RECOMMENDED MAXIMUM LAKE TROUT HARVEST

FOR THE APOSTLE ISLANDS REGION OF LAKE SUPERIOR

FOR THE 2024-2026 FISHING YEARS

(November 28, 2023 – September 30, 2026)

BY

THE BIOLOGICAL COMMITTEE

WISCONSIN STATE-TRIBAL LAKE SUPERIOR FISHING AGREEMENT

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Executive Summary

The purpose of this report is to present the methods, rationale and results used to develop a maximum total allowable catch (TAC) recommendation for lean lake trout in management unit WI-2, or the Apostle Islands region in Lake Superior. To develop a new TAC, all model data were updated through 2022. Notable changes to the current version of the statistical catch at age (SCAA) model were 1) replace previous recreational effort estimates with targeted lake trout fishing effort 2) re-estimate age compositions for fisheries and surveys 3) add annual effective sample size for all age compositions (for data weighting), and 4) use a random walk function to estimate recruitment and hold recruitment constant for the last three years of the time series. The intent of all these changes was to improve model performance and remain consistent with modelling efforts throughout the Great Lakes.

The SCAA model was used to estimate fishery harvest, abundance, recruitment, mortality, gear selectivity, catchability, and assessment CPE from 1986 to 2022 for wild lake trout of ages 4 to 15+. Model results show a decline in lake trout abundance from the early 2000s to 2011 and a steady increase through 2022. The recent increase in lake trout abundance was due to a reduction in fishing mortality and increased recruitment. Action taken in 2015 and preceding years to reduce the TAC for lake trout resulted in lower recreational and commercial effort and harvest and has allowed lake trout biomass to return to levels similar to those observed in the early 2000s.

To calculate a TAC recommendation for the 2024-2026 fishing years, lake trout abundance was projected forward using average values of abundance, natural mortality, sea lamprey mortality, recreational fishing mortality, and commercial fishing selectivity from 2020-22. The current state-tribal agreement stipulates the TAC would be based on a total annual mortality of 42% on the age of maximum commercial selectivity. An annual mortality rate of 42% is likely to be sustainable, assuming adequate spawner biomass is also maintained (Nieland et al. 2008) and has been used as a harvest criterion in other areas of Lake Superior. Age-specific instantaneous commercial fishing mortality (*F*) was set so that total annual mortality would reach but not exceed 42% for any age class. The ultimate recommended TAC was the average total harvest (recreational and commercial) predicted for 2024-26, based on the assumed maximum allowable mortality rates and projected lake trout abundance.

The committee recommends a TAC of 67,000 lake trout for WI-2. The recommended TAC increased by 12% due to above average recruitment and total mortality rates remaining less than 42% in recent years. Updating the model with three more years of data, refining some historical data sets, and incorporating several structural improvements to the model contributed to the observed differences as well. Compliance with the lake trout TAC recommended in this report should result in continued maximum sustainable yield.

INTRODUCTION

The purpose of this report is to present the methods, rationale, and results in the development of a maximum total allowable catch (TAC) recommendation for lean lake trout (*Salvelinus namaycush*) in management unit WI-2. This management unit lies within Wisconsin waters of Lake Superior and extends from Bark Point eastward to the Michigan state line (Figure 1). The entire unit is within the 1842 treaty ceded territory. The TAC has been one tool used to limit mortality on lean lake trout stocks and is intended to apply to lean lake trout removal by all groups: tribal commercial and subsistence, state commercial and sport, and agency (i.e., State, Tribal, Federal) assessments.

From 1985-2003, the TAC was estimated using a cohort model (Wisconsin State/Tribal Technical Committee 1984, 1990, 1995, 2001), but since 2003 a statistical catch at age (SCAA) model has been used to describe lake trout population dynamics. Since the initial WI-2 model was developed (Linton et al. 2007) there have been a series of modifications, which have been guided by input from the Modeling Sub-Committee in 1836 treaty waters and Quantitative Fisheries Center at Michigan State University. Previous reports document the model frameworks used to estimate population parameters and set recommended TACs (Wisconsin State/Tribal Biological Committee 2005, 2009, 2012, 2013, 2014, 2017, 2020).

Committee members for this exercise were Dray Carl (Wisconsin Department of Natural Resources), Ian Harding (Red Cliff Treaty Natural Resources Division), and Jacob Rodmaker (Bad River Natural Resources Department). Technical assistance was provided by Mike Seider (United States Fish and Wildlife Service).

Model inputs were updated through 2022 to estimate parameters used to calculate a TAC recommendation for the 2024-26 fishing years. Notable changes to the current version of the statistical catch at age (SCAA) model were:

1) including only lake trout targeted effort from the recreational creel survey (i.e., combined charter, trout/salmon open-water trolling, ice “bobbing” > 60 ft) and then not down weighting recreational effort

2) recalculating age compositions for fisheries and surveys using reproducible data sets

3) adding annual effective sample size for all age compositions (for data weighting)

4) use a random walk function to estimate recruitment and hold recruitment constant for the last three years of the time series.

Lean lake trout abundance in WI-2 is currently comprised largely of wild fish. The proportion of wild fish caught in the large-mesh assessment fishery outside the refuges has steadily increased from around 45% in the late 1980s to about 93% from 2020-2022. Since the 1980s relative abundance of large juvenile and adult wild lean lake trout has increased, while the abundance of hatchery fish has gradually declined.

Total annual mortality rate is a measure of the proportion of fish that die each year from fishing (subsistence, commercial and recreational), natural sources, and sea lamprey. The Lake Superior Technical Committee (a committee of the Great Lakes Fishery Commission) based their recommendation of 42% maximum total mortality on the work of Healey (1978) (LSLTTC, 1986). However, this recommendation did not explicitly describe how the sustainable limit of total annual mortality should be applied to an age-structured population, and mortality often varies by age-class due in part to different vulnerabilities to fishing among age-classes (i.e., selectivity). Model simulations using the lake trout data from WI-2 indicated the currently accepted mortality rate is likely sustainable (i.e., likely not to cause extirpation) but could cause unsustainable reductions in spawner biomass if not implemented carefully (Nieland et al. 2008). Nieland et al. (2008) went on to recommend that managers avoid low spawner abundance by implementing threshold management strategies. Mortality of both wild and stocked fish exceeded the target rate between 1970 and 1986, before our model time frame. Importantly, the WI-2 SCAA model does not include any data collected from within the no-take refuge system (Gull Island Refuge and Devils Island Refuge) during assessments and so conceptually does not include fish from within refuges in abundance estimates. This is because this committee views some of the primary functions of the refuge system as providing a safeguard component for an aggressive harvest strategy and helping maintain spawner biomass around important spawning habitat (Nieland et al. 2008; Akins et al. 2015).

METHODS

Study Area

Wisconsin waters of Lake Superior are divided into two management units (Figure 1). The WI-2 management unit has a surface area of 4,474 km^2 and includes the 22 Apostle Islands. Shallow, rocky reefs, 3-30 m deep, along the shoreline of both the mainland and islands serve as spawning habitat for lake trout (Coberly and Horrall 1980). The Gull Island Refuge has a surface area of 336 km^2 and the Devils Island Refuge has a surface area of 283 km^2. Both refuges are closed to all fishing except commercial fishing is allowed in limited areas within the refuges with restrictions during June 1 through September 30.

Input Data for Statistical Catch at Age Model

The commercial gill net fishery (i.e., consisting of both tribal and state-licensed fishers) and the recreational angling fishery are the primary sources of lake trout harvest in WI-2 and were modeled in this analysis. Annual catch statistics and biological information associated with the two fisheries were compiled from records maintained by the agencies responsible for fisheries management. The Wisconsin Department of Natural Resources conducts a large-mesh gill net assessment during the spring and a graded-mesh gill net assessment during the summer. The results of these fishery-independent assessments provided age distribution and catch-per-effort (CPE) data for use in the SCAA analysis (Fournier and Archibald 1982; Deriso et al. 1985).

Commercial Fishery

The commercial fishery in WI-2 primarily targets lake whitefish (*Coregonus clupeaformis*) while lake trout are generally a secondary target species (inside 330 feet depth). Several commercially licensed fishers also target lake whitefish using trap nets. Fishers licensed by the Red Cliff Tribe may harvest any lake trout captured, but State-licensed fishers are only allowed to harvest lake trout less than 25 inches captured in trap nets. The harvest of lake trout in trap nets is relatively low, so it is grouped into the gill net harvest with an appropriate effort adjustment.

