced, seed bank duration is not a likely method of seed regeneration. *A. breviligulata* does not require specialist pollinators or any mutualisms to survive. It exhibits phenotypic plasticity by increasing growth when buried by sand.

Fant et al. (2008) found that native populations of *A. breviligulata* were more genetically diverse than expected for a clonal species. They also found that commercial stocks and restored populations derived from these commercial stocks were composed of few genotypes, but restored populations derived from natural sites had a higher genetic diversity. Genetic diversity should not be a limiting factor for climate adaptation strategies even though the species is highly clonal. Genetic adaptation will be an important precursor to evolving in response to selection pressures caused by climate change (Shaw and Etterson 2012).

Environmental Tolerance and Climate Change Research

According to USDA (2013), *A. breviligulata* has a medium drought tolerance, which should facilitate its resistance and adaptation to climate change. *A. breviligulata* uses a medium amount of moisture with a precipitation minimum of 88.9 cm (35 inches) and a precipitation max of 152.4 cm (60 inches). It is resistance to disturbance by storms due to sand burial, but it is unknown if the species is flood resistant. Resistance to sand burial will facilitate the projected increase in storms along coastal habitats.

Several studies have investigated impacts that climate change could have on *A. breviligulata*. Emery et al. (2010) found that the 'Cape' variety or cultivar commonly used for restoration (originated from New Jersey) was less drought sensitive than a Michigan genotype. It is possible that southern genotypes would be more resistant to drought than the Michigan and 'Cape' variety tested here. Indeed, Seneca and Cooper (1971) found that seeds of *A. breviligulata* from North Carolina germinated well without a cold treatment, but Michigan seeds required a cold treatment to germinate. They also found that during germination the North Carolina seeds were less sensitive to high temperatures than seeds from Michigan. These two studies indicate that climate adaptation strategies in northwest Indiana should consider cultivars or genotypes collected from South Carolina for restoration efforts.

The climate change models for *A. breviligulata* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 scenario predicts that between 2070-2100 the Great Lakes range will shift northward to Lake Superior and central Quebec. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *A. breviligulata*. This model is specific to Canada and bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *A. breviligulata*, the 'Cape' cultivar (1970) is available for conservation.

Asclepias syriaca

Distribution

*Ascelpias syriaca (*common milkweed, *Asclepiadaceae*) is an herbaceous plant native to the coastal sand dunes (USDA 2013). *A. syriaca* is found throughout the central and eastern two thirds of North America from the Gulf of Mexico to northern Canada. There are no documented varieties or subspecies of *A. syriaca*. It is found in both the open sand dunes and interdunal wetlands of Indiana Dunes National Lakeshore. It is widespread in Indiana and in the southern U.S. Additionally, *A. syriaca* is abundant in the sand dunes habitat of northwestern Indiana. According to USDA, *A. syriaca* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

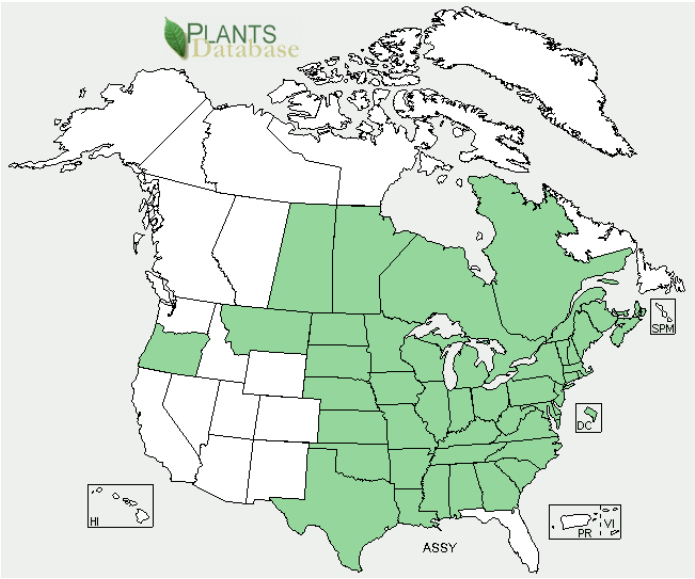

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

A. syriaca is a perennial herbaceous plant that reproduces by rhizomes and seeds (USDA 2013). Seeds are abundant and have high dispersal ability (USDA 2013). Seeds banks are not known to persist for long periods of time (Csontos et al. 2009), thus seed banks are not likely to offer regeneration after disturbance. *A. syriaca* is a generalist species and does not require specialist pollinators or any mutualisms to survive.

Woods et al. (2012) studied genetically based variation in morphology, phenology, and traits related to herbivory defense across a latitudinal gradient with 22 populations from New Brunswick to North Carolina. In common garden studies they found that 13 traits related to morphology and phenology exhibited differences among populations. They also found that phenology, shoot biomass, root buds, clonal growth, root-to-shoot ratio and latex production showed genetically based latitudinal clines. Northern populations also exhibited higher resistance to herbivory. Genetic diversity should not be a limiting factor for climate adaptation strategies. Genetic adaptation will be an important precursor to evolution in response to selection pressures caused by climate change (Shaw and Etterson 2012).

Environmental Tolerance and Climate Change Research

A. syriaca utilizes dry to medium moisture soils (Missouri Botanical Garden 2013). *A. syriaca* is also known to be drought tolerant, which should facilitate its resistance and adaptation to climate change. It is unknown if *A. syriaca* is resistant to flooding or high disturbance such as sand burial.

Vannette et al. (2011) found that genetic variation in insect defense phenotypes may moderate the adaptation of *A. syriaca* to increased CO_2 levels. Specifically, elevated CO_2 increased plant growth and herbivore defenses of toughness and latex, but decreased chemical cardenolides defense in five genotypes of *A. syriaca*. These changes could modify herbivore defense under elevated atmospheric CO_2 and drive changes in species interactions. It will be important to consider species interactions when conducting climate change adaptation and conservation.

Cyperus strigosus

Distribution

*Cyperus strigosus (*strawcolored flatsedge, *Cyperaceae*) is a sedge found throughout North America, including in the sand dunes habitat (USDA 2013). *C. strigosus* is found throughout the central and eastern two thirds of North America from the Gulf of Mexico to northern Canada. There are no documented varieties or subspecies of *C. strigosus*. It is found in interdunal wetlands and sand dune habitats of Indiana Dunes National Lakeshore and northwestern Indiana. It is widespread in Indiana and in the southern U.S. According to USDA, *C. strigosus* is known to exhibit weedy growth in some areas of the U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

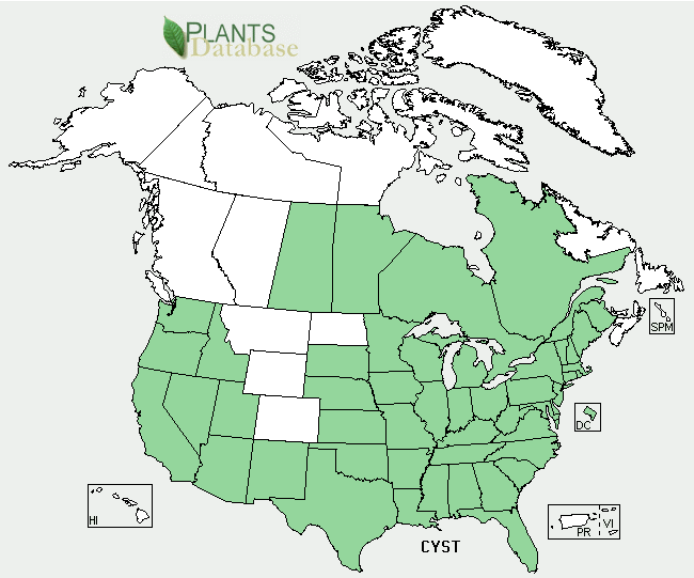

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

C. strigosus is a perennial sedge that reproduces primarily by sprigs and seeds (USDA 2013). Clonal spread is slow, but spread by seeds occurs at a moderate rate (USDA 2013). Spread by seed is likely to aid in changes in habitat suitability due to changes in climate. It is unknown how long seeds of *C. strigosus* persist in seed banks. *C. strigosus* could be considered a generalist species due to its broad geographic and habitat distribution.

No studies have yet been conducted on the genetic diversity of *C. strigosus*. This will be an important area of future research for climate change adaptation efforts using *C. strigosus*, because low genetic diversity can cause inbreeding depression.

Environmental Tolerance and Climate Change Research

According to USDA (2013), *C. strigosus* has a fairly low drought tolerance, which could cause it to be susceptible to the increased number of droughts projected to occur near the end of the century in Indiana. *C. strigosus* uses a medium amount of moisture with a precipitation minimum of 40.6 cm (16 inches) and a precipitation max of 152.4 cm (60 inches). It is somewhat

flood resistant (USDA 2013), thus heavy storm events and increased run-off may be less harmful to *C. strigosus*.

Moore and Frank (2011) found that *C. strigosus* experienced greater competition with *Amaranthus palmeri* and *Xanthanium strumarium* in a drought treatment. It will be important to consider changes in species interactions as climate change proceeds. Changes in interspecific plant competition could alter plant responses to events such as drought and frustrate restoration efforts if these changes were not considered in land management planning.

The climate change models for *C. strigosus* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicts that between 2071-2100 the Great Lakes range (currently over all of Great Lakes) will shift northward into north central Ontario. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *C. strigosus*. This model is specific to Canada and states bordering Canada.

Juncus canadensis

Distribution

*Juncus canadensis (*Canadian wildrush, *Juncaceae*) is an herbaceous plant native to the coastal sand dunes (USDA 2013). *J. canadensis* is found throughout the central and eastern two thirds of North America from the Gulf of Mexico to northern Canada. There are no documented varieties or subspecies of *J. canadensis*. It is fairly widespread in Indiana and in the southern U.S. Additionally, *J. canadensis* is abundant in the sand dunes habitat of northwestern Indiana. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

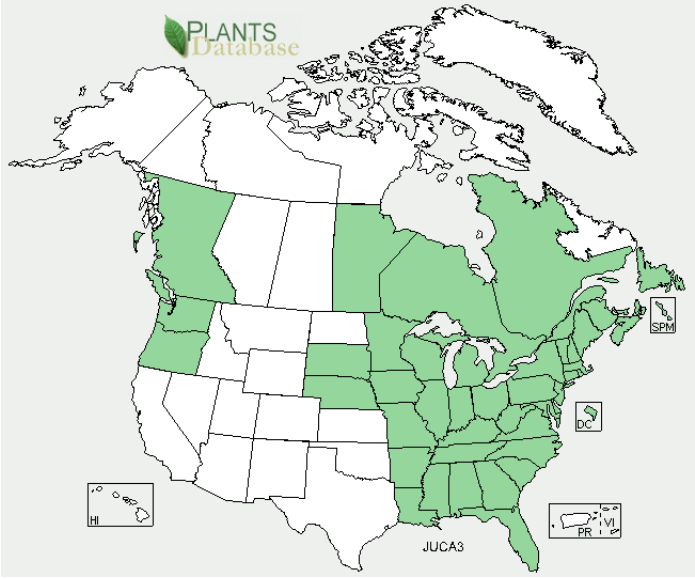

Photo by Nancy Staunton @ USDA-NRCS PLANTS Database

Life history

J. canadensis is a perennial herbaceous plant that reproduces by sprigs and seeds (USDA 2013). Seeds have a moderate rate of spread (USDA 2013). Although not well represented in the adult vegetation, *J. canadensis* was found to be well represented in the seed bank of a Nova

Scotia shoreline plant community (Wisheu and Keddy 1991). This indicates that even when *J. canadensis* is not overly abundant in the adult form the seeds may be able to persist for multiple years in the seed bank and recolonize a site after disturbance.

Environmental Tolerance and Climate Change Research

J. canadensis utilizes medium moisture soils with a precipitation minimum of 71.1 cm (28 inches) and a precipitation maximum of 152.4 cm (60 inches) (USDA 2013). *J. canadensis* probably has a low drought tolerance, but this has not been tested. *J. canadensis* is very resistant to flooding, which could help *J. canadensis* persist with the greater number of storm events predicted over the next century.

The climate change models for *J. canadensis* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Great Lakes range (currently all over Midwest) will shift northward across the center of Canada. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *J. canadensis*. This model is specific to Canada and states bordering Canada.

