Dwarf Lake Iris Recovery and Population Monitoring – Addendum 2022

Prepared By:
Rachel Hackett, Amanda Klain, Jodi Spieles, Lynn Kirkpatrick, William MacKinnon, Phyllis Higman
Michigan Natural Features Inventory
Michigan State University Extension
P.O. Box 13036
Lansing, MI 48901

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Cover: Flowering dwarf lake iris (*Iris lacustris*) and population monitoring quadrat in Emmet County, Michigan (EO ID 7130) on June 8, 2020. Photograph by Rachel Hackett.

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Abstract

Dwarf lake iris (*Iris lacustris* Nutt.) is a perennial iris endemic to the Great Lakes region with its greatest stronghold in Michigan. The species is listed as threatened throughout its range under the Federal Endangered Species Act, and by every state or province where it occurs. Greatest threats to dwarf lake iris include habitat destruction, habitat degradation, succession, sand dune erosion, invasive species, and effects of climate change.

Count-based population analysis conducted in Hackett et al. (2021) was updated with data gathered during the 2022 field season. There were now 50 population change increments across 16 [sub]populations, allowing us to reliably project 5 to 10 years in the future. The new mean instantaneous stochastic growth rate (μ) and variance (σ^2) were -0.0625 and 0.381, respectively. On average, DLI populations are decreasing but there is significant variance in that growth rate: some populations or some years a population are increasing.

Based on the new mean instantaneous stochastic growth rate, variance, and most recent population estimates, a 36.5% probability of population extinction across dwarf lake iris populations in 10 years was predicted; 67.8% in 50 years. The persisting populations represent geographic diversity and with some exceptions, natural community and genetic diversity. Wisconsin populations were under-represented in the persisting populations of DLI which poses a lack in genetic representation, but this could change when more recent population estimates are incorporated.

Efforts should be made to continue documenting the status of remaining DLI populations to better predict its persistence and reduce the variance of the growth rate. More population data can also allow for more robust analyses that can include more variables than population number alone.

Introduction

Dwarf lake iris (*Iris lacustris* Nutt.; henceforth DLI) is a perennial iris endemic to the northern shores and few inland areas of Lake Michigan and Lake Huron of the Great Lakes of North America. The species is listed as threatened at the federal and state level in the USA and as special concern in Canada and Ontario. Greatest threats to DLI include habitat destruction, habitat degradation, succession, sand dune erosion, invasive species, and effects of climate change (e.g., extreme drought, variable Great Lake water levels; U S Fish and Wildlife Service, 2013).

Figure 1. The rare white flower variety grows alongside the typical blue flower of dwarf lake iris (*Iris lacustris*) at EO 10381, Emmet County, Michigan, on May 22, 2019. Photograph by Rachel Hackett.

Population viability analysis (PVA) was a step in the US Fish and Wildlife Service recovery plan (2013). A count-based analysis requires population census data for at least 10 years to predict long-term species viability. DLI fits most assumptions of a count-based approach to PVA for plants: no extreme fluctuations in population size, are easily identified, can have population turnovers between 10-20 years (e.g., not long-lived trees), whose population growth is not density dependent, are not self-compatible, have infrequent sexual reproduction, have low genetic variation within populations, and lack of large dormant seed banks (Dennis et al., 1991; Morris et al., 1999; Brigham and Thomson, 2003).

Our efforts for the addendum focused on 1) updating the count-based population viability analysis with data collected since the last report was submitted (Hackett et al., 2021) and 2) given estimates of dwarf lake iris populations across its range, to extrapolate the viability of the populations to the viability of the species as a whole.

Study areas

Natural Heritage Databases in Michigan, USA; Wisconsin, USA; and Ontario, CA; have 170 element occurrence (EO) records of DLI (U S Fish and Wildlife Service, 2013; Michigan Natural Features Inventory, 2022; Figure 2). The records stretch west to east from Door County, Wisconsin, USA near the shores of Lakes Michigan and Huron through the Straits of Mackinac to Bruce Peninsula and County of Ontario, CA. The populations estimates used to extrapolate the viability the species were collected from Natural Heritage Database Sources in all three states/provinces (COSEWIC, 2010; U S Fish and Wildlife Service, 2013; Michigan Natural Features Inventory, 2022). The State of Wisconsin has more recent populations estimates (2017, *personal communication Kevin Doyle*), but that information was not available at the time of this report. The recently added count-based population data was collected from eight DLI EO records in Michigan, USA (Table 1; Figure 3).

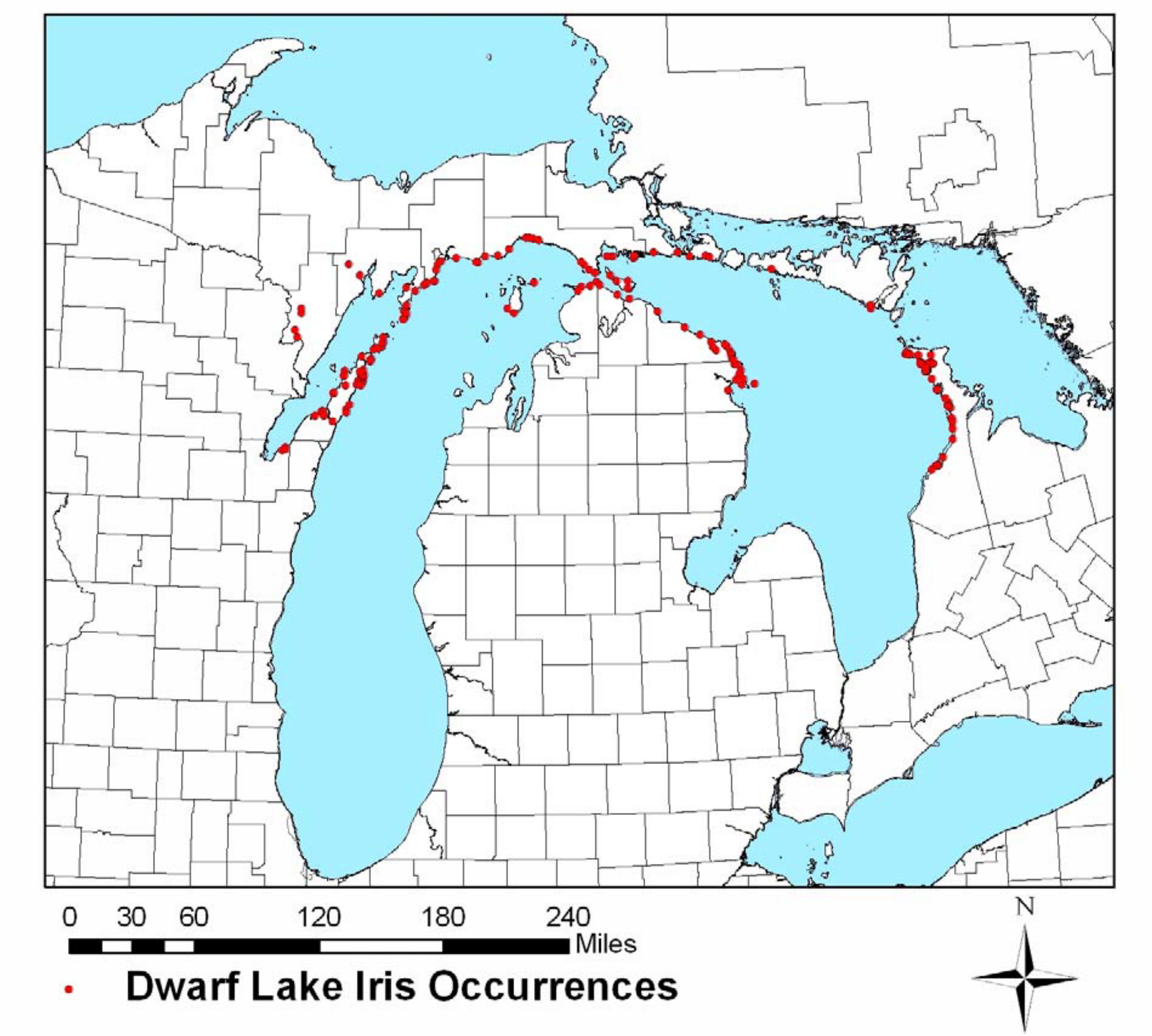

Figure 2. Global distribution of dwarf lake iris (Iris lacustris) from USFWS Dwarf Lake Iris (*Iris lacustris*): Recovery Plan (2013).