Commercial fishers are required to record the aggregate dressed weight of their catch each day, and in addition, state-licensed commercial fishers have been required to report the actual number of harvested lake trout each day since 2016. When necessary, reported dressed weight was divided by the mean weight of dressed fish to obtain the number of lake trout harvested. The wild fish portion of harvest was generated by applying the proportion of wild fish caught during joint commercial onboard monitoring in WI-2. Additionional data collected during onboard monitoring included biological information associated with the lake trout catch (e.g., length-frequency, individual weights, fin-clips, age samples, etc.). To account for under-reporting, discards, and post-release mortality, commercial harvest between 1986 and 1989 was increased by 40% and commercial harvest since 1990 was increased by 10%.

Commercial age composition data for 1986 through 1989 was obtained from aging samples taken directly from Red Cliff fishers. After 1989, age compositions were derived by applying age-length keys developed from ages collected during large-mesh gill net assessment to commercial length frequencies (collected during on-board monitoring) for each year. More recently, ages from fish collected during onboard and dockside monitoring were combined with survey ages to create age-length keys. Age-length keys were not available for 1996, 2001 and 2011 because the large-mesh assessment was not conducted. Age compositions were not estimated for the commercial fisheries in those years.

Recreational Fishery

In Wisconsin waters of Lake Superior, the recreational fishery is surveyed annually via a DNR creel survey to estimate effort (i.e., angler-hours) and harvest. Estimates of wild lake trout harvest were available for each year. For this model and moving forward, only recreational effort targeted at lake trout will be used (i.e., combined charter, trout/salmon open-water trolling, ice "bobbing" > 60 ft). Prior to 2002, age composition data were obtained by assigning ages to fish recorded in the creel survey using age-length keys derived from the large-mesh assessment. From 2002 through 2020, year-specific age-length keys were developed from the large-mesh and graded-mesh assessments when both were available (even-numbered years). In 2021 and 2022, age-length keys were constructed using maxillae-based ages collected from the recreational fishery.

Prior to 2015, sport anglers were allowed to keep three lake trout over 15 inches daily, with only one longer than 25 inches. To help prevent overharvest during a two-year period of low TAC's (2015-2016), daily bag and length regulations were changed. In 2015, recreational anglers could only keep lake trout from 20-25 inches with a daily bag limit of two (one fish 20-25 inches and one fish over 35 inches). In 2016, the bag limit increased to three fish daily (two fish 20-25 inches and one fish over 40 inches). Since 2017, the bag limit is two fish daily with a 15-inch minimum length limit and only one fish per day can exceed 25 inches. Discards and post-release mortality were not accounted for in the recreational fishery, but post-release mortality rates have been recently estimated for Lake Superior (Sitar et al. 2017). This committee will continue investigating post-release mortality in the recreational fishery and make appropriate adjustments to model inputs.

Spring Large-Mesh Assessment

The large-mesh assessment uses standardized gill nets of 4.5-inch stretched-mesh, 210/2 multifilament nylon twine, 18 meshes deep, hung on the 1/2 basis, and fished from April through early June at 19 fixed stations. The numbers of nights the nets were fished varied, so adjustments were made for net saturation according to the following equation from Hansen et al. (1998):

$$Adjusted\ CPE = \alpha(1 - exp(-\beta \cdot time))$$

where $\alpha = 211.443$ and $\beta = -\ln(1\ (CPE/211.443))/time$, CPE was lake trout per kilometer of net, and time was the set duration (nights). Adjusted CPEs were processed in a mixed model as has been done for other Lake Superior management units (Sitar et al. 1999), in order to generate a single log-scale index of annual abundance accounting for variations between sampling stations (e.g., depth, grid).

Ages were estimated from scales or otoliths removed from a sample of fish caught in gill nets. Prior to 1988, only scales were collected from lake trout, whereas after 1988, scales were collected from lake trout shorter than 23 inches and otoliths were collected from lake trout longer than 23 inches. Currently, otoliths serve as the primary structure used to age all fish. Year specific age-length keys were constructed to assign ages to fish with only lengths available and calculate age compositions.

Summer Graded-Mesh Assessment

Relative abundance of lake trout has also been indexed with standardized, graded-mesh gill nets during even-numbered years. The graded-mesh assessment uses nets with a mesh range from 1.5-inch to 7.0-inch stretched-mesh in 0.5-inch increments, hung on the 1/2 basis, set for 24 hours, and fished from July through August at 30 fixed stations. Nylon nets were used from 1970 through 1990, and monofilament nets were used from 1991 through the present. Total catch data from the graded-mesh assessment was converted to log-transformed CPE and fit to a mixed model just as was done for the spring large-mesh survey.

Prior to 2006, age composition was derived by assigning ages to lake trout captured in graded-mesh assessment using a global age-length key based on all ages available during the time series. Since 2006, year specific age-length keys were used to assign ages to lake trout in the graded mesh assessment.

To account for all known removals, the catch from the two fishery-independent assessments was added to the commercial harvest. The catch from the assessments was low compared to the commercial catch.

Statistical Catch-at-Age Model Structure

The SCAA model was used to estimate fishery harvest, abundance, recruitment, mortality, gear selectivity, catchability, and assessment CPE from 1986 to 2022 for wild lake trout of ages 4 to 15+. Net movement of lake trout between refuges and the rest of the management unit and movement between WI-2 and the adjacent management units was assumed to be nil. Model estimates are from the non-refuge portion of WI-2 (only non-refuge data were used) and primarily represent the areas where fishing activity occurs. Prior to 2005, separate SCAA models were run for wild and stocked lake trout for the WI-2 management unit of Lake Superior. However, hatchery lake trout in WI-2 gradually decreased after stocking ceased in 1995, resulting in declining age composition, harvest, and abundance data. The stocked lake trout model failed to converge properly in 2005 and has not been used in subsequent analyses. However, an adjustment has been made to the TAC to account for the expected proportion of stocked fish in the fishery.

The heart of SCAA analysis is the simultaneous estimation of age-specific fishery harvest and the abundance required to produce that harvest. Commercial fishery harvest was estimated using Baranov's catch equation (Ricker 1975, Quinn and Deriso 1999):

$$C_{Cy,a} = \frac{F_{Cy,a}}{Z_{y,a}} N_{y,a}(1 - e^{-Z_{y,a}})$$

where C_C is the commercial harvest of age class *a* in year *y*, F_C was instantaneous commercial fishing mortality of age class *a* in year *y*, *Z* was instantaneous total mortality of age class *a* in year *y*, and *N* was abundance of age class *a* in year *y*. The proportion-at-age of the commercial catch was estimated by dividing the catch-at-age by the total harvest for the given year. The proportion-at-age of the recreational harvest was estimated in the same manner. Abundance of lake trout age 5 through 15+ was estimated using the equation (Ricker 1975, Quinn and Deriso 1999):

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}}$$

where the parameters are as defined above. Parameters were estimated for abundance at each age 5 through 10 (with ages 11-15+ set at the value estimated for age 10) in the first year of data (1986). Abundance at age 4 (recruitment) for each year was determined using a random walk function,

$$N_{4,y} = exp(log_e(N_{4,y\text{-}1}) + \zeta_y)$$

where annual deviations ζ_y are added to the age-4 abundance estimate from the year prior.. Using a random walk function was a shift in this assessment cycle away from white noise function and provides a more realistic view of annual variability in lake trout recruitment. Nevertheless, estimation of age 4 abundance continues to be tenuous at the end of the time series because young fish are often not captured in the fisheries and the spring gill net survey. Lake trout are not fully vulnerable to the fisheries until at least 7-8 years old and the model must typically follow a year class for several years to appreciate its relative magnitude. As an attempt to account for this estimation uncertainty, recruitment is held constant for the last three years of the model.

Total mortality was partitioned into natural mortality, sea lamprey mortality and fishing mortality:

$$Z_{y,a} = M + M_{Ly,a} + F_{y,a}$$

where M was instantaneous natural mortality (i.e., assumed constant over all ages and years), M_L was instantaneous sea lamprey mortality of age class a in year y, and F was instantaneous fishing mortality of age class a in year y. The initial value for natural mortality was estimated using Pauly's equation (Pauly 1980, Quinn and Deriso 1999):

$$log_e(M) = 0.4634 * log_e T - 0.279 * log_e L_\infty + 0.6543 * log_e K$$

where L_∞ was the maximum length from the von Bertalanffy growth equation (cm), K was the Brody growth coefficient (1/year), and T was the average annual temperature (°C). Sea lamprey mortality was separated from natural mortality due to the impact that sea lamprey had on lake trout abundance (Pycha and King 1975, Swanson and Swedberg 1980, Pycha 1980). Sea lamprey mortality was estimated externally to the model using a logistic function:

$$W_{y,l} = \frac{\theta_y}{1 + e^{-\alpha(1-\beta_y)}}$$

where W was the estimated average wounding rate of a lake trout of length l in year y, θ was the asymptotic number of observed wounds on fish, and α and β describe the rate at which observed wounds reach the asymptote. Parameter α was assumed constant while β and θ were estimated for each year. Allowing β to vary annually is suggested by Pritchard and Bence (2013) and was a slight departure from the initial sea lamprey wounding model for Lake Superior (Rutter and Bence 2003). Parameters β and θ were interpolated for years with no scarring data available. The wounding rate was then used to estimate sea lamprey mortality:

$$M_{Ly,l} = W_{y,l}\left(\frac{1 - P_l}{P_l}\right)$$

where P was the probability of surviving a sea lamprey attack as estimated in Greig et al. (1992). Lamprey wounding rate and mean length-at-age from the large-mesh assessment were used to generate a matrix of instantaneous sea lamprey mortality rates by year and age (Rutter and Bence 2003, Pritchard and Bence 2013).

