Lake Michigan
Salmonine Stocking
Strategy
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Lake Michigan Committee

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Background

Lake Michigan is a dynamic ecosystem that has been significantly altered by the introduction of invasive and exotic species. Introduced Pacific salmon (coho and Chinook salmon) in the 1960s provided top-down predatory control for the invasive alewife, and established an extensive recreational fishery. At that time, predator-prey dynamics were most influenced by top-down mechanisms. As managers increased Chinook salmon stocking through the early 1980s, angler catch and harvest likewise increased. Eventually, the amount of stocked Chinook salmon exceeded the available prey and the Chinook salmon population became stressed. Intensive culture of Chinook salmon that carried the Bacterial Kidney Disease (BKD) pathogen resulted in a disease outbreak in the stressed lake population. Although stocking reductions occurred during the BKD outbreak, the first concerted effort to bring the predator-prey relationship into balance, resulting in a 25% lakewide reduction in Chinook salmon stocking, occurred in 1999.

As Lake Michigan's productivity continued to decrease through the 2000s, fishery managers continued to see signs of low prey biomass and over-abundance of predators. In ongoing efforts to achieve predator-prey balance, Chinook salmon stocking was reduced lakewide by 25% in 2006 and 50% in 2013. A subsequent stocking reduction of 900,000 Chinook salmon equivalents (see explanation of equivalents later in this document) was recommended in 2016 and implemented during 2017 and 2018. This reduction represented a change in management strategy from only reducing Chinook salmon to multi-species reductions (including Chinook salmon, coho salmon, lake trout, brown trout and rainbow trout) beginning in 2017. In 2020, agencies increased stocking numbers because of a better predator-prey balance likely brought on by the reductions implemented from 2016-2019. An additional stocking increase occurred in 2023 as predator-prey balance remained favorable. While the actual cause for decreased lakewide productivity has yet to be established, it is apparent that top-down management of the prey resource is no longer a simplistic mechanism. The shift in productivity has contributed to reduced and sporadic prey fish production, which has resulted in variable growth and survival of predatory salmon and trout.

To evaluate the increasingly complex set of information on the Lake Michigan fishery, the Salmonid Working Group of the Lake Michigan Technical Committee created an approach called the "Red Flags". The Red Flags were used from 2004 through 2014 to evaluate the Lake Michigan fishery. Stocking adjustment recommendations were triggered by deviations from historic trends for 15-20 individual time-series of biological and fishery indicators.

The Lake Michigan Technical Committee's Red Flags Analysis was utilized to identify imbalance in the relation between predators and prey fish and was critical for determining when a change in management strategy was justified. Previous changes to stocking levels also were guided by the CONNECT model and a salmon stocking model developed by Drs. Michael Jones and Jim Bence, both with the Quantitative Fisheries Center at Michigan State University. Following a 2005 meeting, the Lake Michigan Committee (LMC) decided that a re-development and expansion of the salmon stocking model would be beneficial in guiding future stocking

recommendations. The redeveloped salmon decision model included catch-at-age model components for estimation of alewife biomass and standing stock of Chinook salmon predators. The model was run for several scenarios (e.g., status quo or 25% reduction in Chinook stocking) and model outputs were used in evaluation of risks (e.g., alewife population collapse) associated with different management actions.

A 50% reduction in Chinook salmon stocking, in addition to altering future stocking based on a Chinook salmon weight feedback mechanism (3-year evaluation), was generally preferred by fishery managers and constituents. This option provided for more rapid reaction to predator-prey imbalance compared to the other options under consideration (3-year vs. 5-year evaluation) and resulted in reduced risk of low alewife biomass, decreased Chinook salmon weights, decreased Chinook salmon harvest, and decreased Chinook salmon catch-per-unit-effort (CPUE).

In addition to adopting the 50% reduction option, several other key decisions were made during this period to guide salmonid management in the future:

1) 2012 stocking plans were established as the stocking baseline
2) Species equivalents could be used in some situations to account for different numbers of salmonids in agency hatcheries
3) The LMC reaffirmed its support for lake trout rehabilitation
4) The LMC agreed to limit overages of actual stocking numbers to 5% of target production numbers
5) The LMC agreed to use a feedback mechanism to identify a predator-prey imbalance and change the salmon stocking strategy when needed
6) Until a better indicator was developed, the LMC adopted weight of age 3+ female Chinook salmon at the Strawberry Creek Weir (WI) as a feedback mechanism trigger.

