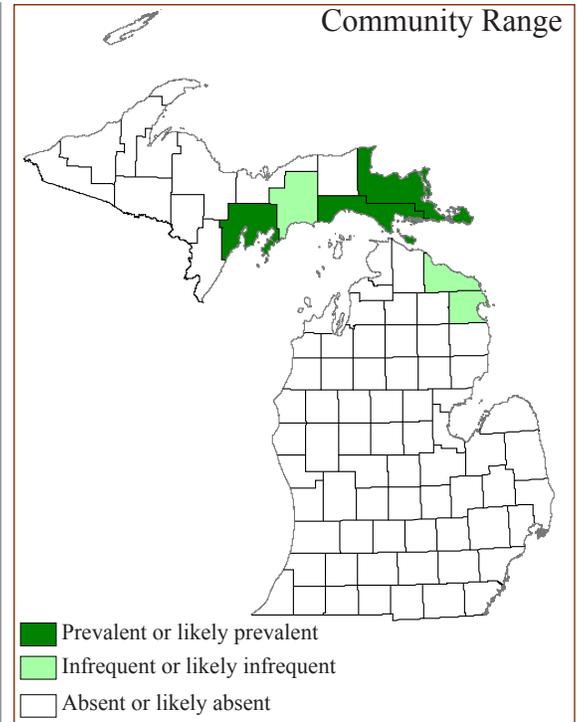




Photo by Michael A. Kost



Global and State Rank: G2G4/S2

Overview: Limestone bedrock glade is a biologically distinct geological feature and natural community associated with limestone and dolomite bedrock occurring along the Laurentian Great Lakes, often in mosaics with other limestone bedrock communities, including alvar, and sharing the distinctive Great Lakes flora and fauna found on alvar (Catling and Brownell 1995, 1999). Limestone bedrock glade consists of an herb and graminoid dominated plant community with scattered clumps of stunted trees and shrubs growing on thin soil over limestone or dolomite. Tree cover is typically 10 to 25 percent, but occasionally as high as 60 percent. Shrub and herb cover is variable and there are typically areas of exposed bedrock.