Instantaneous fishing mortality was separated into two components:

$$F_{y,a} = F_{Cy,a} + F_{Ry,a}$$

where F_C was instantaneous commercial fishing mortality of age class a in year y and F_R was instantaneous recreational fishing mortality of age class a in year y. Commercial fishing mortality was estimated using:

$$F_{Cy,a} = S_{Ca,y} {q_C}_y E_{Cy}$$

where S_C was selectivity of commercial gill nets for age-class a, q_{Cy} was a year specific catchability of the commercial fishery estimated with a random walk model, and E_C was commercial fishing effort in year y. Commercial fishery catchability was estimated using:

$$q_{C_y} = exp(log_e(q_{C_{y-1}}) + \zeta_y)$$

Selectivity of the commercial fishery was estimated with a two-parameter gamma function:

$$S_{C_a} = a^{\alpha} * exp(-\beta * a)$$

where α and β determine the shape of the curve and a was the age class. Selectivity was estimated over mean length-at-age rather than age for the two fisheries. This allowed selectivity to vary annually based on potential changes in growth and alleviated the need for time varying selectivity parameters, thereby greatly reducing the number of estimated parameters. Deviations to the two recreational fishery selectivity parameters were estimated to allow for potentially different selectivity patterns related to the unique recreational regulations in 2015 and 2016. The selectivity curve was standardized to the most selected length at age in each year. Recreational fishing mortality and selectivity were calculated in the same manner as the commercial fishery, but catchability was estimated by a white noise function.

The CPE and age distribution for large-mesh and graded-mesh assessments were estimated as:

$$U_{Ly,a} = S_{Ly,a} q_{Ly} N_{Ly,a}$$

where U_L was the large-mesh assessment CPE for age class a in year y, S_L was the large-mesh survey gear selectivity for age class a as described above for commercial selectivity, q_{Ly} was large-mesh assessment catchability in year y, and N_L was the population abundance at the time of year when the survey was conducted for age class a in year y. Selectivity and catchability for the two assessments were estimated in the same manner as the commercial fishery described above. Large-mesh assessment age distribution was calculated as a proportion-at-age, by dividing the age-specific CPE by the total CPE for the year. Graded-mesh assessment CPE, gear selectivity, catchability, and age distribution were estimated in the same manner.

Errors in age estimation were accounted for in the SCAA analysis. An age-estimation error matrix was constructed from known-age hatchery lake trout. The age-estimation error matrix converted the estimated age distributions for the fisheries and assessments into predicted age distributions that would be seen in the presence of age-estimation error.

Parameters and standard errors were estimated using a quasi-Newton iterative algorithm with maximum likelihood methods that fit model predictions to observed data (ADMB 2009). The log-likelihood function was formulated as:

$$L = \sum_{i=1}^{I} \lambda_i L_i$$

where L_i was the ith log-likelihood component, and λ_i was a factor for weighting the ith log-likelihood component. Fourteen log-likelihood components were included for commercial and recreational fishing effort (2), harvest (2), and age distributions (2), assessment CPE (2), age distribution (2), and survey catchability random walk (2), prior for natural mortality (1), and recruitment (1). All log-likelihood weighting factors were set to 1.0. Log-likelihood components for commercial and recreational fishing effort were of the form:

$$L_i = n\, log_e\, \sigma + \frac{0.5}{\sigma^2} \sum_{y=1}^{n} \sigma_y'^2$$

where n was the number years for which parameters were estimated, σ was observed variability in fishing effort, and σ' was variability in the relationship between fishing mortality and fishing effort in year y estimated by the model. Log-likelihood components for fishery harvest and assessment CPE were of the form:

$$L_i = \sum_{y=1}^{n} \left[log_e\, \sigma_y + \frac{0.5}{\sigma_y^2} \left(log_e \frac{X_y}{X_y'} \right)^2 \right]$$

where σ was variability in observed data for year y, X was observed total fishery harvest or assessment CPE, and X' was predicted total fishery harvest or survey CPE. The σs estimated from the mixed modeling described in the assessment section were used for weighting assessment CPE in the likelihood function. Log-likelihood components for fishery and assessment age distributions were of the form:

$$L_i = -\sum_{y=1}^{n} s_y \sum_{a=1}^{m} \left(P_{y,a} + log_e\, P_{y,a}' \right)$$

where s was the sample size of fish that had ages estimated for the observed age distribution data, m was the number of age classes included in the model, P was the observed proportion-at-age of age class a in year y, and P' was the predicted proportion-at-age of age class a in year y.

Log-likelihood component for natural mortality was of the form:

$$L_i = log_e(\sigma_M) + 0.5(log_e(M/\mu_M)/\sigma_M)^2$$

where μ_M is the initial value estimated with Pauly's equation and σ_M was its expected dispersion (standard error).

Rather than provide hard coded estimates of variance (σ) for fishery catch, fishery effort, and random walk processes, an overall variance is estimated by the model based on ratios that are adjusted through an iterative process until the estimated variabilities are within the range of acceptable values suggested by the 1836 modelling sub-committee (fishery catch (0.05-0.1), effort (<0.5), and selectivity random walk (0.01-0.05)).

A noteworthy change for this assessment was to integrate effective sample size (ESS) to inform the weighting of annual age compositions from the fisheries and surveys. Methods have been derived to minimize that autocorrelation and provide a better means of evaluating the quality (and independence) of the age composition data collected each year from each source. For the 2023 assessment, the ESS was estimated outside of the assessment models using an iterative, linear model approach, which provided a proportional adjustment to the vector of the number of samples collected for each data source in each year. This reduced vector was used to weight the age compositions and resulted in ESS values substantially lower than had been previously used. In some cases, this change altered model fit of age compositions, but seemed to improve model performance.

Future Projections

The recommended TAC for the 2024-2026 fishing seasons was determined with outputs from the SCAA model. Lake trout abundance was projected forward using average values from 2020-22 for abundance, natural mortality, sea lamprey mortality, recreational fishing mortality, and commercial fishing selectivity. Commercial fishing mortalities were generated as a product of age-specific commercial fishing selectivity and a commercial fishing intensity multiplier adjusted by the solver function in Microsoft Excel. Age-specific instantaneous commercial fishing mortality (F) was set so that the estimated total annual mortality would reach but not exceed 42% for any year class. The TAC was the average expected harvest (recreational and commercial) for 2024-26 based on assumed mortality rates and projected lake trout abundance. To further assess the sustainability of the fishery, the committee calculated spawning potential ratio (SPR), the ratio of current spawning stock abundance to spawning stock abundance in the absence of fishing mortality.

RESULTS AND DISCUSSION

Reported commercial fishery harvest of wild lake trout generally declined from 1986 to 1998 and steadily increased from 1999 to 2012. Reported commercial harvest generally declined after 2011 and has remained relatively stable through 2022 (Figure 2). Commercial harvest in 2011 was the highest recorded since 1986 (Figure 2). Estimated recreational harvest of wild lake trout peaked in 2005 but has been relatively stable over the last 20 years (Figure 3).

Relative abundance from the large-mesh and graded-mesh gill net assessments generally increased during the 1986-1990s but have generally remained stable since the early 2000s (Figure 4 and 5). The large-mesh CPE was higher from 2015-2017 due to several above average year classes becoming vulnerable to the survey (Figure 4). The graded-mesh CPE has fluctuated more since the early 2000s potentially because the survey captures a high proportion of young fish and catch rates fluctuates due to variability in year class strength (Figure 5).

Estimated abundance of age 4 and older wild lake trout increased during the 1990s until 2003 but steadily declined until 2011 (Figure 6). Predicted abundance of wild lake trout has steadily increased since 2011 (Figure 6). Recruitment of wild lake trout (as measured by predicted abundance of age-4 fish) has generally increased throughout the time series but with some year classes significantly larger than the long-term average (e.g. 1997, 1998, and 2015 year classes; Figure 7). There is greater uncertainty in the magnitude of recruitment at the end of the times series as these young age-classes are just becoming vulnerable to the fisheries and surveys.