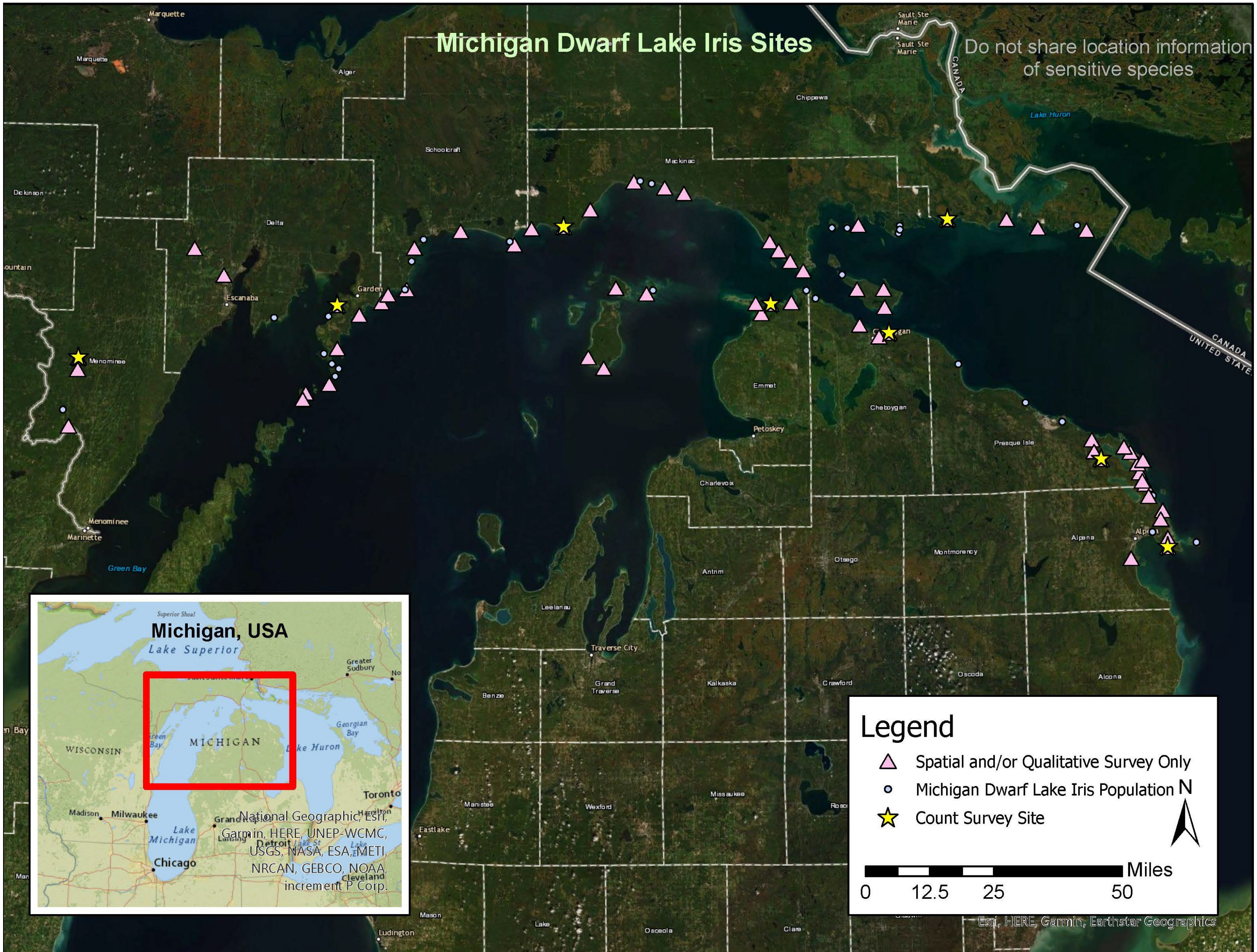

Figure 3. Map of dwarf lake iris (*Iris lacustris* Nutt.) Element Occurrence (EO) records in Michigan, USA(Michigan Natural Features Inventory, 2022). Sites visited from 2019 to 2022 are marked to represent the type of survey conducted: pink triangle - spatial and/or qualitative habitat survey only; yellow star - count survey.

Table 1. List of dwarf lake iris (*Iris lacustris* Nutt.) Element Occurrence (EO) records (Michigan Natural Features Inventory, 2022). EO ID is a unique identifier for each EO record in Michigan's Natural Heritage Database. Rank is a qualitative assessment of estimated viability of species described in Table 2. A record was considered inland if it was greater than 1000 m from a Great Lake coast and appeared to be on post-glacial Lake Nipissing coast. Natural community abbreviations and descriptions can be found in Table 3. Surveys conducted from 2019 to 2022 were marked with a S for spatial survey, Q for qualitative survey, Q_{AS} for qualitative in archeologically sensitive site (i.e., no ground disturbance permitted), C for count survey, and D for demographic sampling. Changes in rank and last observation date due to recent surveys are noted via a strikethrough and listing of new value. Bolded records are categorized as high priority records.

Site	EO ID	Rank	County	Inland or Shore	Natural Communities	Ownership	Last Observation Date	2019-2022 Surveys
[redacted][1]	**256**	**A**	**Alpena**	**Shore**	**BFT, CFN, LBG, RCS**	**P, S**	**~~2010-08-10~~ 2021-05-26**	**S, Q**
[redacted]	**8385**	**~~BC~~ B**	**Alpena**	**Shore**	**BFT, RCS, LBG**	**P**	**~~1981-06-02~~ 2022-06-09**	**S, Q**
[redacted]	2837	~~A~~ F	Alpena	Shore	NFN	P, S	~~2002-05-07~~ 2020-06-11	Q
[redacted][1]	2440	AB	Alpena	Shore	WDS, BFT	N, P	~~1905-06-28~~ 2022-06-21	S, Q
[redacted]	3403	A	Alpena	Shore	WDS	N, P	~~1996-06-25~~ 2022-06-17	C
[redacted]	1625	C	Alpena	Shore	WDS	P, S	2002-08-08	
[redacted]	9817	CD	Alpena	Shore	LBS	F	1981-06-07	
[redacted]	6713	~~B~~ F	Alpena	Shore	RCS	P, S	~~2011-05-16~~ 2021-06-14	S, Q
[redacted]	**8775**	**B?**	**Alpena**	**Shore**	**CFN**	**P**	**2010-08-11**	
[redacted]	2472	~~BC~~ F	Charlevoix	Shore	OD	P	~~1999-08-19~~ 2019-06-25	Q
[redacted]	**1369**	**B**	**Charlevoix**	**Shore**	**BFT, CFN, SGB**	**P, S**	**~~1999-05-21~~ 2019-06-26**	**Q**
[redacted]	8033	C	Charlevoix	Shore	WDS	S	1999-08-19	
[redacted]	22194	~~E~~ D	Charlevoix	Shore	BFT	S	~~2000-07-16~~ 2019-06-27	S, Q
[redacted]	18917	CD	Charlevoix	Shore	LBG, RCS	S	~~2012-08-06~~ 2019-06-26	Q_{AS}
[redacted]	**8439**	**B**	**Cheboygan**	**Shore**	**CFN, GLB, WDS**	**N, S**	**~~1999-07-07~~ 2022-06-13**	**S, C**
[redacted][1]	10464	BC	Cheboygan	Shore	RCS	P	~~1996-08-20~~ 2021-06-16	S, Q
[redacted]	22657	~~E~~ D	Cheboygan	Shore	WDS	N	~~2018-07-19~~ 2022-06-10	S, Q
[redacted]	6907	B	Cheboygan	Shore	BFT, MNF, SGB	P, S	2018-06-20	

[1] Visited subset of area of EO record depending on landowner permissions granted.