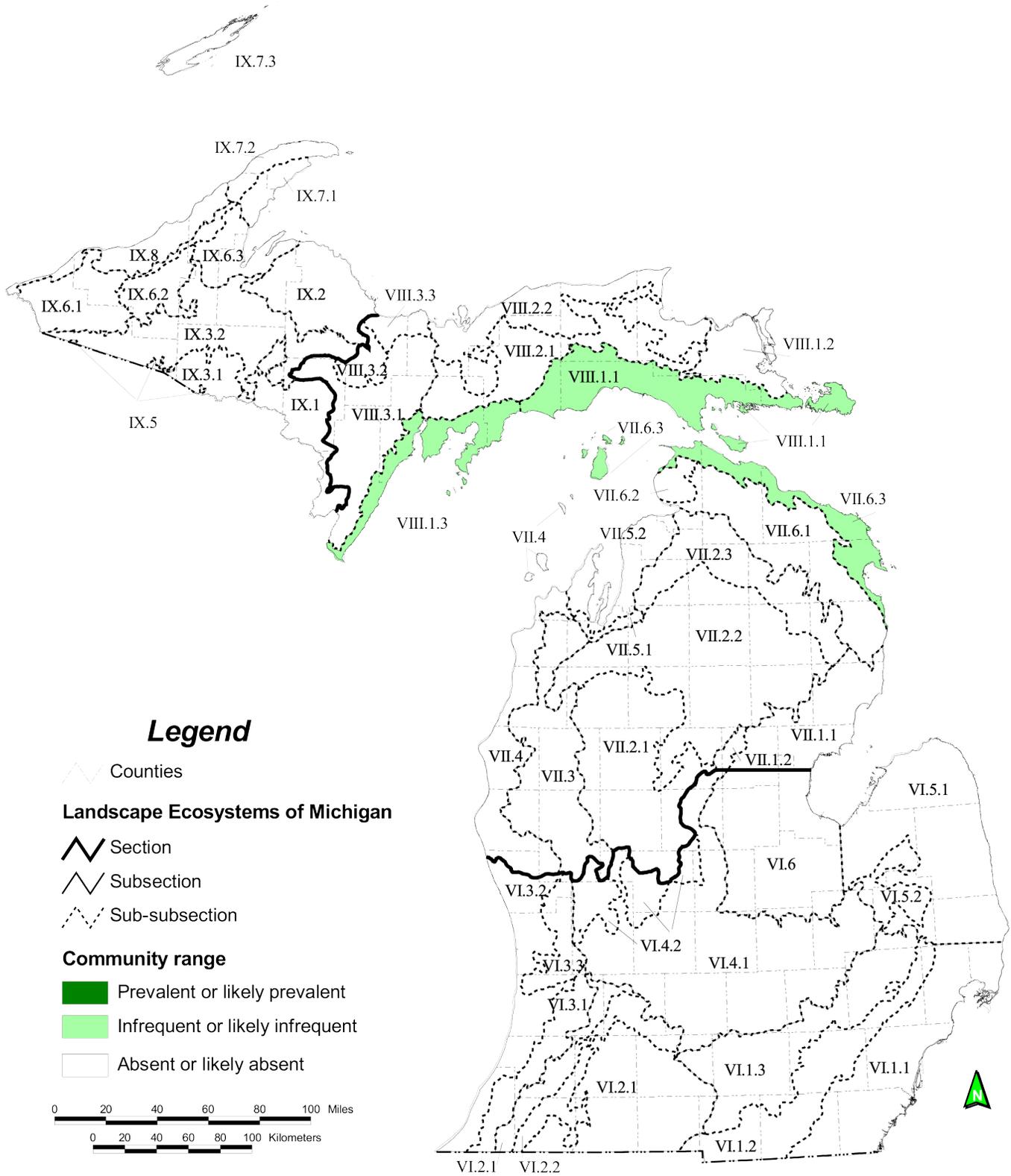
Common Names: Limestone Bedrock Glade (Alvar Glade). As identified by an international alvar working group, the plant communities within this classification include juniper alvar shrubland, scrub conifer / dwarf lake iris alvar shrubland, white cedar - jack pine / shrubby cinquefoil alvar savanna, and mixed conifer / common juniper alvar woodland (Reschke et al. 1999). The term limestone glade will be used in the remainder of the abstract.

Range: Limestone glade is associated with Silurian, Ordovician, and Devonian limestone and dolomite bedrock occurring along the Niagaran Escarpment and

Cuesta of the Laurentian Great Lakes. Great Lakes limestone glades occur in Michigan, New York, Ohio, Wisconsin, and the Canadian province of Ontario (Reschke 1990, Lee et al. 1998a, Reschke et al. 1999, Brownell and Riley 2000, Judziewicz 2001). It should be clarified that the term limestone glade has been used in the southern United State to describe the open, herbaceous-dominated portions of bedrock sites, most of which also contain scattered shrubs and trees, but their overall species composition differs substantially from the more northern alvar glade communities discussed in this abstract. Southern glades are typically dominated by red cedar (*Juniperus virginiana*). Open pine glades dominated by Scotch pine (*Pinus sylvestris*) also occur on the islands of Oeland and Gotland in southern Sweden (Pettersson 1965). In Michigan, limestone glade occurs in the Upper Peninsula near the shorelines of Lakes Huron and Michigan, concentrated in a band from Drummond Island to Cedarville and from Gould City to the Garden Peninsula. In the Northern Lower Peninsula, limestone glade occurs along the Lake Huron shoreline near Rogers City, Alpena, and Thompson's Harbor.

Rank Justification: The international alvar project documented approximately 5,880 hectares (14,522 acres) of limestone glade across the Great Lakes basin (Reschke et al. 1999). Parts of this habitat have been substantially degraded by agriculture and other forms of human land





Ecoregional map of Michigan (Albert 1995) depicting distribution of limestone bedrock glade (Albert et al. 2008)



use. There are approximately 660 hectares (1,625 acres) of limestone glade at 17 sites along Michigan's Great Lakes shoreline, including areas on Lakes Michigan and Huron (Lee et al. 1998b). There are 35 limestone glade sites in Ontario on Manitoulin Island and the Bruce Peninsula of Lake Huron, Georgian Bay, and the Lake Erie Islands of Lake Erie (Brownell and Riley 2000). In addition, there are nine New York sites, one Ohio site, and one Wisconsin site (Reschke et al. 1999).