Indices of total biomass and spawning stock biomass declined precipitously from 2007-2014 (Figure 8). Total biomass declined during the 1980s due to lower mean weights-at-age but then increased during the 1990s as abundance increased. Decline in total biomass from 2007 to 2014 was largely due to declining abundance since mean weight-at-age has remained relatively stable. The recent increase in biomass is mostly due to increased abundance. Female spawner biomass has gradually increased since about 2016. Although the model does not expect the fisheries or assessments to capture large numbers of older fish due to their relatively low estimated vulnerability/selectivity, model estimates of spawning stock biomass may be biased low. Nevertheless, the model estimates provide a relative annual index of spawning stock biomass. Nieland et al. (2008) warned that the target of 42% annual mortality may not cause a reduction in mean recruitment but could cause spawner abundance to fall below levels deemed sustainable. The analysis by Nieland et al. (2008), suggesting that 42% annual mortality is sustainable, is contingent on the ability to maintain age-8+ abundance at approximately 50% of the unfished abundance.

Average annual instantaneous total mortality of wild lake trout was high during the 1980s until effort control was implemented in 1989 (Figure 9). Total annual instantaneous mortality rates remained relatively low throughout the late 1990s and early 2000s but increased steadily after about 2006 (Figure 9). From 2011 to 2014 total annual mortality (A) on the maximally selected age class gradually increased above the target maximum mortality rate (0.42; Figure 10). Total annual mortality has been below the maximum target mortality rate since 2015 when action was taken to drastically reduce TAC's (Figure 10). Since 1986, SPR has been inversely related to annual morality, where SPR declined as annual mortality increased (Figure 11). Since 2015, SPR has remained above the recommendation of 0.5 by Nieland et al. (2008) for seven of the past eight years, after falling below the recommendation the prior eight years (2007-2014).

Total Allowable Catch (TAC)

The SCAA model outputs show a precipitous decline in lake trout abundance from 2000 to 2014 but then a gradual increase through 2022. As a result of the decreased TAC, commercial and recreational harvest has decreased and allowed several larger than average year-classes to begin rejuvenating adult lake trout abundance. Current lake trout abundance is largely supported by consistent recruitment of younger fish. Female spawner biomass is slowly increasing to levels observed in the mid-2000s and may take some time to respond to lowered fishing mortality rates.

Average annual abundance of age-7 and older lake trout during 2024-2026 at a 42% annual mortality rate would be 289,195 wild lake trout (Table 1). The estimated average total harvest would then be 67,067 fish, of which 62,680 are of wild origin and 4,387 are of stocked origin (Table 1).

Table 1. Projected wild lake trout abundance and wild and hatchery lake trout harvest in WI-2 during 2024-2026. The proportion of stocked fish was estimated using results of the large-mesh assessments stations outside the refuges during 2021-2022.

Year	Estimated Abundance of Age 7+ Fish	Estimated Harvest of Wild Fish	Estimated Proportion of Stocked Fish	Estimated Harvest of Stocked Fish	Estimated Total Harvest
2024	298,892	64,918	7.0%	4,544	69,462
2025	287,693	62,373	7.0%	4,366	66,739
2026	280,999	60,748	7.0%	4,252	65,001
Average	289,195	62,680		4,388	**67,067**

The number of fish needed for assessment purposes were deducted as follows:

State (500) + Red Cliff (250) + Bad River (250) = 1000

The committee recommends a TAC of **67,000** lake trout for sport, commercial, and subsistence fishing in WI-2. The TAC represents the **maximum** number of lake trout that should be harvested annually in WI-2 during the 2024-2026 fishing years. The recommended TAC is an attempt to maximize harvest while maintaining self-sustaining populations at or near carrying capacity.

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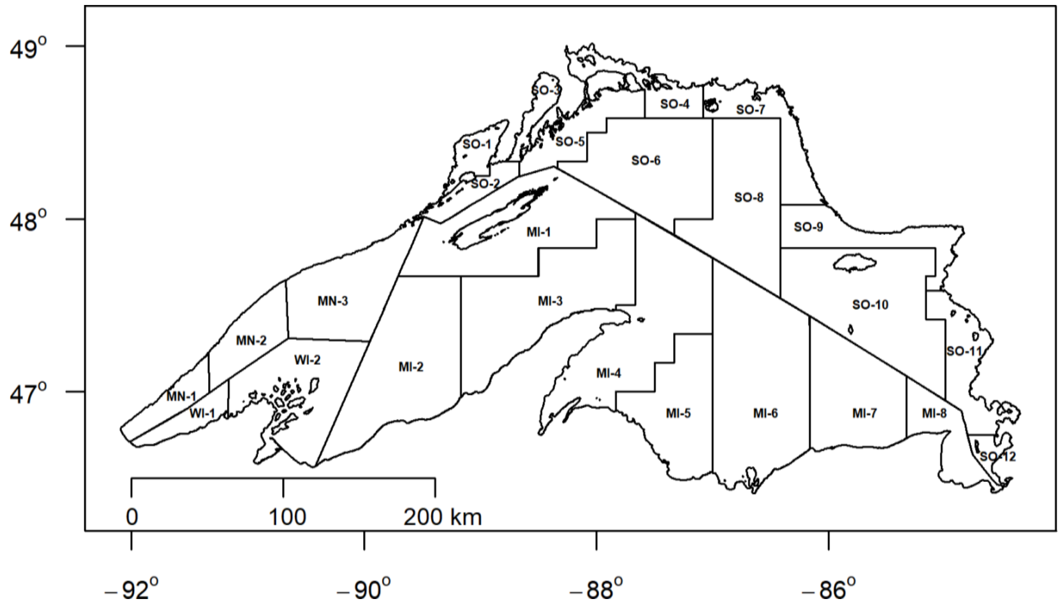

Figure 1. Lake trout management units in Lake Superior. (MI = Michigan; MN = Minnesota; WI = Wisconsin; SO = Ontario).

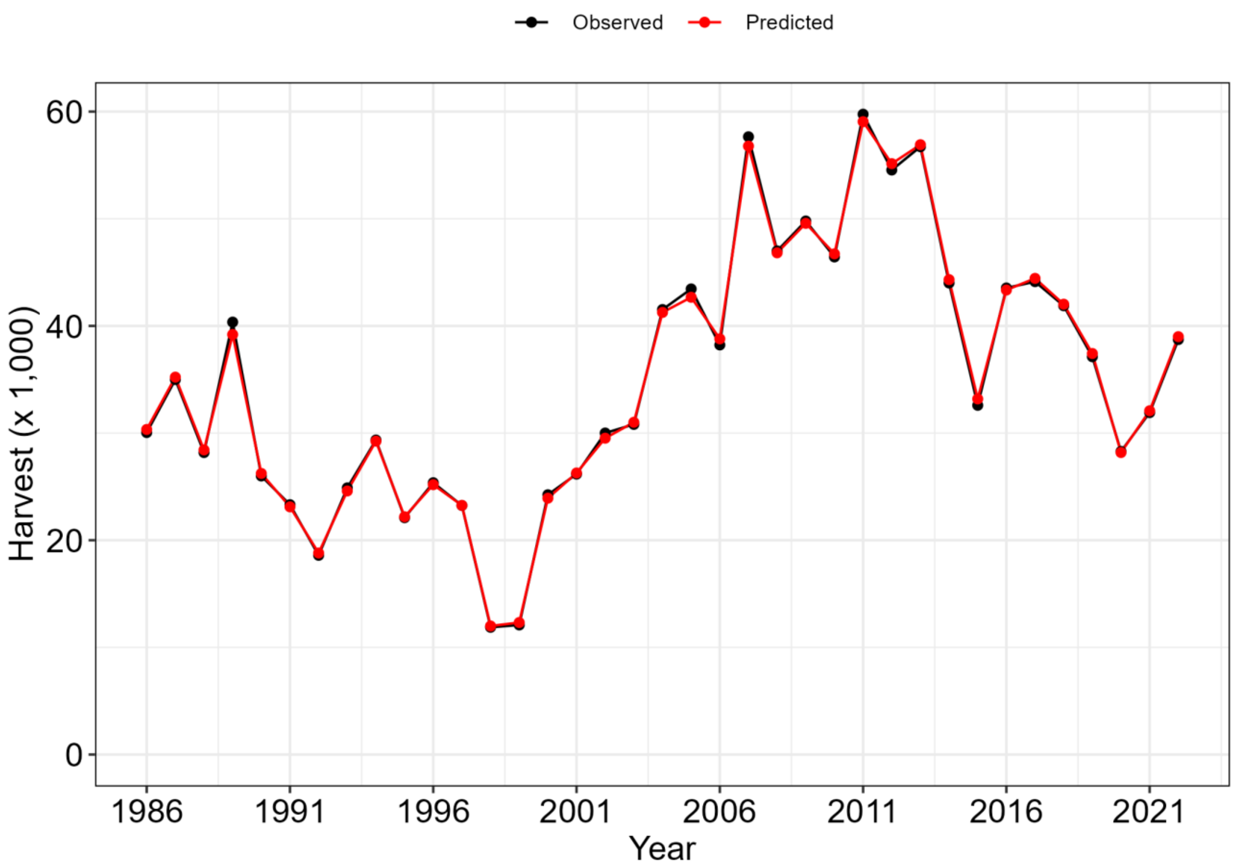

Figure 2. Observed (black) and predicted (red) commercial fishery harvest of wild lake trout in WI-2 management unit of Lake Superior, 1986-2022.

