LMTC Lake Trout Working Group Response Document: Lake Trout Strain Evaluation Task

Group members:

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Premise for task:

"Now that natural reproduction in Lake Michigan is beginning to take hold, and stocking has been reduced in some portions of the lake, this appears to be a good time to evaluate the contribution of the various strains and determine which strain(s) are most influential in producing natural reproduction."

Executive Summary

Of the eight captive lake trout brood stocks stocked in Lake Michigan, the captive brood stocks of the Seneca Lake, Lewis Lake, and Parry Sound strains were genetically distinct, with little overlap in ancestry with other strains (Larson et al. *2020*). The three Lake Superior lean strains (Isle Royale, Marquette, and Apostle Island) were not distinct, and appeared to represent a single Lake Superior lean strain with a substantial amount of genetic overlap. The Klondike humper strain was distinct from other strains but did share some ancestry with the Lake Superior lean strains.

In Lake Michigan, the Seneca and Lewis Lake strain fish had greatest contributions to surveys and fisheries when compared to other strains based on stocking rates. Genetic evaluations of wild fish showed the Seneca Lake strain contributed to wild recruitment at a greater rate than would be expected based on the numbers stocked; the Lewis Lake and Apostle Island strain contributions were similar to expectations while the Green Lake strain contributed less than would be expected. It is too early to fully evaluate how well the Parry Sound and Klondike humper strains contribute to fisheries and to wild recruitment.

Spatial considerations are important when considering strains. The Seneca Lake strain performed better than other strains in areas with higher lamprey marking rates. Where sea lamprey predation was lower, the performance of Seneca Lake strain was similar to or lower than that of the Lewis Lake strain. It is possible that the reduced encounter rates with sea lamprey facilitated the increased survival of Seneca Lake strain lake trout relative to other strains in areas with higher lamprey mortality rates.

Different strains exhibited different levels of dispersal and those with broader distributions had higher

contributions to sport fisheries. Lewis Lake fish tended to disperse more widely relative to other strains and were therefore more frequently captured in sport fisheries. The Klondike humper strain did not disperse widely, tended to remain offshore in the Southern Refuge near original stocking locations and were rarely encountered in sport fisheries where effort is mainly focused nearshore.

We were not able to fully evaluate the contribution of the Klondike humper strain or the Parry Sound lean strain because these strains were only recently introduced and had not yet reached maturity during the time of our analysis. Specifically, we were not able to estimate the degree to which they contributed to wild recruitment. Available data suggest the Klondike humper strain is surviving well relative to other strains and has limited dispersal. This strain is generally not encountered by the sport fishery and occurs mostly within the Southern Refuge where they were stocked. By contrast, the Parry Sound strain has lower returns relative to the Lewis Lake, Apostle Island, or Seneca Lake strains from the same year-classes and stocking locations. Future evaluations are needed to determine recruitment potential and genetic contributions as fish mature and recruit to the parental stock. We suggest routine genetic monitoring to confirm the genetic purity of Klondike humper strain broodstock and continued genetic monitoring of natural recruits to confirm that humper-lean hybrids are rare and not contributing to reduced fitness. The unique ecological attributes of the Klondike humper strain in Lake Superior, such as deeper depth preference, greater reliance on benthic forage than lean lake trout strains (Sierszen et al. 2014; Rogers et al. 2019; Vinson et al. 2020), and low dispersal/high site fidelity observed in Lake Superior and Lake Michigan, suggest that Klondike humper strain warrant further evaluation and additional vetting for possible stocking once data have been compiled and USFWS broodstocks are redeveloped and online.

Based on our results, our primary recommendation is to continue to stock and maintain the Lewis Lake and Seneca Lake strains of lake trout. The Lewis Lake strain of lake trout contains remnant Lake Michigan genetic material and performs well in most areas of the lake, and the Seneca Lake strain appears to possess unique adaptations that allow it to outperform other strains in areas where sea lamprey mortality is high. Additional information is needed to provide similarly complete recommendations on the Klondike humper and Parry Sound strains. The LMC decisions to discontinue stocking the Klondike humper strain may have been premature as the evaluation effort was just beginning to inform their potential contribution to rehabilitation efforts (Chuck Bronte, pers. comm.).

Background description of strains

<u>Lean lake trout forms:</u>

Finger Lakes Form:

<u>Seneca Lake</u>: Seneca Lake strain lake trout are representative of gametes obtained from deep water (30-65 m) spawning lake trout in Seneca Lake, NY. Stocking did occur in Seneca Lake, but only with local gamete sources. This strain was first introduced into Lake Michigan in 1985 (1984 year-class). In the Great Lakes, Seneca strain fish occupied deeper waters than other lean strains and appeared to have lower encounter rates with sea lamprey (Bergstedt et al. 2003; Schneider et al. 1996). This may be related to genetic adaptations to Seneca Lake, which is narrow with steep sides and limited flat bottom habitat relative to the Great Lakes. It has additionally been postulated that the Seneca Lake strain fish are better adapted for survival after a sea lamprey attack relative to other strains (Schneider et al 1996), however this has not been demonstrated in the lab (Swink et al. 1986). When introduced into lakes Michigan, Huron and Ontario, and consistent with observations in Seneca Lake, sea lamprey wounding rates have been lower and post release survival higher relative to other strains (Schneider et al. 1996; Bronte et al. 2007; Johnson et al. 2015). In Lake Michigan, locations where sea lamprey induced mortality is low, Seneca Lake strain have equal or lesser performance compared to other strains. However, in areas with higher sea lamprey predation rates, survival is improved relative to other strains (McKee et al. 2004; Kornis et al. 2019).

Lake Michigan Lean Forms:

<u>Lewis Lake</u>: The Lewis Lake (Wyoming) strain of lake trout represent remnant genetic material from the Lake Michigan basin. The Lewis Lake Wyoming population of lake trout were established from a single stocking event of approximately 12,000 lake trout from gametes that were collected near Manistique, Michigan in 1890. Another stocking occurred in Lewis Lake in 1941 when 6,000 fall fingerlings were stocked from unknown Lake Michigan locations. The current broodstock of Lewis Lake strain lake trout was developed from populations of lake trout in Lewis Lake and Jenny Lake, Yellowstone National Park, Wyoming and are now supplemented by gametes from lake trout in Yellowstone Lake that are genetically similar. This strain was first stocked into Lake Michigan in 1982 (1981 year-class) and then annually since 1989.

Green Lake: The Green Lake (Wisconsin) strain of lake trout also represent remnant genetic material from the Lake Michigan basin. Lake Michigan lake trout were stocked repeatedly into Green Lake from 1886 to 1943. Stocked lake trout were collected from deep water (180-360 ft) in the southern basin of Lake Michigan over hard clay bottom substrate (Hacker 1956). Fingerlings stocked in 1944 were suspected to have been from Lake Superior, however Krueger et al. (1983) believed they weren't and were actually from an egg shipment of northern Lake Michigan strains provided via the Sturgeon Bay, Wisconsin state fish hatchery. Between 1945 and 1952 no lake trout were released in Green Lake, but stocking resumed in 1953 when fish from Lake Superior were stocked. Selection of broodstock has been complex and initially genetic bottlenecks occurred (Kincaid et al., 1993 NAJFM). The Green Lake strain broodstock were first developed from offspring of presumed Lake Michigan lake trout recovered in Green Lake, WI. The original broodstock was discontinued in the mid-1970s and was redeveloped from fish captured from southern Lake Michigan in the 1980s that had fin clips unique to the Green Lake strain (Kincaid et al. 1983). Stocking resumed with the 1991 year-class but was discontinued in 2005 to reduce ecological and genetic redundancies in the strain profile in federal hatcheries.

Lake Superior Lean Forms:

Marquette: The Marquette strain lake trout were the primary lean form stocked into Lake Michigan from 1965 until 1989 (Krueger et al. 1983). Michigan DNR continues to raise a "Lake Superior" strain in their hatchery system developed from gametes of multiple Lake Superior sources. The original Marquette strain lake trout were derived from gametes from remnant wild shallow-water lean lake trout captured in Michigan waters of Lake Superior collected in 1948 by commercial fishermen. The first eggs were hatched at Michigan's Oden Hatchery, and subsequently transferred to the Marquette State Hatchery in 1950. Five additional broodstocks were derived from these, which became the primary source for stocking first Lake Superior in 1954 and then later Lake Michigan. Eggs came from 3 locations: upper Marquette Harbor, Copper Harbor, and later Traverse Island Reef east of the Keweenaw Peninsula. USFWS discontinued raising and stocking of Marquette/Traverse Island strain in Lake Michigan in 2007.

Isle Royale: The Isle Royale strain was developed to increase representation of nearshore forms in Lake Superior. The strain was developed from wild spawning lake trout near Isle Royale in Lake Superior by Minnesota DNR. Gametes were collected from 1981 and 1986 (Page et al. 2003). The strain was first stocked into Lake Michigan in 1989; hatchery production ceased in

2006 because of low recoveries in Lake Michigan in fishery-independent surveys (Bronte et al. 2007; Kornis et al. 2019).

Apostle Island (Gull Island Shoal): The Apostle Island strain from Gull Island Shoal was developed to increase strain representation of nearshore forms of lake trout from Lake Superior. It is one of only a few remnant native populations that survived and recovered from overfishing and sea lamprey predation. Gull Island Shoal is close to one state and one federal hatchery allowing for economies in egg take operations. The strain was first developed and reared by Wisconsin DNR in the 1970s and then by the USFWS at Iron River National Fish Hatchery in the 1980s. Five year-classes of brood stock were established from wild lake trout over the 14-year period, 1986–1999 (Page et al. 2003). Stocking of this strain in Lake Michigan began in 1993 (1992 year-class) and ended in 2013 to reduce genetic and ecological redundancies of lean strains in the hatcheries.

Lake Huron Lean Form:

Parry Sound: The Parry Sound strain represents a nearshore lean form of lake trout. Parry Sound brood stock were created in 2005 from the only surviving strain of wild lake trout in Parry Sound, Lake Huron. The strain was first stocked into Lake Michigan in 2013 (2012 year-class) and stocking continues to the present.