Site	EO ID	Rank	County	Inland or Shore	Natural Communities	Ownership	Last Observation Date	2019-2022 Surveys
[redacted]	12375	~~E~~ F	Chippewa	Shore	CFN	P	~~1989-06-08~~ 2019-07-10	S, Q
[redacted]	743	~~E~~ F	Chippewa	Shore	CFN	P	~~1989-06-22~~ 2019-07-10	S, Q
[redacted]	10288	B	Chippewa	Shore	CFN, RCS	P	1998-08-28	
[redacted]	10263	~~C~~ F	Chippewa	Shore	BFT, LBG, LBL	P	~~1990-06-15~~ 2021-06-16	S, Q
[redacted]	4640	~~C~~ F	Delta	Inland	BFT, NFN	P	~~1990~~ 2019-06-19	Q
[redacted][1]	**5552**	**BC**	**Delta**	**Inland**	**ALV, RCS**	**P**	**~~1991-06-02~~ 2019-06-19**	**S, Q**
[redacted]	10711	X	Delta	Shore	LBL	S	1939-05-30	
[redacted]	**22191**	**E**	**Delta**	**Shore**	**ALV**	**P, S**	**1998-05-29**	
[redacted][1]	**2811**	**A**	**Delta**	**Shore**	**BFT, LBG, LBL**	**S**	**~~2004-06-02~~ 2022-06**	**S, Q_{AS}**
[redacted]	**5633**	**A**	**Delta**	**Shore**	**LBG, LBL**	**S**	**~~2008-09-08~~ 2019-06-19**	**Q**
[redacted]	11586	~~C~~ F	Delta	Shore	BFT, LBL	F	~~1996-06-15~~ 2021-07-28	
[redacted]	4466	BC	Delta	Shore	BFT, LBL, LCS	N	~~1981-07-08~~ 2022-06-14	S, C
[redacted]	23699	F	Delta	Shore	BFT, LCS	F, P	~~2014-06-22~~ 2021-06-03	S, Q
[redacted]	23701	~~E~~ D	Delta	Shore	BFT	F	~~2014-06-22~~ 2021-06-04	S, Q
[redacted]	11928	CD	Delta	Shore	BFT	S	1995-06-23	
[redacted]	3615	H	Delta	Shore	BFT, LBL	P	1968-05-30	
[redacted]	116	H	Delta	Shore	BFT, LBL	S	1968-06-01	
[redacted]	3132	C	Delta	Shore	BFT, WDS	F	2017-08	
[redacted]	7130	~~B~~ C	Emmet	Shore	LBL, LCS, WDS	S	~~2005-08-26~~ 2022-05-31	S, C, D
[redacted]	13051	CD	Emmet	Shore	WDS	P, S	1981-05-14	
[redacted]	**10381**	**C**	**Emmet**	**Shore**	**BFT**	**S**	**~~1991-05~~ 2019-06-17**	**S, Q**
[redacted][1]	3606	B	Emmet	Shore	LSC, WDS	M, P, S	~~2001-06-20~~ 2021-06-18	S, Q
[redacted]	11844	~~H~~ F	Emmet	Shore	CFN	S	~~1966-06-11~~ 2020-06-20	S, Q
[redacted]	**8964**	**A**	**Mackinac**	**Shore**	**BFT, LBG, LBL**	**N, P, S**	**~~2010-08-15~~ 2022-06-15**	**C**

Site	EO ID	Rank	County	Inland or Shore	Natural Communities	Ownership	Last Observation Date	2019-2022 Surveys
[redacted]	5954	B	Mackinac	Shore	WDS	S	~~2001-06-05~~ 2020-06-17	S, Q
[redacted]	15826	C	Mackinac	Shore	CFN,	P	1993-08-10	
[redacted]	12376	AB	Mackinac	Shore	WDS	P, S	~~2002-08-23~~ 2022-06-03	C, D
[redacted].	8201	C	Mackinac	Shore	BFT	P	2001-05-23	
[redacted]	12548	B	Mackinac	Shore	IDW, LBC	P	2001-08-23	
[redacted]	10153	C	Mackinac	Shore	BFT, CFN	S	~~2001-06-06~~ 2019-06-21	S, Q
[redacted]	835	~~C~~ B	Mackinac	Shore	BFT	S	~~2001-06-01~~ 2020-06-18	Q
[redacted]	1885	BC	Mackinac	Shore	BFT	P	1994-09	
[redacted]	**5377**	**AB**	**Mackinac**	**Shore**	**BFT, NFN**	**P**	**1999-06-11**	
[redacted][1]	8623	~~C~~ B	Mackinac	Shore	BFT	S	~~1991-05-31~~ 2020-06-17	S, Q
[redacted][1]	834	C	Mackinac	Shore	BFT, LBL, LCS	P	~~2001-06-04~~ 2021-06-11	Q
[redacted]	8202	C	Mackinac	Shore	BFT	P	2001-06-04	Q
[redacted]	24196	E	Mackinac	Shore	RCS	S	2019-07-12	
[redacted]	12503	AB	Mackinac	Shore	BFT, NFN	P	1999-06-11	
[redacted]	4458	F	Mackinac	Shore	WDS	F	~~1991-09-10~~ 2021-06-10	Q
[redacted]	3635	BC	Mackinac	Shore	CFN, SGB	P	2011-06-08	
[redacted]	10154	BC	Mackinac	Shore	BFT, SGB	F	2008-06-19	
[redacted][1]	12862	A	Mackinac	Shore	BFT, WDS	N, P, S	~~1997-07-11~~ 2020-06-16	S, Q
[redacted]	15825	C	Mackinac	Shore	BFT, NFN	P	1993-08-12	
[redacted]	24245	~~E~~ C	Mackinac	Shore	CFN	F	~~2016-07-20~~ 2020-06-15	S, Q
[redacted][1]	**12221**	**AB**	**Mackinac**	**Shore**	**BFT, CFN, LCS**	**P, S**	**~~2002-07-24~~ 2020-06-19**	**S, Q**
[redacted][1]	12547	C	Mackinac	Shore	BFT	P	~~1993-09-15~~ 2020-06-12	Q
[redacted]	**15125**	**BC**	**Menominee**	**Inland**	**BFT, MNF**	**S**	**~~2005-05-20~~ 2022-06-04**	**S, C, D**
[redacted]	**16477**	**AB**	**Menominee**	**Inland**	**BFT, MNF**	**P**	**2005-05-26**	
[redacted][1]	**5149**	**BC**	**Menominee**	**Inland**	**MNF**	**P**	**~~2010-07-18~~ 2021-06-05**	**S, Q**
[redacted]	**15176**	**C**	**Menominee**	**Inland**	**MNF**	**S**	**~~2005-06-02~~ 2019-06-18**	**S, Q**
[redacted]	**2058**	**C**	**Presque Isle**	**Shore**	**ALV**	**P**	**2002-07-11**	

Site	EO ID	Rank	County	Inland or Shore	Natural Communities	Ownership	Last Observation Date	2019-2022 Surveys
[redacted][3]	2235	D	Presque Isle	Shore	BFT	P, S	~~1996-06-26~~ 2022-05-27	S, QAS
[redacted]	10481	C	Presque Isle	Shore	BFT, LCS, RCS	P	~~1989-07-13~~ 2019-05-28	S, Q
[redacted]	1854	C	Presque Isle	Shore	BFT	P	1981-06-26	
[redacted]	4553	C	Presque Isle	Shore	BFT	P	1996-06-28	
[redacted]	15944	B	Presque Isle	Shore	LBG	S	~~1996-06-15~~ 2020-06-30	Q
[redacted][1,2]	11321	B	Presque Isle	Shore	WDS	P	~~1998-06-10~~ 2019-05-31	S, Q
[redacted][3]	**5551**	**C**	**Presque Isle**	**Shore**	**CFN, WDS**	**S**	2022-05-27	**Q**
[redacted]	**8162**	**B**	**Presque Isle**	**Shore**	**LBG, BFT**	**P, S**	**~~1996-06-15~~ 2022-06-16**	**S, C**
[redacted][3]	**10080**	**A**	**Presque Isle**	**Shore**	**CFN, WDS**	**S**	**~~2002-05-07~~** 2022-05-27	**S, Q**
[redacted]	23795	C	Presque Isle	Shore	LBG, LCS	P	2019-05-28	S, Q
[redacted][1]	**10918**	**A**	**Presque Isle**	**Shore**	**BFT, LBG, NFN, WDS**	**P, S**	**~~2010-08-13~~ 2022-05-28**	**QAS**
[redacted][1,]	10888	B	Presque Isle	Shore	WDS	P	~~2016-06-23~~ 2021-06-16	S, Q
[redacted]	9196	C	Schoolcraft	Shore	BFT, LBL	P	2000-08-09	
[redacted]	6351	C	Schoolcraft	Shore	BFT, LCS, SGB	P	~~2017-08-06~~ 2021-06-03	S, Q
[redacted]	**12942**	**B**	**Schoolcraft**	**Shore**	**BFT, CFN, WDS**	**P**	**~~2000-08-09~~ 2021-06-04**	**S, Q**
[redacted]	4465	BC	Schoolcraft	Shore		P	~~1981-06-26~~ 2021-06-09	Q
[redacted]	1788	C	Schoolcraft	Shore	BFT, WDS	P	2000-08-08	
[redacted][1]	**3589**	**BC**	**Schoolcraft**	**Shore**	**BFT, LBG, LCS**	**P, S**	**~~2016-07-30~~ 2021-06-07**	**S, Q**
[redacted][1]	6809	B	Schoolcraft	Shore	BFT, LCS	P	~~2006-08-22~~ 2021-06-03	Q
[redacted]	8842	C	Schoolcraft	Shore	WDS	P	2000-08-08	
[redacted]	973	C?	Schoolcraft	Shore	BFT	P	2001-08-13	
[redacted][1]	8015	BC	Schoolcraft	Shore	WDS	P, S	~~1991-06-01~~ 2021-06-02	Q