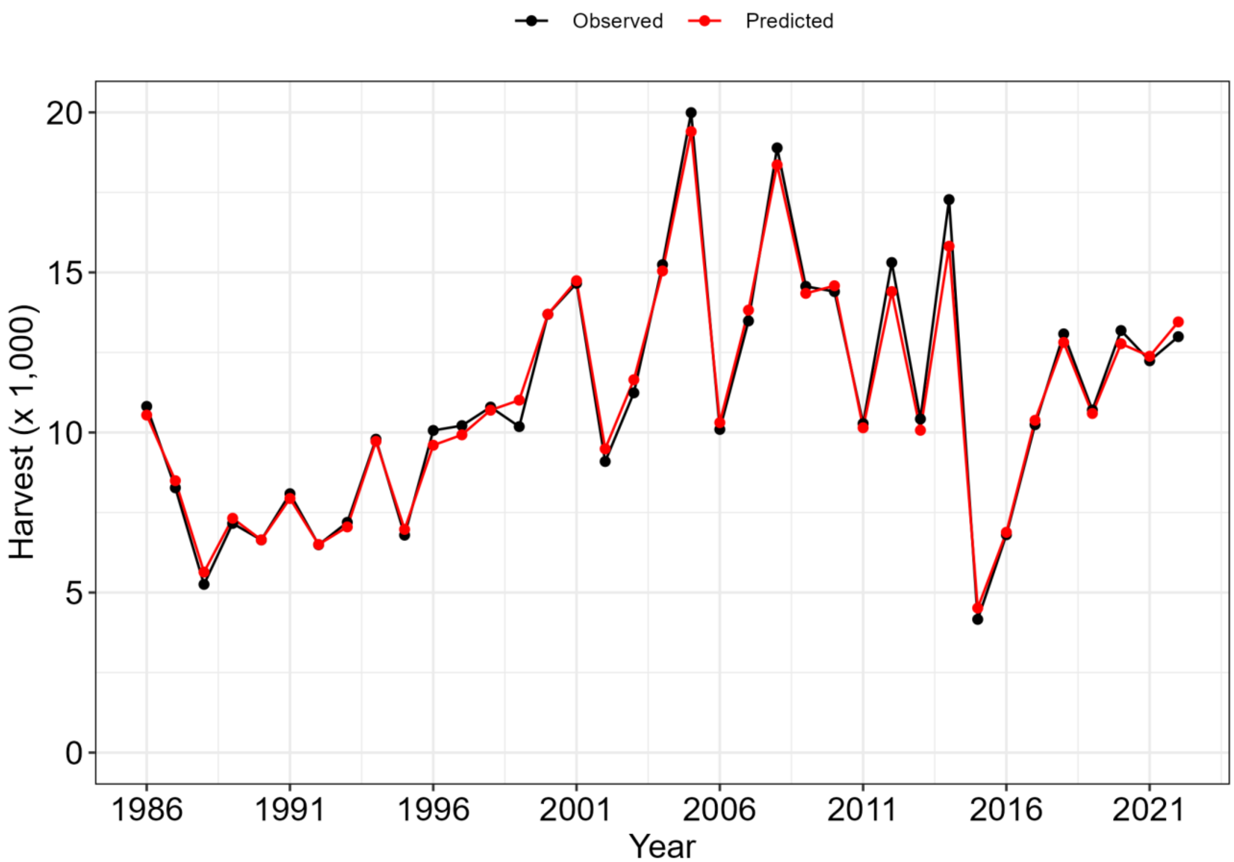

Figure 3. Observed (black) and predicted (red) recreational fishery harvest of wild lake trout in WI-2 management unit of Lake Superior, 1986-2022.

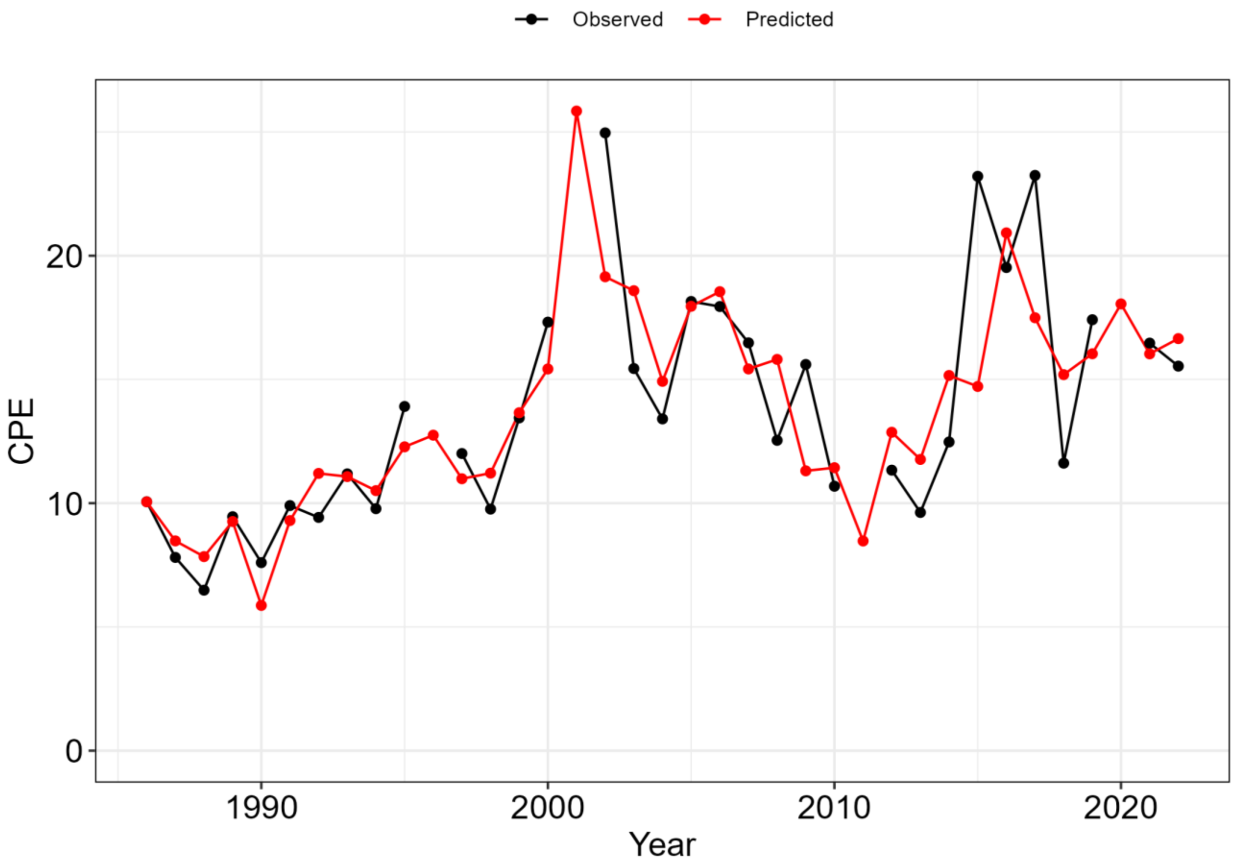

Figure 4. Observed (black) and predicted (red) large-mesh gill net assessment catch per effort (CPE, fish per km net night) of wild lake trout in WI-2 management unit of Lake Superior, 1986-2022. The large-mesh assessment was not conducted in 1996, 2001, 2011 and 2020.