Other lake trout forms:

Klondike Reef (Humper): Klondike Reef (humper) lake trout originated from gametes collected in the mid-1990s from a deep (160-250 ft) offshore reef which was located 56 km north of Grand Marais, Michigan in Lake Superior. The brood stock development effort was initiated to support stocking requests from Lake Erie. The humper morphotype has been observed at a variety of other locations, which include the banks between Caribou and Michipicoten islands, Lake Superior, and were especially abundant on the northernmost bank of Superior Shoal in Canadian waters of Lake Superior (Goodier 1981) and offshore waters around Isle Royale (Eschmeyer 1955; Moore and Bronte 2001). In a study of morphometric and meristic variation, humper lake trout were clearly separated from lean and siscowet forms, but Khan and Qadri (1970) were hesitant to assign this form subspecific status until more was known of its biology and distribution. Humper strain lake trout mature at a smaller size than is typical of lean lake trout strains and spawn in August and September, which is earlier than most lean forms or most siscowet stocks. In collections from Isle Royale, humper males as small as 323 mm were mature and 100% of both sexes were mature at 485 mm, whereas other lean forms typically do not mature until >650 mm (Rahrer 1965). Although small, the humper strain is long-lived and can reach ages that approach 30-40 years (Burnham-Curtis and Bronte 1996; Hansen et al. 2016). The fat content of humpers is, in most cases, intermediate to that of lean and siscowet forms (Eschmeyer and Phillips 1965). Humpers were recommended for stocking into Lake Michigan the 1990s (LMTC 1993) and again in 2008 (Bronte et al. 2008). Humper lake trout were first stocked into Lake Michigan in 2012 (2011 year-class), and stocking ceased in 2021, due to issues with a disease outbreak that forced elimination of the captive brood stock and a lack of management interest in continuing the strain. Lake Erie managers ceased stocking humpers based on poor post-release survival at older ages and slower growth than lean strains. Humpers grow slower and have different diet than leans in Lake Superior but may have greater longevity (Hansen et al. 2016). However, NYDEC has requested the USFWS for the humper strain to be stocked into Lake Ontario. The process to redevelop the Klondike humper strain broodstock will begin in 2021 and they will be available in the future if the Lake Committee reconsiders their use in restoration efforts.

Siscowet: Siscowet lake trout are a deep-water form that were found principally in 90 to 300 m of water (Eschmeyer and Phillips 1965; Bronte and Sitar 2008). Khan and Qadri (1970) compared morphometric and meristic variation among lean, siscowet, lean/siscowet hybrids (aka “half breeds”), and humper trout forms and concluded that siscowet should be considered for separate subspecific status, genetic evidence supports this. Two osteological characters, the dorsal opercular notch and radii on the anterodorsal part of the supraethmoid, can be used to differentiate between lean and siscowet lake trout (Burnham-Curtis and Smith 1994). The high fat content of siscowet is a characteristic mentioned in virtually every reference on this morphotype. As with the other forms of lake trout, different stocks or varieties of siscowet seem possible (see Bronte and Moore 2007). Siscowet were recommended for stocking in Lake Michigan (Bronte et al. 2008), however, this was never implemented and gametes were never brought into federal hatcheries.

Genetic structure of captive broodstocks:

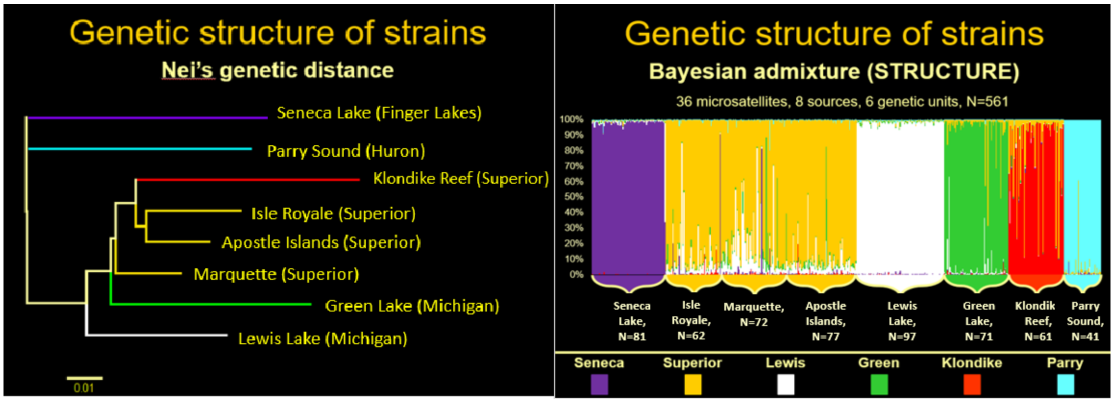


Figure 1. Genetic distinctions of captive broodstock strains stocked into Lake Michigan.

The Seneca, Lewis Lake, and Parry Sound strains were the most genetically distinct, with little overlap in ancestry with other strains (Larson et al. 2022). The three Lake Superior lean strains (Isle Royale, Marquette, and Apostle Island) were not distinct, and appeared to represent a single Lake Superior lean strain with a substantial amount of genetic overlap, which provides further justification to reduce strain redundancy in federal broodstocks. Klondike humper lake trout were distinct from other strains but did share some ancestry with the Lake Superior lean strains, possibly due to accidental inclusion of some lean morphs during egg take operations to establish broodstock or to gene exchange already occurring in Lake Superior (Baillie et al. 2016). The Green Lake strain was distinct genetically and showed some overlap with the Lewis Lake strain and lean Lake Superior strains--the latter likely due to mixing of gametes in the past.

LMC Requested Information and responses (January 2020):

1. History of strain stocking

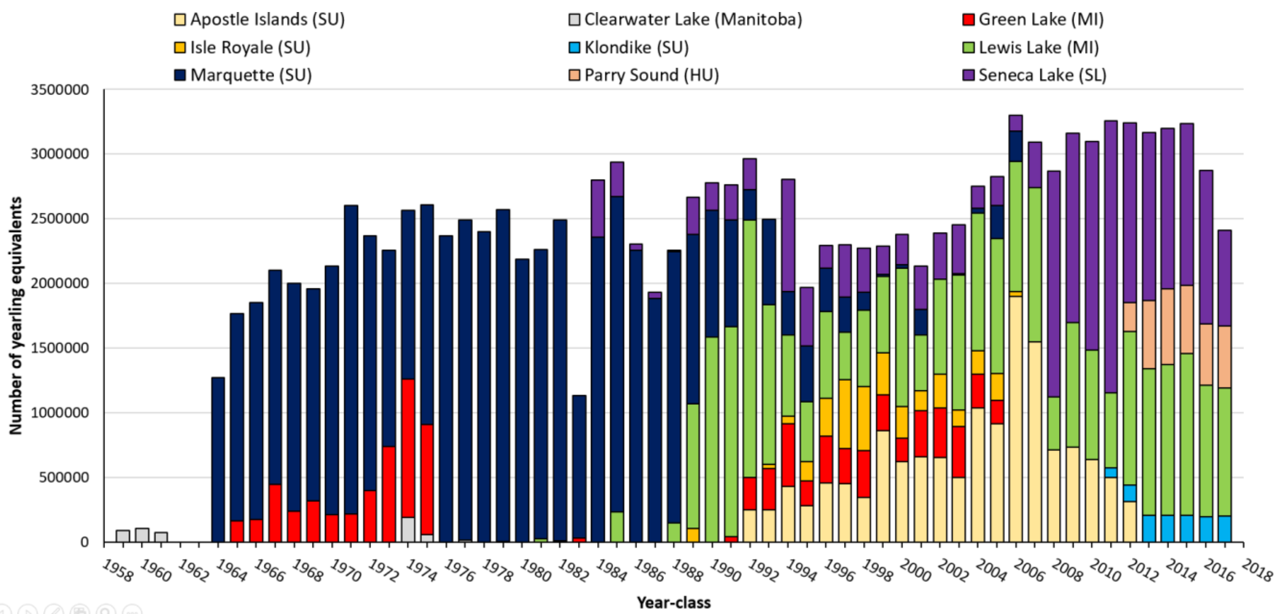


Figure 2. Numbers of yearling equivalents stocked into Lake Michigan for the 1958 – 2017 year-classes by genetic strain.

The Marquette strain and Green Lake strain (Lake Michigan origin) predominated early (1964 – 1988 year-classes) stocking efforts in Lake Michigan. Stocking of the Green Lake strain was temporarily discontinued after the 1975 year-class but was reinitiated from 1991-2005. A more diverse array (including Green Lake strain) were introduced into Lake Michigan beginning with the 1989 year-class. Strains included:

1) Seneca Lake strain, which has been stocked every year since the 1983 year-class. Stocking was increased for the 2008 – 2017 year-classes because of perceived survival advantages.
2) Lewis Lake strain that provided the largest contributions to the 1989 – 2017 year-classes.
3) Green Lake strain, from redeveloped broodstock, modest contributions to the 1990 – 2005 year-classes.
4) Apostle Island, Isle Royale and Marquette strains, which contributed to stocking efforts for the 1989 – 2012 year-classes.

5) In the most recent 5 year-classes 2013 – 2017), four strains from diverse origins were stocked including the Seneca Lake, Parry Sound, Lewis Lake and the Klondike humper strains.

Table 1. Lake trout yearling equivalents stocked into Lake Michigan by year-class and principle genetic strain (same data as Figure 2).

Year-Class	Apostle Islands (SU)	Clearwater Lake (Manitoba)	Green Lake (MI)	Isle Royale (SU)	Klondike (SU)	Lewis Lake (MI)	Marquette (SU)	Perry Sound (HU)	Seneca Lake (SL)
1959	-	88,235	-	-	-	-	-	-	-
1960	-	104,640	-	-	-	-	-	-	-
1961	-	72,936	-	-	-	-	-	-	-
1962	-	0	-	-	-	-	-	-	-
1963	-	0	-	-	-	-	-	-	-
1964	-	0	-	-	-	-	1,273,878	-	-
1965	-	0	164,990	-	-	-	1,601,200	-	-
1966	-	0	177,810	-	-	-	1,677,010	-	-
1967	-	0	445,190	-	-	-	1,658,550	-	-
1968	-	0	239,215	-	-	-	1,760,590	-	-
1969	-	0	320,000	-	-	-	1,640,000	-	-
1970	-	0	215,400	-	-	-	1,920,145	-	-
1971	-	0	220,000	-	-	-	2,383,320	-	-
1972	-	0	398,700	-	-	-	1,972,610	-	-
1973	-	0	740,000	-	-	-	1,517,100	-	-
1974	-	190,813	1,072,000	-	-	-	1,305,374	-	-
1975	-	59,600	853,300	-	-	-	1,694,500	-	-
1976	-	0	0	-	-	-	2,370,100	-	-
1977	-	19,000	0	-	-	-	2,474,400	-	-