For a full description of this information, please read the document titled "Lake Michigan Salmonine Stocking Strategy, Lake Michigan Committee, July 2014." http://www.glfc.org/pubs/lake_committees/michigan/Lake%20Michigan%20Committee%20Salmon%20Stocking%20Strategy%202014.pdf

A critical review of the Red Flags Analysis was started in 2012 and completed in 2014. This review led to a new approach called the predator-prey ratio (PPR) analysis. This analysis is based on a simple concept of maintaining a predator (Chinook salmon) and prey (alewife) balance, but incorporates detailed datasets and analytical approaches to account for the complexity in the Lake Michigan fishery. The PPR analysis was created with the intention of replacing the Red Flags Analysis.

Herein, we describe how the PPR analysis will be used to inform salmonine stocking levels in future years. First, we describe the PPR approach, associated secondary indicators and additional principles (e.g., Fish Community Objectives) that the LMC views as important when making stocking adjustment recommendations. Then we present a salmonine stocking

strategy that incorporates the PPR as a feedback mechanism trigger to inform the LMC about appropriate stocking adjustments to achieve and maintain balance in predator and prey fish communities. Maintaining balance between predators and prey is key to sustaining quality fisheries because too many predators might contribute to substantial reductions in prey populations (e.g., alewife in Lake Huron) and too few predators may lead to inefficient use of resources and overabundant prey populations (e.g., alewife in Lake Michigan during the 1960s). The guidance provided in this strategy document supersedes the guidance provided by the LMC in its 2014 document titled *Lake Michigan Committee Salmon Stocking Strategy* and in its 2018 document titled *Lake Michigan Salmonine Stocking Strategy November 2018.*

Chinook Salmon and Alewife Predator-Prey Ratio

The PPR is used to annually evaluate the relationship between salmonine predators and prey fish in Lake Michigan. Specifically, it is a ratio of total lakewide biomass of Chinook salmon (≥ age 1) to total lake-wide biomass of alewives (≥ age 1; Figure 1). Statistical-catch-at-age (SCAA) models are used to estimate abundance of Chinook salmon and alewife by age class using data from multiple agency surveys. Abundance estimates are then multiplied by species- and age-specific average body weights and summed across ages to generate total lakewide biomass estimates for each species. For example:

$$(abundance \times ave.weight\ of\ age\ 1\ Chinook)$$
$$+ (abundance \times ave.weight\ of\ age\ 2\ Chinook)$$
$$+ (etc.\ for\ each\ age\ class) = total\ Chinook\ biomass$$

The ratio of Chinook salmon to alewife biomass is used as an indicator of lakewide balance of predators and pelagic prey because Chinook salmon and alewife are principal components of the sport fishery and pelagic prey fish community, respectively, which provide adequate data for producing biomass estimates for both species. The PPR is relatively simple to interpret: a high ratio suggests too many predators with few prey fish, while a low ratio suggests too few predators with abundant prey. Although conceptually simple, the ratio is a very comprehensive and complex analysis that incorporates datasets from multiple agencies throughout Lake Michigan and integrates many of the predator and prey fish population parameters formerly used in the Red Flags Analysis.

A target of 0.05 and an upper limit of 0.10 have been established as reference points to guide interpretation of PPR results. These values were chosen based on literature reviews, risk assessment models from previous stakeholder meetings, and comparisons with Lakes Huron and Ontario. For example, ratio values near the 0.05 target suggest an acceptable predator-prey situation, whereas, ratio values approaching or above the upper limit of 0.10 suggest an unbalanced and potentially problematic ratio with overabundant predators relative to available prey biomass.