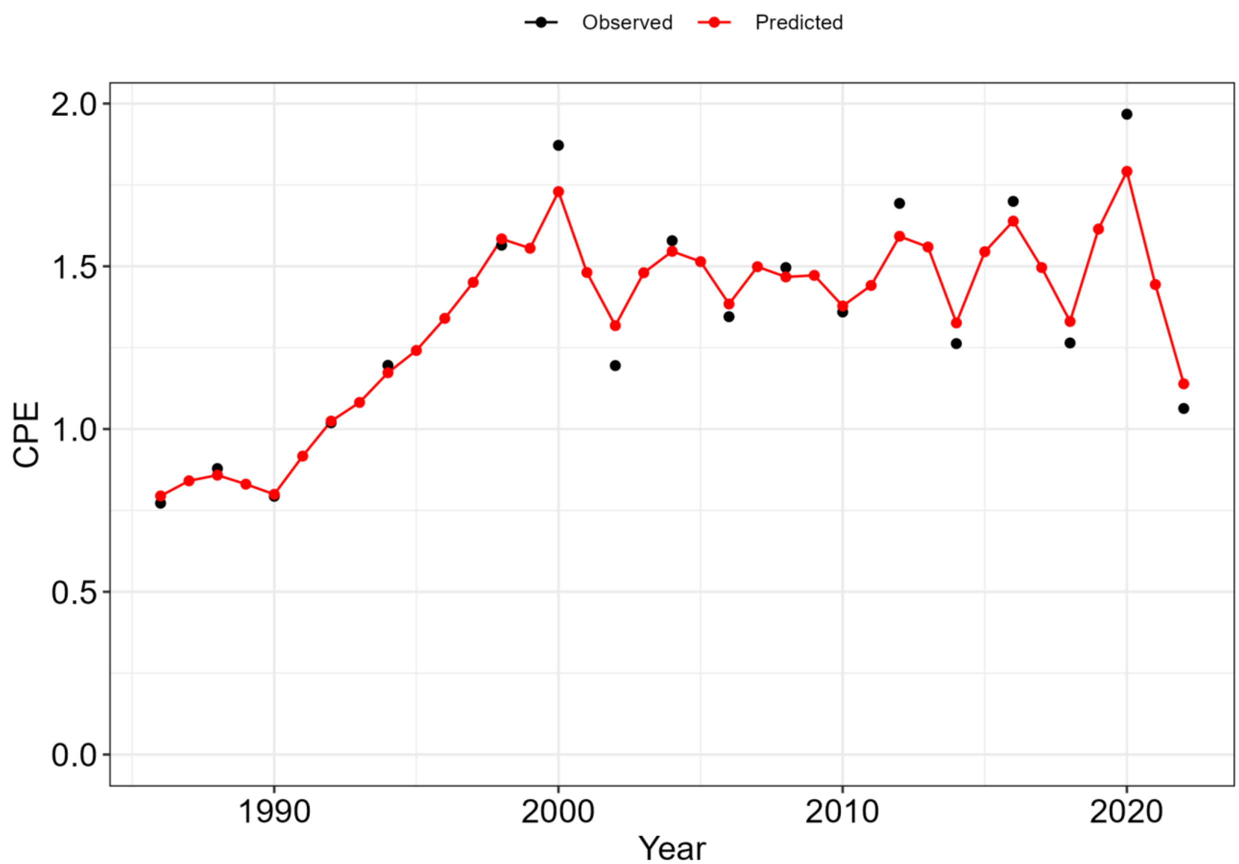

Figure 5. Observed (black) and predicted (red) graded-mesh gill net assessment catch per effort (CPE, fish per km net night) of wild lake trout in WI-2 management unit of Lake Superior, 1986-2022. The graded-mesh assessment was conducted in all even-numbered years except in 1996 and 2020.

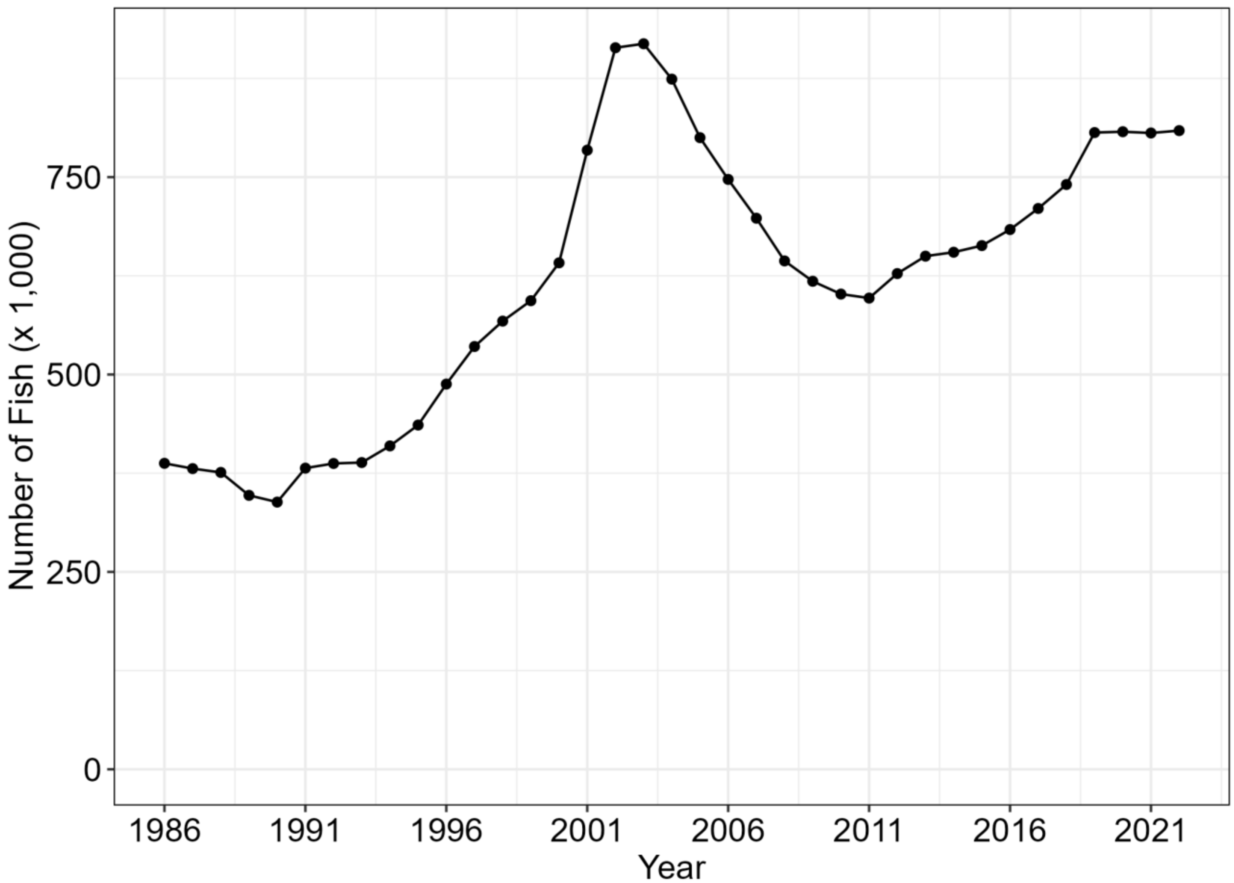

Figure 6. Estimated abundance of age-4 and older wild lake trout in WI-2 management unit of Lake Superior, 1986-2022.