1978	-	0	0	-	-	-	2,402,601	-	-
1979	-	5,560	0	-	-	-	2,565,148	-	-
1980	-	-	0	-	-	-	2,189,010	-	-
1981	-	-	0	-	-	29,540	2,233,450	-	-
1982	-	-	0	-	-	13,231	2,479,298	-	-
1983	-	-	33,032	-	-	0	1,098,700	-	-
1984	-	-	0	-	-	0	2,360,002	-	441,785
1985	-	-	0	-	-	234,388	2,435,113	-	268,271
1986	-	-	0	-	-	0	2,257,990	-	44,400
1987	-	-	0	-	-	0	1,885,080	-	47,542
1988	-	-	0	-	-	149,000	2,097,720	-	8,320
1989	-	-	0	106,087	-	963,301	1,309,323	-	286,852
1990	-	-	0	0	-	1,588,163	977,466	-	213,853
1991	-	-	45,153	0	-	1,623,256	824,245	-	268,590
1992	251,002	-	252,202	0	-	1,986,348	233,900	-	242,831
1993	251,369	-	316,943	34,000	-	1,234,100	659,600	-	0
1994	431,010	-	482,674	58,968	-	630,880	331,554	-	872,570
1995	282,913	-	189,011	151,600	-	460,866	430,950	-	456,108
1996	460,699	-	361,980	290,423	-	669,500	333,400	-	176,650
1997	451,100	-	270,800	533,600	-	370,100	271,090	-	405,450
1998	347,800	-	358,533	497,950	-	588,485	139,036	-	341,822
1999	863,004	-	274,880	325,500	-	590,457	16,100	-	220,280
2000	623,484	-	179,500	248,400	-	1,066,228	26,000	-	238,000

2001	657,763	-	361,594	151,230	-	434,454	192,927	-	338,690
2002	656,587	-	380,626	260,629	-	734,663	1,100	-	355,432
2003	498,222	-	394,997	129,301	-	1,042,418	11,538	-	379,552
2004	1,037,721	-	262,038	182,123	-	1,060,307	38,212	-	169,180
2005	914,900	-	180,750	206,540	-	1,043,398	256,879	-	222,190
2006	1,899,168	-	-	39,634	-	1,006,444	233,262	-	119,183
2007	1,551,260	-	-	-	-	1,187,837	-	-	351,041
2008	710,967	-	-	-	-	412,077	-	-	1,743,701
2009	734,254	-	-	-	-	963,038	-	-	1,466,963
2010	637,432	-	-	-	-	849,552	-	-	1,612,216
2011	498,220	-	-	-	79,065	576,531	-	-	2,102,407
2012	313,058	-	-	-	128,542	1,188,625	-	221,153	1,387,661
2013	-	-	-	-	206,486	1,137,703	-	524,434	1,298,287
2014	-	-	-	-	206,333	1,166,548	-	587,964	1,237,963
2015	-	-	-	-	207,400	1,249,206	-	527,860	1,254,217
2016	-	-	-	-	199,319	1,014,041	-	474,893	1,184,558
2017	-	-	-	-	200,797	990,501	-	480,628	741,675

Spatial distributions of strains stocked (2013 – 2017 year-classes):

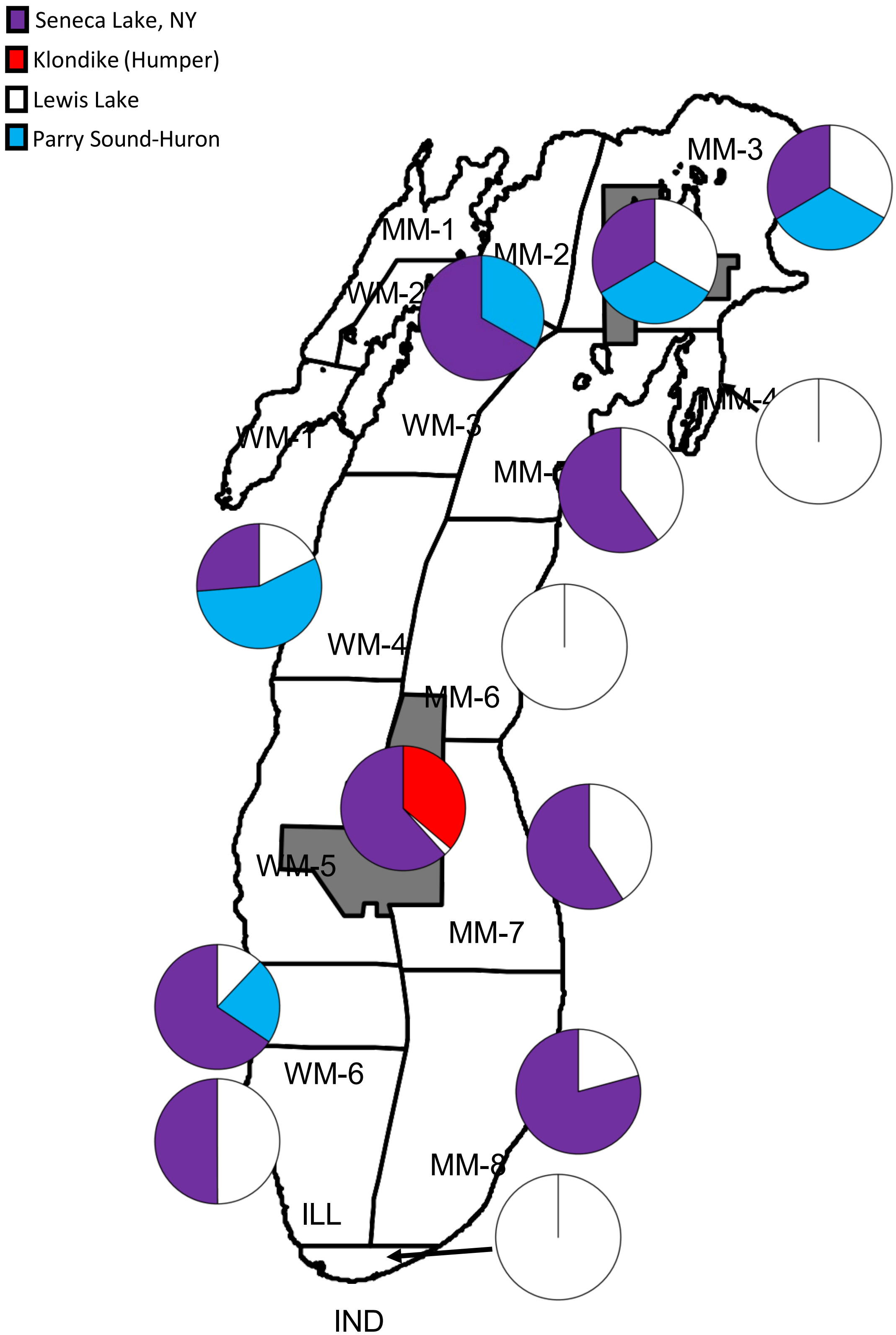


Figure 3. Map of Lake Michigan indicating the distribution of strains stocked in statistical districts and refuges from 2014-2018 (2013-2017 year-classes).

Table 2. Total numbers of lake trout yearling equivalents stocked from 2014-2018 (2013-2017 year-classes) by strain, state and statistical district; Northern and Southern Refuges were treated as separate districts (same data as Figure 3).

	Strain				Stat District
Stat District	**Klondike**	**Lewis Lake**	**Parry Sound**	**Seneca Lake**	**totals**
ILL		305,122		305,906	611,028
IND		220,135			220,135
N_refuge		1,482,340	1,489,187	1,490,263	4,461,790
MM3		945,116	952,830	955,788	2,853,734
MM4		1,553,425			1,553,425
MM5		405,008		612,013	1,017,021
MM6		405,256			405,256
MM7		63,863		92,202	156,065
MM8		79,410		302,458	381,868
S_refuge	1,020,335	59,470		1,739,051	2,818,856
WM3			50,206	100,760	150,966
WM4		23,661	75,135	35,248	134,044
WM5					0
WM6		15,192	28,420	83,011	126,623
Strain totals	1,020,335	5,557,998	2,595,778	5,716,700	
			Grand total		14,890,811

Recently (last 5 year-classes), the northern region of Lake Michigan (MM-3) is stocked with the Seneca Lake strain with reduced susceptibility to sea lamprey mortality, the Parry Sound strain from Lake Huron, and the Lewis Lake strain with Lake Michigan origins. The Southern Refuge area is stocked with two primary strains the Seneca Lake strain and the Klondike humper strain from Lake Superior; both of these strains spawn in deep water in their native environments. The 2017 year-class also included a small number of surplus Lewis Lake fish from Lake Huron which were stocked in the Southern Refuge in lieu of stocking additional fish in nearshore areas.

2. Composition of strains in the population, and the commercial and sport harvest

Methods

We compared the number of CWT lake trout recovered per 100,000 fish stocked (return rate) of each strain from distinct stocking locations in spring fishery-independent surveys (LWAP and lake whitefish surveys) and in sport and commercial fisheries. Analysis was limited to only CWT 2010-2015 year-classes because fish stocked at all locations were not tagged in prior year-classes. Both yearling and fall fingerling tag lots were included, but tag lots whose stocking locations spanned across two or more of the five spatial units we analyzed (Fig. 4), or included fish from two or more genetic strains, were not included; this removed 5 of 14 fall fingerling tag lots and zero yearling tag lots. Tag lots stocked outside of the five spatial units in Fig. 4 (e.g., stocked in Wisconsin waters or in Lake Huron) were also not analyzed (included one fall fingerling and nine yearling tag lots from Lake Huron and three yearling tag lots from nearshore Wisconsin). In total, the analysis included 234 yearling and six fall fingerling tag lots. All fall fingerling lots were stocked in the Southeast Region and language in the results for that section specify which year- classes were affected. All CWT fish had codes that identified strain, year-class, stocking location, and hatchery of origin. There were few recoveries from the 2016 – 2019 year-classes because they were too young to be recruited to most fishing gears. For comparative purposes, a comparison of strain return rate patterns from legacy tags (1994 – 2003 year-classes) is provided at the end of this section and can be further reviewed in Kornis et al. (2019).

Three data sources:

1) **Lake-Wide Assessment Plan (LWAP) Survey:** In this document, LWAP will refer to fishery independent surveys of similar characteristics including both LWAP assessments and Fishery Independent Whitefish Surveys. LWAP is a fishery-independent graded mesh gill net (2.5-6 inch) assessment of lake trout and lake whitefish populations in the spring (April – June) in depths of 50 feet out to over 150 feet. Fishery independent whitefish surveys are graded mesh gill net (2-6 inch) assessments set at a variety of depths greater and less than 100 feet. Survey returns were corrected for sampling effort (net length in km X number of net nights, hereafter 'km*nights') as well as the number of lake trout stocked. Catch rates were standardized to the number of lake trout per km*night, per 100,000 fish stocked (CPUE) to allow for less biased comparisons which were not influenced by stocking numbers.

2) **Sport Fishery:** CWT lake trout were collected from the sport fishery lake wide by the USFWS Great Lakes Mass Marking program. Recoveries during the years 2014 – 2019 of CWT fish from the 2010 – 2015 year-classes were evaluated. The 2010 and 2011 year-classes were not well represented in the 2012-2013 recovery years and the 2016-2018 year-classes were underrepresented in recent years as the catchability of lake trout <age 3 in sport fishery is low. Catch was corrected for sampling effort by standardizing to the number of lake trout per sampling day. Average CPUE (catch per sampling day) was calculated from each month in each statistical district and averaged within each year of recovery. Average CPUE values for each tag lot were then estimated by averaging across years; average CPUE was then divided by the number of fish stocked and multiplied by 100,000 (i.e., catch per sampling day per 100,000 fish stocked).