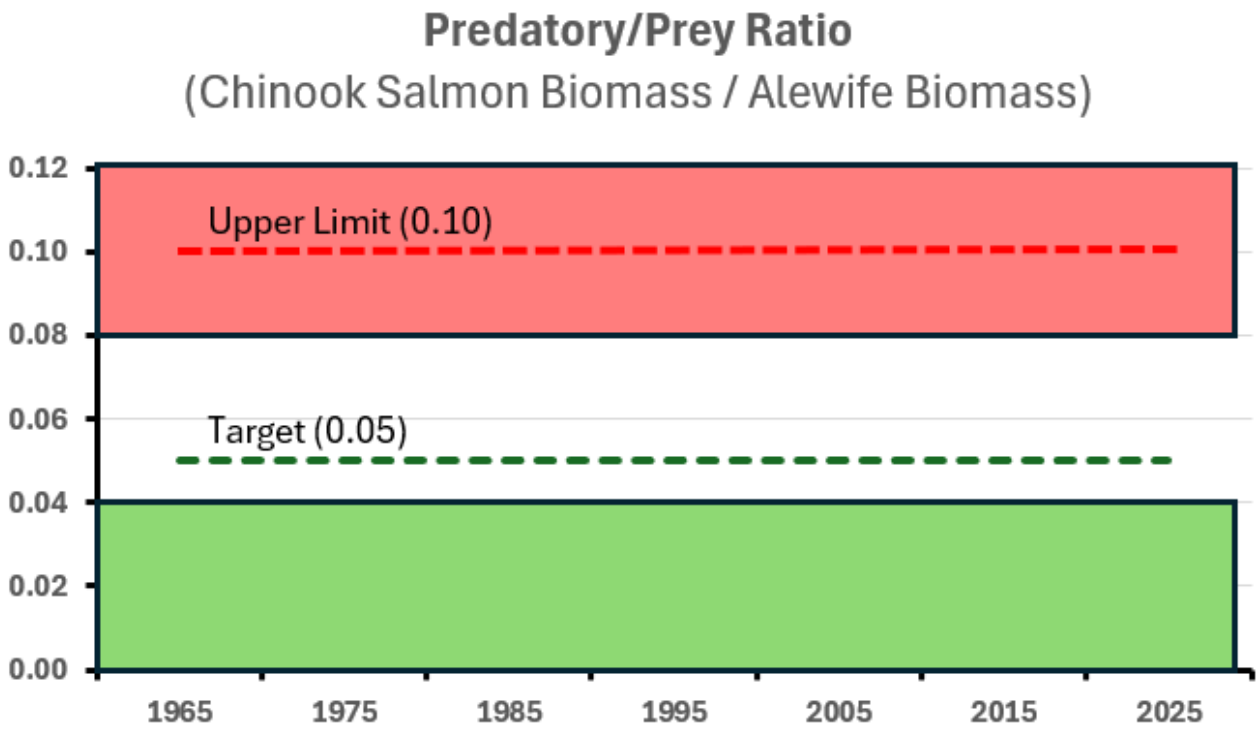

Figure 1. Predator-prey ratio (PPR) with target and upper limit reference points and color coded management action zones.

The LMC has set management action zones to help determine when discussions on modifications to lakewide stocking should be considered. The red area in Figure 1 (ratio at or above 0.08) suggests stocking reductions might be needed, the white area (ratio between 0.04 and 0.08) suggests no change in stocking is necessary and the green area (ratio at or below 0.04) suggests stocking increases might be needed.

The biological and fishery data needed to generate the PPR comes from a variety of sources and includes information from multiple agencies and species. These datasets are critical components of the analysis and represent extensive federal, state and tribal resource expenditures. Continued agency support for these projects should remain a high priority. Following is a list of lakewide datasets that are updated yearly and used in the analysis.

Lake-wide datasets used for Chinook salmon SCAA:

- Number of Chinook salmon stocked
- Percent wild for age-1 Chinook salmon (mass marking)
- Number of Chinook salmon harvested (charter & creel)
- Targeted salmonine boat fishing effort (charter & creel)
- Age & maturity of Chinook salmon harvested (creel & mass marking)
- Average weight of Chinook salmon harvested (creel & mass marking)
- Standard weight of 35-inch Chinook salmon
- Chinook salmon age composition from fall weir and harbor sampling

Lake-wide datasets used for alewife SCAA:

- Alewife abundance (trawl & hydro-acoustic)
- Age and weight distributions of alewife (trawl or hydro-acoustics)
- Numbers of salmon and trout stocked
- Estimates of salmon and trout abundance and consumption

(Contributing agencies for Chinook & alewife SCAA data include: Chippewa-Ottawa Resource Authority (CORA), Illinois Department of Natural Resources (DNR), Indiana DNR, Michigan DNR, U.S. Fish & Wildlife Service (USFWS), U.S. Geological Survey (USGS), & Wisconsin DNR.)