Monarda punctata

Distribution

*Monarda punctata (*spotted beebalm, *Lamiaceae*) is an herbaceous plant native to the coastal sand dunes (USDA 2013). *M. punctata* is found throughout the central and eastern two thirds of North America from the Gulf of Mexico to northern Canada. There are two varieties of *M. punctata*, including *immaculata and punctata*. It is fairly widespread in Indiana and is even more widespread in the southern U.S. Additionally, *M. punctata* is abundant in the sand dunes habitat of northwestern Indiana. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

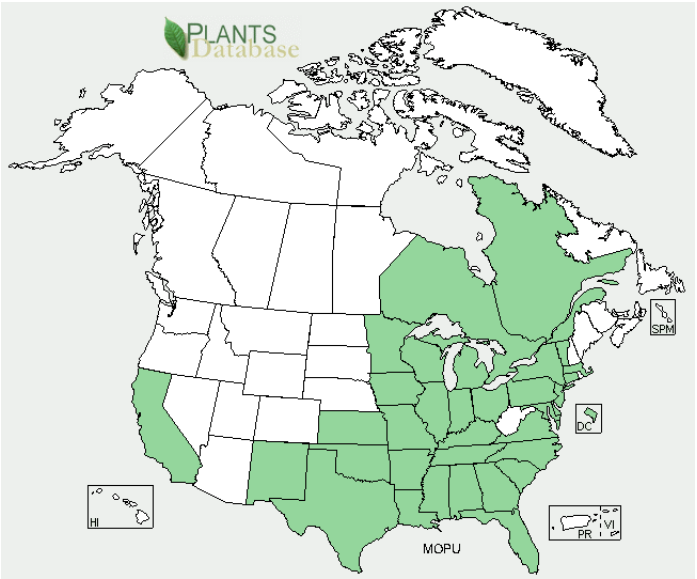

Photo by Ted Bodner @ USDA-NRCS
PLANTS Database from Miller and Miller (2005)

Life history

M. punctata is an annual herbaceous plant that reproduces by seed, but can also be regenerated by cuttings (USDA 2013). The dispersal ability of the seeds are unknown. Seed banks are not likely to persist for long periods of time or be very abundant, because Dohl and Nomsen (1987) only found six seeds of *M. punctata* from 10 soil cores at a prairie site. *M. punctata* is a generalist species and does not require specialist pollinators or any mutualisms to survive. There is no information available on the genetic diversity of *M. punctata* populations.

Environmental Tolerance and Climate Change Research

M. punctata utilizes dry to medium moisture soils (Missouri Botanical Garden 2013). *M. punctata* is also known to exhibit moderate drought tolerance, which should facilitate its resistance and adaptation to climate change. *M. punctata* was found to have a good come back after invasive species removal at Indiana Dunes National Lakeshore (Choi and Pavlovic 2002), thus disturbance from sand burial, fire, or floods may not be as limiting for *M. punctata.*

The climate change models for *M. punctata* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicts that between 2071-2100 the Great Lakes range (currently southern Great Lakes) will primarily only be found near Lake Superior. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *M. punctata*. This model is specific to Canada and states bordering Canada.

Oenothera biennis

Distribution

*Oenothera biennis (*evening primrose, *Onagraceae*) is an herbaceous plant native to the coastal sand dunes (USDA 2013). *O. biennis* is found throughout North America from the Gulf of Mexico to northern Canada. There are no documented varieties or subspecies of *O. biennis*. It is widespread in Indiana and in the southern U.S. Additionally, *O. biennis* is abundant in the sand dunes habitat of northwestern Indiana. According to USDA, *O. biennis* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

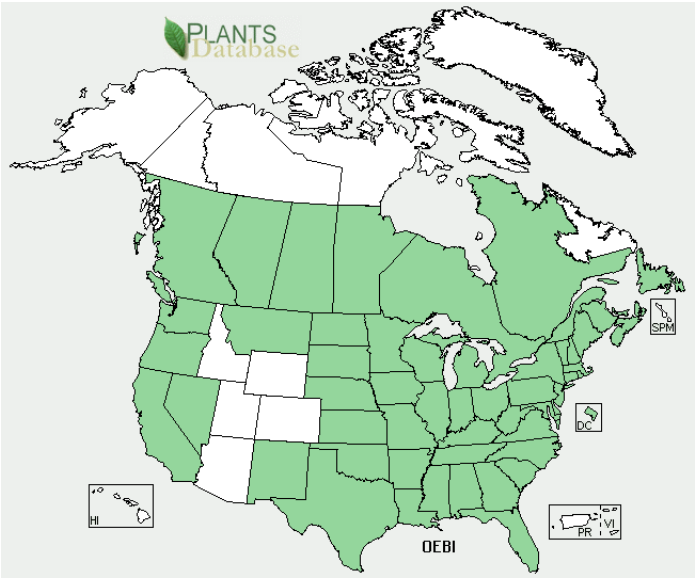

Photo by Thomas G. Barnes
@ USDA-NRCS PLANTS Database

Life history

O. biennis is an annual or biennial herbaceous plant that reproduces only by seed (USDA 2013). Seeds have a moderate rate of spread (USDA 2013). *O. biennis* has a long term seed bank potential (Baskin 1994). It is a generalist species with no known special pollinators or mutualisms needed for survival.

O. biennis likely has a sufficient amount of genetic diversity to avoid problems associated with habitat fragmentation such as inbreeding depression. Johnson and Agrawal (2005) collected 14 genotypes from five habitats that spanned a range of ~200 km. These genotypes differed genetically in different morphological and life history traits, including biomass and generation time. It was also found that variation among genotypes of *O. biennis* impacted the resident arthropod community differently. Thus selection due to climate change for specific genotypes could change in the insect community associated with native plants, such as *O. biennis* on the sand dunes habitat in northwest Indiana.

Environmental Tolerance and Climate Change Research

O. biennis utilizes medium moisture soils with a precipitation minimum of 50.8 cm (20 inches) and a precipitation maximum of 139.7 cm (55 inches) (USDA 2013). *O. biennis* has a medium drought tolerance, which should help it survive drought conditions predicted to become more frequent over the next century due to climate change. *O. biennis* is not flood resistant. Godoy et al. (2011) found that *O. biennis* had 50% mortality at 41.5 °C under water stress. This study indicates that *O. biennis* could indeed be resistant to climate change at the end of the century when temperature is predicted to increase 2-4 °C and summers to become drier.

The climate change models for *O. biennis* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Great Lakes range (currently all over Midwest) will shift northward into Ontario and the Upper Peninsula of MI. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *O. biennis*. This model is specific to Canada and states bordering Canada.

Panicum capillare

Distribution

*Panicum capillare (*witchgrass, *Poaceae*) is a gramminoid native to the coastal sand dunes (USDA 2013). *P. capillare* is found throughout North America, except in the very northern portions of Canada (e.g. not the tundra habitat). There are no documented varieties or subspecies of *P. capillare*. It is widespread in Indiana and in the southern U.S. Additionally, *P. capillare* is abundant in the sand dunes habitat of northwestern Indiana. According to USDA, *P. capillare* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

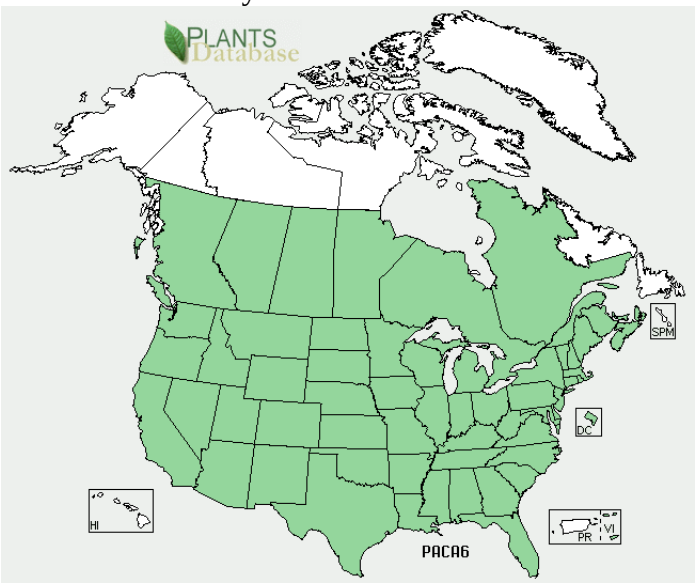

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA SCS (1991)

Life history

P. capillare is an annual grass that reproduces by seeds (USDA 2013). Seeds can be dispersed when the plants at pulled up and blown by the wind like a tumble weed (Clements et al. 2004). Seed banks are known to persist for long periods of time sometimes up to 47 years (Clements et al. 2004), thus seed banks are likely to offer a good regeneration option after disturbance. *P. capillare* is a generalist species and does not require specialist pollinators or any mutualisms to survive.

Clements et al. (2004) describe *P. capillare* as exhibiting substantial phenotypic variation among different soils or climates, which could be due to phenotypic or genetic causes. There are various ecotypes corresponding to different climatic regions that can be characterized by color and size of spikelets, inflorescences, and leaves. Genetic diversity should not be a limiting factor for climate adaptation strategies, especially considering there appears to ecotypes corresponding to different climate zones across North America. Genetic adaptation will be an important precursor to evolution in response to selection pressures caused by climate change (Shaw and Etterson 2012).

Environmental Tolerance and Climate Change Research

P. capillare utilizes a medium amount of moisture and exhibits a moderate drought tolerance (Clements et al. 2004). Drought tolerance should facilitate its resistance and adaptation to climate change. It is unknown if *P. capillare* is resistant to flooding or high disturbance such as sand burial. There is no information available on how *P. capillare* responds to abiotic or biotic impacts caused by climate change.

***Schizachyrium scoparium* Syn [*Andropogon scoparius*]**

Distribution

Schizachyrium scoparium (little bluestem, *Poaceae*) is a gramminoid native to the coastal sand dunes (USDA 2013). *S. scoparium* is found throughout North America. There are three documented subspecies of *S. scoparium*, including *divergens, scoparium, stoloniferum*. It is widespread in Indiana and in the southern U.S. Additionally, *S. scoparium* is abundant in northwestern Indiana and found in both the sand dunes and mesic prairie habitat. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

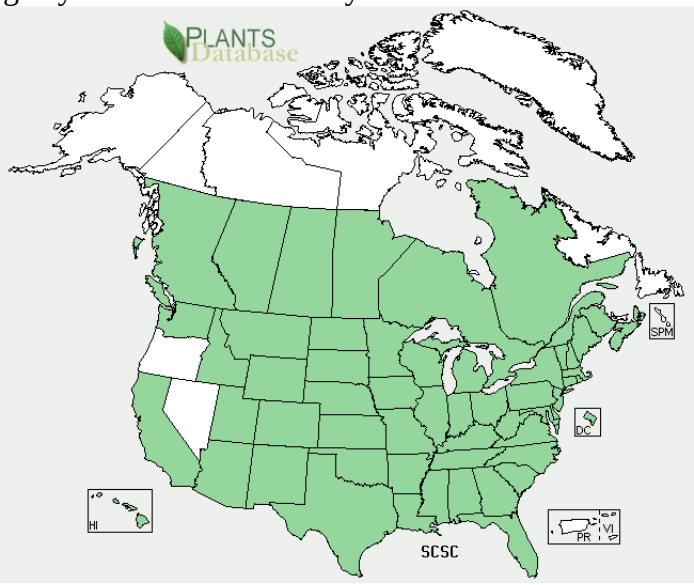

Photo by J.S. Peterson @ USDA-NRCS PLANTS Database

Life history

S. scoparium is a perennial gramminoid that reproduces by seed (USDA 2013). Seeds have a moderate rate of spread (USDA 2013). *S. scoparium* has a seed bank of intermediate longevity (Steinberg 2002). It is a generalist species with no known special pollinators or mutualisms needed for survival.

S. scoparium likely has a sufficient amount of genetic diversity to avoid problems associated with habitat fragmentation such as inbreeding depression. Fu et al. (2004) used AFLP molecular markers to study genetic variation in six natural populations of adult *S. scoparium* and seed collections from Saskatchewan. They found a high amount of genetic variation within populations, while a statistically significant but smaller amount of genetic variation was found among the six populations. Seeds did not exhibit as much genetic variation as the adults, thus

replanting by seeds may not provide as much genetic diversity as replanting from collected plants during restoration efforts. Boe and Bortnem (2009) found that 16 genotypes of *S. scoparium* from the Badlands of eastern South Dakota exhibited genetic variation for biomass related traits. They found that the number of tillers per plant, mass per tiller, axillary branches per tiller, and biomass exhibited genetic variation in a common garden experiment. There was also evidence for phenotypic plasticity in these plants, thus plasticity might help *S. scoparium* acclimate to some climate change impacts to northwestern Indiana.