3) **Commercial Fishery:** The commercial gill net fishery uses trap nets and gill nets that target lake whitefish and lake trout in northern Lake Michigan and Grand Traverse Bay. Catch of CWT fish was standardized to the number of lake trout per 100,000 lake trout stocked, which simply represents a return rate (not CPUE). Commercial fishery effort data were not available to apply standardizations to commercial fishery return data because net length of monitored lifts was inconsistently reported in the commercial landings database.

Background

Different fishing effort levels among areas were accounted for to reduce bias in catches when attempting to compare return rates. The effort-corrected data from the LWAP survey and sport fishery data have the least bias and represent indices of relative survival (although are referred to throughout this document as 'return rate' for consistency); observations were generally similar for commercial fisheries data even though they were not adjusted for fishing effort. To address our inability to correct for effort in the commercial survey, the returns of lake trout strains were only compared among fish stocked in the same region, as fish stocked in the same region likely undergo similar movement dynamics and thus are likely exposed to similar probabilities of catch from effort in different recovery regions. We evaluated fish stocked from the following five regions: Northern Refuge, Southern refuge, Julian's Reef, nearshore stocking in the northeast region (MM3, MM4, MM5) and nearshore stocking in the southeast region (MM6, MM7, MM8). There were not enough recoveries of lake trout stocked in nearshore Wisconsin waters, to allow for analysis (N=9 fish in LWAP).

The dispersal of lake trout strains from three specific stocking locations (Northern Refuge, Southern Refuge, Julian's Reef) was evaluated using data from the LWAP survey. Maps indicate the recoveries of lake trout from each of the three stocking locations and indicate the return rates (CPUE) of each strain within each statistical district of the lake. To allow for comparison among strains, we computed the percentage of fish that were captured in specified areas by dividing the return rates (CPUE) from that area by the total return rates (CPUE) from all areas. Two of the spatial units (Northeast and Southeast) were larger regions and spanned multiple statistical districts. Maps were not included because spatial resolution is difficult in these larger units to adequately reflect specific stocking locations, and low sample sizes constrained our ability to evaluate movement of strains among statistical districts within the two regions.

Regional Summaries

1. Northern Refuge
2. Southern Refuge
3. Julian's Reef
4. Northeast Region
5. Southeast Region

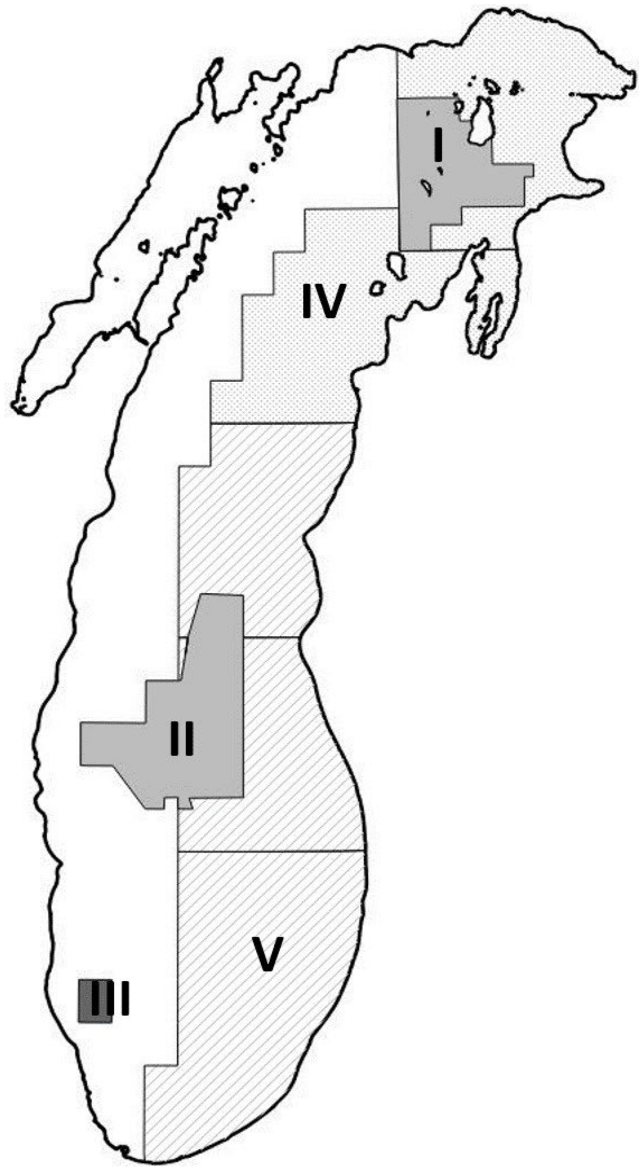


Figure 4. Stocking regions of Lake Michigan where strain returns were evaluated.

I. Fish Stocked in the Southern Refuge

Return rates:

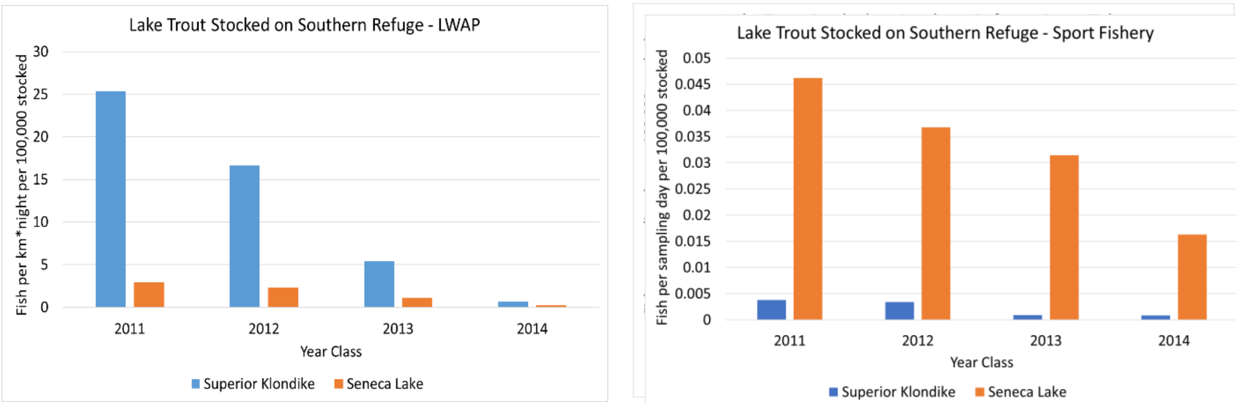


Figure 5. Return rates (CPUE) of Klondike humper strain (blue) and Seneca Lake strain (orange) lake trout stocked on the Southern Refuge and recovered in the LWAP survey (left panel) and sport fishery (right panel). The 2010 year-class only included Seneca Lake strain and thus was excluded from the figures. Not enough fish stocked on the Southern Refuge were recovered from the commercial fishery to merit inclusion in analysis (n = 15).

Lake trout captured in the fishery independent LWAP survey on the southern refuge were primarily Klondike humper strain whereas returns in sport fisheries were primarily Seneca strain, with a strong inverse relationship between returns in the two surveys.

Dispersal:

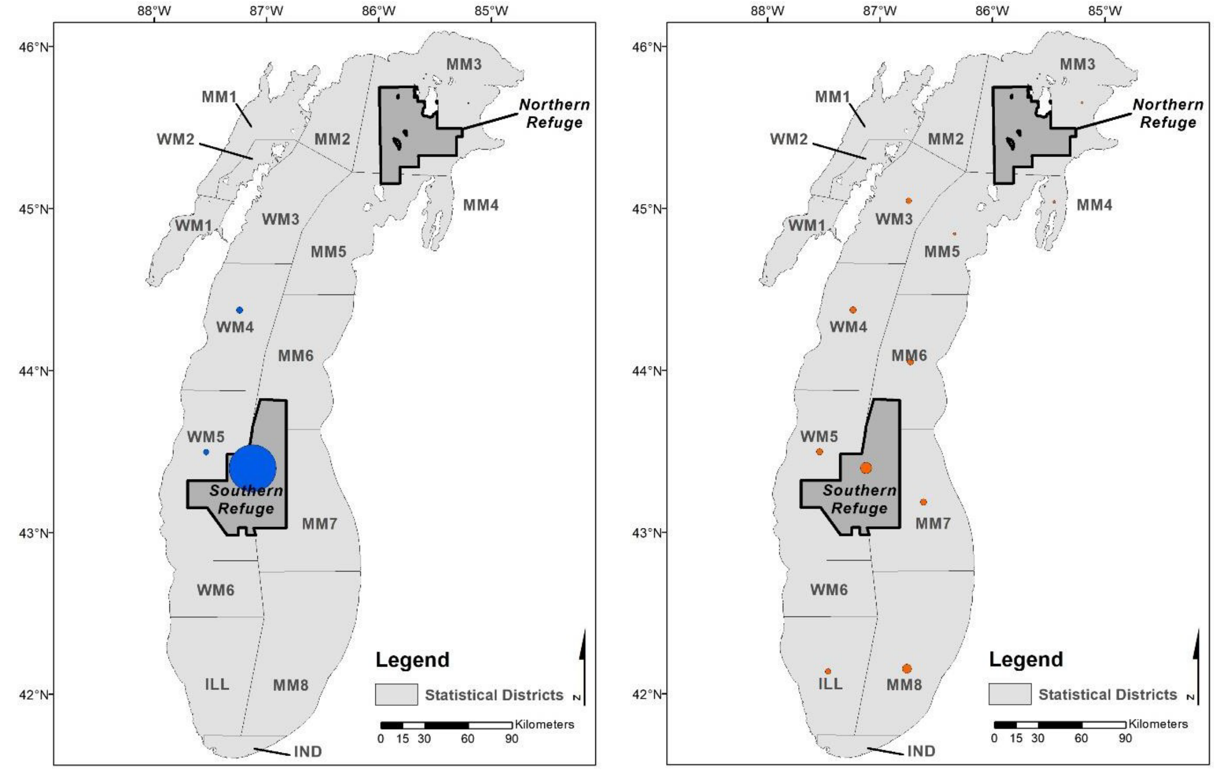


Figure 6. Return rates (CPUE) of Klondike humper strain (blue, left panel) and the Seneca Lake strain (orange, right panel) stocked in the Southern Refuge and recovered from each statistical district in the LWAP surveys. Circle size is proportional to CPUE and is on a consistent scale in both maps.