Landscape Context: In Michigan, limestone glades are located within sub-subsections VII.6.3, VIII.1.1, and VIII.1.3 of the Regional Landscape Ecosystems as delineated by Albert (1995). In these regions, proximity to the Great Lakes results in moderated climate and high precipitation. The soils and substrate are neutral to slightly alkaline (pH 6.7-8.0). Limestone glades are commonly found along northern Great Lakes shores where flat bedrock pavement associated with the Niagaran Escarpment is exposed (Albert et al. 1997). The bedrock of the Niagaran Series is Silurian-age limestone formed from marine reefs that were common in shallow portions of the Michigan Basin (Dorr and Eschman 1970, Ehlers 1973, Reed and Daniels 1987). Much of the limestone along the Niagaran Escarpment has been converted through geological processes to dolomite (also called dolostone), a magnesium-rich form of limestone. These marine limestones typically dip gently (average 1% slope) toward the south into the Michigan Basin, but there are a few areas of limestone cliff as well.

Ordovician-age limestone also supports glade on northern Drummond Island, while glades on Devonian-age limestone occurs in Presque Isle and Alpena Counties in Lower Michigan. Being formed from marine organisms, these rocks are rich in calcium carbonates. Resistance to erosion is variable; limestone and dolomite are readily dissolved by rain water, producing solution cracks that often connect to the underlying groundwater system. In contrast, those limestones rich in sand, silt, or clay impurities from terrestrial sources are more resistant to solution and typically contain few broad cracks (also referred to as grykes).

Low ridges of limestone or dolomite cobble, typically 1-2 m high, occasionally occur on the glades. These cobble ridges were deposited by ice scour and major storm events during earlier post-glacial times, when

present-day inland sites were inundated by higher Great Lakes lake levels. Limestone glades of northern white-cedar (*Thuja occidentalis*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), and paper birch (*Betula papyrifera*) occur where there is deeper soil development or better drainage than on nearby alvar. Both thin soils and poor drainage result in greater dominance of herbaceous vegetation.



Photo by Michael A. Kost

Limestone glade occurs on thin neutral to alkaline soils overlying limestone bedrock. Shallow soils result in seasonal flooding in flat portions of glade from fall to spring and in drought stress during summer months.

Natural Processes: Most glades suffer summer drought or water stress in July and August (Reschke et al. 1999). Surface temperatures can reach 43 to 53 °C (109 to 127 °F) on exposed bedrock within the glades (Schaefer and Larson 1997). Stephenson and Herendeen (1986) hypothesized that many of the dead trees on the Drummond Island glades died due to moisture stress or increased susceptibility to insect or other pathogens as a result of moisture stress. They also observed that creeping juniper (*Juniperus horizontalis*) suffered heavy mortality during drought. However, they also noted that immediately following this short-term drought, white spruce produced a heavy seed crop, which might result in increased tree dominance in the future. In Michigan, carpenter ants (*Camponotus* spp.) create extensive galleries in the boles of both trembling aspen and balsam fir in the glades, sometimes resulting in tree mortality and subsequent breakage of the trunk. Wind-thrown trees occur on limestone glades because of shallow soil and resultant shallow rooting of plants (Kost et al. 2007).



A combination of thin soils and flat topography can result in seasonal flooding from fall through spring in flat, wetter portions of the glade, but wet conditions do not characterize all limestone glades. Wet portions of the glade are open, typically consisting of exposed rock, mosses, algae, lichens, and herbaceous plants. Seasonal flooding is less prevalent where there are abundant cracks in the rock, which provide improved internal drainage. However, sites with internal drainage are more prone to early desiccation and drought. Fire, both natural and human-induced, has been documented for Great Lakes limestone glade in both the United States and Canada (Catling and Brownell 1998, Jones and Reschke 2005), but the fire-regime is believed to be quite variable and fire is not considered important for maintaining biological diversity (Reschke et al. 1999, Schaefer and Larson 1997). Jones and Reschke (2005) concluded that fire reduces biomass within glades, but that fire is an incidental event rather than being either necessary for creation or maintenance of glades. Controlled burns can increase plant diversity (Catlin and Brownell 1998), while wildfires can sometimes greatly reduce diversity.