Environmental Tolerance and Climate Change Research

S. scoparium utilizes low moisture soils with a precipitation minimum of 30.5 cm (12 inches) and a precipitation maximum of 114.3 cm (45 inches) (USDA 2013). *S. scoparium* has a high drought tolerance, which should help it survive drought conditions predicted to become more frequent over the next century due to climate change. Derner et al. (2001) manipulated the amount of precipitation available to a mesic southern tallgrass prairie ecosystem for a 3 year period and found that species richness, species diversity, species evenness, and functional group richness were not affected by the treatment. Specifically, total aboveground biomass of *S. scoparium* did not change over the three year period. Volder et al. (2010) found that a 1.5 °C increase in temperature and an intensified summer drought scenario, resulted in a 56% decrease in *S. scoparium* compared to a 66% decrease in ambient conditions. Over the duration of the summer the drought has an increasingly negative impact on *S. scoparium.* Additionally, *S. scoparium* has poor flood tolerance.

Increased CO_2 and soil nitrogen may also have long-term impacts on *S. scoparium*. Lau et al. (2008) found that elevated CO_2 did not increase biomass of *S. scoparium*. Over multiple generations, they found increased soil nitrogen for five generations and an elevated CO_2 environment increased *S. scoparium* height. Different abiotic changes due to climate change may impact *S. scoparium* differently than changes in a single factor such as CO_2.

The climate change models for *S. scoparium* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Great Lakes range (currently in Michigan) will shift into northern Ontario. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *S. scoparium*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *S. scoparium*, the 'Aldous' (1966), Badlands ecotype (1996), Central Iowa Germplasm (1997), Cimarron (1979), Itasca Germplasm (2001), Northern Iowa Germplasm (1999), Northern Missouri Germplasm (1999), OK Select Germplasm (2010), 'Pastura' (1963), Prairie View Indiana Germplasm (2005), Southern Iowa Germplasm (1999), Southern Missouri Germplasm (2004), Southlow Michigan Germplasm (2001), Suther Germplasm (2002) are all available for conservation.

Sphenopholis obtusata

Distribution

Sphenopholis obtusata (prairie wedgescale, *Poaceae*) is a gramminoid native to the coastal sand dunes (USDA 2013). *S. obtusata* is found throughout North America. There are no documented subspecies of *S. obtusata.* It is fairly widespread in Indiana and widespread in the southern U.S. Additionally, *S. obtusata* is abundant in northwestern Indiana. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

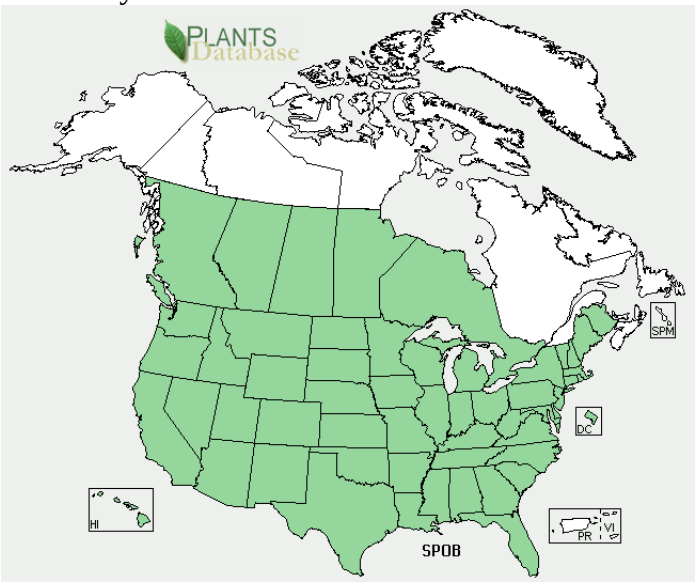

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

S. obtusata is an annual graminoid that reproduces by seed and can also be regenerated by cuttings (USDA 2013). Seeds have a slow rate of spread (USDA 2013). It is a generalist species with no known special pollinators or mutualisms needed for survival. There is a need for research on genetic diversity and seed bank duration to determine how these two factors might help *S. obtusata* resist or adapt to climate change.

Environmental Tolerance and Climate Change Research

S. obtusata utilizes medium moisture soils with a precipitation minimum of 25.4 cm (10 inches) and a precipitation maximum of 152.4 cm (60 inches) (USDA 2013). *S. obtusata* has a low drought tolerance and a low flood tolerance. More research is necessary to determine how *S. obtusata* will respond to climate change. Research should focus on the response of *S. obtusata* to environmental changes such as drought, temperature, disturbance, and interspecific interactions.

Xanthium strumarium

Distribution

Xanthium strumarium (rough cockbur, *Asteraceae*) is an herbaceous plant native to the coastal sand dunes (USDA 2013) and is found throughout North America. There are three documented subspecies of *X. strumarium*, including *canadense, glabratum, strumarium*. It is widespread in Indiana and in the southern U.S. Additionally, *S. scoparium* is abundant in northwestern Indiana. According to USDA, *X. strumarium* is known to exhibit weedy growth in

some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

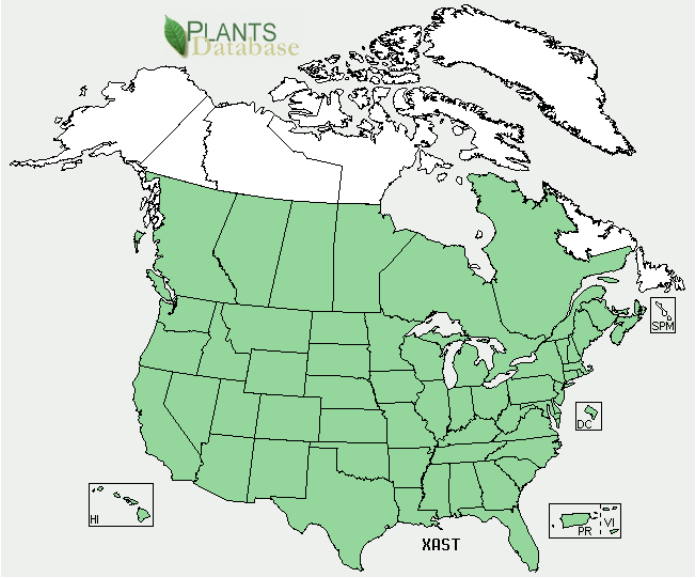

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA SCS (1989)

Life history

X. strumarium is an annual herbaceous plant that reproduces by seed (Uchytil 1992). Seeds catch on animals due to the barbed seed coat and can also float (Uchytil 1992), thus *X. strumarium* has a good long distance dispersal ability. Seeds can be viable for up to 30 months, which provides an intermediate length seed bank (Uchytil 1992). It is a generalist species with no known special pollinators or mutualisms needed for survival.

X. strumarium possesses a large amount of genetic variation across its North American range. Tranel and Wassom (2001) used microsatellite markers to test genetic relationships among 217 accessions of *X. strumarium* from across the U.S. They found a wide variety of genetic variation across different regions of the U.S., including a main northern and southern cluster and a latitudinal gradient of genetic variation. *X. strumarium* should not experience immediate negative impacts of low genetic diversity as climate change proceeds, because it is starting with a high level of diversity. Indeed, Halvorson and Guertin (2003) found morphological variability within and among populations, which could be attributed to either phenotypic plasticity or genetic variation.

Environmental Tolerance and Climate Change Research

X. strumarium utilizes medium moisture soils and can survive in dry soils (Uchytil 1992). This indicates that *X. strumarium* will exhibit some drought tolerance, but it is unknown to what extent *X. strumarium* will ultimately be resistant to the predicted increase in droughts by the end of the century in Indiana. *X. strumarium* is also flood tolerant (Uchytil 1992).

In order to determine if a species could survive long enough beyond its current northern range to reproduce and be able to potentially evolve increased reproduction timing to survive in a different climate, Griffith and Watson (2006) transplanted *X. strumarium* beyond its current northern range. They found that *X. strumarium* seedlings were able to reproduce earlier

(phenotypic plasticity) and produce mature seeds. This might allow *X. strumarium* enough time to adapt to a new climate under climate change shifts.

Shapiro et al. (2004) studied the impact of increased CO_2, nitrogen, and temperature to leaf respiration rates of *X. strumarium*. They found that the low respiration inhibition was at the elevated CO_2 and high nitrogen treatment. In general, respiration increased in response to all CO_2 and nitrogen increases. Increased CO_2 and greater temperature treatments had an even high rate of respiration. These results indicate that with increased atmospheric CO_2, nitrogen deposition, and higher temperatures *X. strumarium* will increase its respiration rate and potentially its growth. Plants with an increased respiration rate will likely need more water, thus droughts could confound increased growth due to other factors such as greater CO_2.

The climate change models for *X. strumarium* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Great Lakes range will shift into Ontario and the Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *X. strumarium*. This model is specific to Canada and states bordering Canada.

Interdunal Wetlands (Pannes) Habitat

Agrostis hyemalis

Distribution

Agrostis hyemalis (winter bentgrass, *Poaceae*) is a grass native to the interdunal wetlands and coastal sand dunes (USDA 2013). It is found north from Ontario, south to Texas and the Gulf of Mexico and from the east coast to the edge of the Midwest. There are no documented subspecies of *A. hyemalis*. It is widespread in Indiana and in the southern U.S. Additionally, *A. hyemalis* is abundant in northwestern Indiana. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

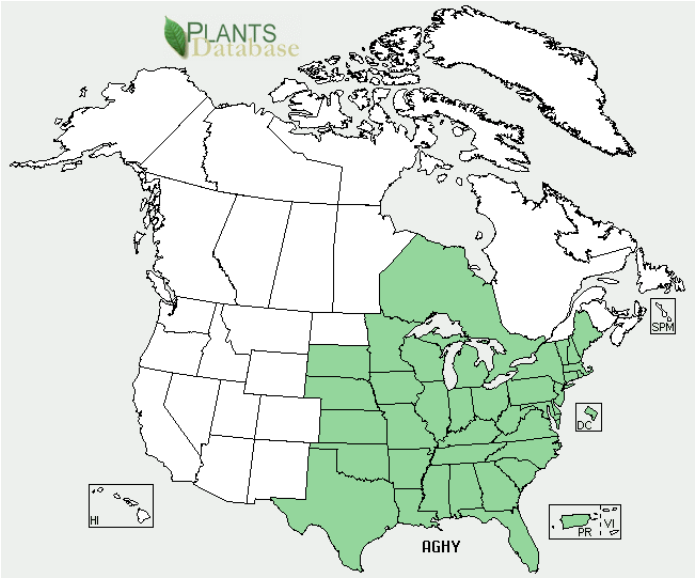

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

A. hyemalis is a perennial grass that reproduces vegetatively and by seed (USDA 2013). Seed spread is slow and vegetative rate of spread is moderate (USDA 2013). 4.23 % of seeds found in the seed bank of six soil cores on grassland and shrub land on Nantucket Island, MA were composed of *A. hyemalis* (Omand 2012), indicating that this species can regenerate from the seed bank without difficulty. It is a generalist species with no known special pollinators or mutualisms needed for survival. There is no genetic information available on *A. hyemalis*. Future research should investigate the genetic diversity of *A. hyemalis* for restoration efforts.

Environmental Tolerance and Climate Change Research

A. hyemalis utilizes high moisture soils with a precipitation minimum of 50.8 cm (20 inches) and precipitation maximum of 114.3 cm (45 inches) (USDA 2013). It has low drought tolerance (USDA 2013). This indicates that *A. hyemalis* may exhibit sensitivity to drought, but it is unknown to what extent southern vs. northern genotypes might differ in their resistance to high temperatures and water stress. Low drought tolerance is a problem that will be common to many wetland plants, thus the exploration of water stress tolerance of the southern range of wetland species may be critical for maintaining this habitat over the next century. *A. hyemalis* has high flood tolerance due to its preference for wetlands (USDA 2013).

Campanula aparinoides

Distribution

Campanula aparinoides (marsh bellflower, *Campanulaceae*) is a native herbaceous plant found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found north from Ontario, south to Georgia and Alabama, to the east coast, and to the western Midwest. There are no documented subspecies of *C. aparinoides*. It is fairly widespread in Indiana but is not very widespread in the southern U.S. Additionally, *C. aparinoides* is abundant in northwestern Indiana. Although, *C. aparinoides* is not as widespread to the south, these southern genotypes may provide individuals that could be more resilient to climate change than those in northwestern Indiana. In general wetlands are an internationally threatened ecosystem, so it may be necessary to focus on species for climate change adaptation strategies than would be less common than the standard for other critical habitats.