Only 3% of Klondike humper strain fish were recovered in nearshore areas outside of the Southern Refuge; conversely, 72% of Seneca strain fish were recovered in nearshore areas off-refuge.

Conclusion for the Southern Refuge:

The Klondike humper strain had substantially higher return rates than the Seneca Lake strain in LWAP surveys, which suggests higher relative survival. However, this pattern was driven by very high return rates of Klondike humper strain in LWAP surveys within the southern refuge. In 23 of 25 possible occurrences in statistical districts outside of the Southern Refuge, the Seneca Lake strain exhibited higher return rates in the LWAP survey than Klondike humper strain (statistical districts were specific to returns from each of four year-classes and were therefore represented multiple times in the analysis). Thus, LWAP survey catches indicated that Klondike humper strain were captured more frequently at offshore locations within the Southern Refuge where they were stocked and did not move nearshore, which was consistent with substantially higher return rates of Seneca Lake strain and relative rarity of

Klondike strain fish in the sport fishery. The Seneca Lake strain showed greater dispersal, were recovered in a broader range of statistical districts, and contributed more to the sport fishery than the Klondike humper strain. Ninety-seven percent (97%) of all Klondike humper strain fish were captured in the Southern Refuge, whereas only 28% of Seneca Lake strain were captured in the Southern Refuge.

II. Fish Stocked in the Northern Refuge

Return rates:

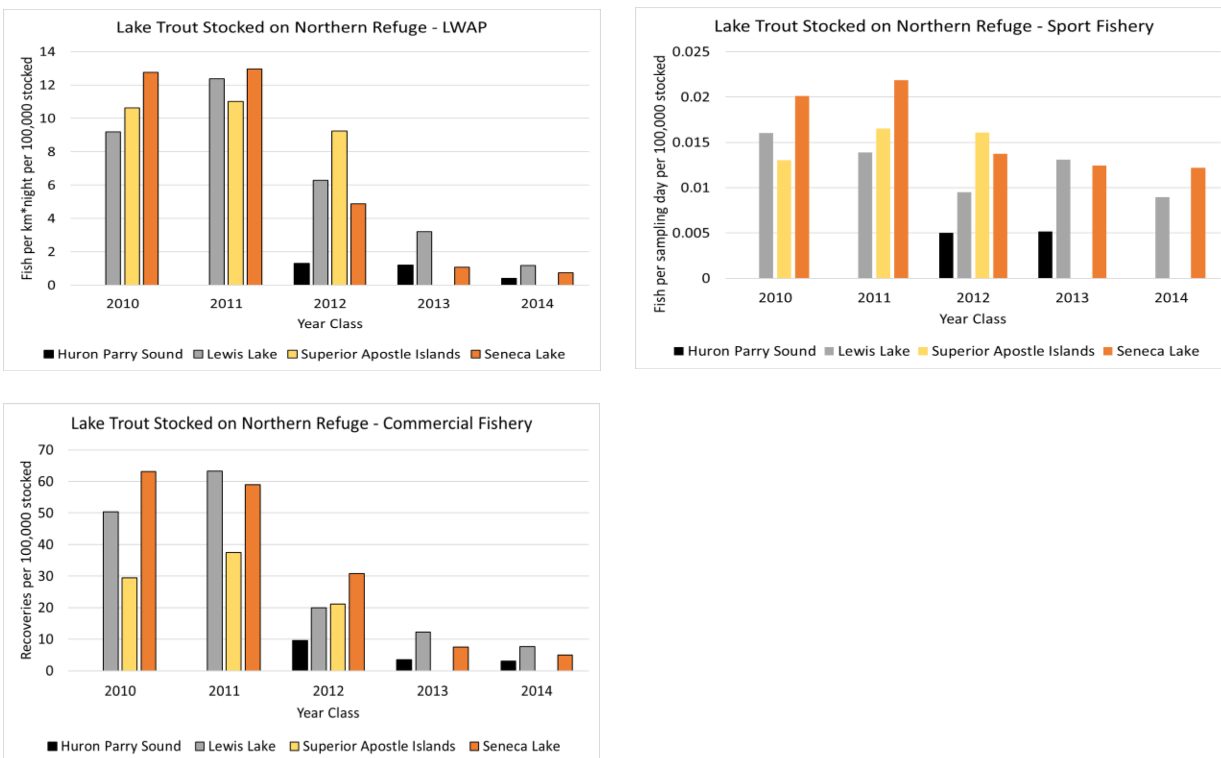
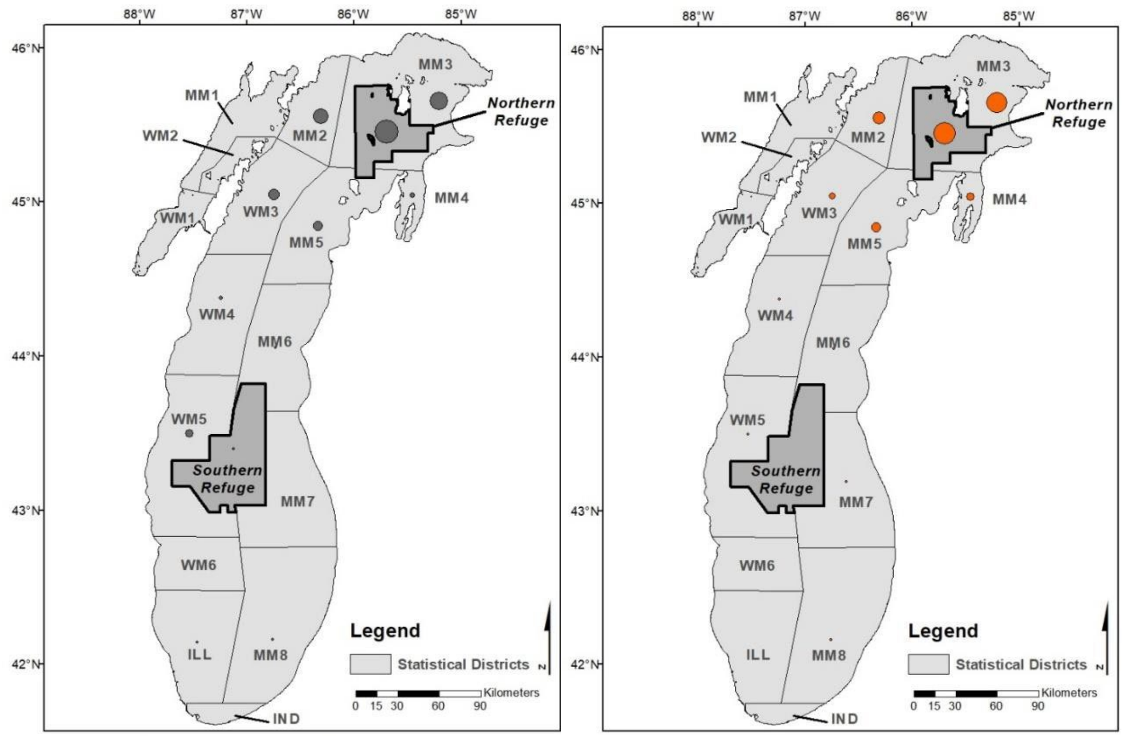


Figure 7. Return rate (CPUE) in the LWAP (top left), sport fishery (top right), and return rate in the commercial fishery (bottom left) of Parry Sound (black), Lewis Lake (gray), Apostle Islands (yellow) and Seneca Lake (orange) strains of lake trout stocked on the Northern Refuge.

The Seneca Lake and the Lewis Lake strains generally performed better than the Apostle Island and Parry Sound strain. Returns of the Apostle Islands strain, which was stocked through the 2012 year-class, were similar to the Seneca and Lewis Lake strains in the effort-corrected LWAP and sport fishery surveys but was lower in the commercial fishery, which was not corrected for effort (Figure 7). The Parry Sound strain had relatively low recoveries in all three data sources. Stocking of this strain began with the 2012 year-class, and these fish are just beginning to recruit to the surveys and fisheries making it premature to assess their performance.

Dispersal:



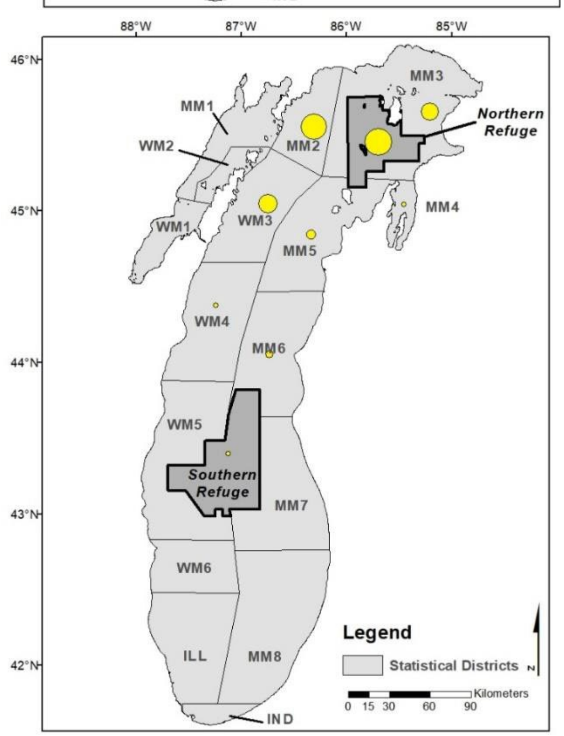


Figure 8. LWAP survey return rates (CPUE) of Lewis Lake strain (gray, top left panel), Seneca Lake strain (orange, top right panel), and Apostle Islands strain (yellow, bottom left panel) stocked in the Northern Refuge and recovered in each statistical district and refuge. Circle size is proportional to CPUE and is on a consistent scale in all maps.

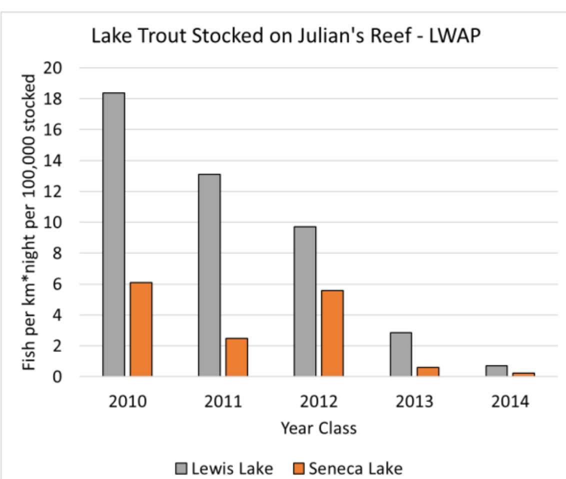
Based on LWAP catches, dispersal was similar for the three strains of lake trout stocked into the Northern Refuge. 71% of Seneca Lake strain, 61% of the Lewis Lake strain and 45% of the Apostle Islands fish were recovered within the Northern Refuge and MM3. The Apostle Islands strain of lake trout were recovered more frequently in waters to the west (MM2 and WM3) when compared to the other two strains, and 55% of returns (CPUE) occurred outside of the Northern Refuge or MM3.