[2] With new survey, Presque Isle Harbor (EO 11321) and Wreck Point (EO 10888) no longer have sufficient separation distance and will be combined.
[3] With new survey, Rockport North (EO 5551), Besser Natural Area South (EO 2235), and Stevenson's Fen (EO 10080) no longer have sufficient separation distance and will be combined.

Table 2. Definitions of basic EO Ranks for species as defined by NatureServe. Abridged table of that developed by NatureServe (2021).

Rank	Definition
A	**Excellent estimated viability** (species) - Based on current information on EO rank factors (i.e., condition, size, and landscape context) for the EO, it is believed to have an excellent probability of persisting, if current conditions prevail, for a defined period of time, typically 20-100 years.
B	**Good estimated viability** (species) - Based on current information on EO rank factors (i.e., condition, size, and landscape context) for the EO, it is believed to have a good probability of persisting, if current conditions prevail, for a defined period of time, typically 20-100 years.
C	**Fair estimated viability** (species) - Based on current information on EO rank factors (i.e., condition, size, and landscape context) for the EO, it is believed to have a fair probability of persisting, if current conditions prevail, for a defined period of time, typically 20-100 years.
D	**Poor estimated viability** (species) - Based on current information on EO rank factors (i.e., condition, size, and landscape context) for the EO, it is believed to have a poor probability of persisting, if current conditions prevail, for a defined period of time, typically 20-100 years.
E	**Verified Extant** (species) - EO has been recently verified as still existing, but sufficient information on the factors used to estimate viability of the occurrence has not yet been obtained. Use of the E rank should be reserved for those situations where the occurrence is thought to be extant, but an A, B, C, D, or range rank cannot be assigned.
H	**Historical** (species) - There is a lack of recent[4] field information verifying the continued existence of the E0, such as when the occurrence is based only on historical collections data, or when the occurrence was ranked A, B, C, D, or E at one time and is later, without field survey work, considered to be possibly extirpated due to general habitat loss or degradation of the environment in the area.
F	**Failed to find** - EO has not been found despite a search by an experienced observer at a time and under conditions appropriate for the Element at a location where it was previously reported, but that still might be confirmed to exist at that location with additional field survey efforts. For EOs with vague locational information, the search must include areas of appropriate habitat within the range of locational uncertainty. An F rank, when applicable, supersedes an A, B, C, D, E, or H rank.
X	**Extirpated** - There is documented destruction of the habitat or environment of the EO, or persuasive evidence of its eradication based on adequate survey (i.e., thorough or repeated survey efforts by one or more experienced observers at times and under conditions appropriate for the Element at that location).
U	**Unrankable** - An EO rank cannot be assigned due to lack of sufficient information on the occurrence.
NR	**Not Ranked** - An EO rank has not yet been assigned to the occurrence.

[4] The term *recent* is generally interpreted as follows: […] For plants or communities, there has been a field survey of the occurrence within the last 20 to 40 years. This higher maximum time limit is based upon the assumption that occurrences of these Elements generally have the potential to persist at a given location for longer periods of time due to plant biology and community dynamics. However, landscape factors must also be considered; thus, areas with more anthropogenic impacts on the environment will be at the lower end of the range, and less-impacted areas will be at the higher end. These time frames represent suggested maximum limits, however the actual time period for historical EOs may vary according to the biology of the Element and the specific landscape context of each occurrence (including anthropogenic alteration of the environment).

Table 3. Natural community types where Michigan DLI populations have been observed. Descriptions have been abridged from Cohen et al. (2015).

Abbr.	Natural Community	Description
ALV	Alvar	a grass- and sedge-dominated community, with scattered shrubs and sometimes trees. The community occurs on broad, flat expanses of calcareous bedrock covered by a thin veneer of mineral soil, often less than 25 cm.
BFT	Boreal forest	a conifer or conifer-hardwood forest occurring on moist to dry sites characterized by species dominant in the Canadian boreal forest. The community occurs primarily on sand dunes, glacial lakeplains, and thin soil over bedrock or cobble. Sand and sandy loam are moderately acid to neutral, but heavier soils and more acid conditions are common.
CFN	Coastal fen[5]	a sedge- and rush-dominated wetland that occurs on calcareous substrates along Lake Huron and Lake Michigan north of the climatic tension zone. The community occurs where marl and organic soils accumulate in protected coves and abandoned coastal embayments and grade to moderately alkaline glacial tills and lacustrine sediments lakeward. Sediments along the lakeshore are typically fine-textured and rich in calcium and magnesium carbonates.
GLB	Great Lakes barrens[5]	a coniferous savanna community of scattered and clumped trees, and an often dense, low or creeping shrub layer. The community occurs along the shores of the Great Lakes where it is often associated with interdunal wetland and open dune.
IDW	Interdunal wetland	a rush-, sedge-, and shrub-dominated wetland situated in depressions within open dunes or between beach ridges along the Great Lakes, experiencing a fluctuating water table seasonally and yearly in synchrony with lake level changes.
LBG	Limestone bedrock glade	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%, but occasionally as high as 60%. Shrub and herb cover is variable and there are typically areas of exposed bedrock. Mosses, lichens, and algae can be abundant on the exposed limestone bedrock or thin organic soils. Seasonal flooding and summer drought maintain the open conditions.
LBL	Limestone bedrock lakeshore	a sparsely vegetated natural community dominated by lichens, mosses, and herbaceous vegetation. This community, which is also referred to as alvar pavement and limestone pavement lakeshore, occurs along the shorelines of northern Lake Michigan and Lake Huron on broad, flat, horizontally bedded expanses of limestone or dolomite bedrock.
LCS	Limestone cobble shore	occurs along the northern Lake Michigan and Lake Huron shorelines. The community is typically sparsely vegetated, because cobbles cover most of the surface and storm waves prevent the development of a diverse, persistent community.
MNF	Mesic northern forest[5]	a forest type of moist to dry-mesic sites lying mostly north of the climatic tension zone, characterized by the dominance of northern hardwoods, particularly sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*). It is primarily found on coarse-textured ground and end moraines, and soils are typically loamy sand to sandy loam.
NFN	Northern fen[5]	a sedge- and rush-dominated wetland on neutral to moderately alkaline saturated peat and/or marl influenced by groundwater rich in calcium and magnesium carbonates. The community is found where calcareous bedrock underlies a thin mantle of glacial drift on flat areas or shallow depressions.
OD	Open dunes[5]	a grass- and shrub-dominated multi-seral community located on wind-deposited sand formations near the shorelines of the Great Lakes. Dune formation and the patterning of vegetation are strongly affected by lake-driven winds.
RCS	Rich conifer swamp[5]	a groundwater-influenced, minerotrophic, forested wetland dominated by northern white-cedar (*Thuja occidentalis*) that occurs on organic soils (i.e., peat). The community is also referred to as cedar swamp.
SGB	Sand and gravel beach[5]	occur along the shorelines of the Great Lakes and on some larger freshwater lakes, where wind, waves, and winter ice cause the shoreline to be too unstable to support aquatic vegetation. These beaches are typically open, with sand and gravel sediments and little or no vegetation.
WDS	Wooded dune and swale complex	a large complex of parallel wetland swales and upland beach ridges (dunes) found in coastal embayments and on large sand spits along the Great Lakes. The upland dune ridges are typically forested, while the low swales support a variety of herbaceous or forested wetland types, with open wetlands more common near the shoreline and forested wetlands more prevalent further from the lake. Wooded dune and swale complexes may encompass several natural communities.