Secondary Indicators

Six secondary indicators also were developed to complement the PPR and provide additional information on predator and prey fish balance. Secondary indicators are calculated with lakewide datasets from several management agencies and include:

1) average weight of age-3 female Chinook salmon from fall weir and harbor surveys,
2) catch-per-hour for Chinook salmon from charter boats,
3) percent composition of angler harvested weight by species,
4) lakewide biomass of alewives,
5) annual alewife mortality and
6) age structure of the alewife population.

Additional Principles

In addition to the PPR and secondary indicators, the LMC will evaluate the levels of salmon and trout in Lake Michigan and the available prey to determine if objectives, as outlined in "Fish-Community Objectives for Lake Michigan. 1995," are being met. Specifically, these objectives call for the following:

Establish a diverse salmonine community capable of sustaining an annual harvest of 2.7 to 6.8 million kg (6 to 15 million lb), of which 20-25% is lake trout and establish self- sustaining lake trout populations.

Maintain a diversity of planktivore (prey) species at population levels matched to primary production and to predator demands. Expectations are for a lakewide planktivore biomass of 0.5 to 0.8 billion kg (1.2 to 1.7 billion lb).

In addition to making recommendations about the balance of predators and prey that are consistent with the Fish Community Objectives for Lake Michigan, the LMC will also seek consistency with other LMC-approved guidance documents, including *A Stocking Strategy and Evaluation Objectives for the Rehabilitation of Lake Trout in Lake Michigan*. (Stocking Strategy) https://www.glfc.org/pubs/lake_committees/michigan/LMC%20-%20LAT%20Implementation%20Strategy.pdf

Salmonine Stocking Strategy with PPR

In 2016, the LMC responded to record low alewife abundance estimates and a PPR value in excess of the 0.10 upper limit and recommended a predator stocking reduction of 900,000 Chinook salmon equivalents to be implemented over 2 years (2017 and 2018). This stocking reduction represented a change in strategy from only reducing stocking of Chinook salmon (as in 1999, 2006 and 2013) to including all stocked salmon and trout species (i.e., Chinook salmon, coho salmon, lake trout, rainbow trout and brown trout) in agency stocking reduction proposals.

In 2020, and again in 2023, the LMC agreed to increase predator stocking in response to improved PPR values that were below the 0.05 target.

The LMC has agreed to continue the use of this multispecies approach for stocking adjustments based on Chinook salmon equivalences and to use the PPR as a primary feedback mechanism to inform stocking decisions until a new strategy is adopted by the committee.

Species equivalence

Fishery biologists commonly agree that not all species are equivalent in terms of diet requirements, overlap with specific prey fish, annual consumption or consumption over lifespan. "Chinook salmon equivalents" were developed in the 1980s for Lake Michigan salmonines as a way to compare prey fish consumption rates among species. The LMC has adopted these equivalence values (Table 1) for use in this stocking strategy. In addition, the LMC adopted a previously proposed equivalence rate for lake trout of 1.0 fall fingerling = 0.4 yearling lake trout. While these equivalence values are currently the best option for comparisons among stocked species, future research may provide updated values better suited to current lake conditions. The LMC will evaluate and consider using updated equivalence values should they become available in the future.

Table 1. Number of each species equivalent to one stocked Chinook salmon.

Species	Number of fish equivalent to one (1) Chinook salmon
Chinook salmon	1.00
Coho salmon	3.20
Lake trout (yearling)	2.30
Lake trout (fall fingerling)	5.75
Rainbow trout	2.40
Brown trout	2.20

Per LMC agreement, agencies will use species equivalences in Table 1 to determine the numbers of salmon and trout to be stocked in their jurisdictions when stocking adjustments are deemed necessary. Agencies may also account for hatchery shortages of one species by stocking more of a different species by using these species equivalences such that the number

of Chinook salmon equivalences stays the same (e.g., replace a 24,000 rainbow trout shortfall with 32,000 coho salmon).