Grazing by native ungulates is important for reducing woody encroachment and lack of grazing can result in cool-season Eurasian grasses replacing native grassland dominants (Reschke et al. 1999). Browsing by white-tailed deer (*Odocoileus virginianus*) is strongly evident at many glade sites, with grazing heavy on northern white-cedar, balsam fir, and trembling aspen (*Populus tremuloides*). There may also be competition between grasses and trees that maintains the relatively sharp boundary that often occurs between these two vegetation groups (Jones and Reschke 2005).

Vegetation Description: Limestone bedrock glade consists of an herb and graminoid dominated plant community with scattered clumps of stunted trees and shrubs. Tree cover typically ranges between 10 and 25%, with maximum tree cover of 60%. Shrub cover is typically greater than 25%. Shrubs and trees grow where the soil depth is greatest or where cracks or grykes provide additional moisture needed by woody vegetation (Albert et al. 1997, Reschke et al. 1999). Open portions of the glade, characterized by shallow soils, tend to support greater concentrations of herbs, lichens, and mosses. *Nostoc* and other algae are often concentrated in small, seasonally wet depressions in the rock. Based on Michigan plot data, perennial herbs make up 36% of the flora,

followed by 20% shrubs and 17% trees. Six percent of the flora is perennial grasses, 5% perennial sedges, and 3% ferns. Dominant trees include northern white cedar (*Thuja occidentalis*), white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*). Tree height is typically less than 20 feet (6 m). Common shrubs include soapberry (*Shepherdia canadensis*) and bearberry (*Arctostaphylos uva-ursi*). Common herbs are Canada mayflower (*Maianthemum canadense*), wild strawberry (*Fragaria virginiana*), balsam ragwort (*Senecio pauperculus*), and large-leaved aster (*Aster macrophyllus*). Poverty grass (*Danthonia spicata*), slender wheat grass (*Agropyron trachycalum*), and bracken fern (*Pteridium aquilinum*) are also common. Common non-native herbs are ox-eye daisy (*Chrysanthemum leucanthemum*) and lawn prunella (*Prunella vulgaris*).

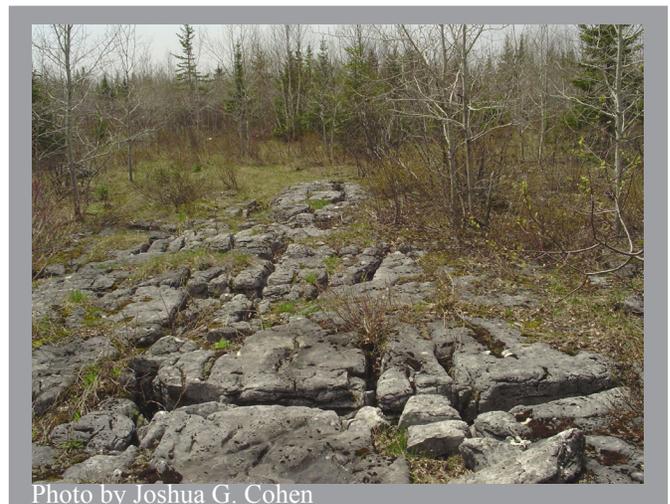


Photo by Joshua G. Cohen

Carbonic and organic acids from decomposing vegetation and plant respiration accelerate the rate of dissolution in the structural joints of the limestone bedrock, creating broad cracks called grykes. These cracks in the limestone allow for soil accumulation and the establishment of trees and shrubs.

Characteristic Plants: Other characteristic trees are trembling aspen (*Populus tremuloides*) and balsam poplar (*P. balsamifera*). Characteristic shrubs include choke cherry (*Prunus virginiana*), snowberry (*Symphoricarpos albus*), red osier dogwood (*Cornus stolonifera*), common juniper (*Juniperus communis*), alder-leaved buckthorn (*Rhamnus alnifolia*), and bush honeysuckle (*Diervilla lonicera*). Other herbs include small yellow lady's-slipper (*Cypripedium calceolus* var. *parviflorum*), yarrow (*Achillea millefolium*), columbine (*Aquilegia canadensis*), dwarf lake iris (*Iris lacustris*), wood lily (*Lilium philadelphicum*), northern bog violet





Limestone bedrock glade consists of an herb- and graminoid-dominated plant community with scattered clumps of stunted trees and shrubs growing on thin soil over limestone or dolomite. Photos by Joshua G. Cohen.