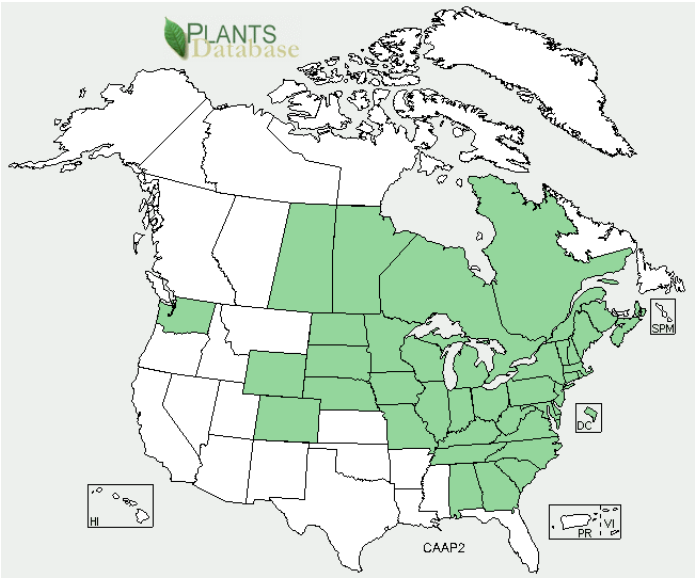

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database / USDA NRCS. 1995. *Northeast wetland flora: Field office guide to plant species*. Northeast National Technical Center, Chester.

Life history

C. aparinoides is a perennial plant that reproduces by rhizomes and by seed (USDA 2013). Both rate of seed spread and rhizome spread is slow (USDA 2013). No information is available on the genetic diversity of *C. aparinoides* populations or on the persistence of *C. aparinoides* seeds in the seed bank. *C. aparinoides* could be considered to be a wetland specialist species, although it is unknown whether it can tolerant a wide range of conditions found in wetland habitats. Future research should investigate the genetic diversity, seed bank persistence, and environmental tolerance of *C. aparinoides* for climate change adaptation efforts.

Environmental Tolerance and Climate Change Research

C. aparinoides utilizes high moisture soils with a precipitation minimum of 50.8 cm (20 inches) and precipitation maximum of 152.4 cm (60 inches). It has low drought tolerance (USDA 2013). This indicates that *C. aparinoides* may exhibit sensitivity to drought, but it is unknown to what extent southern vs. northern genotypes might differ in their resistance to high temperatures and water stress. Low drought tolerance is a problem that will be common to many wetland plants, thus the exploration of water stress tolerance of the southern range of wetland species may be critical for maintaining this habitat over the next century. *C. aparinoides* has high flood tolerance (USDA 2013).

The climate change models for *C. aparinoides* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Great Lakes range will shift into the entire southern region of Canada. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *C. aparinoides*. This model is specific to Canada and states bordering Canada.

Carex stricta

Distribution

Carex stricta (upright sedge, *Cyperaceae*) is a native sedge found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found north from Ontario and south to the Gulf of Mexico. There are no documented subspecies of *C. stricta*. It is fairly widespread in Indiana and in the southern U.S. Additionally, *C. stricta* is abundant in northwestern Indiana. Southern genotypes might provide individuals to be used in restoration efforts that are drought, thermal or disturbance tolerant.

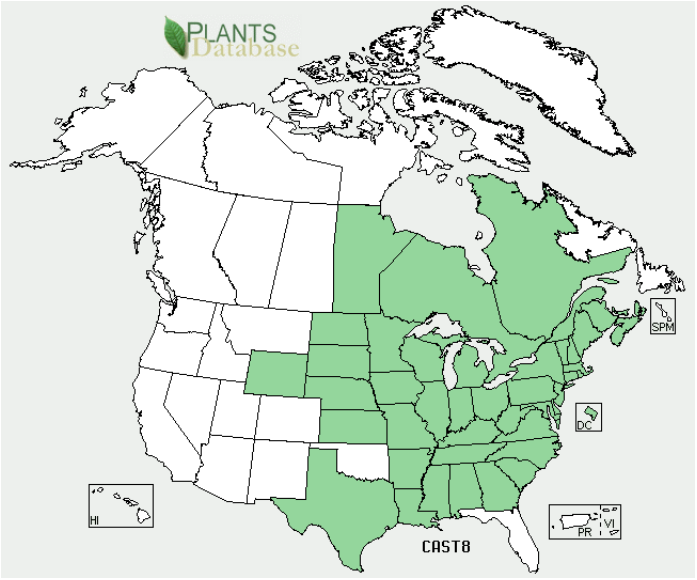

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA NRCS (1995)

Life History

C. stricta is a perennial plant that reproduces by sprigs and seed (USDA 2013). The rate of seed spread is slow (USDA 2013). Seeds that were two and a half years old have been shown to germinate after a cold, moisture treatment (Budelsky et al. 1999), thus the seed bank may provide a method of regeneration after disturbance at least for short time periods. No information is available on the genetic diversity of *C. stricta* populations. *C. stricta* could be considered to be a wetland specialist species, although it is unknown whether it can tolerant a wide range of conditions found in wetlands. Future research should investigate the genetic diversity and environmental tolerance of *C. stricta* for climate change adaptation efforts.

Environmental Tolerance and Climate Change Research

C. stricta utilizes medium moisture soils with a precipitation minimum of 82.3 cm (32 inches) and precipitation maximum of 172.8 cm (68 inches). It has low drought tolerance (USDA 2013). This indicates that *C. stricta* may exhibit sensitivity to drought, but it is unknown to what extent southern vs. northern genotypes might differ in their resistance to high temperatures and water stress. Low drought tolerance is a problem that will be common to many wetland plants, thus the exploration of water stress tolerance of southern genotypes of many species from the interdunal wetlands may be critical for maintaining this habitat over the next century. *C. stricta* has a moderate flood tolerance (USDA 2013).

The climate change models for *C. stricta* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern US range will shift into Ontario, southern Quebec, and the Northeastern US. This does not

predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *C. stricta*. This model is specific to Canada and states bordering Canada.

Cladium mariscoides

Distribution

Cladium mariscoides (smooth sawgrass, *Cyperaceae*) is a native sedge found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found north from Ontario and south to the Gulf of Mexico. There are no documented subspecies of *C. mariscoides*. It is fairly widespread in Indiana and but not very widespread in the southern U.S. Southern genotypes might provide resilience to predicted climate change scenarios for the Midwest, thus climate adaptation strategies should investigate the use of southern genotypes.

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA NRCS (1995)

Life history

C. mariscoides is a perennial plant that reproduces by rhizomes and by seed (Bernard et al. 1985). Seeds can spread by small animals and by water (Bernard 1985). No information is available on the genetic diversity of *C. mariscoides* populations or the seed bank duration of *C. mariscoides*. *C. mariscoides* could be considered to be a wetland specialist species, although it is unknown whether it can tolerant a wide range of wetland conditions. Future research should investigate the genetic diversity, seed bank duration, and environmental tolerance of *C. mariscoides* for climate change adaptation efforts.

Environmental Tolerance and Climate Change Research

It is unknown what amount of moisture that *C. mariscoides* utilizes, although it is known to be flood tolerant (USDA 2013). It has been shown that when water levels drop in wetlands that *C. mariscoides* has difficulty competing with shrubs (Bernard et al. 1985). This indicates that *C. stricta* may exhibit sensitivity to drought, but it is unknown to what extent *C. mariscoides* is drought sensitive or if southern vs. northern genotypes might differ in their resistance to high

temperatures and water stress. Low drought tolerance is a problem that will be common to many wetland plants, thus the exploration of water stress tolerance of southern genotypes of many wetland species may be critical for maintaining this habitat over the next century.

The climate change models for *C. mariscoides* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern US range will shift to be across southern Canada. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *C. mariscoides*. This model is specific to Canada and states bordering Canada.

Euthamia graminifolia

Distribution

Euthamia graminifolia (flat-top golden top, *Asteraceae*) is a native herbaceous plant found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found north from southern Canada and south to Louisiana and New Mexico. There are two subspecies of *E. graminifolia*, including *graminifolia* and *hirtipes*. It is fairly widespread in Indiana and somewhat widespread in the southern U.S. Southern genotypes might provide resilience to predicted climate change scenarios for the Midwest, thus climate adaptation strategies should investigate the use of southern genotypes.

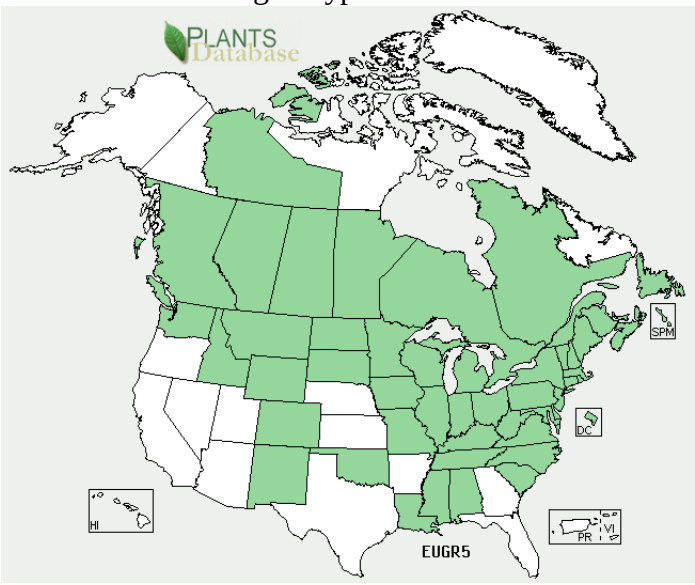

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA SCS (1989)

Life history

E. graminifolia is a perennial plant that reproduces by rhizomes and by seed (USDA 2013). Rhizome spread can be very aggressive (USDA 2013). Viable seeds were found in the seed bank from six soil cores on grassland and shrub land on Nantucket Island, MA (Omand 2012), indicating that this species can regenerate from the seed bank. *E. graminifolia* is a generalist species without any known special mutualisms necessary for survival. Price et al. (2004) found that there was genetic diversity in response to leaf rust, which could indicate that there might be genetic diversity in other phenotypic traits. A formal analysis of genetic diversity within and among populations should be conducted for *E. graminifolia* in order to determine the likely success in climate adaptation efforts.

Environmental Tolerance and Climate Change Research

E. graminifolia has a moderate drought and flood tolerance (USDA 2013). This indicates that this species may exhibit some resistance to the increase in the number of droughts predicted for the end the century in Indiana, especially compared to the many drought sensitive wetland plants native to the interdunal wetlands. *E. graminifolia* could be a very important plant for rehabilitating the interdunal wetlands of northwestern Indiana and should be considered as a top priority for future research efforts on climate change adaptation in this threatened habitat.

The climate change models for *E. graminifolia* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern US range will shift primarily into Ontario. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *E. graminifolia*. This model is specific to Canada and states bordering Canada.

Lycopus americanus

Distribution

Lycopus americanus (American water horehound, *Lamiaceae*) is a native herbaceous plant found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found throughout all of North America except northern Canada and Mexico. There are no subspecies of *L. americanus*. It is widespread in Indiana and in the southern U.S. According to USDA, *L. americanus* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

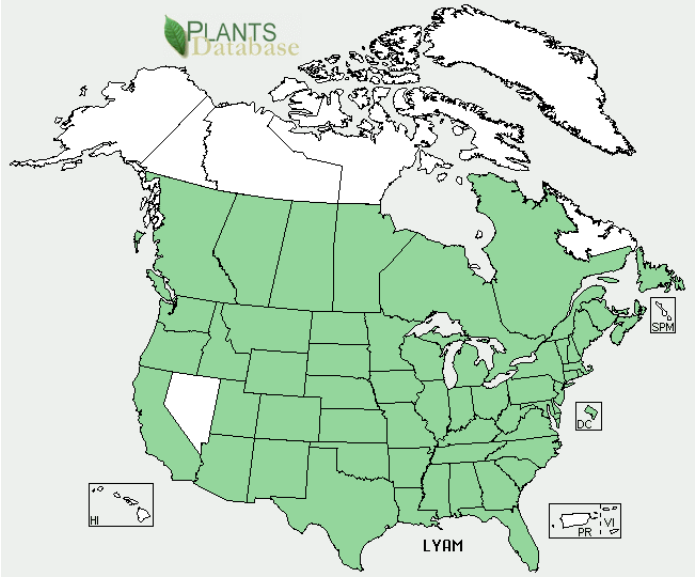

Photo by Robert H. Mohlenbrock @ USDA-NRCS PLANTS Database in USDA SCS (1989)

Life history

L. americanus is a perennial plant that reproduces by tubers and by seed (USDA 2013). Seed spread rate can be moderate (USDA 2013). Seeds were found in 3 out of 10 prairie wetland soil cores (Dahl and Nomesen 1987). *L. americanus* is a generalist species although it found in wetland habitats and it is not known to need any special mutualisms for survival. No research has

been conducted on the genetic diversity of *L. americanus* populations, but this should be a focus for future climate change adaption work.