Lake trout rehabilitation and changes to stocking

The LMC reaffirmed its commitment to lake trout rehabilitation for Lake Michigan with a stocking goal of 2.285 million yearlings, consistent with stocking location priorities outlined in its document, *A Stocking Strategy and Evaluation Objectives for the Rehabilitation of Lake Trout in Lake Michigan.* Reductions in lake trout stocking from the previous stocking target of 2.75 million yearlings resulted in the elimination of lake trout fall fingerlings in 2016 and reductions in yearlings in 2017 and 2018, in recognition of the strong imbalance between trout and salmon predators and their pelagic prey. The LMC acknowledges: 1) the USFWS should be notified of any LMC requests to modify the stocking plans outlined in the updated Stocking Strategy (including revised tables); 2) when changes to lake trout stocking numbers are requested, fish already in the hatchery system should be used for stocking; 3) there is a lag between development of fish for stocking and potential requests for stocked fish; and, 4) changes to numbers of lake trout requested per the Stocking Strategy will likely become permanent if USFWS reduces its production capacity to coincide with LMC requests for reduced lake trout stocking (i.e., it will be very difficult for USFWS to reinstate a stocking event that has been discontinued by the LMC).

Planned and actual numbers

The LMC has agreed in good faith to keep actual stocking numbers of salmon and trout as near to target production numbers as possible. Deviations from targeted production numbers will be determined on an agency and calendar year basis by comparing production target totals for all species combined (measured in Chinook salmon equivalents) with equivalence measures of the actual number of stocked fish. Maintaining accurate stocking numbers will require communication between LMC members and their respective state hatchery managers. In addition, USFWS should be notified regarding changes to target lake trout production numbers, as the number of lake trout stocked should also be as near to the stated stocking target as possible.

Feedback mechanism and frequency of stocking adjustments

The LMC adopted the PPR approach in 2014 with the intent to develop protocols on how this analysis would inform stocking recommendations in the future. After much discussion, the LMC decided to evaluate the PPR on an annual basis, along with the six secondary indicators and related Fish-Community Objectives targets, to guide future stocking recommendations. Except under extenuating circumstances, the LMC does not anticipate additional lakewide stocking changes for a minimum of 3 years following implementation of an adjustment. However, agencies can adjust individual species stocking numbers within their jurisdiction, as needed, assuming no net gain in stocked predator equivalences and assuming consistency with the LMC's lake trout stocking strategy.

The LMC will use the following protocol to determine if salmonine stocking levels need to be

adjusted.

1) Determine the current year PPR value. If the last two annual ratio values are within the red zone (at or above 0.08; see Figure 1), the LMC will hold discussions to determine if stocking reductions are appropriate. If the last two annual ratio values are within the green zone (at or below 0.04) and prey fish abundance is deemed adequate (e.g., alewife biomass > 100 kt), the LMC will hold discussions to determine if stocking increases are appropriate. If the last two values are within the white zone (between 0.04 and 0.08), the LMC will hold discussions to confirm that no change in stocking is necessary. Discussions will take place during the summer and a final recommendation to management agencies will be made prior to fall egg take. For example, during the summer, the LMC will evaluate the current and previous year's PPR values. If both values are in the red zone or both values are in the green zone, the Committee will discuss stocking changes.

2) The six secondary indicators will be calculated and made available for review annually. When the PPR triggers a stocking adjustment discussion, the LMC will evaluate the six secondary indicators to help determine an appropriate course of action (e.g., alewife biomass > 100 kt and increasing, fall weight of age-3 female Chinook salmon above 15 pounds and increasing, and charter boat angler catch rates declining would support a stocking increase).

3) Evaluate estimates of salmon and trout harvest potential and planktivore biomass in relation to achievement of Lake Michigan Fish-Community Objectives.

Baseline stocking numbers

The LMC used 2012 state agency stocking plan numbers, rather than actual stocking numbers for Lake Michigan, as a baseline for the 2013 stocking reduction. For the most recent stocking reduction, the LMC agreed to use the average of the number of salmon and trout stocked from 2013-2015 as a more realistic baseline. These stocking data were provided by each jurisdiction and were based on calendar year (January 1-December 31). Numbers stocked were converted to Chinook salmon equivalents using values from Table 1. Species other than lake trout do not have fingerling-to-yearling conversion values, so the same equivalency value was used for fingerlings and yearlings in these species. In addition, the LMC agreed that stocking of undersized surplus fish from hatchery overproduction will be excluded from the annual stocking totals because these small fish are expected to have an extremely low survival rate. On average, about 10.8 million salmon and trout comprised of fall fingerlings, spring fingerlings and yearlings were stocked during 2013-2015 (Table 2). This number of stocked fish equaled 5.3 million Chinook salmon equivalents, which represented the new lakewide baseline for the 2016 reduction. Individual agency baselines ranged between 0.47 and 2.51 million equivalents (Table 2).