(*Viola nephrophylla*), smooth aster (*Aster laevis*), harebell (*Campanula rotundifolia*), Indian paintbrush (*Castilleja coccinea*), and cow wheat (*Melampyrum lineare*). Characteristic grasses and sedges include rough-leaved rice grass (*Oryzopsis asperifolia*), the introduced Canada bluegrass (*Poa compressa*), ebony sedge (*Carex eburnea*), and Richardson's sedge (*Carex richardsonii*). The Great Lakes alvar initiative identified common mosses to include *Tortella* spp. and *Schistidium* spp. and common lichens to include *Cladonia rangifera* and *Peltigera canina* (Reschke et al. 1999). Most of the exposed bedrock also had an alga, *Gloeocapsa alpina*, growing at its surface.

Associated Species: Limestone bedrock glades support many of the same species found on limestone bedrock lakeshores and alvars. Most of the species in Michigan's limestone glades have a northern distribution, but a small number of species have western or prairie affinities or are found on limestone or dolomite glades in the southern U.S., including Missouri, Tennessee, Kentucky, and Alabama (Quarterman et al. 1993, Baskin et al. 1995, Catling and Brownell 1995, Heikens 1999). Among the most widespread species are those typical of upland grasslands, including little bluestem and poverty grass.

Invasive Plants: Invasive plant species are common at many limestone glade sites, and almost half of the non-natives were also found growing on alvars in the U.S. and Canadian sites (Reschke et al. 1999). Two non-natives, ox-eye daisy (*Chrysanthemum leucanthemum*) and lawn prunella (*Prunella vulgaris*) grew on greater than 75% of the sampling sites, while the following were found on less than half of the sites: Canada bluegrass (*Poa compressa*), St. John's-wort (*Hypericum perforatum*), common mullein (*Verbascum thapsus*), orange hawkweed (*Hieracium aurantiacum*), wild carrot (*Daucus carota*), redtop (*Agrostis gigantea*), thyme-leaved sandwort (*Arenaria serpyllifolia*), common barberry (*Berberis vulgaris*), spotted knapweed (*Centaurea maculosa*), marsh thistle (*Cirsium palustre*), common buttercup (*Ranunculus acris*), common dandelion (*Taraxacum officinale*), and red clover (*Trifolium pratense*).

Michigan Indicator Species: Northern white cedar (*Thuja occidentalis*), white spruce (*Picea glauca*), paper birch (*Betula papyrifera*), balsam fir (*Abies balsamea*), soapberry (*Shepherdia canadensis*), bearberry (*Arctostaphylos uva-ursi*), mayflower (*Maianthemum*

canadense), wild strawberry (*Fragaria virginiana*), large-leaved aster (*Aster macrophyllus*), poverty grass (*Danthonia spicata*), slender wheat grass (*Agropyron trachycaulum*), bracken fern (*Pteridium aquilinum*), balsam ragwort (*Senecio pauperculus*), trembling aspen (*Populus tremuloides*), balsam poplar (*P. balsamifera*), choke cherry (*Prunus virginiana*), snowberry (*Symphoricarpos albus*), red osier dogwood (*Cornus stolonifera*), common juniper (*Juniperus communis*), small yellow lady's-slipper (*Cypripedium calceolus* var. *parviflorum*), dwarf lake iris (*Iris lacustris*), harebell (*Campanula rotundifolia*), rough-leaved rice grass (*Oryzopsis asperifolia*), and ebony sedge (*Carex eburnea*).

Other Noteworthy Species: Several ant species (family *Formicidae*) occupy various habitats within the glade, nesting beneath rocks, in dead wood, and in live wood of the drought-stressed trees. The abundance of ants and other insects attracts black bears (*Ursus americanus*), which are extremely common in some areas of limestone bedrock. The lime-rich habitat is home of many species of land snail as well, and the open grassland vegetation provides habitat for many prairie insects.