[5] Natural community may be included under the WDS Complex.

Methods

Count surveys

Count surveys produce precise data with repeatable methods to be used to predict population trends using population viability analysis derived from other populations or, if collected for at least 10 growing seasons, as a portion of a count-based population viability analysis. Count surveys are best conducted during flowering or fruiting periods.

The methods of Van Kley (1989) were adopted to maintain consistency among usable count census records. Ten random transects were placed approximately perpendicular the shore. At inland sites, the transects were placed perpendicular to the topography. If there was not a colony intersecting the random transect, the transect was conducted at the nearest colony of DLI. A belt transect was used to determine the number of colonies and percent DLI cover for each transect. Each colony that has a ramet that falls within 2 m of the belt transect was considered intercepted. The transect ran until no DLI was intercepted for 40 m. For records with multiple delineated polygons for the same population, one of three courses of action was taken: 1) if the record was a site of previous research, only polygons included in that study were surveyed, 2) polygons were selected based on accessible permissions and 3) transects were divided among the polygons in an area-proportional manner with at least one transect in a polygon greater than 1 ha.

Quadrats of 0.25 m^2 area were placed on a randomly selected intercepted colony. At least 10 quadrats were placed at each site. The quadrats were placed a random distance from where the colony first intercepted the transect. The separation distance between colonies was at least 1 m between ramets.

A census of the number of ramets in each stage, flowers, and capsules were counted for each quadrat (Table 4). Soil depth, soil type, litter depth, canopy openness, and either full spectrum solar radiation or categorical sunlight amount (e.g., partial sun) were measured depending on availability and functionality of equipment. Soil moisture in each transect and quadrat was categorized into dry, moist, wet, saturated, inundated, or other. Signs of animal impact (e.g., browsing, trampling) were noted and categorized for each belt transect and quadrat into no impact (0% of DLI affected), low impact (0 – 50% of DLI affected), or high impact (51 – 100% of DLI affected) as used by the Chicago Botanic Garden's Plants of Concern program (Bernardo et al., 2018; Goad et al., 2018).

The mean ramet count was used to estimate a number of stems across the population. These estimates were comparable to the methods of the Chicago Botanic Gardens Species of Concern Handbook methods: To estimate DLI counts per colony, the number of plants in each quadrat were calculated, averaged (i.e., mean), transformed to 1 unit area, and extrapolated across the population area based on the area of the population polygon on record (Goad et al., 2018).

At least one photograph was captured from approximately 1.5 m above the quadrat so that the entire quadrat is contained in the frame (Figure 4b). At least one of the sides of the quadrat was marked in metric units to provide a unit measurement for image comparison.

Table 4. Description of DLI life stages for surveys at/after flowering time.

Stage	Description
Young Ramet	Ramet less than 5.25 cm tall and lacks sexual reproductive organs (i.e., flower, fruit)
Sterile Adult	Ramet greater than 5.25 cm, but lacks sexual reproductive organs
Reproductive Adult	Ramet has sexual reproductive organs
Dead	No vegetative growth in subsequent year

a) b)

Figure 4. Examples of photographs taken at a quadrat during a count survey at EO 8439, Cheboygan County, Michigan, on June 1, 2019: a) a photograph of the habitat, b) a photograph of the quadrat and density. Photographs by Rachel Hackett.

Count-based population viability analysis

The methods of population estimation used by Chicago Botanic Gardens in their Plants of Concern Volunteer program were adapted to provide count-based population data for a population viability analysis (Bernardo et al., 2018; Goad et al., 2018). For the populations that underwent count surveys, each mapped polygon of the population was called a sub-population and had a separation distance of at least 50 m between DLI colonies. The mean ramet count per quadrat in each polygon during the same year was used to determine plants per 1 m^2 in each polygon. The mapped area was used to extrapolate DLI from population density to the total area of the polygon for estimated total ramets per [sub]population, although it is recognized that DLI was not contiguous throughout the area. Since the area values were consistent for the count years, it is unlikely to affect the end result of the population viability analysis overall.

We followed the methods of Dennis et al. (1991) as described by Elderd et al. (2003) to determine the mean instantaneous stochastic growth rate (μ) and variance of stochastic growth

(σ^2). In alignment with this process, we transformed the count data to be described by a linear model of the rate of population change over time verses the length of time using the formulas:

$$x = \sqrt{t_j - t_i}$$

$$y = \frac{\ln(N_j) - \ln(N_i)}{x}$$

where *j* is the later year of the two counts, *i* is the earlier year of the two counts, *t* is year value, and *N* is the population estimate. Using a linear regression on the resulting line with *y*-intercept set at 0, the slope of the line is an estimate of μ and the variance of the individual data points on the line gives variance σ^2.

Population simulations

To determine the probability of extinction of a DLI population the cumulative distribution function (CDF) was used (Dennis et al., 1991; Morris and Doak, 2002; Elderd et al., 2003). The quasi-extinction threshold was set at 500 ramets; carrying capacity (*K*) at the maximum of population estimates. The simulations ran for 50 years, and 1,000 replicate simulations were run. An extinction probability was calculated from these simulations. Starting population numbers set at different ramet estimates were used to illustrate the effects on populations of differing size.

To extrapolate the probability of extinction to DLI as a species, extant DLI populations with populations estimates were simulated using the minimal population estimate of the most recent visit. For DLI populations in Michigan, the populations estimates were retrieved from Michigan Natural Heritage Biotics Database including data collected for this project (Michigan Natural Features Inventory, 2022). For DLI populations in Canada and Wisconsin, the populations estimates reported in *USFWS Dwarf Lake Iris (*Iris lacustris*): Recovery Plan* and *COSEWIC Assessment and Status Report on the Dwarf Lake Iris (*Iris lacustris*) in Canada* were used (COSEWIC, 2010; U S Fish and Wildlife Service, 2013). The State of Wisconsin has conducted more recent surveys (2017), but the data were not available at the time of this report (*Kevin Doyle, personal communication*).

Simulations were run using the minimal population estimate as a starting population, quasi-extinction-threshold of 500 ramets, and the μ and σ^2 derived from the count viability analysis. One thousand simulations for each population ran from the year of the visit the population estimate was made until 2032 and 2072 (10- and 50-years post 2022). An extinction probability was calculated from these simulations. Those populations with 50% or greater extinction probability were categorized as extinct. The populations remaining extant in the sample were examined for representation, resiliency, and redundancy.

Analyses were conducted using R version 4.1.2.

Results

Count-based population viability analysis
The combination of 2019 through 2022 count survey data and count data available in the literature produced 50 population change increments across 16 [sub]populations (Table 5). Using this data, μ was derived to be -0.0625 with σ^2 of 0.381 (Figure 5). The μ did not change much from the 2019 through 2021 data (-0.0657), but the variance increased more than double from 0.114 (Hackett et al., 2021).

Population simulations
The results of the CDF illustrated likely extinction for populations with less than 5,000 ramets within 10 years (Figure 6). Populations with more than 50,000 ramets were likely to persist for at least 50 years.

When we ran simulations using minimal population estimates, 36.5% populations will likely be extinct in 10 years (i.e., 2032), 67.8% in 50 years (n = 115; Table 6). Only five of the twenty-four Michigan populations marked as high conservation priority (Table 1) were likely to become extinct (EOID 10381, 5377, 15176, 2058, 5551; Table 6).

Geographically, Wisconsin, USA, populations seemed disproportionately affected, but otherwise at least one population per county was likely to persist in the next 10 years. Upon 50 years, Emmet County, Michigan, USA lacked representation.