Conclusion for the Northern Refuge:

It is too early to assess the performance of the Parry Sound strain. The Seneca Lake and the Lewis Lake strains had similar survival as evidenced by return rates from all three data sources. The catch rates of the Apostle Islands strain were similar to the Seneca and Lewis Lake strains in the LWAP survey and sport fishery but were lower in the commercial fishery. The dispersal of the three strains was similar for fish stocked into the Northern Refuge as most returns occurred within the Northern Refuge and MM3. However, the Apostle Islands lake trout were recovered more frequently in waters to the west (MM2 and WM3) compared to the other two strains and 55% of returns (CPUE) occurred outside of the Northern Refuge or MM3. The area encompassed by MM2 and WM3 is less frequently fished by commercial fishers than other areas of northern Lake Michigan, perhaps explaining the lower catch of Apostle Island strain in this data source.

III. Fish Stocked on Julian's Reef (IL)

Return rates:



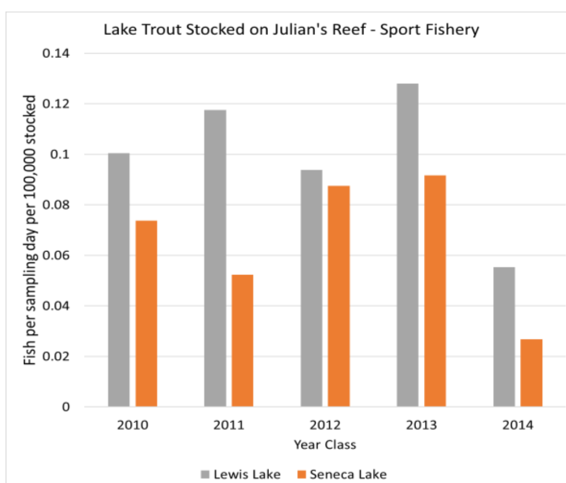


Figure 9. Return rate (CPUE) of Lewis Lake (gray) and Seneca Lake (orange) strains of lake trout stocked on Julian's Reef in the LWAP (left) and sport fishery (right) surveys.

Lewis Lake strain returned at a higher rate than the Seneca Lake strain in both the LWAP and sport fishery surveys. Kornis et al. (2019; see later section of this document) observed a similar pattern for CWT returns of remnant strains (Lewis Lake and Green Lake) of lake trout, which had greater relative survival compared to the Seneca Lake strain in southern Lake Michigan (1994–2003 year-classes). No lake trout stocked on Julian's Reef were recovered in commercial fishery monitoring efforts from 2011–2018.

Dispersal:

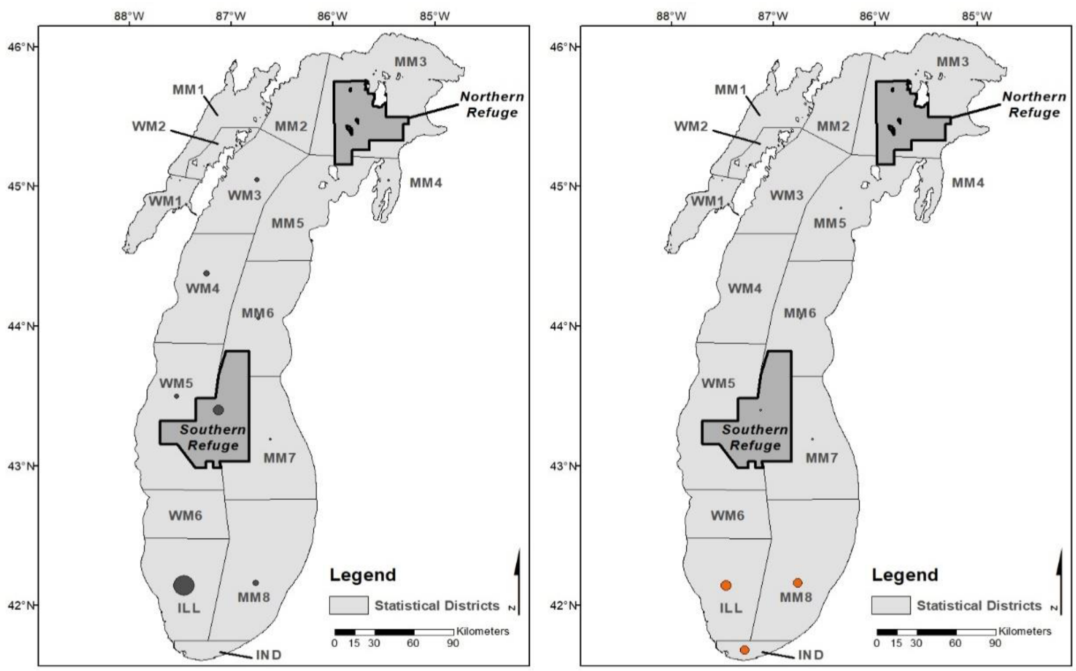


Figure 10. Return rates of Lewis Lake strain (gray, left panel) and the Seneca Lake strain (orange, right panel) in each statistical district and refuge in the spring fishery-independent gill net surveys. Circle size is proportional to CPUE and is on a consistent scale in all maps.

The Lewis Lake strain dispersed greater distances than Seneca Lake strain, which tended to remain in southern Lake Michigan. Lewis Lake fish were captured in LWAP surveys in the Southern Refuge as well as along the western shore of Lake Michigan up to the Door Peninsula. 31% of Lewis Lake strain returns (CPUE) occurred outside of ILL, IND and MM8 compared to only 8% for the Seneca Lake Strain.

Conclusion for Julian's Reef:

The Lewis Lake strain lake trout stocked on Julian's Reef had higher relative survival than Seneca Lake strain based on return rates in both LWAP and sport fishery surveys. The Seneca Lake strain was more likely to remain in southern waters of Lake Michigan (92% recovered in ILL, IND, and MM8, compared to 69% for Lewis Lake strain). Lewis Lake strain lake trout were captured over a broader range of statistical grids in LWAP surveys and 31% were captured outside of southern Lake Michigan waters. The broader dispersal range of Lewis Lake strain lake trout may have increased their contribution to sport fisheries.

IV. Fish Stocked in Nearshore Waters of Northeastern Lake Michigan (non-refuge MM3, MM4 and MM5)

Return rates:

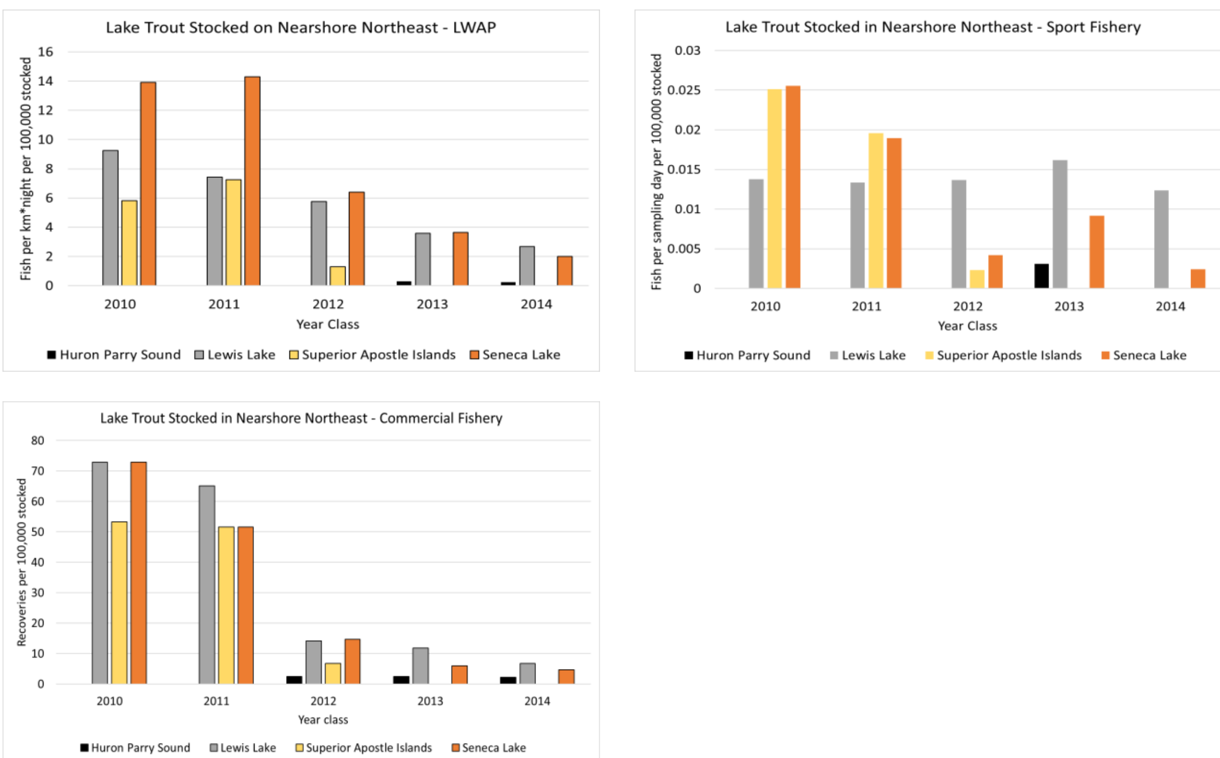


Figure 11. Return rate (CPUE) of Parry Sound (black), Lewis Lake (gray), Apostle Islands (yellow), and Seneca Lake (orange) strain fish stocked in nearshore areas of northeastern Lake Michigan. Recoveries are from the LWAP (top left), sport fishery (top right) and commercial fishery (bottom left).

The Seneca Lake strain had a higher return rates than the other strains in the LWAP survey for the 2010–2011 year-classes; Seneca Lake and Apostle Islands strain were both higher than Lewis Lake strain for the 2010-2011 year-classes in the sport fishery. Recoveries of the Seneca Lake and Lewis Lake strains were roughly equivalent in the LWAP survey and commercial fishery for the 2012–2014 year-classes, but the Lewis Lake strain had higher return rates to the sport fishery than the other strains from the same year- classes. In all sample sources, the Apostle Islands strain return rates were less than or equal to either the Lewis Lake or Seneca Lake strains. There were few observations of Parry Sound strain lake trout and it too early to fully evaluate the performance of the strain. Taken together, the results from the three return sources suggested roughly equivalent performance of the Lewis Lake and Seneca Lake strains with some variation among year-classes and return sources.