Special Animals associated with limestone glade in Michigan include Blanding's turtle (*Emydoidea blandingii*, state special concern), red-legged spittlebug (*Prosapia ignipectus*, state special concern), a leafhopper (*Flexamia delongi*, state special concern), and several land snails including *Vallonia gracilicosta albula* (state endangered), tapered vertigo (*Vertigo elatior*, state special concern), Hubricht's vertigo (*Vertigo hubrichti*, state endangered), deep-throat vertigo (*V. nylanderi*, state endangered), crested vertigo (*V. pygmaea*, state special concern), and *V. paradoxa* (state special concern).

Special Plants include Cooper's milk vetch (*Astragalus neglectus*, state special concern), calypso (*Calypso bulbosa*, state threatened), Richardson's sedge (*Carex richardsonii*, state special concern), bulrush sedge (*C. scirpoidea*, state threatened), shortstalk chickweed (*Cerastium velutinum*, state threatened), field chickweed (*C. velutinum*, presumed extirpated from Michigan), Hill's thistle (*Cirsium hillii*, state special concern), ram's-head lady's-slipper (*Cypripedium arietinum*, state special concern), Tennessee bladder fern (*Cystopteris tennesseensis*, state threatened), dwarf lake iris (*Iris lacustris*, state and federally threatened), Philadelphia



panic-grass (*Panicum philadelphicum*, state threatened), Alaska orchid (*Piperia unalascensis*, state special concern), and small skullcap (*Scutellaria parvula*, state threatened).

Conservation and Biodiversity Management: The principle threats to limestone glade are over-grazing, alteration of hydrology from road construction and off-road vehicle use, construction of summer residences within the open grassland, dumping of waste materials, and quarry development (Reschke et al. 1999). All of these disturbances provide pathways for the introduction or spread of invasive, non-native plant species. While encroachment of non-native plants is a concern, it appears that the majority of invasive shrubs have a more southern distribution than the range of Michigan's limestone glades (based on Catling and Brownell 1995).

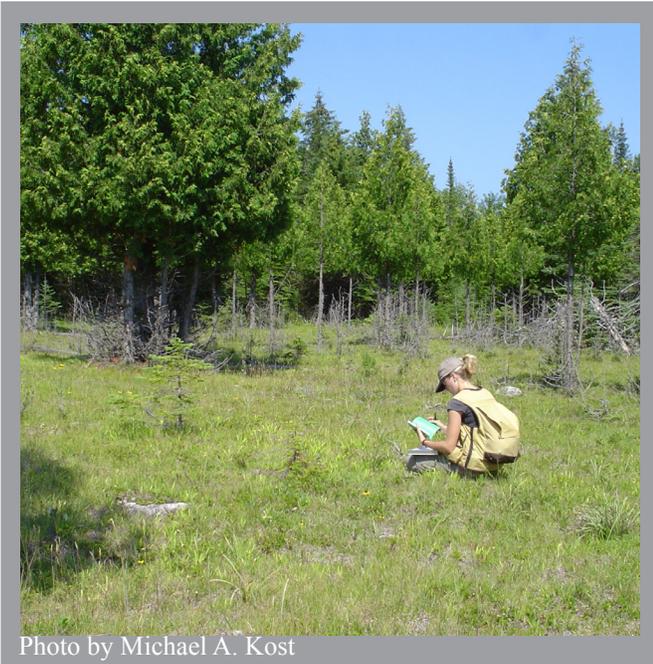


Photo by Michael A. Kost

A distinct deer-browse line is evident on white cedar on limestone bedrock glade, Garden Peninsula, Delta County. Deer herbivory can limit cedar regeneration.

Given that the thin soils and slow-growing lichen and moss cover are sensitive to anthropogenic disturbance and recover slowly, conservation efforts should focus on preserving the existing ecological integrity of glades. Prescribed burns may provide a useful management tool to maintain open conditions and increase herbaceous plant diversity, yet the response of this plant community to fire has not been well documented. The prevalence of charcoal at many glade sites indicates that fire was

relatively common in the past, and most of the common plant species are fire tolerant (Jones and Reschke 2005).