Environmental Tolerance and Climate Change Research

L. americanus utilizes high moisture soils with a precipitation minimum of 30.5 cm (12 inches) and a precipitation maximum of 152.4 cm (60 inches). It has low drought tolerance (USDA 2013). This indicates that *L. americanus* may exhibit sensitivity to drought, but it is unknown to what extent southern vs. northern genotypes might differ in their resistance to high temperatures and water stress. Low drought tolerance is a problem that will be common to many wetland plants, thus the exploration of water stress tolerance of southern genotypes of wetland species may be critical for maintaining this habitat over the next century. *L. americanus* has a high flood tolerance (USDA 2013).

The climate change models for *L. americanus* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern US range will shift into Ontario and southwestern Quebec. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *L. americanus*. This model is specific to Canada and states bordering Canada.

Lysimachia terrestris

Distribution

Lysimachia terrestris (earth loosestrife, *Primulaceae*) is a native herbaceous plant found in the interdunal wetlands (USDA 2013). It is found north from Ontario and south to South Carolina and Georgia. There are no subspecies of *L. terrestris*. It is fairly widespread in Indiana and somewhat widespread in the southern U.S. Even though *L. terrestris* is not extremely widespread throughout the southern US, southern genotypes might be tolerant to projected climate change scenarios by the end of the century for northwestern Indiana.

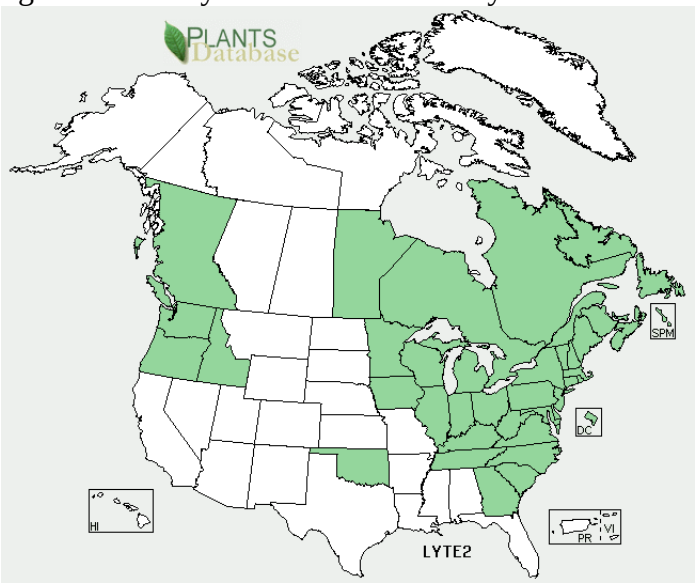

Photo by Nelson DeBarros @
USDA-NRCS PLANTS Database

Life history

L. terrestris is a perennial plant that reproduces by bulbets, tubers and seeds (Reznicek et al. 2011). *L. terrestris* can spread very rapidly (Earth Tones 2010). *L. terrestris* is a generalist species although it is restricted to wetland habitats and it is not known to need any special mutualisms for survival. No research has been conducted on the genetic diversity or seed bank duration of *L. terrestris* populations, and his should be a focus in future climate change research.

Wilson (1991) found that *L. terrestris* exhibited phenotypic plasticity in biomass, but not number of leaves or root to shoot biomass in an environmental gradient of 10 soil nutrient treatments. Phenotypic plasticity has been suggested to be an important response to a changing climate (Shaw et al. 2012). This plasticity in response to soil nutrients could be important for the observed and predicted increases in nitrogen deposition.

Environmental Tolerance and Climate Change Research

L. terrestris prefers moist soils (Native Plant Database 2013), but it is unknown if *L. terrestris* is drought tolerant or not. This is critical information for wetland plants to be considered for climate change adaptation strategies, because droughts are predicted to increase in number by the end of the century in Indiana and the Great Lakes. It is also unknown to what extent southern vs. northern genotypes might differ in their resistance to high temperatures and water stress.

The climate change models for *L. terrestris* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the range from the Great Lakes region and eastern US will shift into Ontario and Quebec. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *L. terrestris*. This model is specific to Canada and states bordering Canada.

Schoenoplectus acutus var. acutus

Distribution

Schoenoplectus acutus var. acutus (hardstem bulrush, *Cyperaceae*) is a native sedge found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found north from Ontario and south to Texas and Kentucky. There are two subspecies of *S. acutus*, including *acutus* and *lacustris*, but *acutus* is found in Indiana Dunes National Lakeshore (NPS Species Database 2009). It is widespread in Indiana and in the southern U.S. According to USDA, *S. acutus* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

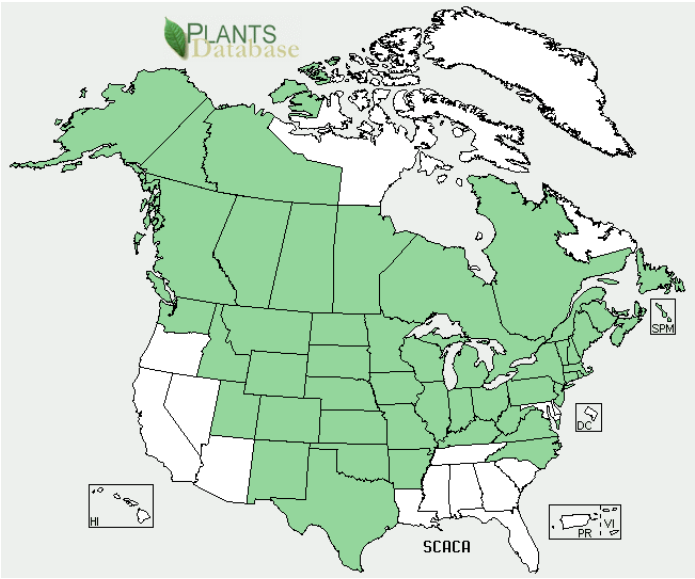

Photo by Mark W. Skinner @
USDA-NRCS PLANTS Database

Life history

S. acutus is a perennial plant that reproduces by sprigs and by seed (USDA 2013). Both seed and vegetative spread rate can be moderate (USDA 2013). *S. acutus* can establish well from a seed bank (Esser 1995). *S. acutus* is a generalist species although it found in wetland habitats, and it is not known to need any special mutualisms for survival. No research has been conducted on the genetic diversity of *S. acutus* populations, but this should be focused on in the future for climate change adaption.

Environmental Tolerance and Climate Change Research

S. acutus utilizes high moisture soils with a precipitation minimum of 30.5 cm (12 inches) and a precipitation maximum of 152.4 cm (60 inches). It has medium drought tolerance (USDA 2013), thus it is likely to be an important choice for climate change adaptation strategies in the interdunal wetlands. Southern genotypes may provide even more resistance to high temperatures and potentially drought. *S. acutus* also has a high flood tolerance (USDA 2013).

The climate change models for *S. acutus* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern and eastern US range will shift into Ontario and Quebec. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *S. acutus*. This model is specific to Canada and states bordering Canada.

Schoenoplectus pungens

Distribution

Schoenoplectus pungens (common threesquare, *Cyperaceae*) is a native sedge found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found throughout North America. There are three subspecies of *S. pungens*, including *badius*, *longispicatus*, and *pungens*. It is widespread in Indiana and in the southern U.S.

Photo by Derek Tilley. NRCS, Idaho

Life history

S. pungens is a perennial plant that reproduces by rhizomes and by seed (USDA 2013). Both seed and vegetative spread rate can be moderate (USDA 2013). Titus and Titus (2008) found that in an Arizonia wetland that *S. acutus* was the dominant plant and many seedlings grew from the seed bank. *S. pungens* is a generalist species, although it found in wetland habitats. It is not known to need any special mutualisms for survival. *S. pungens* exhibited some genetic diversity in a preliminary study using microsatellite molecular markers with six individuals (Blum et al. 2005). These genetic markers could be used to further investigate the genetic diversity of *S. pungens* in natural populations.

S. pungens is known to exhibit some phenotypic plasticity in traits related to survival in a wetland. Albert et al. (2013) found that aerenchyma tissue (an adaptation that wetland plants may possess to living in anaerobic soils) increased with flooding. Poor et al. (2005) also found that rhizomes will forage for good soil. These adaptations to changing soil or flooding conditions could help *S. pungens* survive immediate environmental changes that could occur due to climate change.

Environmental Tolerance and Climate Change Research

S. pungens utilizes high moisture soils with a precipitation minimum of 30.5 cm (12 inches) and a precipitation maximum of 152.4 cm (60 inches). It has medium drought tolerance (USDA 2013), thus it is likely to be an important choice for climate change adaptation strategies in the interdunal wetlands of northwestern Indiana. Southern genotypes may provide even more resistance to high temperatures and potentially drought. It is also known to spread rapidly in emergent areas after a water draw down (Wilcox and Nicols 2008). This rapid spread after water reduction may indicate that during drought events it may spread quickly. *S. acutus* has a high flood tolerance (USDA 2013).

S. pungens is a very important plant for erosion and pollution control in coastal wetlands. Bell-Derske and Albert (2008) investigated the growth potential of *S. pungens* in three zones of water depth along two coastal wetlands of the Great Lakes. They found that the two dry zones that are either dry year round or where the water-level fluctuates seasonally exhibited reduced growth compared to the deeper and continuously wet zone. They suggested that the growth

potential of *S. pungens* may not be able to keep up with predicted reductions in lake level in the Great Lakes due to climate change.

***Schoenoplectus tabernaemontani* Syn [*Scirpus validus*]**

Distribution

Schoenoplectus tabernaemontani (softstem bulrush, *Cyperaceae*) is a native sedge found in the interdunal wetlands of the coastal sand dunes (USDA 2013). It is found throughout North America. There are no subspecies of *S. tabernaemontani*. It is widespread in Indiana and in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

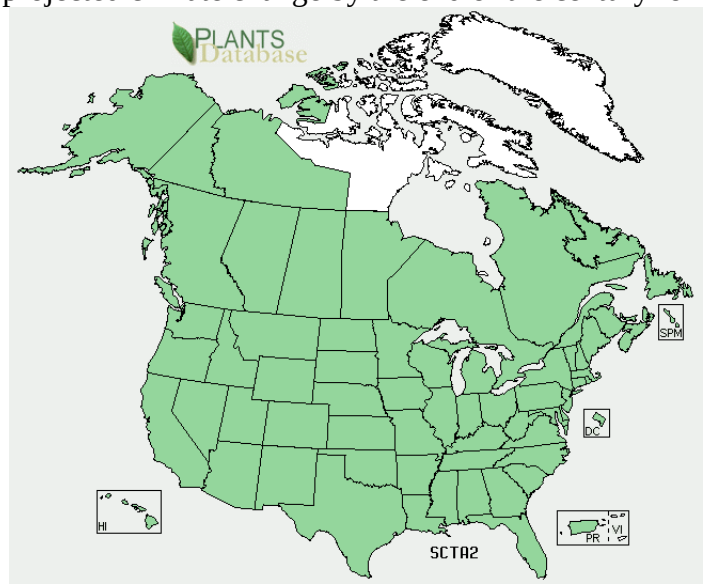

Photo by James H. Miller @ USDA-NRCS
PLANTS Database in Miller and Miller (2005)

Life history

S. tabernaemontani is a perennial plant that reproduces by rhizomes and by seed (USDA 2013). Rate of seed spread is slow but vegetative spread rate is rapid (USDA 2013). Jutita (2001) found that germination of seeds was higher in a flood treatment. *S. tabernaemontani* regenerates well from the seed bank because seeds can last up to 20 years in soil (Snyder 1993). *S. tabernaemontani* is a generalist species although it found in wetland habitats. It is not known to need any special mutualisms for survival. *S. tabernaemontani* has been introduced to Belgium, where de Greef and Tirst (2003) found two genetically distinct groups of *S. tabernaemontani* using molecular markers (RAPDs). They also observed hybrids between *Scirpus* spp.