Table 2. Lakewide salmon and trout stocking numbers and Chinook salmon equivalents for Michigan, Wisconsin, Illinois and Indiana waters of Lake Michigan. Values represent the 2016 baseline (actual number of fish stocked for 2013-2015) and the proposed targets for 2025. Stocking plan numbers from 2012 are included for comparison.

	Stocking Plan 2012		2016 Baseline		2025 Stocking Targets	
Agency	Number	Equivalents	Stocked number	Equivalents stocked	Target Number	Equivalents
Michigan	6,928,500	3,711,635	5,665,070	2,514,635	5,784,822	2,884,041
Wisconsin	3,966,000	2,257,770	3,211,775	1,780,625	2,805,000	1,887,652
Illinois	870,000	483,045	882,858	473,914	875,000	462,174
Indiana	1,171,000	584,079	1,095,371	538,899	835,000	492,708
Grand total	**12,935,500**	**7,036,529**	**10,855,074**	**5,308,073**	**10,299,822**	**5,726,575**

The adopted 2025 lakewide and agency stocking targets in Chinook salmon equivalents (Table 2) will remain in effect until a new stocking adjustment is recommended by the LMC. At that time, the LMC will determine a new baseline by calculating the average of the annual numbers of salmon and trout stocked by each jurisdiction for the 3-year period before the adjustment decision year, and then use the new baseline when making stocking adjustments. If unexpected production issues occur for any species during the 3-year averaging period (e.g., due to egg availability, production losses, disease outbreaks, pump failures, hauling mishaps or other production facility problems), and with consensus approval by the LMC, an individual jurisdiction may substitute their planned baseline stocking numbers for actual stocking numbers for affected species when calculating the new baseline stocking level. This will prevent uncontrollable production events during the averaging period from negatively affecting agency baseline stocking numbers.

Annually each spring, the LMC will provide individual agency salmon and trout stocking targets and actual numbers stocked during the previous stocking year. Providing stocking information annually as both numbers of fish and corresponding Chinook salmon equivalents should simplify tracking of lakewide salmon and trout predator introductions in Lake Michigan.

Stocking adjustment procedure

When making future stocking adjustments, the LMC will recommend a lakewide predator stocking level increase or decrease that is measured in Chinook salmon equivalents. Adjustments may include more than one stocked species and will be informed by the best available scientific data on predator and prey fish populations. The overarching goal for stocking adjustments is to move toward balance between salmon and trout predators and their pelagic prey while maintaining a sustainable sport fishery for Lake Michigan anglers.

The outline below is intended as a procedural guide for future stocking adjustments. In stocking adjustment years, it is anticipated that this process will occur between March (Lakes Meetings) and early October (prior to egg take).

1. Annually evaluate need for stocking adjustment using PPR, secondary indicators and related Fish-Community Objectives targets.
2. When a stocking adjustment is recommended, calculate new lakewide baseline stocking

level as the average number of salmon and trout stocked during the previous 3 stocking years following protocols outlined above in section on baseline stocking numbers.

3. Determine lakewide change in predator stocking (reduction or increase) based on equivalences and forward the new consensus-derived stocking level recommendation for agency review.
4. Agencies begin constituent engagement and inform state and federal production facilities of potential stocking changes.
5. Each agency develops stocking adjustment options consistent with the LMC consensus recommendations. Agency stocking options may include adjustments to one or more species based on hatchery production capabilities and agency management goals and objectives.
6. LMC reviews, discusses and seeks consensus on agency stocking adjustments.
7. Agencies work with local constituents to finalize stocking plans.
8. With agency approval, consider announcement of proposed lakewide stocking adjustment recommendation in a LMC press release.
9. Stocking changes should be implemented the year following the adjustment recommendation year. Stocking adjustments may require 2 years following LMC decision to be fully implemented for species stocked as yearlings.

Adopted by the Lake Michigan Committee – April 2025

Rod Edgell
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