Research Needs: Additional characterization of non-vascular plants and insects is needed, as well as more detailed research on the structure and tree age within limestone glades. Further inventory is needed to identify remaining limestone bedrock glades. Research aimed at restoration and biodiversity management of limestone glades is needed. A better understanding of the historic and current roles of deer and other ungulates in structuring the community and maintaining open conditions will help inform management and protection efforts. Documenting response of the community to fire will also help inform management efforts.

Similar Communities: In Michigan similar communities include alvar (Reschke et al. 1999, Albert 2006), limestone bedrock lakeshore (Comer et al. 1997), non-acid cliff, limestone cobble shore, limestone lakeshore cliff, boreal forest (Cohen 2007), and Northern White-cedar Limestone Bedrock Woodland, whose canopy cover can reach 90% (Faber-Langendoen 2001). Elsewhere in U.S.: Limestone Bluffs Cedar-Pine Forest in Vermont (Sorenson and Popp 2006), Ozark dolomite glade (Erickson et al. 1942, Heikens 1999), and Southeastern U.S. cedar glade (Baskin and Baskin 1985, 1999, Quarterman et al. 1993).

Other Classifications:

Michigan Natural Features Inventory (MNFI) Circa 1800 Vegetation (MNFI): 74, exposed bedrock.

Michigan Department of Natural Resources (MDNR): K, rock

Michigan Resource Information Systems (MIRIS): 74, exposed rock.

National Wetland Inventory (NWI): none.

The Nature Conservancy National Vegetation Classification: (Faber-Langendoen 2001, NatureServe 2006): CODE; ALLIANCE; ASSOCIATION; COMMON NAME

II. A.4.N.b; *Thuja occidentalis* Woodland Alliance; *Pinus banksiana* - *Thuja occidentalis* - *Picea glauca* / *Juniperus communis* Woodland; Jack Pine - Northern White-cedar - White Spruce / Common Juniper Woodland; Mixed Conifer / Common Juniper Alvar Woodland



III.A.3.N.a; *Juniperus communis* Shrubland Alliance; *Picea glauca* - *Thuja occidentalis* - *Juniperus communis* / *Iris lacustris* - *Carex eburnea* Shrubland; White Spruce - Northern White-cedar - Common Juniper / Dwarf Lake Iris - Bristleleaf Sedge Shrubland; Scrub Conifer / Dwarf Lake Iris Alvar Shrubland

V.A.6.N.f; *Thuja occidentalis* Wooded Herbaceous Alliance; *Thuja occidentalis* - *Pinus banksiana* / *Dasiphora fruticosa* ssp. *floribunda* / *Clinopodium arkansanum* Wooded Herbaceous Vegetation; Northern White-cedar - Jack Pine / Shrubby-cinquefoil / Low Calamint Wooded Herbaceous Vegetation; White-cedar - Jack Pine / Shrubby-cinquefoil Alvar Savanna

Related Abstracts: alvar, boreal forest, limestone bedrock glade, limestone cobble shore, Calypso, Richardson's sedge, Hill's thistle, ram's-head lady's-slipper, dwarf lake iris, Blanding's turtle, red-legged spittlebug.

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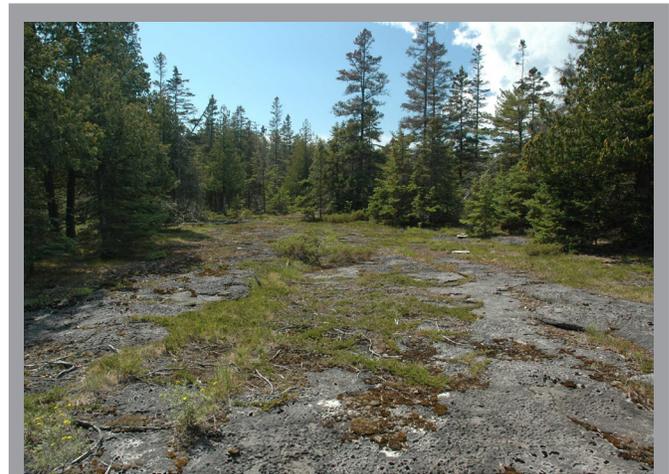


Photo by Dennis A. Albert

Alvar grassland grades to limestone bedrock glade on Drummond Island.

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