Environmental Tolerance and Climate Change Research

S. tabernaemontani utilizes high moisture soils with a precipitation minimum of 45.7 cm (18 inches) and a precipitation maximum of 139.7 cm (55 inches). It has low drought tolerance (USDA 2013). Southern genotypes may provide more resistance to high temperatures and potentially drought, thus future research should investigate the use of southern genotypes for climate change adaptation strategies.

It is also known to spread rapidly in emergent areas after a water draw down (Wilcox and Nicols 2008). *S. tabernaemontani* has a high flood tolerance (USDA 2013). During a lake draw

down *S. tabernaemontani* stayed in wet areas close to the lakeshore (Wilcox and Nicols 2008). Additionally, it replaced *Typha* sp. after a lake draw down in wet areas (Snyder 1993). Roots can dry out during draw down, which may contribute to its low drought tolerance and it does not grow well in fluctuating water levels (Hunter et al. 2000).

The climate change models for *S. tabernaemontani* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Michigan range will shift into northern Ontario. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *S. tabernaemontani*. This model is specific to Canada and states bordering Canada.

Mesic Prairie Habitat

Andropogon gerardii

Distribution

Andropogon gerardii (big blustem, *Poaceae*) is a native grass found in mesic prairies (USDA 2013). It is found from Canada to the southern US and west to the Rocky Mountains. There are no subspecies of *A. gerardii.* It is widespread in Indiana and in the southern U.S. According to USDA, *A. gerardii* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

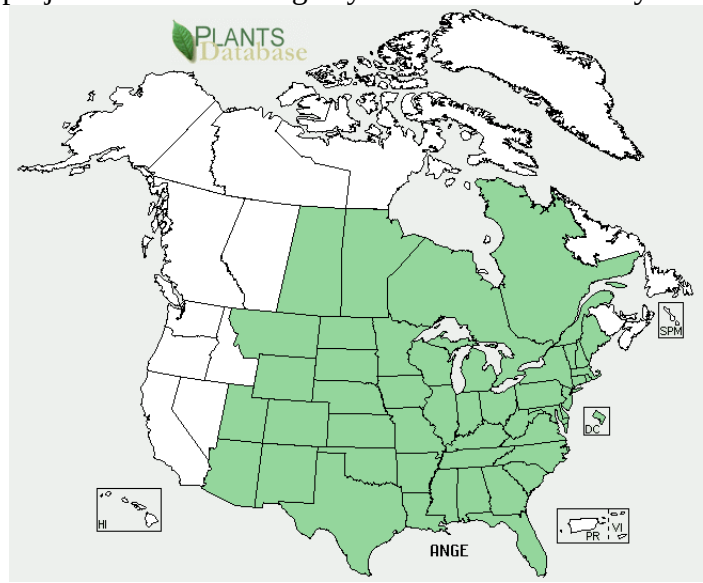

Photo by Jennifer Anderson @ USDA-NRCS PLANTS Database

Life history

A. gerardii is a perennial plant that reproduces vegetatively and by seed (USDA 2013). Rate of seed and vegetative spread is slow (USDA 2013). Few seeds were found in the soil under a large stand of *A. gerardii*, but this may have been the result of the rarity of flower production (Uchytil 1988). *A. gerardii* often heavily relies on vegetative reproductive (Uchytil 1988), thus the seed bank may not provide a very reliable regeneration of *A. gerardii* after disturbance. *A.*

gerardii is a generalist species. It is not known to need any special mutualisms for survival as it is wind pollinated, although it relies on mycorrhiza (Owsley).

Genetic variation has been well studied in *A. gerardii*. Avolio et al. (2011) found that a one meter square area had an average of 5.2 unique genotypes. Genetic diversity is relatively high on a small spatial scale despite the prevalence of clonal reproduction. Gustafson et al. (2004) found that remnant populations of *A. gerardii* had sufficient genetic variation to be used for restoration, but natural and restored populations were genetically distinct. There may also be much phenotypic plasticity in *A. gerardii*, because it exhibits ecotypic variation across its geographic range including northern, southern, and dry regions (Uchytil 1988). This variation in phenotypic plasticity or genetic variability has not been investigated experimentally.

Changes in precipitation may have negative impacts on *A. gerardii* as climate change proceeds. Avolio et al. (2013) experimentally modified the amount of precipitation experienced by *A. gerardii* over a ten year period and found that decreased precipitation led to a decrease in genetic diversity. As climate change proceeds droughts may select for more drought tolerant genotypes, but may also reduce genetic diversity of populations making it more difficult for a population to respond to future selective pressures (i.e. not enough genetic variation to respond to natural selection). Additionally, Avolio et al. (2013) found that genetic distance between individuals increased with increased precipitation. Avolio et al. (2013 b) highlights the importance than genetic variation might have for microevolution in response to climate change induced precipitation variability, because different genotypes of *A. gerardii* performed differently in response to water variation manipulations. Lambert et al. (2011) determined that cultivars had higher WUE than natural genotypes, so cultivars may perform better in some drought situations than natural populations.

Environmental Tolerance and Climate Change Research

A. gerardii utilizes low moisture soils with a precipitation minimum of 30.5 cm (12 inches) and a precipitation maximum of 139.7 cm (55 inches). It has high drought tolerance (USDA 2013). Hypostomatal leaves fold in response to low leaf water potential contributing to its drought tolerance, which is supported by high rates of carbon gain over a wide range of leaf temperatures (Owsley 2013). Northern genotypes may exhibit some tolerance to the increase in drought predicted by the end of the century.

A considerable research effort has been conducted to investigate the impact of different climate factors on *A. gerardii*. The maximum relative growth rate and biomass is known to be at 25 °C, while these decrease at higher and lower temperatures (Delucia et al. 1992). Over 15 years, Silletti and Knapp (2002) observed a decrease in mean cover of *A. gerardii* that was correlated with decreasing summer maximum temperatures. Travers et al. (2010) identified genes that changed gene expression profiles in experiments that manipulated temperatures and water changes similar to those projected under a climate change scenario. Some of these genes were involved in chlorophyll fluorescence and could be important for adaptation to climate change conditions (Travers et al. 2010). Compared to *Sorghasrum nutans*, *A. gerardi*i is better able to tolerate drought, because it had greater allocation to roots, reduced allocation to flowering, more rapid leaf turnover, and more rapid recovery of photosynthesis after wilt in a wilting treatment (Swemmer et al. 2006). Alternatively, frequency of *A. gerardii* decreased in response to decreased water and elevated CO_2, which suggested that as climate change proceeds with drought this species may be outcompeted by more drought tolerant species (Nie et al. 1992).

Overall, *A. gerardii* will likely exhibit reasonable resilience to initial climate changes especially drought, although the outcome of competitive interactions may be less certain.

The climate change models for *A. gerardii* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwest range will shift into Ontario and the western Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *A. gerardii*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *A. gerardii*, the 'Bison' (1989), 'Bonilla' (1987), 'Bounty' Germplasm (2012), 'Central Iowa' Germplasm (1998), 'Earl' (1996), 'Hampton' Germplasm (2007), 'Kaw' (1950), 'Niagara' (1986), 'Northern Iowa' Germplasm (2001), 'Northern Missouri' Germplasm (1999), 'OH 370' Germplasm (1997), 'OZ-70' Germplasm (2004), 'Prairie View' (2005), 'Refuge' Germplasm (2006), 'Rountree' (1983), 'Southern Iowa' (1999), 'Southlow Michigan' Germplasm (1998), 'Sunnyview' (1998), 'Suther' Germplasm (2002) are all available for conservation. Combining these genotypes in restoration projects may also provide a buffer for climate change impacts.

Euphorbia corollata

Distribution

Euphorbia corollata (flowering spurge, *Euphorbiaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found from the eastern coast of the US to North Dakota, Texas, and the Gulf of Mexico. There are no subspecies of *E. corollata*. It is widespread in Indiana and in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

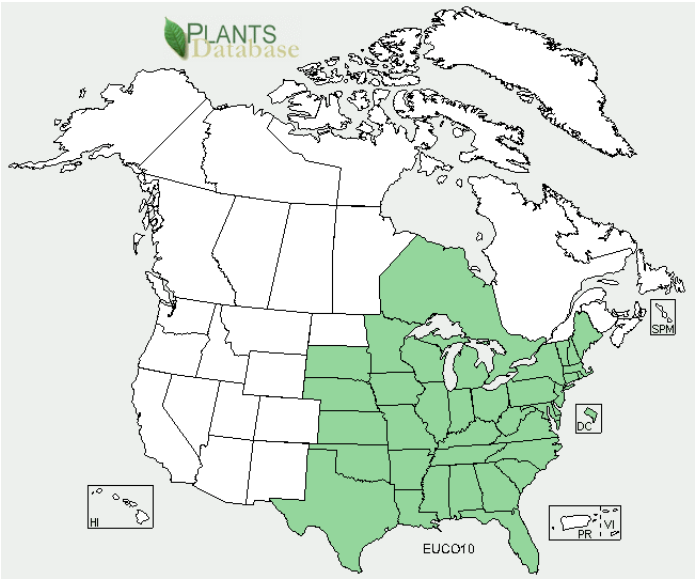

Photo by Larry Allain @
USDA-NRCS PLANTS Database

Life history

E. corollata is an annual plant that reproduces by seeds and vegetatively (USDA 2013). Vegetative spread is slow (Illinois Wildflowers 2012). *E. corollata* is a generalist species and it is not known to need any special mutualisms for survival. There is currently no information available on the genetic diversity of *E. corollata* populations and the duration of the seed bank. Future research should investigate these factors to inform climate change adaptation strategies.

Environmental Tolerance and Climate Change Research

E. corollata utilizes low moisture soils and prefers mesic to dry soil (Illinois Wildflowers 2012). It has a high drought tolerance (Illinois Wildflowers 2012). Little is known about the actual tolerance of *E. corollata* to projected climate conditions at the end of the century. Southern genotypes may provide more resistance to high temperatures and drought, thus future research could investigate the use of southern genotypes and broad climatic tolerances for climate change adaptation strategies.

The climate change models for *E. corollata* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Illinois, Indiana, and Ohio range will shift into the western Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *E. corollata*. This model is specific to Canada and states bordering Canada.

Lespedeza capitata

Distribution

Lespedeza capitata (roundhead lespedeza, *Fabaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found from Ontario to the Gulf of Mexico and Texas to the east coast of the US. There are no subspecies of *L. capitata.* It is widespread in Indiana and in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

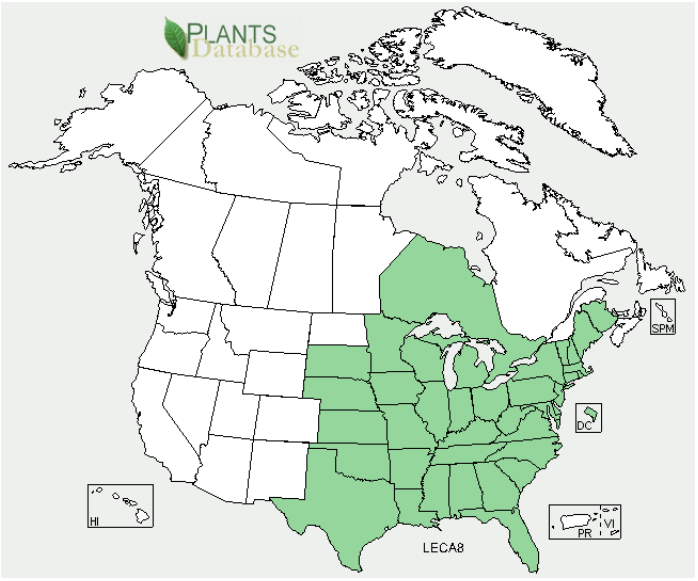

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

L. capitata is a perennial plant that reproduces by seed (USDA 2013). Rate of seed spread is slow (USDA 2013). *L. capitata* is a generalist species and it is utilizes a mutualistic relationship with rhizobium (USDA 2013). No information is available about the duration of the seed bank, so future research should investigate this to predict the regeneration potential of *L. capitata* to disturbances. Genetic differentiation was found among 12 populations by Cole and Biesboer (1992), but they suggested that gene flow was low among populations probably due to inbreeding.