Dispersal:

Dispersal was difficult to estimate because the stocking group encompassed a wide area of the lake. Seneca Lake, Lewis Lake, and Superior Apostle Island strains had similar dispersal where 79–90% of the lake-wide returns (CPUE) occurred within MM3, MM4, MM5 and the Northern Refuge. Dispersal of the Parry Sound strain was not evaluated due to low returns.

V. Nearshore waters of southeastern Lake Michigan (MM6, MM7, MM8 and IND)

Return rates:

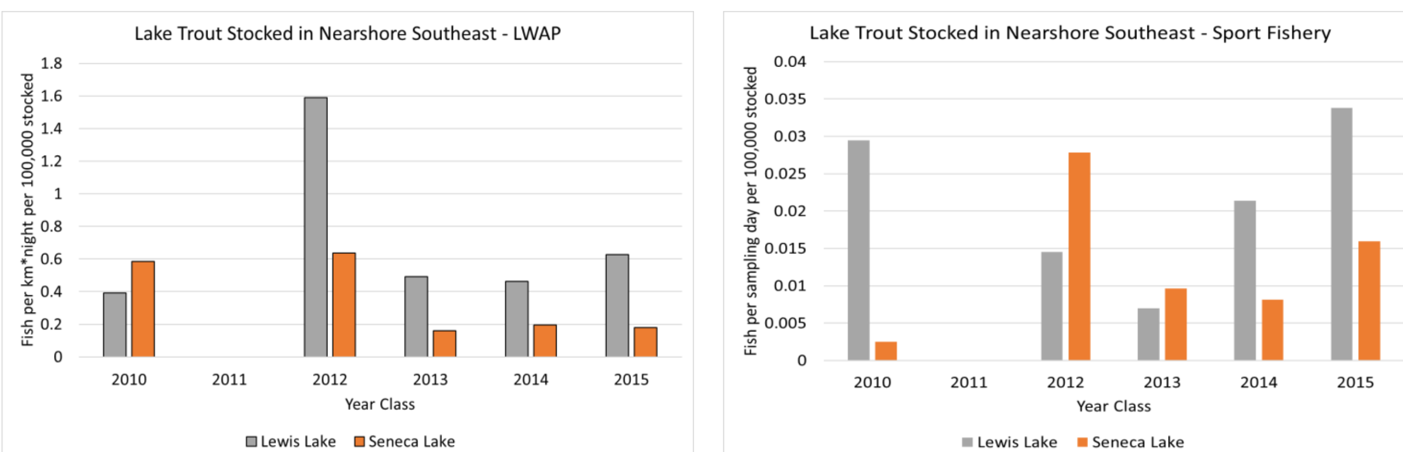


Figure 12. Return rate (CPUE) of Lewis Lake (gray) and Seneca Lake (orange) strains of lake trout stocked in nearshore areas of southeastern Lake Michigan. Data from the LWAP (left) and sport fishery (right) surveys are shown. The 2011 year-class only involved the stocking of the Seneca Lake strain in this area

of Lake Michigan, so we omitted the data from the 2011 year-class as there were no Lewis Lake strain fish to compare with. Note that all fish from the 2013 and 2014 year-classes of Seneca Lake fish were stocked as fall fingerlings, while Lewis Lake fish from those year-classes were either a mix of fall fingerlings and yearlings (2013 year-class) or all yearlings (2014 year-class). The Lewis Lake strain of lake trout had substantially greater returns than the Seneca Lake strain in both the LWAP and sport fishery for most year-classes even when considering only those year-classes where all fish were stocked as yearlings (2010, 2012 and 2015 year-classes).

Dispersal:

Dispersal was difficult to estimate because the stocking group encompassed a wide area of the lake. For both strains, most recoveries were within the stocking area – 87% of Seneca Lake returns (CPUE) and 97% of Lewis Lake strain returns (CPUE) occurred within the nearshore waters of southeastern Lake Michigan.

Overall summary of performance of strains in the fishery independent survey (LWAP), and in the commercial and sport harvest

- Across all data sources, Lewis Lake strain lake trout generally had higher return rates in fishery-independent surveys and the sport fishery than Seneca Lake strain when stocked at southern locations. This finding is consistent with returns of older year-classes in LWAP surveys reported by Kornis et al. (2019).
- The Seneca Lake strain generally had equal or higher return rates than Lewis Lake strain when stocked at northern locations.
- Klondike humper Strain lake trout had a substantially higher return rates than the Seneca Lake strain in LWAP surveys when stocked in the Southern Refuge. The vast majority of Klondike humper strain lake trout (97%) were captured in the refuge, and hence few moved to nearshore areas as none were captured by the sport fishery.
- Apostle Islands strain lake trout were only stocked in the north and generally had equal or lower return rates than either Lewis Lake or Seneca Lake strains.
- The Klondike humper strain lake trout had lower dispersal rates than the other strains and remained for the most part in the Southern refuge area where they were stocked.
- The Lewis Lake strain dispersed more from Julian's Reef than the Seneca Lake strain which remained in southern Lake Michigan.

Conclusions

Spatial considerations are important when selecting strains to stock and evaluating overall performance.

- Seneca Lake fish survive better in areas with higher lamprey populations.
- Where risks of lamprey predation are lower, Seneca Lake relative survival is equal to or lower than returns of the Lewis Lake strain.

Broader dispersal mechanisms may increase vulnerability to sport and commercial fisheries.

- Lewis Lake fish tended to disperse broadly relative to other strains and were more frequently captured in sport fisheries.
- Klondike humper strain lake trout exhibited minimal dispersal from their Southern Refuge stocking location and thus were not encountered by sport fisheries.

Legacy coded-wire tag evaluations 1994-2003 (Kornis et al. 2019; NAJFM):

Kornis et al. (2019) examined recoveries of legacy coded-wire tagged lake trout from the 1994-2003 year-classes in spring gill net assessment surveys (1998–2014). Lake Michigan remnant genetic strains (Lewis Lake and Green Lake) had higher return rates (CPUE per 100,000 stocked) than Seneca Lake strains in the southern basin of Lake Michigan. This result was probably linked to lower lamprey-induced mortality in southern Lake Michigan, which would negate any competitive advantage that the Seneca Lake strain may have in avoiding sea lamprey predation. The figure below is excerpted that study and reprints are available from Matt Kornis or at https://www.researchgate.net/profile/Matthew_Kornis/publication/334754747_Factors_Affecting_Postrelease_Survival_of_Coded-Wire-Tagged_Lake_Trout_in_Lake_Michigan_at_Four_Historical_Spawning_Locations/links/5e18cbb492851c8364c2d968/Factors-Affecting-Postrelease-Survival-of-Coded-Wire-Tagged-Lake-Trout-in-Lake-Michigan-at-Four-Historical-Spawning-Locations.pdf

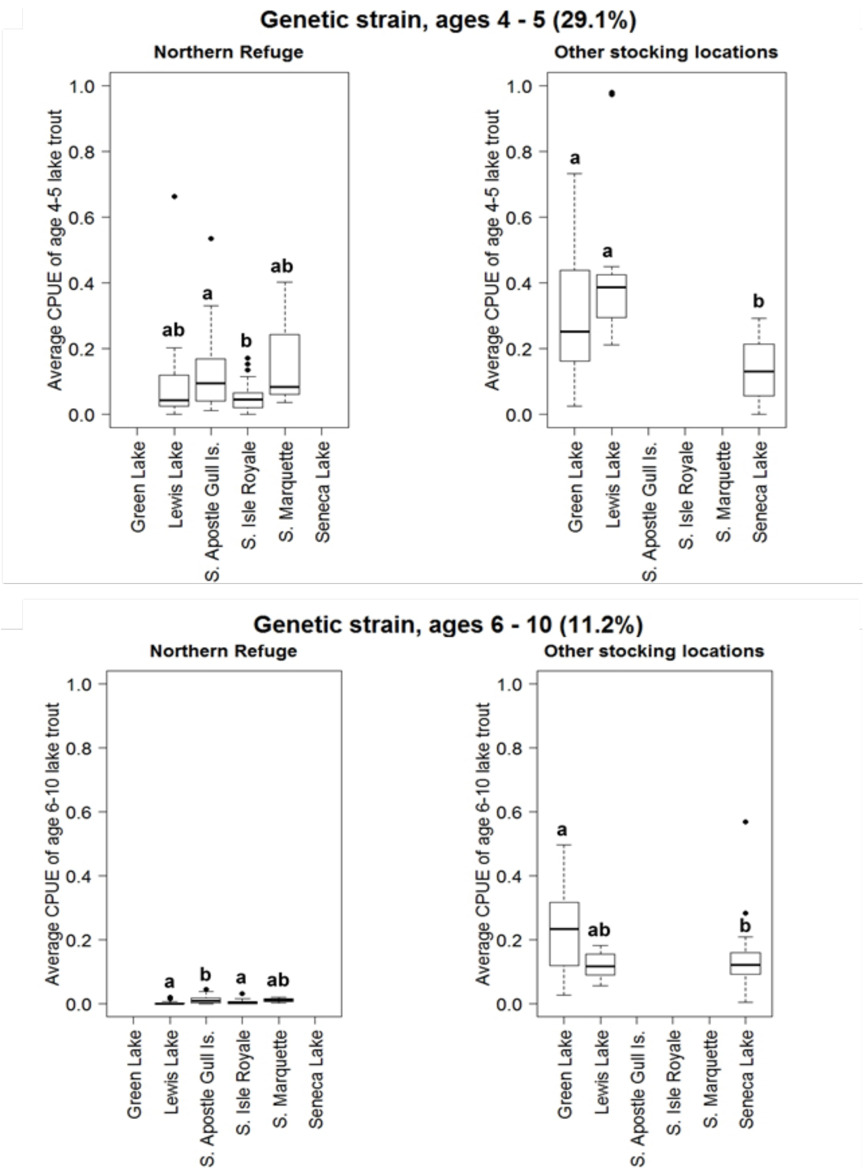


Figure 13: Effect of genetic strain on average relative survival of younger (top) and older (bottom) lake trout in the Northern Refuge (left) and three other stocking locations (right; from Kornis et al. 2019. Percentages are the average relative influence of this predictor in the age group-specific boosted regression tree models. Effects are split between the Northern Refuge and other stocking locations due to the large effect of stocking location on lake trout relative survival, and an interaction between genetic strain and stocking location identified by the boosted regression tree analysis. Groups with the same letters are not statistically different. "S." stands for "Lake Superior".

3. Genetic composition of wild fish in the population

Larson et al. (2020) used genotypes from 36 microsatellites to investigate strain compositions of naturally produced lake trout (i.e., wild recruits) sampled across Lake Michigan.