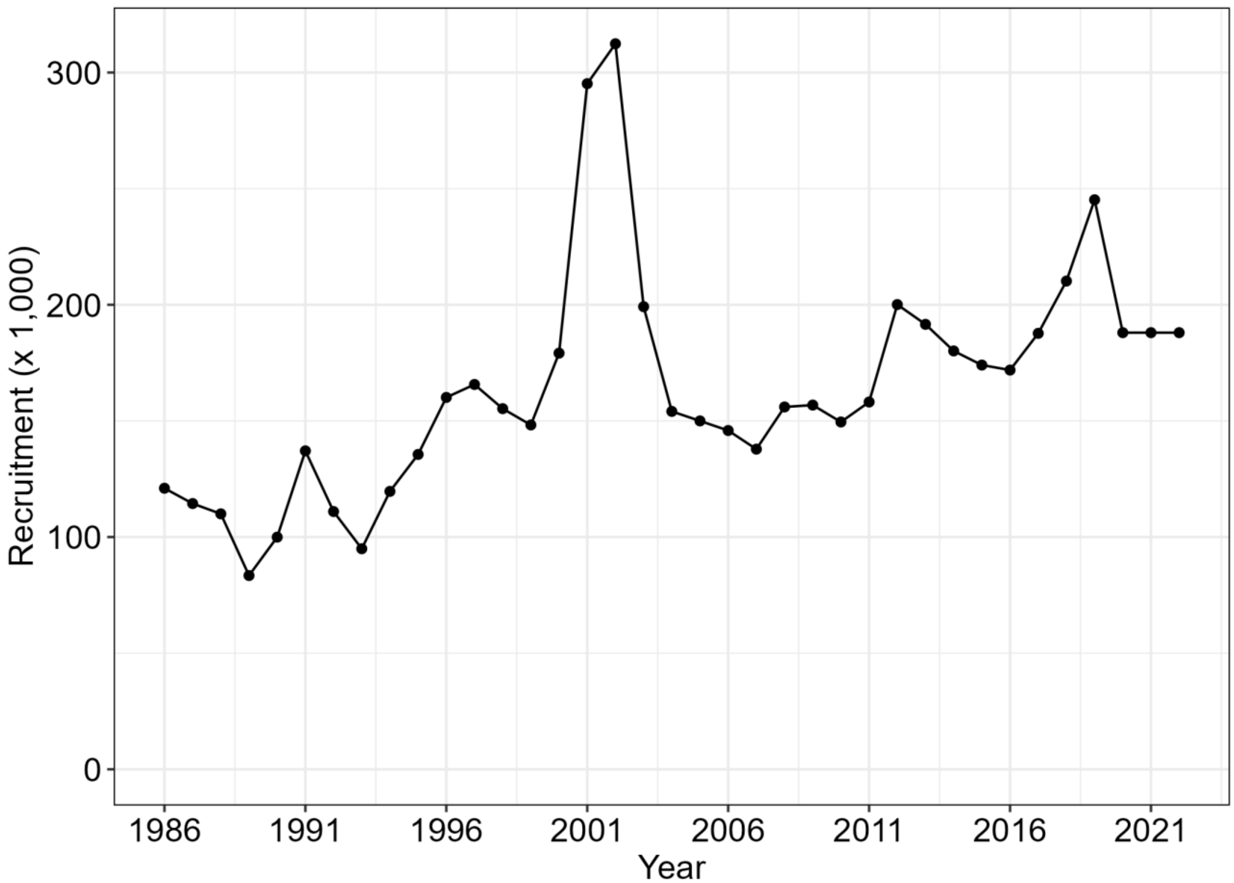

Figure 7. Estimated wild lake trout lake trout recruitment (age-4) in WI-2 management unit of Lake Superior, 1986-2022.

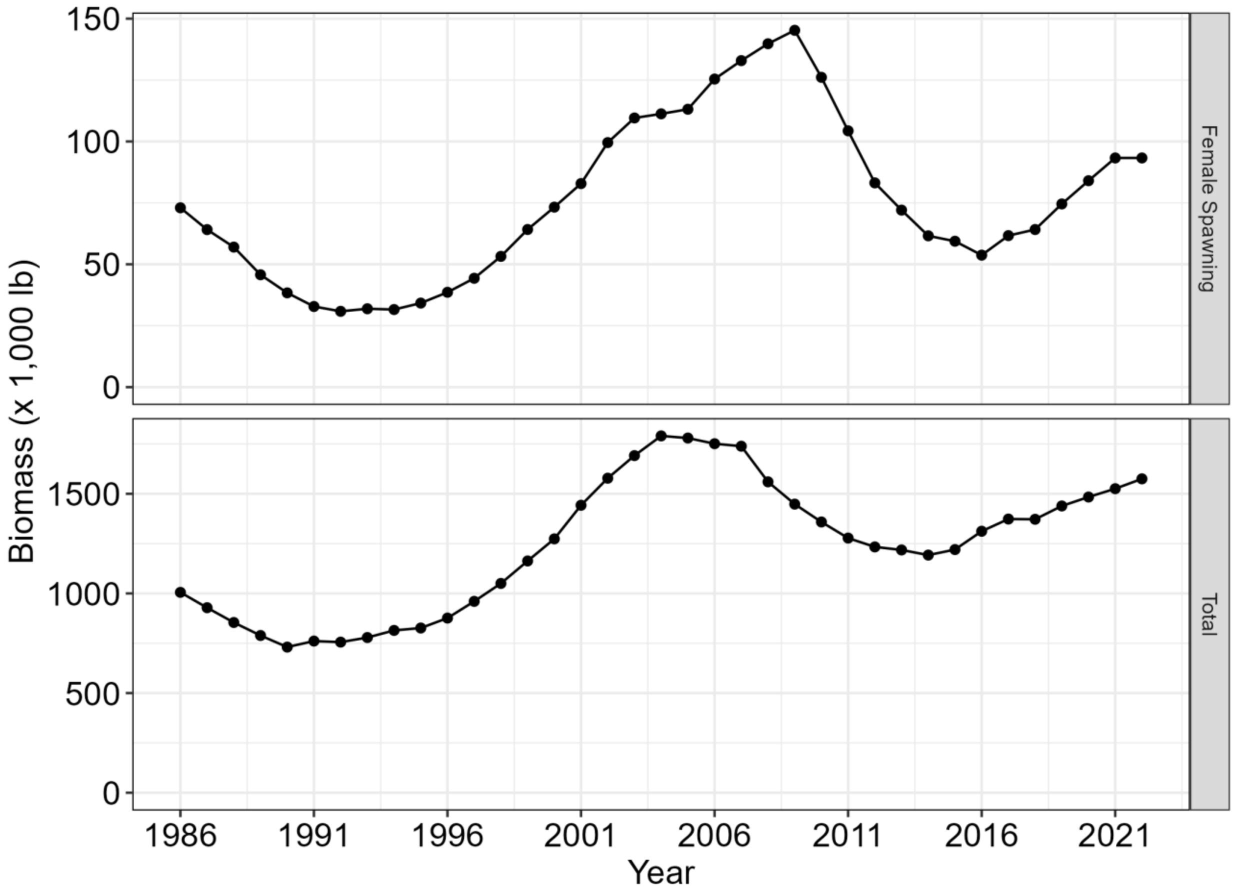

Figure 8. Indices of female (spawning stock) and total biomass of wild lake trout lake trout in WI-2 management unit of Lake Superior, 1986-2022.

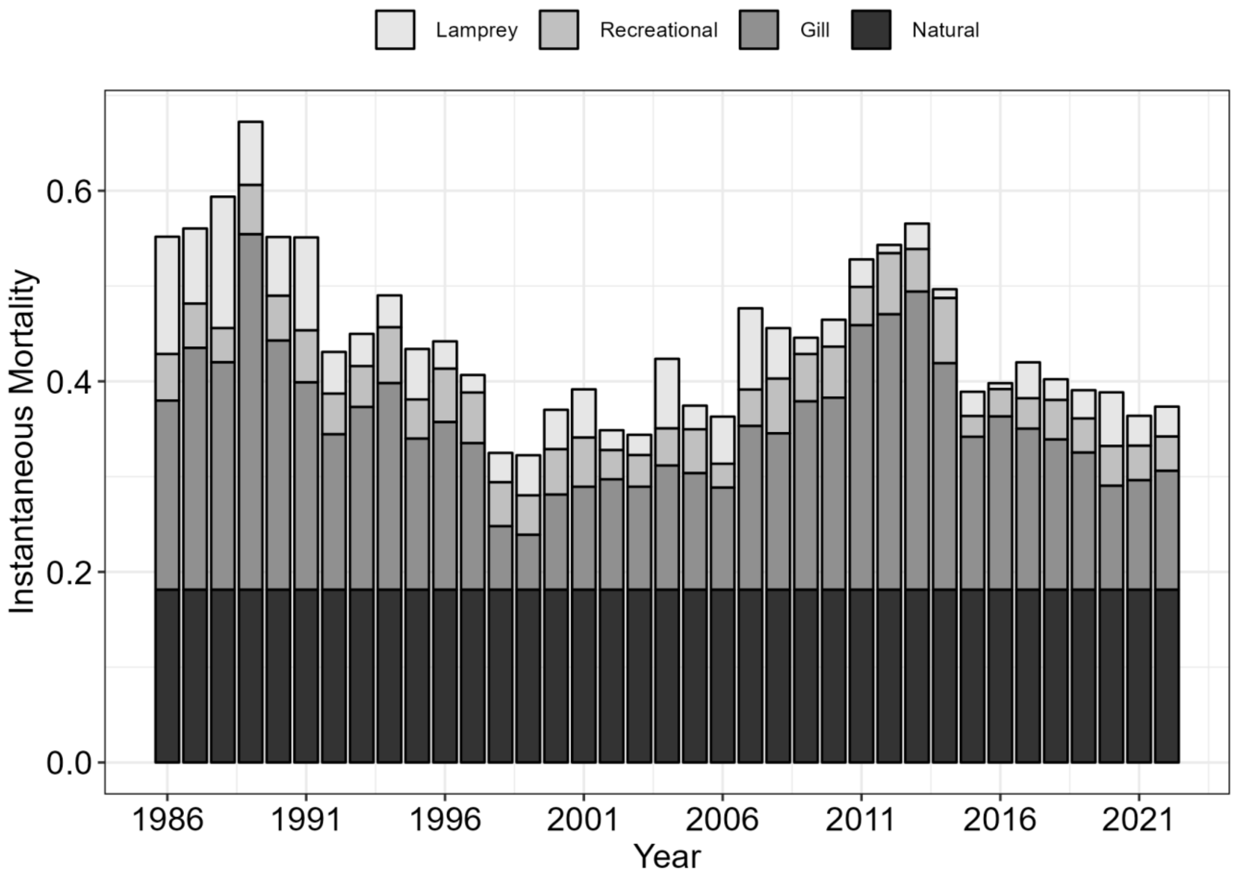

Figure 9. Estimated average instantaneous mortality rates of wild lake trout (age-4 and older) in WI-2 management unit of Lake Superior, 1986-2022. Total instantaneous mortality rates included natural, sea lamprey, commercial fishery, and recreational fishery components.