Environmental Tolerance and Climate Change Research

L. capitata utilizes low moisture soils with a precipitation minimum of 42.3 cm (19 inches) and a precipitation maximum of 114.3 cm (45 inches). It has high drought tolerance (USDA 2013). Wittington et al. (2012) found that increased temperature and nitrogen source increased growth and higher shoot nitrogen content at 28 °C. Southern genotypes may provide more additional resistance to high temperatures and drought, thus future research could investigate the use of southern genotypes for climate change adaptation strategies.

The climate change models for *L. capitata* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the southern Midwest range will shift into southern Quebec, the western Upper Peninsula of Michigan, Southern New York, and Pennsylvania. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *L. capitata*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *L. capitata*,

the Central Iowa Germplasm (1996), Kanoka (1998), Northern Iowa Germplasm (2001), Southern Iowa Germplasm (1997) are all available for conservation.

Liatris aspera

Distribution

Liatris aspera (tall blazing star, *Asteraceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found from the eastern coast of the US to North Dakota, Texas, and the Gulf of Mexico. There are three subspecies of *L. aspera*, including *asper*, *intermedia*, and *salutans.* It is widespread in Indiana and in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

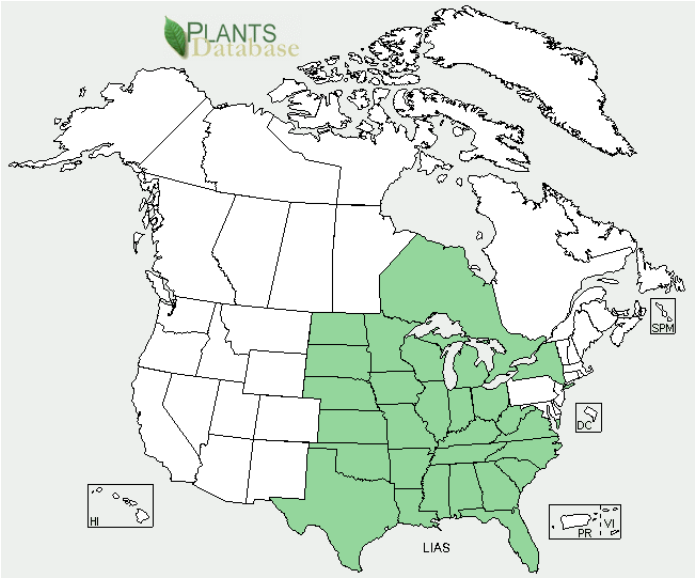

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

L. aspera is a perennial plant that reproduces by seeds (USDA 2013). *L. aspera* seeds have been shown to disperse at distances of 8 m by wind (Levin and Kerster 1969). *L. aspera* is a generalist species and it is not known to need any special mutualisms for survival. A study by Kitchen et al. (2001) found that 22% of genetic variation among six remnant prairie populations and 78% within populations. This suggests that there may be enough variation within populations rather than among populations for seed collections for restoration. There is currently no information available on the duration of the seed bank.

Environmental Tolerance and Climate Change Research

L. aspera utilizes low to medium moisture soils and prefers mesic to dry soil (Missouri Botanical Gardens 2013). It has a high drought tolerance (Missouri Botanical Gardens 2013). *L. aspera* is intolerant of wet soils particularly in the winter months (Missouri Botanical Gardens 2013). Little is known about the actual tolerance of *L. aspera* to projected climate conditions at the end of the century. Southern genotypes may provide more resistance to high temperatures

and drought, thus future research could investigate the use of southern genotypes and broad climatic tolerances for climate change adaptation strategies.

The climate change models for *L. aspera* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the southern Midwestern range will shift into the western Upper Peninsula of Michigan, Pennsylvania, New York, and southeastern Quebec. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *L. aspera*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *L. aspera*, the 'Central Iowa' Germplasm (2003), 'Northern Iowa' Germplasm (2003), 'Southern Iowa' Germplasm (2003) are all available for conservation.

Lithospermum canescens

Distribution

Lithospermum canescens (hoary puccoon, *Boraginaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found from the eastern coast of the US to North Dakota, Texas, and the Gulf of Mexico. There are no subspecies of *L. canescens.* It is widespread in Indiana and in the southern U.S. Additionally, *L. canescens* is abundant in northwestern Indiana. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

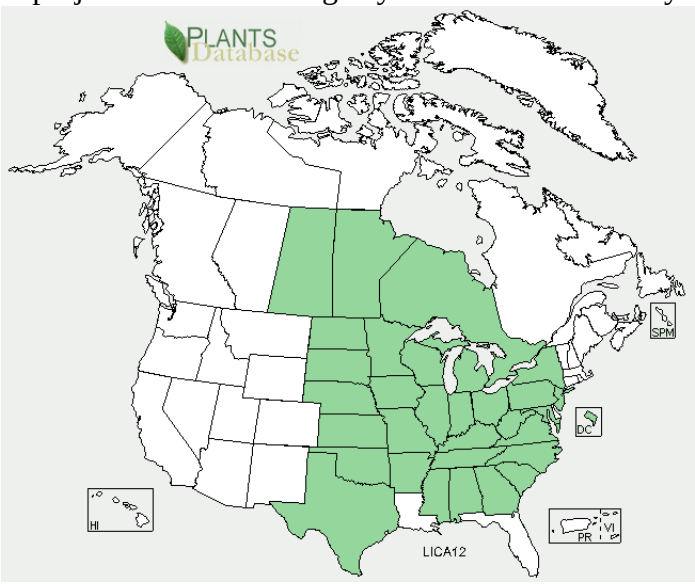

Photo by Elaine Haug @ USDA-NRCS PLANTS Database

Life history

L. canescens is a perennial plant that reproduces by seed and it can be difficult to germinate *L. canescens* from seed (Illinois Wildflowers 2012). *L. canescens* is a generalist

species and it is not known to need any special mutualisms for survival. Kittelson et al. (2006) investigated the genetic diversity among three patches of a remnant prairie. They found that there was considerable genetic variation within the populations, but the populations were genetically similar indicating that gene flow between them was high. This study suggests that remnant prairie populations of *L. canescens* possess enough genetic variation and connectivity to provide a source for restoration seed collections.

Environmental Tolerance and Climate Change Research

L. canescens utilizes low moisture soils and is drought tolerant (Native Plant Database 2013). Little is known about the actual tolerance of *L. canescens* to projected climate conditions at the end of the century. Southern genotypes may provide more resistance to high temperatures and potentially drought, thus future research could investigate the use of southern genotypes and broad climatic tolerances for climate change adaptation strategies.

The climate change models for *L. canescens* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern range will shift into Ontario. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *L. canescens*. This model is specific to Canada and states bordering Canada.

Phlox pilosa

Distribution

Phlox pilosa (downy phlox, *Polemoniaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found throughout the eastern half of North America. There are nine subspecies of *P. pilosa*, including *deamii, detonsa, fulgida, latisepala, ozarkana, pilosa, pulcherrima, riparia, sangamonensis.* It is widespread in Indiana and fairly widespread in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

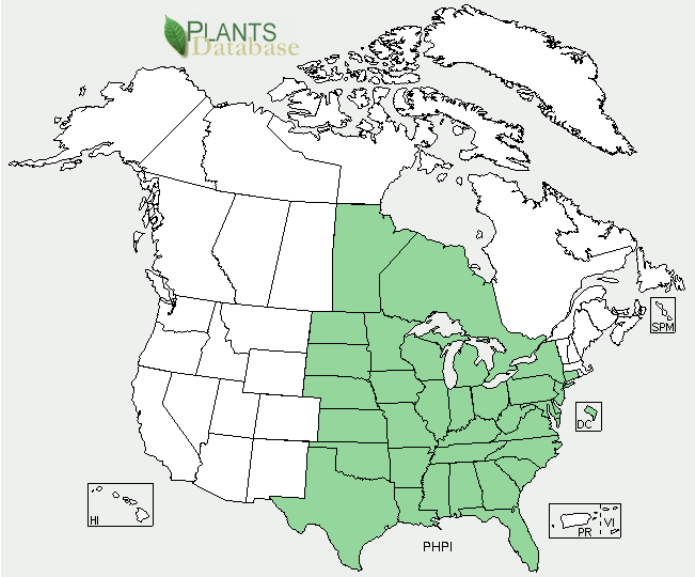

Photo by Larry Allain @ USDA-NRCS PLANTS Database

Life history

P. pilosa is a perennial plant that reproduces by seed and stolons (USDA 2013). Seeds can be spread by wind for a short distance (Illinois Wildflowers 2012) and it can spread rapidly by stolons (Missouri Botanical Garden 2013). *P. pilosa* is a generalist species and it is not known to need any special mutualisms for survival.

Low genetic variation and inbreeding may be important for *P. pilosa* population reproduction ability and should be carefully considered in restoration projects. Hendrix and Kyhl (2000) found that small populations had lower reproduction which was likely due to reduced pollen dispersal and inbreeding. They suggested that for the best population viability a minimum of 1000-2000 ramets should be maintained. Fehlberg et al. (2008) developed microsatellite molecular markers and found that there was an average of 10 markers per locus from one population that was sampled. This suggests that not all populations exhibit low genetic diversity, thus it may be important to consider the source of *P. pilosa* propagules or seeds for restoration.

Environmental Tolerance and Climate Change Research

P. pilosa utilizes low to medium moisture soils (Illinois Wildflowers 2012). *P. pilosa* tolerates dry soil compared to other *Phlox* species (Missouri Botanical Garden 2013), which suggests it may be somewhat drought tolerant. There is little information on the environmental tolerance of *P. pilosa*, although the current information does imply that *P. pilosa* could exhibit some resilience to drought.

The climate change models for *P. pilosa* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Illinois, Indiana, and Ohio range will shift into northern Wisconsin and New York. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *P. pilosa*. This model is specific to Canada and states bordering Canada.

Sorghastrum nutans

Distribution

Sorghastrum nutans (Indiangrass, *Poaceae*) is a native grass found in mesic prairies (USDA 2013). It is found throughout North America except on the western coast. There are no subspecies of *S. nutans.* It is widespread in Indiana and in the southern U.S. According to USDA, *S. nutans* is known to exhibit weedy growth in some areas of the U.S. (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

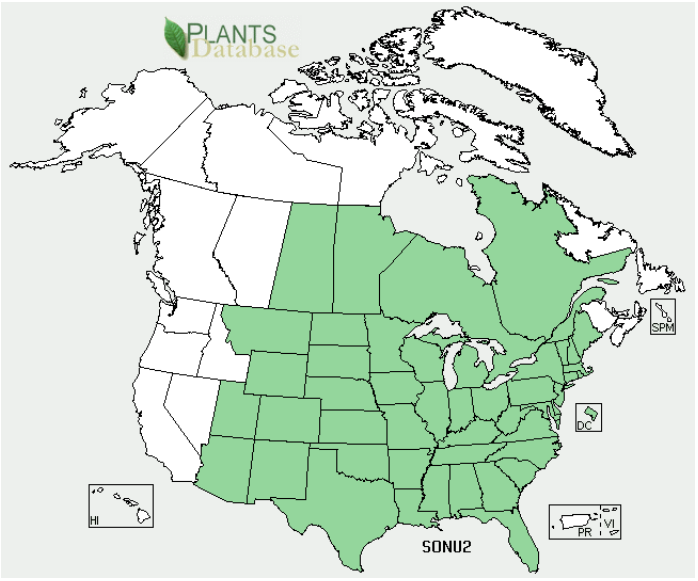

Photo by Jennifer Anderson @
USDA-NRCS PLANTS Database

Life history

S. nutans is a perennial plant that reproduces by rhizomes and by seed (USDA 2013). Rate of seed spread is slow but rate of vegetative spread is moderate (USDA 2013). Seeds have been known to readily germinate unless buried deeper than 1.27 cm (0.5 inches) in the soil (Walkup 1991), but it is unknown how well *S. nutans* would germinate from the seed bank after a disturbance. *S. nutans* is a generalist species. It is not known to need any special mutualisms for survival.