Genetic representation of USA populations followed geographic regions of Lake Huron, Lake Michigan, inland Michigan, and Wisconsin (Figure 7; Cohen et al., 2021). Extinction of all but three of Wisconsin's fifteen populations would influence the genetic representation of the species. The genetics of the Emmet County populations tested were similar to the genetics of other populations near the shore of Lake Michigan.

The diversity of communities of the known Michigan, USA, populations of rich conifer swamp, alvar, and interdunal wetland were more likely to go extinct than persist. Other natural communities had more than half of their populations persisting.

Table 5. Mean density of DLI ramets in units of 1 m^2 by year of counts. Unless otherwise stated, data gathered from 2019 to 2022 surveys conducted by MNFI and source feature (SF) polygons derived from survey efforts and mapped in Michigan Natural Heritage Database (Michigan Natural Features Inventory, 2022). In Natural Heritage Database EO ID refers to unique identifier for a population record and SF ID refers to unique identifier of polygon shape mapped. See Table 1 for more information on DLI EO records.

EO ID	SF ID	Area (m^2)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	2019	2020	2021	2022
1369	11815	6096[6]	472[6]	378[6]													
3403	66099	60,251												141	180	140	220
3403	66104	20,395	1 population change increment											145	142	124	163
4466	66716	24,864												287		261	167
7130	66703	85,349		201[7]										162	98	199	117
8162	15674	1,399,573												287	267	270	392
8439	25454	71,279		275[7]										152	180	161	123
8439	25455	26,544												164	234	380	16
8439	66299	70,565												225	220	113	97
8964	27160	163,989												720		216	172
8964	27162	273,861												307		297	361
8964	27166	31,029												132		73	386
8964	66706	11,416												540		228	464
11321	25462	132[8]			55[8]	49[8]	46[8]	42[8]	54[8]	61[8]	45[8]	41[8]	35[8]	0.2			
12376	66711	137,500		292[7]										168	167	188	323
15125	66717	2359												315	367	281	296

[6] Count data and occupied area derived from Van Kley, 1989
[7] Count data derived from Van Kley, 1989
[8] Count data and occupied area derived from Ewert and Scrimger, 1989; Ballard and Lauffer, 1993; Ballard and Kowal, 1997

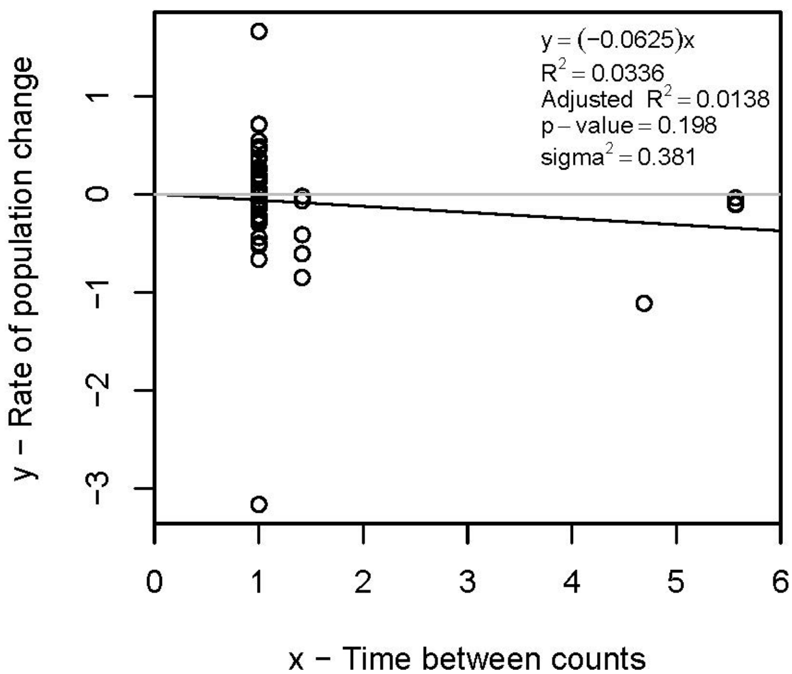

Figure 5. Linear regression of *y* on *x* for DLI count data , where *y* is the natural log transformation of population change between two consecutive counts in a population or subpopulation, and *x* is a transformation of time between those two consecutive counts (equations in text).The slope is an estimate of *μ,* and the variance of the residuals (σ^2) are used for the population viability analysis.

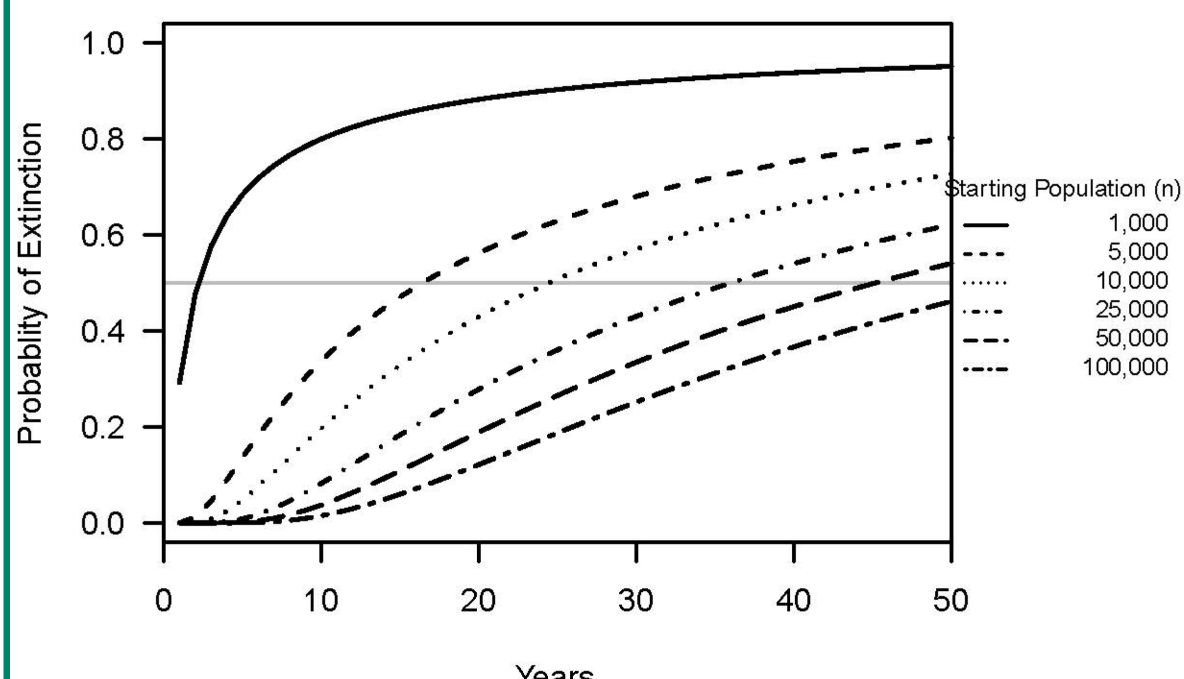

Figure 6. Cumulative distribution function (CDF) for the probability of extinction for DLI at various starting populations (Morris and Doak, 2002). Each style of black line represents the probability of extinction for a population of starting populations listed in the legend. The 0.50 probability is marked with a grey line.

Table 6. List of extant dwarf lake iris (*Iris lacustris* Nutt.) Element Occurrence (EO) records with population estimates (COSEWIC, 2010; U S Fish and Wildlife Service, 2013; Michigan Natural Features Inventory, 2022). EO ID is a unique identifier for each EO record in the State or Province's Natural Heritage Database. Rank is a qualitative assessment of estimated viability of species described in Table 2. Ownership was abbreviated F for Federal, M for Municipal, N for Non-Governmental Organization, P for private, S for State or Province, and T for Tribal. Natural Community (Comm.) described habitat where the population is found (Table 3). EO records with less than 50% extinction probability were bolded.