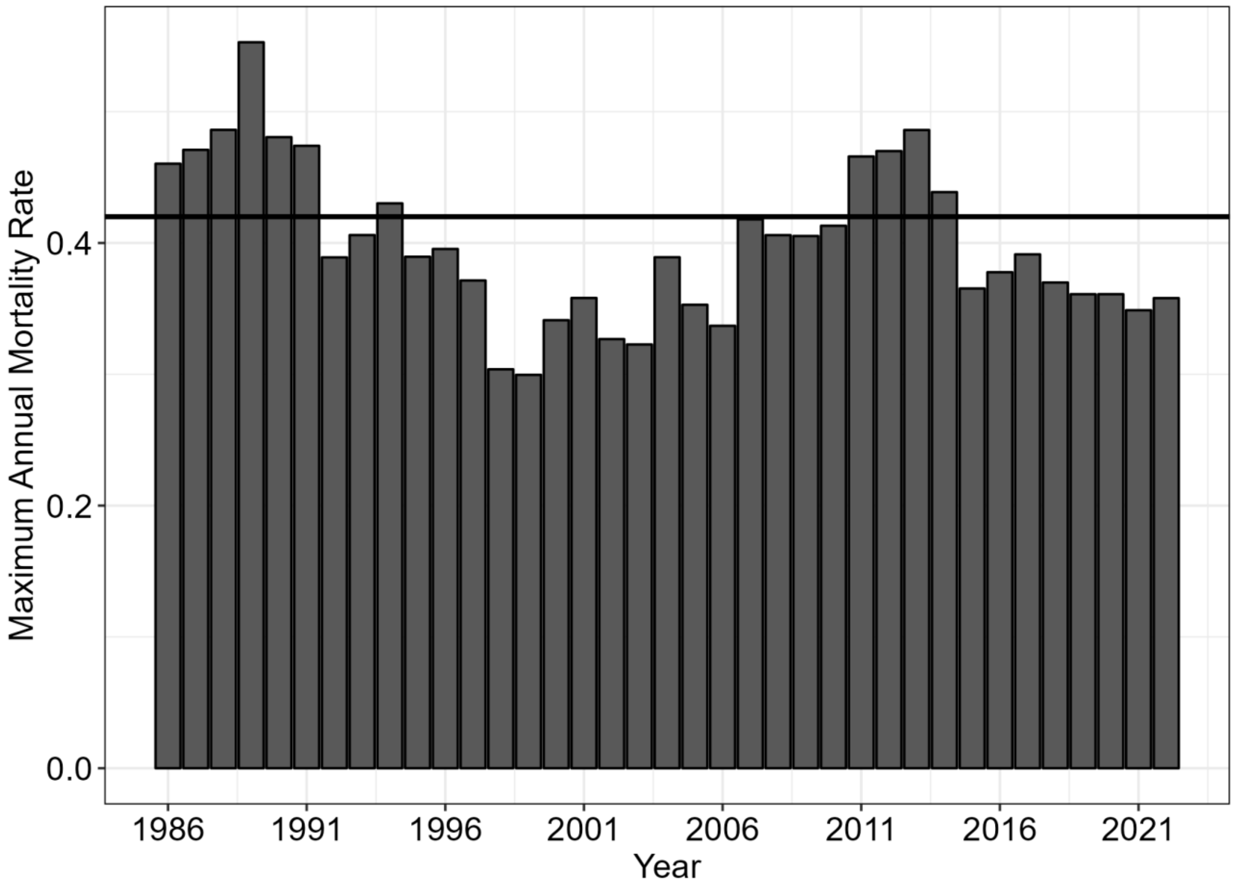

Figure 10. Estimated annual mortality rate (A) for maximally selected wild lake trout age in each year within the WI-2 management unit of Lake Superior, 1986-2022. The dashed line represents the current target maximum annual mortality rate (0.42).

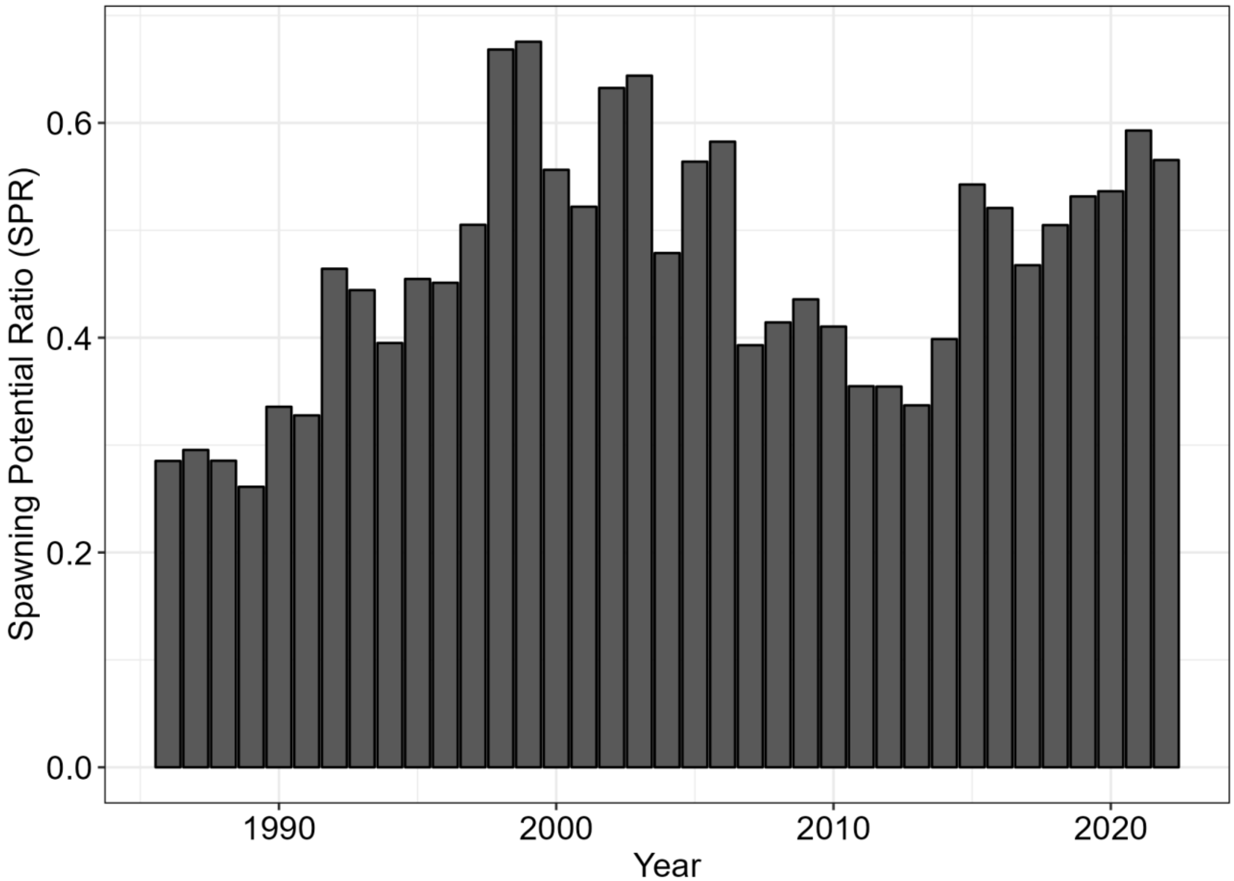

Figure 11. Estimated spawning potential ratio (SPR) for the wild lake trout population within the WI-2 management unit of Lake Superior, 1986-2022.