Genetic variation is likely high enough to provide enough diversity to avoid inbreeding depression in any restored populations. Gustafson et al. (2004) found that genetic diversity in native populations was high. Genetic differentiation between restored and native prairies was high indicating that genetic sources of restoration may have been quite different from native populations. Additionally, genetic similarity between native populations suggests that gene flow is relatively high. Furthermore, there is variation in flowering time across populations, but it is unknown if this is genetically or environmentally induced (Walkup 1991). Lambert et al. (2011) determined that cultivars had higher water use efficiency than native genotypes, so cultivars may perform better in some drought situations than natural populations and might be the best choice for some climate adaptation strategies.

Environmental Tolerance and Climate Change Research

S. nutans utilizes medium moisture soils with a precipitation minimum of 27.9 cm (11 inches) and a precipitation maximum of 114.3 cm (45 inches). It has medium drought tolerance (USDA 2013). *S. nutans* will colonize bare soil, so it does well in disturbed areas (Walkup 1991). It can grow in low lands and tolerant occasional flooding (Native Plant Database 2013).

A considerable research effort has been conducted to investigate the impact of different climate factors on *S. nutans*. Derner et al. (2011) found that increased precipitation variability did not result in a reduction in biomass of *S. nutans* (Derner et al. 2011). Nie et al. (1992) found that an elevated CO_2 treatment didn't impact *S. nutans*, but it grew better in a high and low moisture treatment over the two year study period (Nie et al. 1992). Over 15 years Silletti and

Knapp (2002) observed a slight decrease in mean cover of *S. nutans* in a Kansas prairie and interannual turnover of percent cover was correlated to annual precipitation. Compared to *S. nutans*, *A. gerardi*i is better able to tolerate drought, because it had greater allocation to roots, reduced allocation to flowering, more rapid leaf turnover, and more rapid recovery of photosynthesis after wilt in a wilting treatment (Swemmer et al. 2006). This indicates that a competitive interaction could change between these two dominant prairie species. Overall, *S. nutans* will likely exhibit reasonable resilience to initial climate changes especially drought, although the outcome of competitive interactions may be less certain.

The climate change models for *S. nutans* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwest range will shift into Ontario, southern Quebec, and the western Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *S. nutans*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *S. nutans*, the 'Americus' (2002), 'Central Iowa' Germplasm (1996), 'Cheyenne' (1945), 'Coastal' Germplasm (2007), 'Llano' (1963), 'Lometa' (1981), 'Newberry' (2005), 'Northern Iowa' (1997), 'Northern Missouri' Germplasm (1999), 'Osage' (1966), 'Prairie View' Indiana Germplasm (2005), 'Rumsey' (1983), 'Southern Iowa' Germplasm (2001), 'Suther' Germplasm (2002), 'Tomahawk' (1988), and 'Western Missouri' Germplasm (1999) are all available for conservation.

***Symphyotrichum novae-angliae* Syn [*Aster novae-angliae*]**

Distribution

Symphyotrichum novae-angliae Syn [*Aster novae-angliae*] (New England aster, *Asteraceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found throughout most of North America. There are no subspecies of *S. novae-angliae.* It is widespread in Indiana and fairly widespread in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

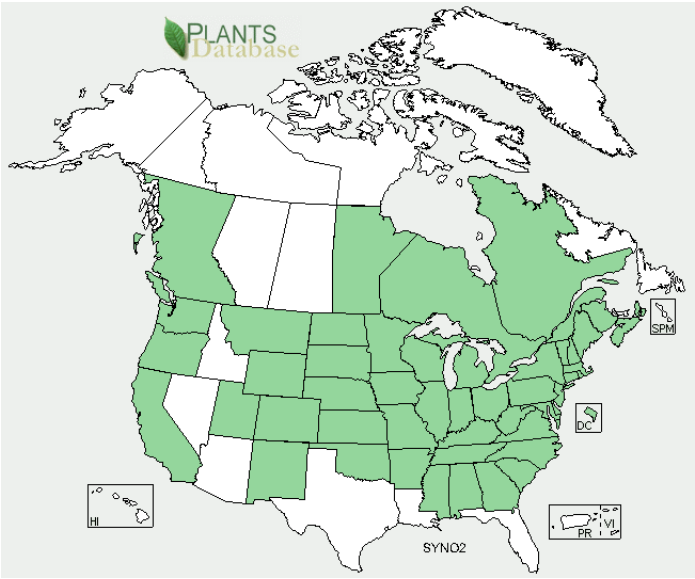

Photo by Thomas G. Barnes @ USDA-NRCS PLANTS Database

Life history

S. novae-angliae is a perennial plant that reproduces by seeds and rhizomes (USDA 2013). Seeds can be spread by wind or water (Brandeis Ecological Research Repository 2013). *S. novae-angliae* seeds germinated after one year (Chemielewski and Semple 2003), but it is unknown if seeds can be dormant in the seed bank for longer than one year. *S. novae-angliae* is a generalist species and it is not known to need any special mutualisms for survival. There is a non-random distribution of narrow versus broad leaf forms in eastern and western North American, but it is not known if these differences are caused by environmental or genetic mechanisms (Chemielewski and Semple 2003). Information on genetic or phenotypic plasticity that is adaptive to certain climatic conditions would be valuable for climate change adaptation strategies.

Environmental Tolerance and Climate Change Research

S. novae-angliae utilizes medium moisture soils (Missouri Botanical Garden 2013). *S. novae-angliae* is drought tolerant (Amanda's Garden 2013). *S. novae-angliae* also is tolerant to seasonal flooding (Native Plant Database 2013). These sources suggest *S. novae-angliae* may be both drought and flood tolerant, but little is known about the actual tolerance of *S. novae-angliae* to projected climate conditions at the end of the century. It is known that *S. novae-angliae* is moderately sensitive to ground level ozone (Kline et al. 2008).

The climate change models for *S. novae-angliae* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Midwestern and eastern coast range will shift into Ontario and the Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *S. novae-angliae*. This model is specific to Canada and states bordering Canada.

The Natural Resources Conservation Services (NRCS 2013) of the USDA lists plant materials that have been released for conservation uses, such as habitat restoration. These plant materials would be readily accessible for climate change adaptation strategy, but further

investigation should be pursued to determine if a given cultivar or germplasm will exhibit resilience to climate change in northwestern Indiana or the region of restoration. For *S. novae-angliae*, the Central Iowa Germplasm (2002), Northern Iowa Germplasm (2002), Southern Iowa Germplasm (2002) are all available for conservation.

Tradescantia ohiensis

Distribution

Tradescantia ohiensis (bluejacket, *Commelinaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found throughout the eastern half of North America. There are no subspecies of *T. ohiensis.* It is widespread in Indiana and fairly widespread in the southern U.S. The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

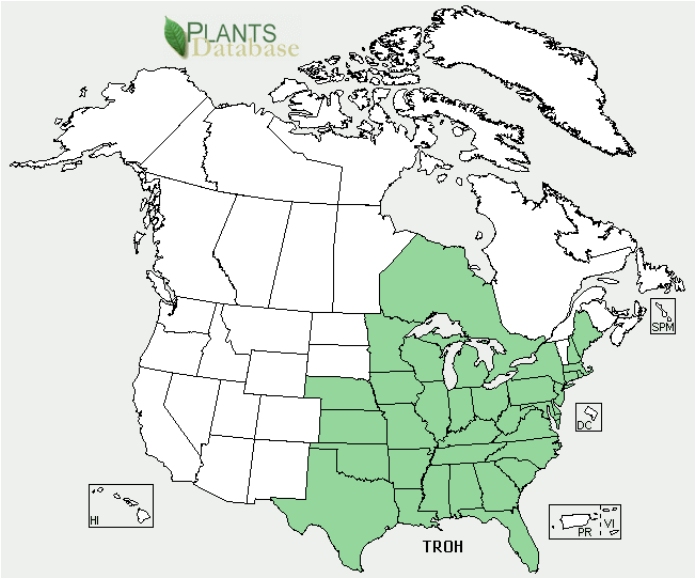

Photo by Ted Bodner @ USDA-NRCS
PLANTS Database in Miller and Miller. (2005)

Life history

T. ohiensis is a perennial plant that reproduces by seed and root division (USDA 2013). Seeds can spread aggressively (USDA 2013). Information on genetic diversity and seed bank duration is lacking and would be useful in directing climate change adaptation strategies, so should be investigated.

Environmental Tolerance and Climate Change Research

T. ohiensis utilizes low to medium moisture soils (Missouri Botanical Garden 2013). *T. ohiensis* is drought tolerant (Missouri Botanical Garden 2013). *T. ohiensis* can tolerate moist soil (Missouri Botanical Garden 2013) so might be able to tolerate some flooding from the projected increase in large storm events, but this has not been confirmed experimentally. Unfortunately, little is known about the actual tolerance of *T. ohiensis* to projected climate conditions.

A mismatch between flowering phenology and pollinator emergence may result due to climate change. Rafferty and Ives (2012) found that fruit set in *T. ohiensis* varied with flowering time and explored how taxonomic composition of pollinators impacted pollination

effectivenessThe effectiveness of pollinators was reduced when buds flowered before or after historical flowering times. The differences in pollinator effectiveness for different flowering times in *T. ohiensis* were driven by the combination of composition changes in pollinator taxa and increases over time of effectiveness of some pollinator taxa. These mismatches in pollinators and flowering phenology may negatively impact *T. ohiensis* and other plants.

The climate change models for *T. ohiensis* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Illinois, Indiana, and Ohio range will shift into the western Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *T. ohiensis*. This model is specific to Canada and states bordering Canada.

Verbena stricta

Distribution

Verbena stricta (hoary verbena, *Verbenaceae*) is a native herbaceous plant found in mesic prairies (USDA 2013). It is found throughout most of North America, except for California, Oregon, Florida, Louisiana, Virginia, South Carolina, and New England. There are no subspecies of *V. stricta.* It is widespread in Indiana and fairly widespread in the southern U.S. According to USDA, *S. nutans* is known to exhibit weedy growth in some areas of the U.S (USDA 2013). The broad climatic tolerance could provide southern genotypes that might be tolerant to projected climate change by the end of the century for northwestern Indiana.

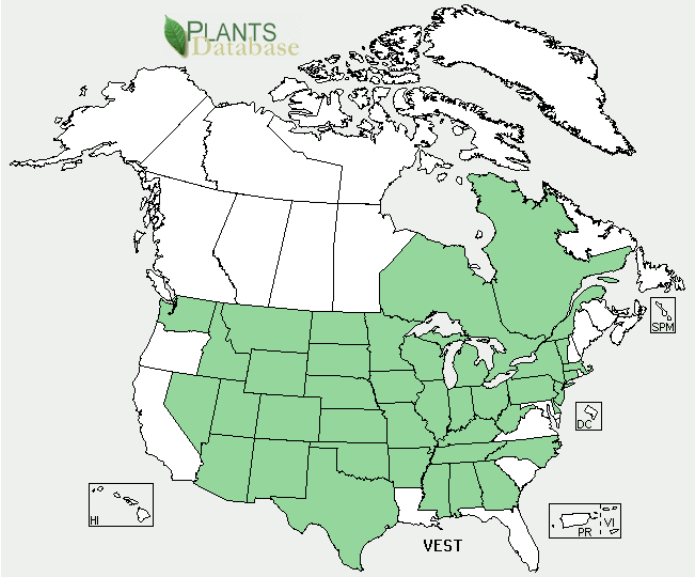

Photo by Jennifer Anderson @
USDA-NRCS PLANTS Database

Life history

V. stricta is an annual plant that reproduces by seeds (USDA 2013). The 50th percentile of seeds measured for the distance traveled by wind traveled a distance of 0.54 m (Platt and Weiss 1977). *V. stricta* is a generalist species and it is not known to need any special mutualisms for survival. Information on genetic diversity and seed bank duration is currently lacking, but should be investigated for purposes of climate adaptation strategies.

Environmental Tolerance and Climate Change Research

V. stricta utilizes low to medium moisture soils (Missouri Botanical Garden 2013). *V. stricta* is drought tolerant (Missouri Botanical Garden 2013). *V. stricta* also likes disturbed habitat so may be resilient to disturbances such a fire or drought (Illinois Wild Flowers 2012). Little is known about the actual tolerance of *V. stricta* to projected climate conditions at the end of the century, but this information is necessary if *V. stricta* is to be used in climate change adaptation strategies.

The climate change models for *V. stricta* developed by the Plant Hardiness of Canada (NRCan 2013) for an A2 emission scenario predicted that between 2071-2100 the Illinois, Indiana, and Ohio range will shift into the Upper Peninsula of Michigan. This does not predict that this plant species will be found in northwest Indiana, and the model does not include the southern distribution of *V. stricta*. This model is specific to Canada and states bordering Canada.

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