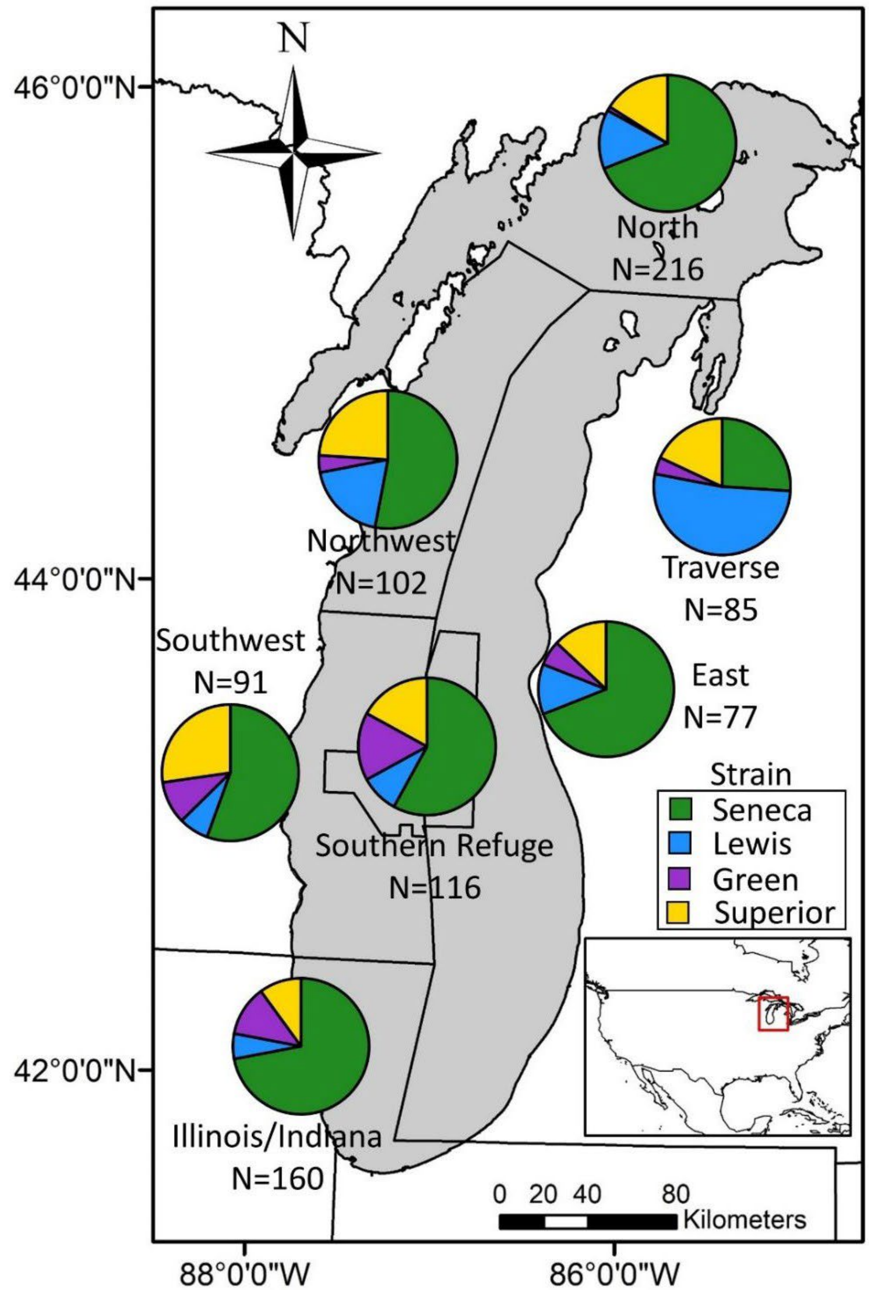


Figure 14. Estimates of the genetic proportion of reference strains for wild recruits from seven geographic strata in Lake Michigan. Sample sizes are below each pie. Colors represent reference strains.

With the exception of Grand Traverse Bay, the composition of strains in natural recruits was relatively consistent throughout Lake Michigan. Seneca Lake strain contributed the most to wild recruits, with Apostle Islands and Lewis Lake strains providing secondary genetic contributions. In Grand Traverse Bay, the Lewis Lake strain was the primary contributor to naturalized lake trout with Apostle Island and Seneca providing secondary contributions.

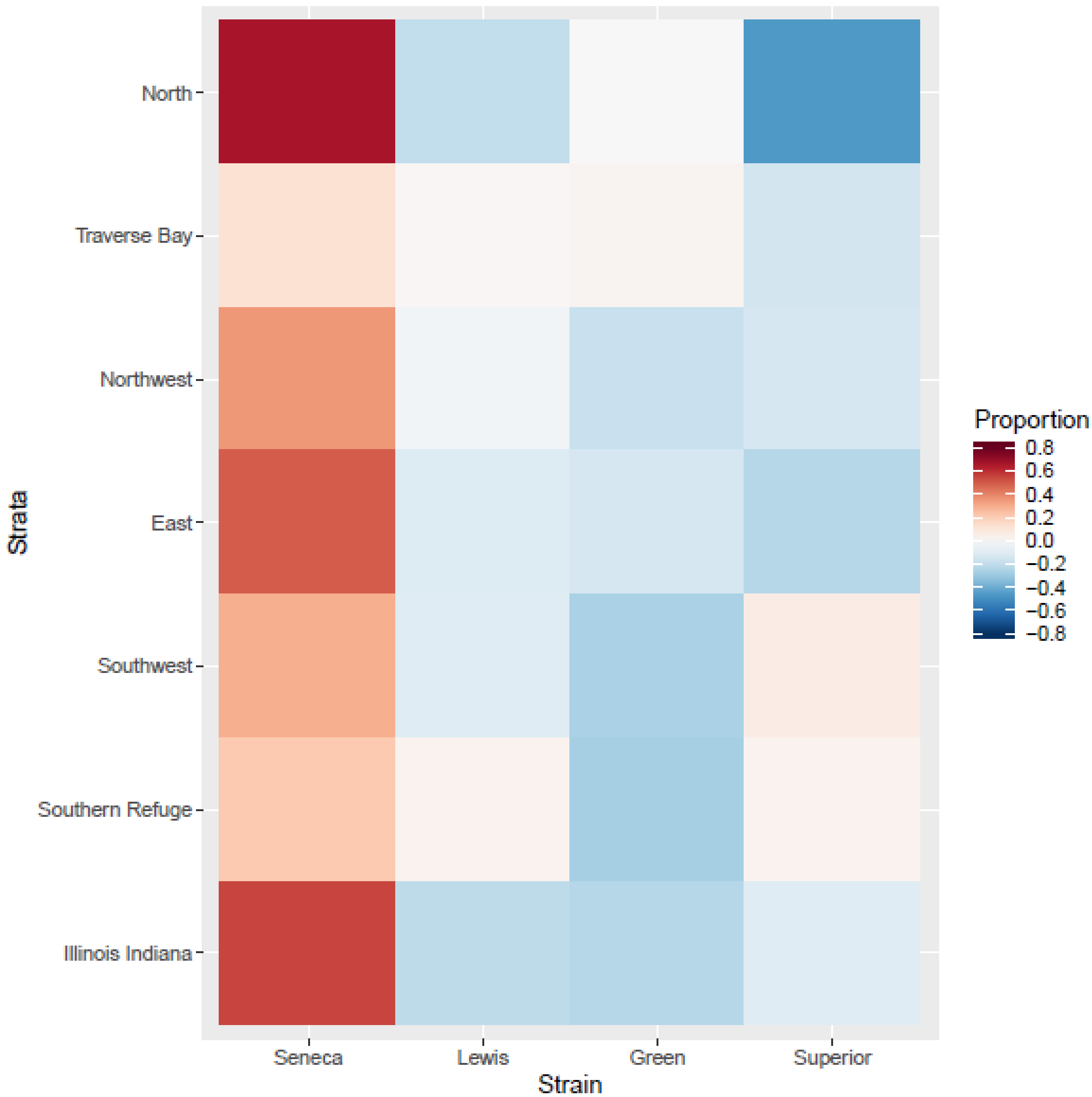


Figure 15. Heatmap of observed versus expected strain proportions of wild lake trout recruits from seven geographic strata in Lake Michigan. Observed proportions were calculated from genetic data and expected proportions were calculated from stocking data that accounted for pre-spawning movement

among regions and age-specific fecundity (Larson et al. 2020). Positive values (warm colors) indicate a given strain is overrepresented in the genetic data relative to stocking levels.

When genetic contributions to wild recruits are considered based on stocking rates, our earlier observations prove consistent. In all units evaluated, the Seneca Lake strain had a higher representation of genetic contributions than would be expected, and the highest contributions were observed in northern Lake Michigan. Conversely, the Green Lake strain genetics were underrepresented based on stocking rates in naturally produced lake trout. The Lewis Lake and Apostle Islands strains had genetic contributions to wild recruitment that were similar to what was expected from stocking rates and were secondary contributors to wild recruitment (results varied by region).

It is possible that the movement of wild lake trout recruits from areas such as the Southern Refuge, where the Seneca Lake strain is heavily stocked, may at least partially explain the large differences between observed and expected proportions for Seneca Lake strain, especially in the Northern region. Fewer wild recruits are observed in the northern area of Lake Michigan, so many of the wild fish observed in this area may have immigrated from other locations. Movement of naturally produced lake trout from recruitment hotspots in southern Lake Michigan to other areas is worth additional consideration and may influence observed and expected proportions in other areas of the lake as well.

Figure 16. Heatmaps of observed versus expected proportions of pure and hybrid crosses for seven geographic strata in Lake Michigan. Observed proportions for both panels (a) and (b) were the proportions of each cross type observed in the genetic data. Expected proportions for panel (a) were calculated based on stocking data. In panel (b), simulations were used to calculate the frequency of each cross type expected under random mating given the proportions of each strain. These expected values based on random mating were then compared to observed proportions of each cross type. Positive values (warm colors) indicate a given cross type is overrepresented in the genetic data and simulations.

Contributions to wild lake trout based on stocking rates and including observations of hybridization are presented in Figure 16. Similar to observations of pure strain naturalized fish (Figure 15), inter-strain hybrid wild recruits that included the Seneca Lake strain were slightly better represented than expected from stocking rates (Figure 16a). When simulations were run to calculate the expected frequency of mating between strains, observations of genetic contributions indicated that strains in Lake Michigan are essentially breeding at random (i.e., lake trout do not only mate with members of the same genetic strain; Figure 16b).

Evaluations of Parry Sound and Klondike humper strains are incomplete as they were only recently introduced and hadn't reached maturity for this evaluation. When multiple cohorts of these strains have reached maturity, further evaluation is needed to determine how Parry Sound and Klondike humper strains contributed to wild recruitment of lake trout in Lake Michigan.

Upcoming summer winter 2021 meeting products

1. Biological and technical-based recommendations regarding strategies for use of strains going forward.
2. A summary of future research needs, data gaps, information needs.
3. Synthesize forces and changes that led to natural reproduction of lake trout in Lake Michigan.

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