State/ Prov.	County	EOID[9]	Rank	Owner-ship	Natural Comm.	Year of Est.	Pop. Est. (min.)	Extinction Probability	
								10 yrs.	50 yrs.
MI	**Alpena**	**256**	**A**	**P, S**	**BFT, CFN, LBG, RCS**	**2021**	**50,000**	**16%**	**45%**
MI	Alpena	1625	C	P, S	WDS	1996	2000	53%	57%
MI	**Alpena**	**2440**	**AB**	**N, P**	**WDS, BFT**	**2021**	**25,000**	**21%**	**48%**
MI	**Alpena**	**3403**	**A**	**N, P**	**WDS**	**2022**	**8000**	**30%**	**49%**
MI	**Alpena**	**8385**	**B**	**P**	**BFT, RCS, LBG**	**2021**	**50,000**	**16%**	**47%**
MI	Alpena	9817	CD	F	LBS	1981	20	100%	100%
MI	**Charlevoix**	**1369**	**B**	**P, S**	**BFT, CFN, SGB**	**2019**	**8000**	**31%**	**49%**
MI	Charlevoix	8033	C	S	WDS	1999	100	100%	100%
MI	Charlevoix	18917	CD	S	LBG, RCS	2019	300	93%	94%
MI	Charlevoix	22194	D	S	BFT	2019	500	57%	60%
MI	**Cheboygan**	**8439**	**B**	**N, S**	**CFN, GLB, WDS**	**2022**	**10,000**	**28%**	**47%**
MI	Cheboygan	10464	BC	P	RCS	2021	250	97%	97%
MI	**Cheboygan**	**22657**	**D**	**N**	**WDS**	**2020**	**4000**	**37%**	52%
MI	Chippewa	10288	B	P	CFN, RCS	1998	1000	55%	56%
MI	**Delta**	**2811**	**A**	**S**	**BFT, LBG, LBL**	**2021**	**102,000**	**15%**	**48%**
MI	Delta	3132	C	F	BFT, WDS	2017	1000	52%	52%
MI	**Delta**	**4466**	**BC**	**N**	**BFT, LBL, LCS**	**2021**	**8000**	**29%**	50%
MI	**Delta**	**5633**	**A**	**S**	**LBG, LBL**	**2019**	**10,000**	**32%**	50%
MI	Delta	11928	CD	S	BFT	1995	5	100%	100%
MI	Delta	23701	D	F	BFT	2021	800	54%	56%
MI	**Emmet**	**3606**	**B**	**M, P, S**	**LSC, WDS**	**2021**	**2150**	**42%**	54%
MI	**Emmet**	**7130**	**C**	**S**	**LBL, LCS, WDS**	**2022**	**1,500**	**45%**	54%
MI	**Emmet**	**10381**	**C**	**S**	**BFT**	**2019**	**1000**	**49%**	55%
MI	Emmet	13051	CD	P, S	WDS	1981	10	100%	100%
MI	**Mackinac**	**834**	**C**	**P**	**BFT, LBL, LCS**	**2021**	**10,000**	**30%**	53%
MI	**Mackinac**	**835**	**B**	**S**	**BFT**	**2020**	**100,000**	**14%**	**45%**
MI	Mackinac	1885	BC	P	BFT	1994	100	100%	100%
MI	Mackinac	3635	BC	P	CFN. SGB	2019	1000	51%	54%
MI	**Mackinac**	**5377**	**AB**	**P**	**BFT, NFN**	**1994**	**10,000**	**44%**	53%
MI	**Mackinac**	**5954**	**B**	**S**	**WDS**	**2020**	**8000**	**33%**	50%
MI	Mackinac	8201	C	P	BFT	2001	100	100%	100%

[9] For Wisconsin records, only EO number, not EO ID was available for reference

State/ Prov.	County	EOID[9]	Rank	Owner-ship	Natural Comm.	Year of Est.	Pop. Est. (min.)	Extinction Probability 10 yrs.	50 yrs.
MI	Mackinac	8202	C	P	BFT	2001	100	100%	100%
MI	Mackinac	8623	B	S	BFT	2020	500,000	10%	42%
MI	Mackinac	8964	A	N, P, S	BFT, LBG, LBL	2022	10,000	25%	51%
MI	Mackinac	10153	C	S	BFT, CFN	2019	300	92%	93%
MI	Mackinac	10154	BC	F	BFT, SGB	1993	25,000	45%	50%
MI	Mackinac	12221	AB	P, S	BFT, CFN, LCS	2020	30,000	24%	50%
MI	Mackinac	12376	AB	P, S	WDS	2022	16,000	24%	49%
MI	Mackinac	12503	AB	P	BFT, NFN	1999	10,000	46%	53%
MI	Mackinac	12547	C	P	BFT	1993	1000	53%	55%
MI	Mackinac	12548	B	P	IDW, LBC	2019	100	100%	100%
MI	Mackinac	12862	A	N, P, S	BFT, WDS	2020	6000	34%	51%
MI	Mackinac	15825	C	P	BFT, NFN	1993	300	94%	92%
MI	Mackinac	24196	E	S	RCS	2019	10	100%	100%
MI	Mackinac	24245	C	F	CFN	2020	5000	36%	48%
MI	Menominee	5149	BC	P	MNF	2021	5000	35%	51%
MI	Menominee	15125	BC	S	BFT, MNF	2022	5000	34%	51%
MI	Menominee	15176	C	S	MNF	2019	3500	41%	53%
MI	Menominee	16477	AB	P	BFT, MNF	2005	200,000	36%	48%
MI	Presque Isle	2058	C	P	ALV	2002	300	93%	92%
MI	Presque Isle	2235	D	P, S	BFT	2022	250	98%	99%
MI	Presque Isle	4553	C	P	BFT	1996	100	100%	100%
MI	Presque Isle	5551	C	S	CFN, WDS	2022	1000	49%	52%
MI	Presque Isle	8162	B	P, S	LBG, BFT	2022	50,000	14%	47%
MI	Presque Isle	10080	A	S	WDS	2022	500,000	6%	43%
MI	Presque Isle	10481	C	P	BFT, LCS, RCS	2019	5300	39%	52%
MI	Presque Isle	10888	B	P	WDS	2021	10,000	28%	49%
MI	Presque Isle	10918	A	P, S	BFT, LBG, CFN, NFN WDS	2022	50,000,000	0%	34%
MI	Presque Isle	15944	B	S	LBG	2020	10,000	29%	51%
MI	Presque Isle	23795	C	P	LBG, LCS	2019	500	53%	56%
MI	Schoolcraft	973	C?	P		2000	100	100%	100%
MI	Schoolcraft	1788	C	P	BFT, WDS	2000	100	100%	100%
MI	Schoolcraft	3589	BC	P, S	BFT, LBG, LCS	2021	791,690	5%	41%
MI	Schoolcraft	4465	BC	P	WDS	2021	5000	36%	54%
MI	Schoolcraft	6351	C	P	BFT, LCS, SGB	2021	60,800	16%	46%
MI	Schoolcraft	6809	B	P	BFT, LCS	2021	103,000	14%	46%
MI	Schoolcraft	8015	BC	P, S	WDS	2021	106,600	15%	45%
MI	Schoolcraft	8842	C	P	WDS	2000	10,000	46%	54%
MI	Schoolcraft	9196	C	P	BFT, LBL	2000	100	100%	100%
MI	Schoolcraft	12942	B	P	BFT, CFN, WDS	2021	600,000	6%	46%
ON	Bruce	NEW	E	P		2006	5000	44%	55%
ON	Bruce	003	E	P		1998	9500	48%	52%

State/ Prov.	County	EOID[9]	Rank	Owner-ship	Natural Comm.	Year of Est.	Pop. Est. (min.)	Extinction Probability 10 yrs.	50 yrs.
ON	Bruce	3134	E	N, P		2008	2200	50%	55%
ON	**Bruce**	**3140**	**E**	**P**		**2008**	**300,000**	**29%**	**44%**
ON	**Bruce**	**3142**	**E**	**N, P**		**2006**	**25,000**	**42%**	52%
ON	Bruce	3144	E	P		2003	3000	51%	56%
ON	**Bruce**	**3147**	**E**	**F, P**		**2007**	**26,836**	**42%**	53%
ON	**Bruce**	**3148**	**E**	**F**		**2007**	**561,800**	**29%**	**44%**
ON	**Bruce**	**3149**	**E**	**P**		**2007**	**11,000**	**47%**	**49%**
ON	**Bruce**	**3150**	**F**	**N, P**		**2004**	**40,000**	**39%**	50%
ON	**Bruce**	**3162**	**E**	**P**		**2006**	**12,000**	**42%**	51%
ON	Bruce	3163	F	N		2004	100	100%	100%
ON	**Bruce**	**5930**	**E**	**S**		**2005**	**270,400**	**33%**	**46%**
ON	**Bruce**	**5931**	**E**	**F, N**		**2005**	**145,461**	**35%**	**48%**
ON	Bruce	5934	E	N		2006	1500	51%	56%
ON	**Bruce**	**64287**	**E**	**S**		**2006**	**7,000**	**45%**	54%
ON	**Bruce**	**64288**	**E**	**P**		**2003**	**10,400**	**44%**	49%
ON	Bruce	91764	E	P		2003	1000	56%	53%
ON	**Bruce**	**91788**[10]	**E**	**N, P, S**		**2007**	**45,280,430**	**15%**	**36%**
ON	**Bruce**	**92779**	**F**	**P**		**2008**	**15,300**	**41%**	53%
ON	Manitoulin	NEW	E	M		2008	1000	54%	57%
ON	**Manitoulin**	**NEW**	**E**	**T**		**2007**	**75,000**	**35%**	**47%**
ON	**Manitoulin**	**NEW**	**E**	**T**		**2007**	**1,000,000**	**27%**	**45%**
ON	**Manitoulin**	**NEW**	**E**	**T**		**2007**	**30,000**	**40%**	51%
ON	**Manitoulin**	**064**	**E**	**M, P**		**2006**	**1,000,000**	**28%**	**44%**
ON	**Manitoulin**	**3156**	**E**	**T**		**2007**	**10,000**	**45%**	54%
ON	**Manitoulin**	**3157**	**F**	**M, P**		**2006**	**10,000**	**46%**	50%
ON	**Manitoulin**	**3158**	**E**	**M, P**		**2006**	**1,000,000**	**28%**	**44%**
WI	**Brown**	**023**	**A**	**P**		**2001**	**10,000**	**47%**	52%
WI	**Brown**	**028**	**C**	**P**		**1999**	**8,000**	**47%**	51%
WI	Door	008	B	M, P		1981	2000	55%	55%
WI	Door	011	A	N, P		1989	10,000	50%	52%
WI	Door	012	B	S		1987	10,000	50%	52%
WI	Door	013	D	S		2000	2000	50%	56%
WI	Door	013	E	P		2003	3000	52%	56%
WI	Door	014	B	S		1987	2,000	53%	56%
WI	Door	017	B	S		1979	1,000	56%	60%
WI	**Door**	**018**	**AB**	**S**		**2000**	**200,000**	**41%**	**49%**
WI	Door	024	C	P		2000	2000	51%	54%
WI	Door	040	D	F		1998	775	55%	57%
WI	**Door**	**044**	**BC**	**F, P**		**1998**	**30,000**	**41%**	**49%**
WI	Door	046	BC	M		2005	2000	50%	56%
WI	**Door**	**047**	**C**	**P**		**1999**	**100,000**	**38%**	50%
WI	Door	048	E	P		2000	2000	55%	56%
WI	Door	050	C	M		1999	1000	54%	57%

[10] Populations contains 4 EO records as reported in 2010: EOID 91788, 91763, 84794, and 3147

Figure 7. Map of Dwarf Lake Iris populations used in population genetics and count-based population viability analysis. Populations where genetic samples were collected are represented by small pink squares, count-based population viability analysis large yellow squares. Populations are labeled with background colors representing population assignation for 4-groups (K4) based on the results of population genetic analyses for diploid (2N) data for MCR 90 gene. Figure from Cohen et al. (2021)

Discussion

Resiliancy of the dwarf lake iris populations
The resiliency of dwarf lake iris is highly variable with the current data as supported with the high variance (σ^2 = 0.381) of the slightly negative stochastic growth rate (μ = -0.0625). The addition of the 2022 data did not greatly affect the μ (-0.0657 with 2019-2021 data), but the variance more than doubled from 0.114 (Hackett et al., 2021). Upon closer examination of the 2021 to 2022 count data, the [sub]populations that decreased by more than 50 ramets per 1 m^2 in 2022 were shoreline populations on limestone cobble or sand dunes (Table 5; EOID 4466, EOID 7130, EOID 8439-SF25425), but not all dune and limestone cobble DLI populations saw an overall decrease in density. The three [sub]populations that were most greatly affected are on the southern or eastern shores of a Great Lake, while the others were at a northern shore (EOID 3403, EOID 8964, EOID 12376). These shoreline populations may have been affected more than others by the high Great Lakes water levels in 2019 to 2021 and subsequent substrate deposition in 2022. At EOID 8439, surveyors dug several decimeters in the sand where they were observed above ground in previous years before finding DLI rhizomes that were buried at places.

With fluctuating Great Lakes water levels and increasing frequency of storms as a symptom of climate change, DLI populations on the immediate shoreline may be at greater risk of extinction than populations found on secondary dunes, boral forests, fens, or glades. These disturbances may be happening at a frequency that does not promote recovery time for the population. Longer term population data is needed to further understand the recovery time of such populations and this threat. According to the rule of thumb developed by Fieberg and Ellner (2000), our population analysis model can produce reliable estimates for only 5 to 10 years with current data.

The count-based PVA we used did not incorporate any catastrophic changes in the model (Elderd et al., 2003). The assumption of normally distributed population growth simplifies the model, but increases in weather extremes due to climate change could affect DLI population growth, thereby invalidating this assumption. The exposed populations along the Great Lakes lakeshore are particularly vulnerable, which was observed by the missing quadrats at the two lakeshore sites undergoing demographic surveys between 2019 and 2020. Conducting spatial surveys or measuring percent cover of ramets in occupied area at count sites each year could better account for such changes in count surveys. These actions would change the occupied area for each interval, but add considerable field and data analysis time.

Redundancy in dwarf lake iris populations
Geographically, most likely viable populations lacked redundancy from Emmet County, Michigan, USA. In Wisconsin, USA, populations seemed disproportionately affected, but otherwise at least one population per county was likely to persist. Incorporating the more recent estimates from Wisconsin Natural Heritage Program may alter these results.

There are flaws with using DLI population estimates in the simulations including 1) cognitive limitations for visualizing large numbers, 2) variation among surveyors, and 3) hidden occupied areas of DLI not used when estimating total occupied area. For surveys from 2019 to 2022 in Michigan, we attempted to preemptively counteract the first two items with standardized training including components to help with visualization. Seasonal technicians were trained to associate certain numbers with similar visual densities. Use of items as size reference (e.g., rulers, a standard piece of paper) were required for use when taking density photographs downward on a colony for non-count surveys. This allowed technicians to maintain a relative density visual in their head regardless of the type of survey they were conducting.

Representation in dwarf lake iris populations

The simulations on the population estimates did not support the hypothesis that the lakeshore or wooded dune and swale natural communities to be more vulnerable than more inland boreal and forest sites from the demographic study in Hackett et al. (2021). These simulations were based solely on population estimates, the year they were made, and the μ and σ^2 derived from all DLI count sites. If enough data was available, separate viability analyses for lakeshore/dune DLI populations from other communities may be able to support different conclusions.

As mentioned in the resiliency discussion, representation across the breadth of natural communities where DLI is found is important for the species' persistence. These natural communities undergo different natural processes that affect rates of succession, and they have different levels of threats and disturbances.

The genetic representation of DLI populations across the USA regions was related to the geography, likely because of historical migration patterns (Cohen et al., 2021). The genetic groupings with the exception of the Wisconsin, USA, populations are well represented in the persisting populations. The Wisconsin population genetics were both distinct and more diverse than other populations tested (Cohen et al., 2021). Those qualities mark Wisconsin populations as high priority for conservation to maintain genetic representation.

Conservation of DLI

To protect, conserve, and manage DLI populations, examination of the species relative to its redundancy, resiliency, and representation is needed (US Fish and Wildlife Service, 2016). The PVA conducted for this project indicated a general small decline in population growth for the species, but the variance of the growth rate throws uncertainty onto any sweeping statements about its growth, stability, or decline (Figure 5). As more reliable population data is collected, efforts should be made to prioritize, conserve, and protect known DLI populations. Populations categorized as high-priority or fitting into the characteristics described in Hackett et al. (2021), should be targeted for focused attention with the addition of the genetically distinct Wisconsin populations. Efforts should be made to continue documenting the status of remaining DLI populations to better predict its persistence.

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